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**A PARAMETRIC APPROACH TO THE LIFE CYCLE
ASSESSMENT (LCA) IN EARLY DESIGN STAGE:**

THE CASE STUDY OF A YOGA GUEST HOUSE IN LATVIA

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Abstract

This study explores the integration of Life Cycle Assessment (LCA) methodologies, specifically the parametric approach, into the early stages of design processes. Recognizing the significance of early design decisions in influencing environmental impacts, the research aims to simplify and streamline the assessment for architects, whose knowledge of LCA might be limited. Traditional LCA methods are noted for their complexity and time-consuming nature, especially during critical design decision-making.

The thesis focuses on implementing the parametric LCA approach, using Bombyx and Hive tools, to offer real-time and simplified assessments for architects. The research follows a comprehensive process, understanding the LCA framework, establishing links between parametric and conventional approaches, and selecting appropriate tools for assessment.

A competition project, the Yoga house in the Latvian bog, serves as a case study. Researchers address project requirements and needs, gather necessary data, and focus on LCA modules (A1-A3 and B6). The insights gained inform the creation of design strategies, resulting in a conventional design proposal (Solution 0) and subsequent improvements, namely Solution 1 (technological enhancements) and Solution 2 (material modifications).

Integration of parametric LCA tools (Bombyx and Hive) into the early design process is achieved through Rhino and Grasshopper environments. Real-time results for Solution 1 and Solution 2 are obtained, and a comparative analysis of Global Warming Potential (GWP) and annual energy consumption guides the selection of the optimum design solution, illustrated as the final design.

This study serves as an example of applying parametric LCA tools in the early design stages, emphasizing the importance of considering specific project needs. The findings underscore the environmental impact of architects' decisions and aim to raise awareness, encouraging the incorporation of LCA approaches and parametric LCA methodologies as decision-making tools in early design stages.

Introduction

1

Architecture always tries to answer recent problems by developing new design strategies and collaborating with new tools. Especially in the recent years, climate change and shortage of resources became global issues that affect all sectors and lead them to take precautions. Also new approaches in architecture are shaped by taking into account that these issues, and new considerations are occurred in design stages. In several sources they mention the built environment is responsible for one third of the Global Greenhouse Gas (GHG) emissions and more than 40% of the World's primary energy demand (Columbia University GSAPP, 2017)¹. Especially after the global effects of built environment are taken into consideration, it is evident that **architects** have an important role.

Efforts to reduce GHG emissions mainly focused on the use phase of building. These measures have successfully reduced the operational energy demand and the limits for the energy optimization in the use phase have mostly been achieved. For new designs, embodied GHG emissions related to the material production, construction, maintenance and end of life at buildings account for half of the total emissions (Basic et al., 2019)². In this regard, new efforts started to include Life Cycle Assessments (LCA), mostly at the end of the design phases. In order to create meaningful difference on environmental effects of architectural designs, **architects should make the new ecological needs central to their form finding and they should apply LCA at the very beginning of the design process since it is related with material and geometry of design.**

While performing life cycle assessment in the early design phase, it is important to see environmental impact of the design and make improvements in real time while developing concept by architects. For this reason, parametric design tools become a good option since they can integrate with recent LCA tools and at the same time keep the design flexible and open for changes until the end of the design process. Because of these features they can help to create design strategies which can **make LCA as a design habit.**

In this regard, a competition project is chosen in order to make an example which can bring architectural approach and life cycle approach together. Essentially, the decisions that are taken regarding the architectural concept will be evaluated and improved while looking for a relation between **embodied emissions** that derives from building's materials and systems; and **operational emissions** that comes from operational usage. It is aimed to create **well-balanced design decisions** and find **the optimal solution** that takes both energy consumption and environmental impact into account.

1 Basic S, Hollberg A, Galimshina A, Habert G. (2019). *A design integrated parametric tool for real-time Life Cycle Assessment– Bombyx project*. Zurich, Switzerland: IOP Publishing.

2 Columbia University GSAPP, David Benjamin (ed.). (2017). *Embodied Energy and Design*. Lars Müller Publishers.

1.1. Research question

“How can LCA analysis be integrated into the early conventional design process?”

1.2. Statement of the problems

Integrating LCA into the early design process is challenging due to its complexity and the fact that it is typically conducted at the end of the design phase by professionals. However, early design decisions, particularly related to material selection and load-bearing systems, can significantly impact a building’s environmental footprint, even before detailed design work is complete. Architects have the potential to make substantial reductions in a building’s life cycle impacts through these decisions. Indeed, it is crucial to establish a streamlined process for integrating LCA, especially for architects, so they can effectively use the assessment as a **decision-making tool** in their design processes.

1.3. Background and needs

In recent years, **parametric design tools** have emerged to streamline the life cycle assessment (LCA) process in design, making it faster and more accessible for architects and professionals who may not be LCA experts. These tools offer **real-time results, optimization capabilities, and the ability to explore various design alternatives**, all of which facilitate the integration of LCA into the decision-making process. Given these advancements, there is a growing interest in architectural fields to develop design strategies that incorporate the **parametric approach for LCA**.

1.4. Purposes of the study

The research aims to develop a design strategy for a selected project by integrating life cycle assessment (LCA) as a decision-making tool in the design process. This integration will be facilitated through the use of a parametric design workflow involving parametric tools (Bombyx and Hive). **The goal is to establish a relationship between architectural design choices, environmental impacts, and energy consumption within the project.**

During this process, it is crucial to thoroughly understand the needs and requirements of the project’s end-users to ensure that all efforts on the design improvements are aligned with the specific needs and objectives.

Topic

Architectural design process, LCA in early design stages, Parametric approach to LCA, Parametric LCA tools, Decision making tool, Design alternatives, Screening LCA

References

Basic S, Hollberg A, Galimshina A, Habert G. (2019) *A design integrated parametric tool for real-time Life Cycle Assessment–Bombyx project*. Zurich, Switzerland: IOP Publishing.

Columbia University GSAPP, David Benjamin (ed.). (2017). *Embodied Energy and Design*. Lars Müller Publishers.

Methodology

The primary aim is to elucidate the tools that can aid in conducting a Life Cycle Assessment (LCA) during the early design phase. The explanation will commence with defining LCA, emphasizing the rationale and significance of its early integration into the design process by gathering data from the literature.

Delving into a parametric approach to LCA, drawing insights from existing literature research. Furthermore, exploring the tools, Bombyx and Hive, by utilizing the materials provided by their developers as guidance.

2.1. A Parametric Approach to LCA

2.1.1. Life Cycle Assessment

In order to grasp the parametric approach to LCA, it's helpful to first provide an explanation of LCA.

The LCA methodology dates back to the 1960s, when governments and global companies identified the issue of limited resources of raw materials. In the early 2000s, LCA broadened to the building industry, primarily because of the formalization of LCA standards in the ISO (International Organization for Standardization) 14000 series (Kamari et al., 2022) ¹.

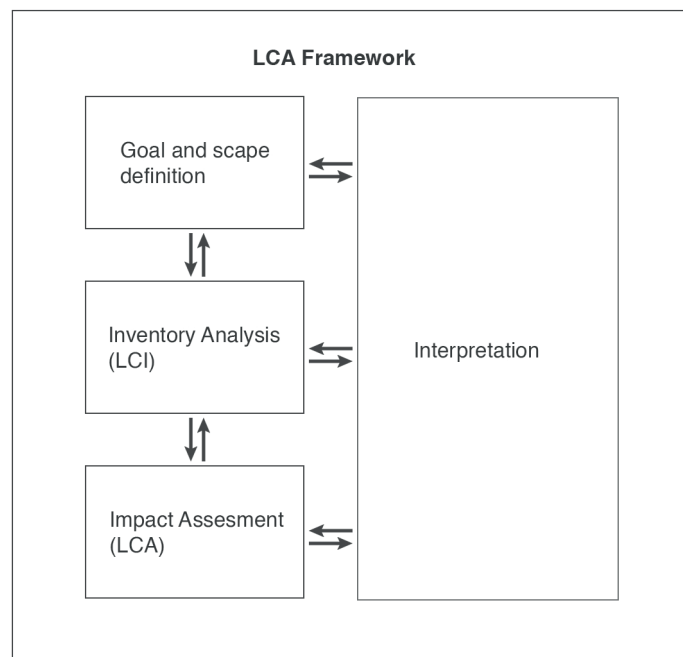


Figure 1: Diagram of the structure of the LCA based on ISO 14040/14044, the figure was redrawn based on the source: Thiebat, F. (2019). *Life Cycle Design, An Experimental Tool for Designers*. Turin, Italy: PoliTO Springer Series.

The UNI EN ISO 14040 standard defines the LCA a “compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle” (Thiebat, 2019) ².

LCA methodology is standardized in the ISO 14040/44 framework. The method consists of four phases (as it is shown in Figure 1): goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation.

In the book named, ‘Life Cycle Design, An Experimental Tool for Designers’ (Thiebat, 2019) ², these four phases are described briefly. To summarize:

Goal and Scope Definition: In this initial stage, the objectives, scope, boundaries, and

¹ Kamari, A., Schultz, C., & Kotula, B. M. (2022). *A BIM-based LCA tool for sustainable building design during the early design stage*. Smart and Sustainable Built Environment.

² Thiebat, F. (2019). *Life Cycle Design, An Experimental Tool for Designers*. Turin, Italy: PoliTO Springer Series.

limitations of the LCA study are defined.

Life Cycle Inventory Analysis (LCI): This stage involves collecting and calculating data to quantify inputs and outputs of a system, including energy and raw materials. It's a complex stage often using dedicated software and databases.

Life Cycle Impact Assessment (LCIA): During this stage, the results of LCI are processed to evaluate potential environmental impacts, such as alterations caused by emissions and resource consumption during production. Data is classified and normalized.

Life Cycle Interpretation: The final stage combines results from inventory and impact assessments with the study's goals. It aims to draw conclusions and make recommendations for reducing environmental impacts, with an iterative evaluation process.

According to the ISO 14000 series, process-based LCA consists of four types of assessment, cradle-to-grave, cradle-to-gate, cradle-to-cradle and gate-to-gate. Likewise, an LCA analysis also includes particular stages. Each life cycle stage describes in-depth the input of resources (raw material, energy use) and output (emissions to the environment) (Kamari et al., 2022) ¹.

EN 15804:2012 has been developed for the LCA of building materials and provides a basis for Environmental Product Declarations (EPDs) and EN 15978:2011 describes one approach for the LCA of a building and defines several life cycle stages; A production and construction, B use, C end-of-life of buildings and D loads beyond the system boundary (Hollberg et al., 2020) ³. These initiatives were launched with the aim of establishing a standardized framework for conducting LCAs of building products and entire buildings.

| Product | | | Construction | | Use | | | | | | | End of Life | | | | Benefits and Loads beyond the System Boundary |
|---------------------|-----------|---------------|--------------|--------------|-----|-------------|--------|-------------|---------------|------------------------|-----------------------|-------------|-----------|------------------|----------|---|
| A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 | D |
| Raw material supply | Transport | Manufacturing | Transport | Construction | Use | Maintenance | Repair | Replacement | Refurbishment | Operational energy use | Operational water use | Demolition | Transport | Waste processing | Disposal | Reuse, recovery and recycling potential |



³ Hollberg, A., Kiss, B., Röck, M., Soust-Verdaguer, B., Houlihan Wiberg, A., Lasvaux, S., Galimshina, A. & Haber, G. (2020). *Review of visualising LCA results in the design process of buildings*. Building and Environment.

Figure 2 Life cycle modules based on EN15978/11, the figure was redrawn based on the source: *A design integrated parametric tool for real-time Life Cycle Assessment– Bombyx project.* (2019). Zurich, Switzerland: IOP Publishing.

Figure 2 provides an illustration of the stages of the LCA process and their connection to different types of assessments, as well as marking these stages according to the types of environmental impacts they are responsible for. Specifically, the stages are divided into **embodied and operational impact**; this visualization helps clarify how different stages of the LCA process contribute to assessing both embodied and operational impacts in a building's life cycle.

The two types of carbon emissions can be referred to as embodied and operational carbon emissions. Embodied carbon encompasses all the CO₂ emissions generated during the production of the building. Similar to this, embodied carbon results from specific, rather than continuous, processes that produce carbon. This involves the extraction and manufacturing of materials used in construction and their transportation, as well as the carbon emissions from machinery and equipment used during the building process.

On the other hand, operational carbon represents the carbon emissions released during the continuous operation of the building. Sources of operational carbon include lighting, power usage, heating, ventilation, air conditioning, and other infrastructure systems⁴.

LCA has become a widespread method for environmental impact assessment of consumer products and services. In the last ten years, it has also increasingly been applied for the assessment of buildings, especially in an academic context. Further, the assessment is used as post-design evaluation as a mandatory part of sustainability certification schemes such as DGNB, BNB, BNK, and MinergieEco; while others, such as LEED or BREEAM, award additional credits for performing an LCA ("A design integrated parametric tool", 2019)⁵ (Meex et al., 2018)⁶.

2.1.2. Application of the LCA in The Early Design Phase

In general, decisions made in the early stages of the design process, have the greatest influence, as they set general conditions for the subsequent design process. As such, the early design phase has the highest influence on costs, operational energy demand and environmental impacts. Therefore, the biggest potential for optimization and reduction of GHG (Green House Gas) emissions lies in the early stages of the design process (Hollberg et al., 2020)³.

The design process is typically divided into several phases, which are generally similar in most industrialized countries. In the article of Hollberg and Ruth, (2016)⁷, the process has been divided into six stages, in the Figure 3, the stages are illustrated.

4 <https://www.renewableenergyworld.com/energy-efficiency/embodied-carbon-vs-operational-carbon-whats-the-difference-and-why-does-it-matter/#gref>

5 *A design integrated parametric tool for real-time Life Cycle Assessment– Bombyx project.* (2019). Zurich, Switzerland: IOP Publishing.

6 Meex, E., Hollberg, A., Knapen, E., Hildebrand, L., & Verbeeck, G. (2018). *Requirements for applying LCA-based environmental impact assessment tools in the early stages of building design.* Building and Environment.

7 Ruth, J., Hollberg, A. (2016). *LCA in architectural design—a parametric approach.* ResearchGate.

Here, the application of LCA and its integration with the design stages is being explored and understood.

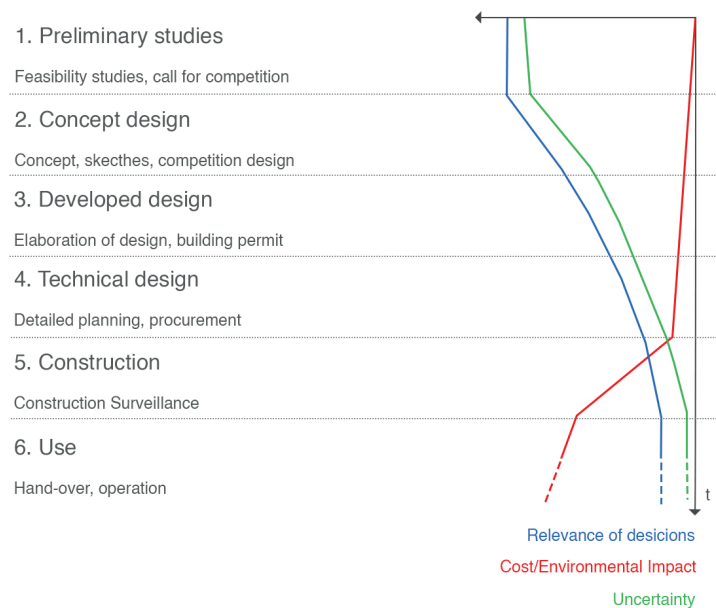


Figure 3 Six stages in the architectural design process, the figure was redrawn based on the source: Ruth, J., Hollberg, A. (2016). *LCA in architectural design—a parametric approach*. ResearchGate.

Stage 1 involves initial preparations, including research, feasibility studies, and defining project roles.

Stage 2 is where the basic architectural concept is developed, with crucial decisions on building characteristics (e.g., the number of story's, building orientation, and the massing of the building). **LCA could be valuable here**, but it's challenging due to limited information.

Stage 3 refines the design and determines the final geometry. **Material choices are made in a generic way**; while the general choice of material is known, e.g., concrete, its precise quality characteristics and manufacturer are not yet decided. Additionally, the building permit application usually follows this stage.

Stage 4 focuses on design details, technical specifications, and procurement. **Specific Environmental Product Declarations (EPDs) can be used for LCA if available.**

Stage 5 is the construction phase, with some influence on energy consumption. However, many operational demands are predefined during the design process.

The challenge with LCA lies in Stage 2, where decisions have the most impact but information is limited. Detailed information for LCA is only available after Stage 4, making it impractical to implement changes. **Simplified and time-efficient LCA approaches are in demand to bridge this gap.**

Since in early design not all (environmental) data are always available, the EeBGuide discusses possible simplifications of the LCA methodology for early design by reducing the set of life cycle modules and environmental indicators for **screening and simplified LCA**. Furthermore, also the data quality should be assured (Meex et al., 2018)

6.

In the article named ‘Requirements for applying LCA’ (Meex et al., 2018) ⁶, the simplifications are explained (as it shown in Figure 4).

| Level of LCA | Screening LCA | Simplified LCA | Complete LCA |
|-------------------------------------|--|--|--|
| Strength of database | Generic LCA data | Generic or average LCA data | Specific LCA data (EPDs) |
| Scope of LCA assesment | A1-A3, B6, B7 | A1-A3, B4, B6, B7, C3, C4, D | A1-A3, A4, A5, B1-B7, C1-C4, D |
| Number of impact indicators | At least one or two indicators | Reduced indicator set | EN 15978 or lisd from ILC Handbook |
| Types of building elements measured | Roof, load-bearing structure, building envelope including windows, floor slabs, foundation, floor finishes/coverings | Roof, load-bearing structure, building envelope including windows, floor slabs, foundation, floor finishes/coverings | Roof, load-bearing structure, building envelope including windows, floor slabs, foundation, floor finishes/coverings, wall finishes/coatings, doors, building services, escalators/lifts, water system |

Figure 4 Three levels of LCA, the figure was redrawn based on the source: Budig, M., Heckmann, O., Hudert, M., Ng, A. Q. B., Conti, Z. X., & Lork, C. J. H. (2021). *Computational screening-LCA tools for early design stages*. International Journal of Architectural Computing.

“ The European research project “EeBGuide” is focused on developing methods and guidelines for conducting Life Cycle Assessment (LCA) studies for energy-efficient buildings and building products. This project is part of the broader Energy Efficient Building European Initiative, which aims to create technologies that enhance energy efficiency in Europe. LCA is used to evaluate the environmental benefits of these new technologies.

The EeBGuide project provides manuals and guidance to assist LCA practitioners in obtaining comparative results for their work.”

- EeBGuide website,
www.eebguide.eu/eeblog/?p=430

The EeBGuide outlines three levels of LCA: screening LCA, simplified LCA, and complete LCA.

In screening LCA, the assessment should encompass the building envelope (exterior walls, windows, roof, and floor slab) and the primary load-bearing structure, which typically contribute to about 76% of the embodied impact. A declaration of impacts in life cycle modules A1-A3, B6, and B7 is required in screening LCA. **This level mainly focuses on modules A1-A3, representing the product stage of materials, and module B6, representing operational energy use, as they collectively account for a significant portion (70-90%) of the environmental impact in residential buildings.** Moreover, these modules (A1-A3, B6) are supported by highly accurate data available in nearly all EPDs and building material databases. Therefore, their inclusion in screening LCA poses no significant challenges and sets the essential life cycle modules for this level of assessment.

For simplified LCA, a broader set of life cycle modules should be considered, including A1-A3, B4, B6, B7, C3, C4, and optionally D. While module B6 (operational energy use) is relevant and influenced by architects in terms of building-related energy use, module B7 (operational water use) may be less relevant due to its dependence on user behavior, and early material choices may have minimal impact on it. Therefore, it's suggested that module B7 can be omitted from both screening and simplified LCA, but this choice should remain reversible to enable expansion to a complete LCA if needed.

Further, The EeBGuide doesn't specify a fixed number of indicators to be used for screening LCA. Instead, it suggests that a screening study can choose to focus on one or several indicators. However, it recommends that most studies include indicators like PENRT (primary energy non-renewable, total), and if relevant, GWP (global warming potential) and PERT (primary energy renewable, total).

2.1.3. Parametric Tools

Parametric LCA tools have emerged to address the need for early-stage LCA methods in the design process. These tools allow architects and designers to assess environmental impacts during the initial design phases, facilitating informed and sustainable design decisions. In the Figure 5, the role of the parametric tools within ISO 14040/44 framework is illustrated. As evident, these tools can be seamlessly integrated into both the inventory analysis and impact assessment phases within the conventional LCA framework.

*“ A **parametric tool** is a software or program that allows users to create and modify designs by defining specific parameters and rules. These parameters control various aspects of the design, making it easy to create, adjust, and optimize complex and customizable designs in fields such as architecture, engineering, and product design. It enables quick and efficient exploration of design variations and updates.”*

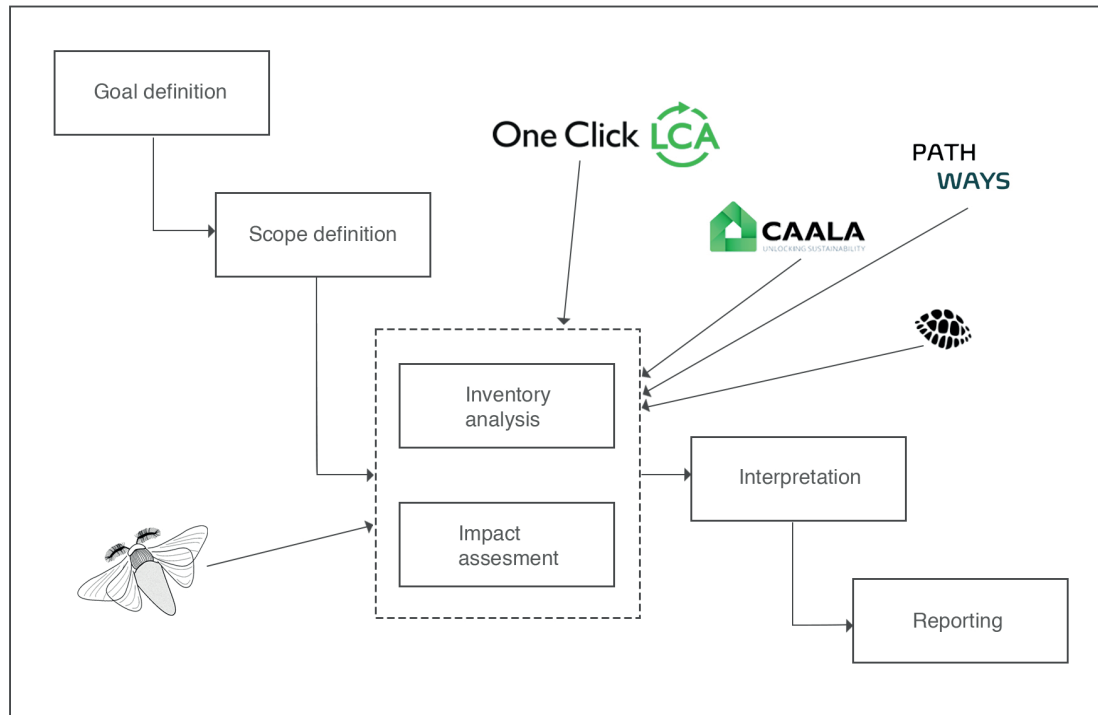


Figure 5 Parametric LCA tools integration in LCA framework, the figure was redrawn based on the source: *Bombyx – A design-integrated parametric tool for real-time Life Cycle Assessment*. (October 2020). Research Collection. Chair of Sustainable Construction. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/456414/20201005_Bombyx_Alina_Galimshina.pdf?sequence=1.

Parametric design is a valuable approach for managing uncertainties in the early design stage, offering benefits like rapid generation, comparison, and evaluation of design alternatives. It also enables adaptability to changing project requirements and optimization possibilities. This sets it apart from other LCA methods, including generic tools, spreadsheet tools, online component catalogs, and Building Information Modeling (BIM) based tools (Sawén et al., 2022)⁸.

In the article titled “Tool characterization framework for parametric building LCA” by Sawén, T., Magnusson, E., Sasic Kalagasidis, A., & Hollberg, A. (2022), the authors focus on assessing various parametric LCA tools. They establish the following criteria for their study:

- They only consider tools that perform LCA.
- They limit their selection to tools that have been readily available and updated within the last five years (the article was published in 2022).
- The investigation is restricted to tools designed for use with Grasshopper®.
- The evaluation is conducted from the perspective of architects involved in the early design stage.
- The assessment is qualitative, focusing on the potential for integration into archi-

⁸ Sawén, T., Magnusson, E., Sasic Kalagasidis, A., & Hollberg, A. (2022). *Tool characterisation framework for parametric building LCA*. Earth and Environmental Science.

tectural design workflows rather than quantitative precision.

- Tools are evaluated based on sample scripts and test cases, rather than real design processes.

They classified tools classification based on how the tools interact with design software (as it shown in the Figure 6).

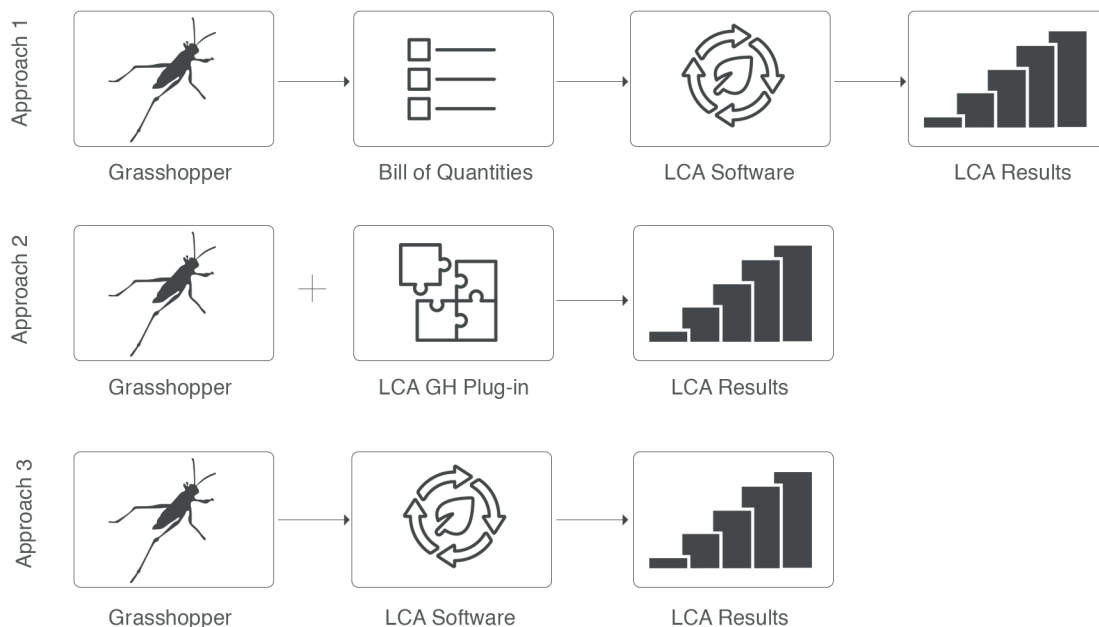


Figure 6 Classification of approaches for LCA integrated in a parametric design environment (Grasshopper), the figure was redrawn based on the source: Säwén, T., Magnusson, E., Sasic Kalagasidis, A., & Hollberg, A. (2022). *Tool characterisation framework for parametric building LCA*. Earth and Environmental Science.

In approach 1, geometry is created in Grasshopper (GH), converted into a bill of quantities in spreadsheet format, and used as input for external LCA software.

In approach 2, all aspects, including geometry, material choices, and calculations, are handled within the Grasshopper environment.

In approach 3, the process involves exporting Rhino or Grasshopper geometry to an external engine for LCA calculations.

The evaluation of these approaches helps establish a comprehensive comparison of the tools. In this study, nine categories were defined to characterize the tools, tailored to their integration in an architect's workflow, though the specific categories and explanations are not provided in the sentence (as it shown in Figure 7).

- The user persona for evaluating the tools in terms of their suitability for architects in the early design stage was defined with the following assumptions:
- The user is an architect with basic skills in Rhino and Grasshopper.
- The user has knowledge of fundamental LCA principles and building performance indicators.
- The user's primary interest is in assessing design alternatives during the early design phases.

- The user has limited time and effort available for conducting the analysis, often in scenarios like client meetings or design competitions.

It is assumed that the core of the script has already been created, and the user’s role is to adapt an existing script to the specific project requirements.

| Category | Characterization parameters | Explanation |
|--------------------------------------|---|---|
| Required knowledge | Low, moderate, high | LCA knowledge level needed to use the tool based on the user persona. |
| Geometry input | Surface, volume, curves | Type of Rhino/Grasshopper geometry accepted by the plug-in. |
| Default settings and adaptability | High, moderate, low | Possibility to adapt the built-in predefined settings. For example: change database, add materials, change scope of LCA. |
| Modelling level | Material, component, building | Level where one can start an LCA. Are there predefined materials, component and/or building specifications. |
| Output of results | Report, charts, surface coloring | Visualization of LCA results. The results processed into a report, charts and or surface coloring (hotspot). |
| Intended application | Education, design evaluation, complete assessment | Specify the purpose of the development and use of the tool. |
| Data source | Material database | Specify the database that is used and eventual possibility to use other databases or import own materials and components. |
| LCA modules | A1-A3; A4-A5; B1-B7; C1-C4; D | Specify the database that is used and eventual possibility to use other databases or import own materials and components. |
| Impact categories in addition to GWP | Yes / No | Impact categories included in the plug-in beyond GWP. |

Figure 7 Categories used to characterize the parametric LCA tools, the figure was redrawn based on the source: Säwén, T., Magnusson, E., Sasic Kalagasidis, A., & Hollberg, A. (2022). *Tool characterisation framework for parametric building LCA*. Earth and Environmental Science.

After the all researches and classifications, authors started to test case and they have found 13 parametric LCA tools; four of them (BHom LCA toolkit, Bombyx, Cardinal LCA, Tortuga) were chosen for in-depth characterization because they met the criteria of being free and open-source plug-ins, demonstrating a high level of maturity and the potential for seamless integration into early-stage design processes. These selected tools have Approach 2 due to these criterias.

In Figure 8, the LCA tools can be explored by their updated years, developers, scopes, and their country of origin. The bold entries represent the selected LCA tools for detailed observation, while the red entries symbolize additional information added since the study conducted in 2022, reflecting new updates. Additionally, the different approaches can be observed, with Approach 2 symbolizing **parametric LCA tools**.

In Figure 9, the four selected parametric LCA tools are compared. The study and its findings are highly valuable for identifying a suitable parametric tool to be used in a case study.

| Tool | Year | Developer | Scope | Type | Country |
|-------------------------|-------------|---|------------|----------|--------------------|
| BHoM LCA toolkit | 2020 | Fisher A. and May R., Buro Happold | LCA | 2 | UK |
| Bombyx | 2023 | ETH Zürich | LCA | 2 | Switzerland |
| CAALA | 2021 | Hollberg A., CAALA GmbH | LCA | 3 | Germany |
| Cardinal LCA | 2021 | Chen J., Kharbanda K., Loganathan H. | EC | 2 | USA |
| COVE | 2021 | cove.tool | LCA | 3 | USA |
| E2B2 LCA tool | - | IVL Svenska Miljöinstitutet AB | EC | 3 | Sweden |
| EPiC | 2022 | Stephan, A. and Prideaux, F., KU Leuven | LCA | 2 | Belgium |
| IDGB | 2016 | Department of Civil Engineering, DTU | LCA | 2 | Denmark |
| LCA tool 1 | 2021 | Berger-Vieweg L. | LCA | 2 | Sweden |
| LCA tool 2 | 2021 | Tjäder M. | LCA | 2 | Sweden |
| One Click LCA | 2023 | Bollinger+Grohmann, One Click LCA | EC | 2 | Finland |
| Tortuga | 2016 | Thumfart M. | EC | 2 | Germany |
| ZEB-tool | 2019 | Norwegian ZEB research centre | LCA | 1 | Norway |

EC: Embodied Carbon
LCA: Life Cycle Assessment

Figure 8 LCA tools, the figure was redrawn based on the source: Säwén, T., Magnusson, E., Sasic Kalagasidis, A., & Hollberg, A. (2022). *Tool characterisation framework for parametric building LCA*. Earth and Environmental Science.

The BHoM LCA toolkit offers a wide range of functionalities but demands a high level of expertise. When considering the importance of the decisions made by architects during the early design stages, it becomes apparent that tools designed to collaborate with architects who have limited experience in LCA can facilitate the effective integration of LCA into the decision-making process. This enables architects to focus on the design process while still making informed assessments of the environmental impact of their designs. Consequently, integrating the other tools can result in a smoother and more streamlined process for architects.

When comparing these three tools, it's possible to directly observe the included modules. While Cardinal LCA and Tortuga focus solely on calculating embodied emissions, the Bombyx tool offers the potential for a more comprehensive assessment. In this aspect, Bombyx excels in offering screening LCA during the early design stages, facilitating the acquisition of results that closely approximate those of a comprehensive and final LCA.

| Category | BHoM LCA toolkit | Bombyx | Cardinal LCA | Tortuga |
|--------------------------------------|--|---|---------------------------------------|---------------------------------------|
| Required knowledge | Moderate-high | Low-moderate | Low | Low-moderate |
| Geometry input | Surface, curves, volumes, points, etc. | Surfaces | Surfaces, volumes | Surfaces, volumes, curves |
| Default setting and adaptability | High adaptability of default settings | Moderate adaptability of default settings | Low adaptability of default settings | Low adaptability of default settings |
| Modelling level | Material | Material, component, building | Material | Material |
| Output of results | Impact divided into impact categories | Impact divided into impact categories | Report, bar charts, surface colouring | Impact divided into impact categories |
| Intended application | Design evaluation | Education, design evaluation | Design evaluation | Design evaluation |
| Data source | Quartz, ICE, EC3, Boverket, Ökobau.dat, EPIC | KBOB, EcoKomposit, Bauteilkatalog | EC3, ICE V3.0 | Ökobau.dat, Quartz |
| LCA modules | All modules available | A1-A3; A4-A5; B4; B6; C1-C4 | A1-A3 | A1-A3; C3;D |
| Impact categories in addition to GWP | Yes | Yes | No | Yes |

Figure 9 Characterisation of the LCA tools investigated in detail., the figure was redrawn based on the source: Säwén, T., Magnusson, E., Sasic Kalagasidis, A., & Hollberg, A. (2022). *Tool characterisation framework for parametric building LCA*. Earth and Environmental Science.

Comparison between conventional LCA and parametric LCA approaches

In the presentation of Bombyx that has made by Alina Galimshina, (“Bombyx”, 2020)⁹, who is Postdoctoral Researcher at ETH Zurich, the idea of the parametric LCA is illustrated and they are redrawn in the Figure 10 and 11. These figures serve to compare the conventional LCA approach with the parametric LCA approach.

In the conventional LCA approach, the design is defined with its geometry, 2D plans, materials, and a bill of quantities. The geometry and plans are used by an energy consultant to calculate the building’s energy demand, while environmental impact calculations require additional steps. An LCA expert uses the bill of quantities list to calculate the environmental impact. This process involves different professionals, and making design improvements can be challenging since the same procedure must be applied repeatedly.

⁹ Bombyx – A design-integrated parametric tool for real-time Life Cycle Assessment. (October, 2020).Research Collection. Chair of Sustainable Construction. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/456414/20201005_Bombyx_Alina_Galimshina.pdf?sequence=1.

In contrast, **the parametric LCA approach** allows architects to obtain design results at the very beginning of the design process by defining the geometry as a 3D model without detailed plans. By matching the design with materials, architects can simultaneously obtain results for both energy demand and environmental impact, streamlining the process and reducing the need for multiple professional inputs.

The parametric approach to LCA enables architects to understand the energy demand and environmental impact of their design. This helps them modify, improve, or diversify their design choices, turning LCA into **a decision-making tool**.

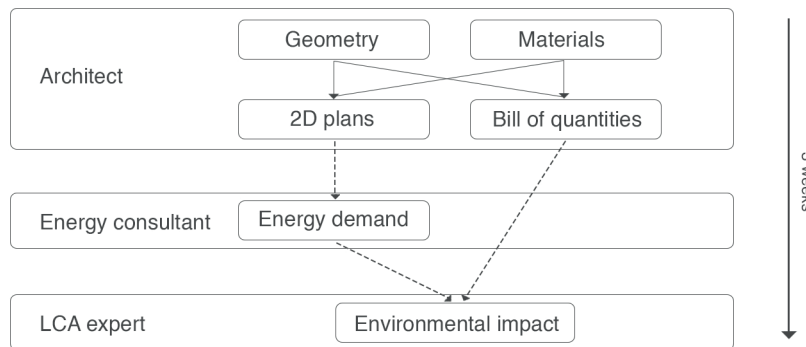


Figure 10 Conventional approach to LCA, the figure was redrawn based on the source: *Bombyx – A design-integrated parametric tool for real-time Life Cycle Assessment*. (October, 2020). Research Collection. Chair of Sustainable Construction. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/456414/20201005_Bombyx_Alina_Galimshina.pdf?sequence=1.

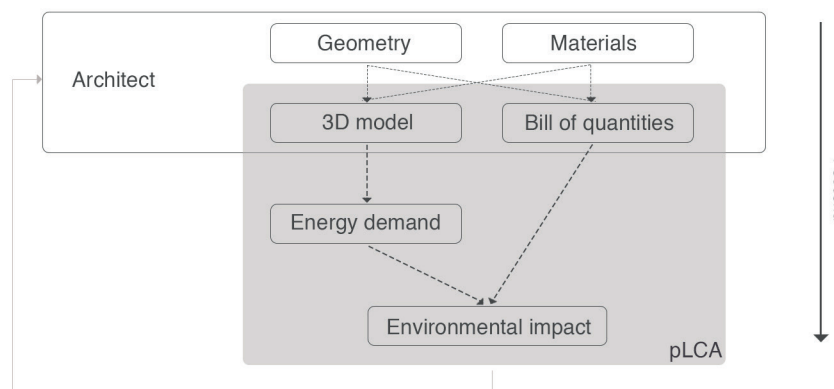


Figure 11 Parametric approach to LCA, the figure was redrawn based on the source: *Bombyx – A design-integrated parametric tool for real-time Life Cycle Assessment*. (October, 2020). Research Collection. Chair of Sustainable Construction. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/456414/20201005_Bombyx_Alina_Galimshina.pdf?sequence=1.

WHY BOMBYX?

*Considering the EeBGuide levels of the LCA scheme, it is crucial to apply the LCA approach in the early design phase and obtain results that closely align with the final design. Given the significance of the A1-A3 and B6 life cycle modules in contributing to the environmental impact, the **Bombyx tool** was selected for a case study due to its inclusion of these modules and the required knowledge of LCA. The tool will be used for conducting screening LCA during the early design phase.*

*In earlier versions, all environmental impacts were calculated solely within the Bombyx tool. However, in the latest version of the Bombyx tool, it has been integrated with the **Hive tool** to enhance the accuracy of results related to the use phase. The upcoming section will provide a detailed explanation of this integration and workflow.*

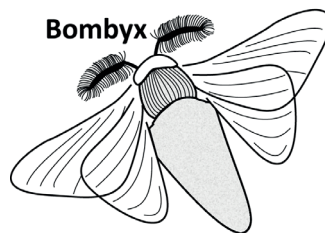


Figure 12 Bombyx tool, source: <https://www.food4rhino.com/en/app/bombyx>



Figure 13 Hive tool, source: <https://www.food4rhino.com/en/app/hive>

2.2. Bombyx and Hive tools

Bombyx is a design-integrated tool for Life Cycle Assessment tool which aims to make whole building LCA of structures **simplified** at the **early design stages**. Bombyx is based on the 3D software Rhinoceros and Grasshopper as a Visual Programming Language (VPL)^{10 11}.

*“ **Rhinoceros** is a commercial 3D computer graphics and computer-aided design (CAD) application software;*

***Grasshopper** is a visual programming environment tightly integrated with Rhino’s 3D modeling tools. Grasshopper requires no knowledge of programming or scripting, but still allows designers to build generative forms from the simple to the awe-inspiring.*

-<https://www.rhino3d.com/>

A modular approach which makes the calculation easier and faster is used to integrate LCA throughout the design process and the current version of Bombyx uses the Swiss LCA database on the building materials to focus on the assessment of **embodied impacts**¹⁰.

The new version of Bombyx tool (2.1.0) is shared on the food4rhino website on the date of 2023-11-21; Hive tool which works with Bombyx to get **operational emission results** is integrated in the latest version as a main difference from the previous versions. Chair of Architecture and Building systems and Chair of Sustainable construction ETH Zurich teams share a guide and example files with on the website to explain the integration workflow.

Hive is a simplified energy simulation tool and the plugin is conceptually intended to be designed as an input-output framework: the user can concentrate on the building design (input) and its impact on energy performance (output), while complex simulation parameters and settings are hidden (still accessible) from the designer in a simulation core. The advantage of such a software architecture is that third-party grasshopper components is employed in **a modular way**¹¹.

Both tools offer a user-friendly workflow for conducting LCA, enabling a focus on design with minimal effort, particularly beneficial for architects.

2.2.1. Bombyx Workflow

In the Figure 14, the Bombyx workflow that is shared by developers is redrawn. Ac

¹⁰ Bombyx-ETH. Github. n.d. <https://github.com/Bombyx-ETH/Bombyx> (accessed 09 14, 2023).

¹¹ Hive-Bombyx team attends the Rhino User Meeting in Basel. Architecture and Building Systems. n.d. <https://systems.arch.ethz.ch/home/hive-bombyx-team-attends-the-rhino-user-meeting-in-basel> (accessed 09 15, 2023).

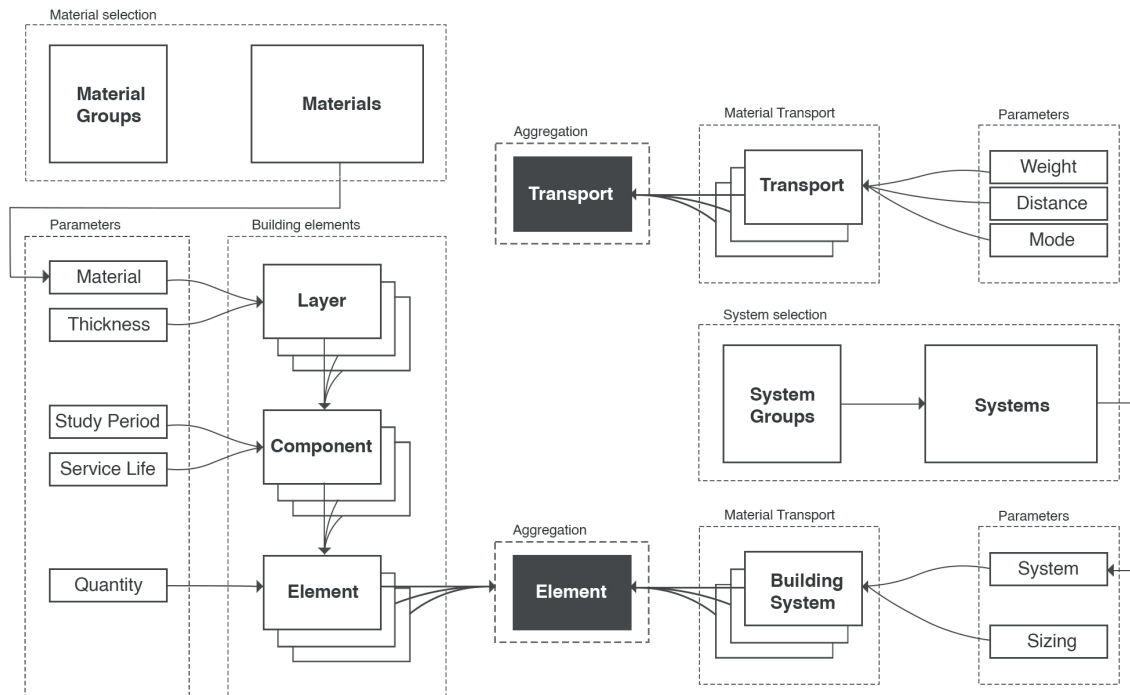


Figure 14 Bombyx workflow, the figure was redrawn based on the source: <https://www.food4rhino.com/en/app/bombyx#lg=1&slide=0>

cordance to the figure, life cycle modules which can be included to the early LCA process can be noticeable; these are production to end of life (A1-A3, C1-C4) and the replacement of building components (module B4). Additionally, the construction stage (A4-A5 modules, inclusive of transport of the materials on site and erection processes) are the modules that can be involved. As will be evident in the subsequent sections, Hive integration facilitates the incorporation of operational energy consumption (module B6).

The early LCA process commences with material selection from various material groups. Each material, along with its thickness, contributes to the creation of a layer.

For instance, cork may be selected as an insulation material with a thickness of 200 mm. Parameters such as study period and service life are then applied to generate component impact assessments, considering the properties derived from the layers (e.g., insulation with a 30-year replacement cycle). Ultimately, the element is constructed by defining its quantity in square meters, based on the component's characteristics.

This process leads to collect building elements. On the other hand, systems are selected from system groups. The chosen system and its sizing (square meters) produce building system (e.g.; heating system). The building elements and system features combine and the building impact can be defined.

Furthermore, emissions associated with transportation can be incorporated into the assessment; weight of the materials, distance between construction site and mode (vehicle) create transportation features (e.g.; 100-ton km via Truck). The all transportation properties become together and create the emissions because of transporta-

tion.

In addition to the theoretical explanation of the Bombyx workflow, it is essential to provide a practical demonstration of the integration of the Bombyx and Hive tools in the design process within the VPL software.

2.2.2. Bombyx and Hive Workflow in the VPL Software

Figure 15 shows the process of intergration of the Bombyx and Hive tools in Garsshopper environment. Basically four main stages are shown; Building Model (A), Bombyx Definition (B), Hive Definition (C) and Results (D). The stages are also divided into seven steps by developers of the tools to explain the process briefly.

In addition, in the figure, the boxes represent the components of the Bombyx and Hive plugins, and the connections between the components are simplified.

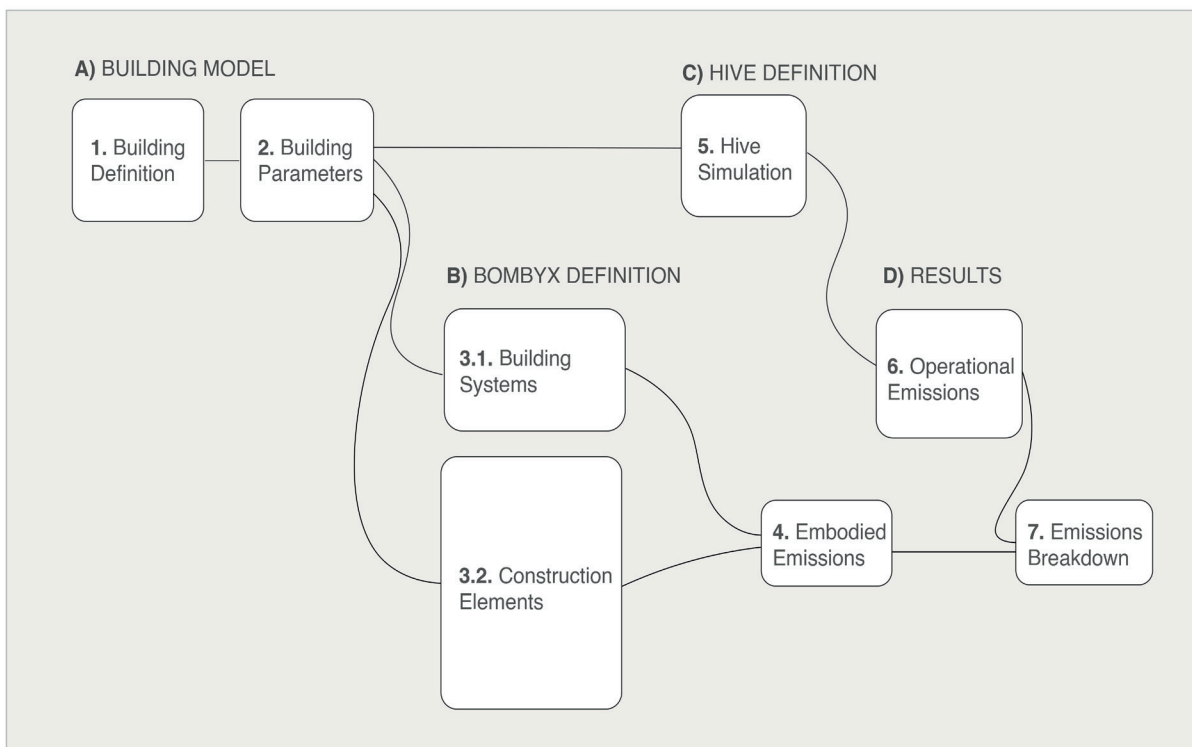


Figure 15 Integration of the Bombyx and Hive tools in Grasshopper Environment

Step 1: Building Model

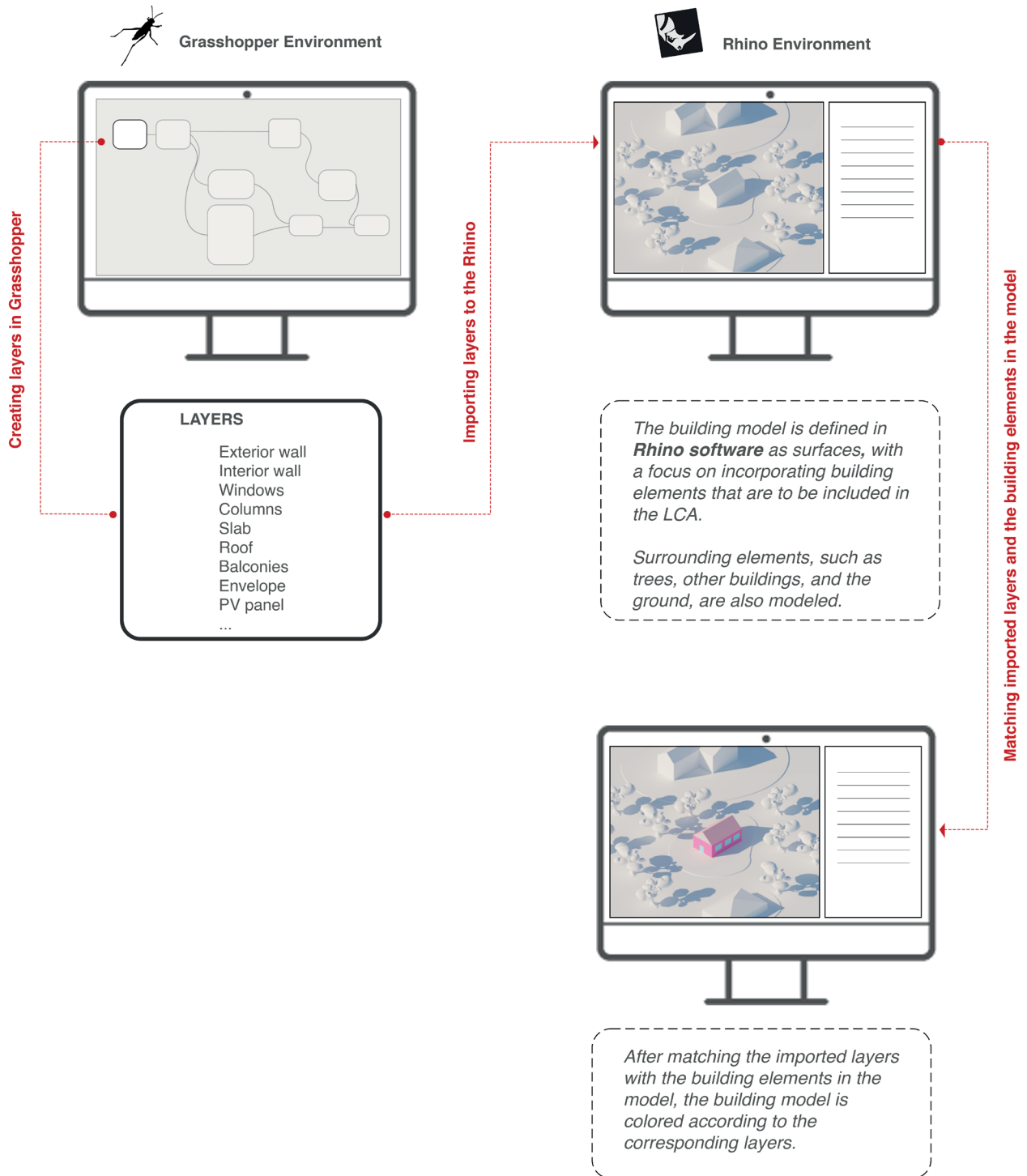


Figure 16 Building model definition

Bombyx enables practical calculations with both model options. It is possible to create geometries parametrically in Grasshopper or manually on Rhino surfaces. In this thesis study, the building model will be created manually in Rhino software.

In Figure 16, regarding the option to create the model in Rhino, building elements such as exterior walls, interior walls, windows, columns, slabs, roofs, balconies, envelopes, PV panels, etc., are generated in Grasshopper. These elements are then imported into Rhino as layers, and the model is constructed by aligning with these layers as surfaces. This is done to ensure that each imported layer matches the building elements in the model. It is essential to follow a metric workflow when creating all drawings.

Through this procedure, the geometries in the Rhino building model are imported into the Grasshopper environment to utilize the Bombyx and Hive tools.

Step 2: Building Parameters

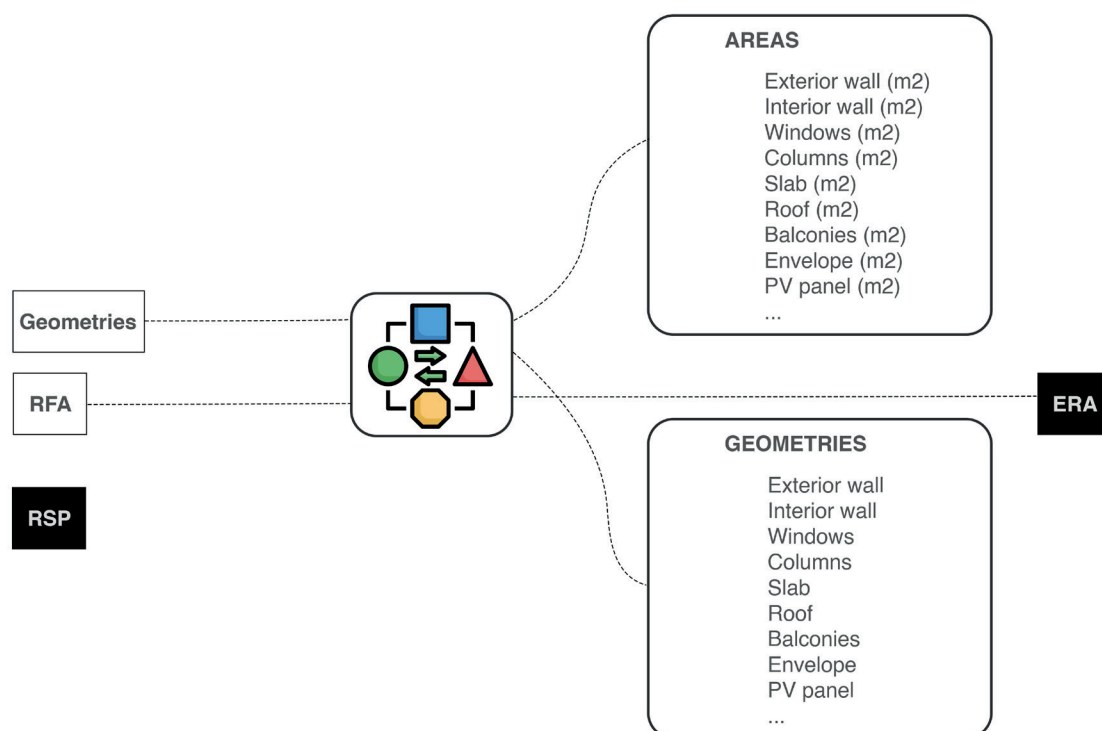


Figure 17 Building parameters

Bombyx operates with areas measured in square meters, whereas the Hive tool works with surfaces and meshes. Figure 17 shows that the geometry data from the building model is adapted for use with the Bombyx and Hive tools, including the incorporation of the Reference Area Factor (ERA Factor). Additionally, this process allows for the calculation of the Energy Reference Area (ERA) in square meters for further analysis.

In this stage, the Reference Service Period (RSP) is also defined.

The RSP and ERA factor are highlighted with a different color because their values will be the same for all related calculations.

The building parameters are established in this manner for use in the definitions of Bombyx and Hive tools.

Step 3: Building Elements

Step 3.1: Building Systems

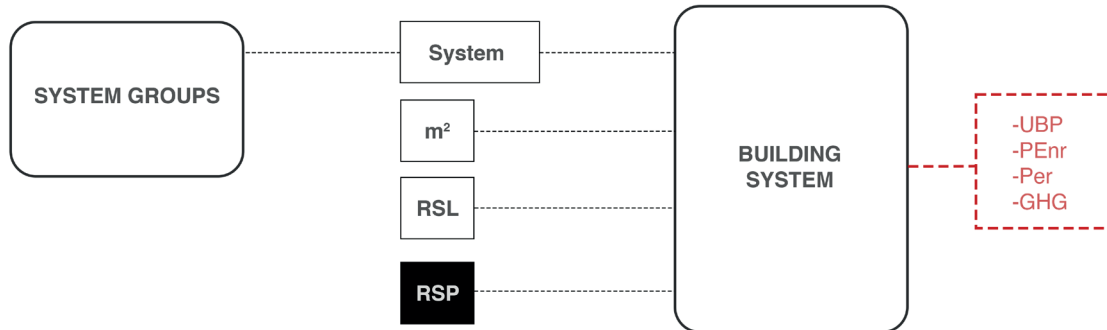


Figure 18 Building systems

This step involves the definition of system groups, including electrical, heating, ventilation systems, and sanitary systems. As shown in Figure 18, the building services are selected from service groups, and parameters such as Reference Service Life (RSL) and RSP values are included in the calculation along with the area of the service group. The same steps can be applied to each building system.

At this stage, it is possible to view the properties of building service systems according to impact categories, such as UBP (Umweltbelastungspunkte), PEnr (Primary Energy nonrenewable), Per (Primary Energy renewable), and GHG (Greenhouse Gas).

Step 3.2: Building Construction Elements

Each building element consists of component properties, and each component is created by incorporating layer properties. Each layer, in turn, is composed of material properties.

Figure 19 depicts the selection of materials from material groups, which are categorized into concrete, brick, metal building materials, wood and wooden products, thermal insulation, etc. At this level, the characteristics of materials, such as density and thermal conductivity, can be observed and assessed.

It is essential to emphasize that, currently, only materials available in the database can be chosen; custom materials cannot be created. This feature aids in obtaining and evaluating results that closely approximate the exact outcomes derived from the design.

Material properties are combined with material thickness to determine layer properties. Layer properties, along with RSP, RSL values are entered to generate component properties.

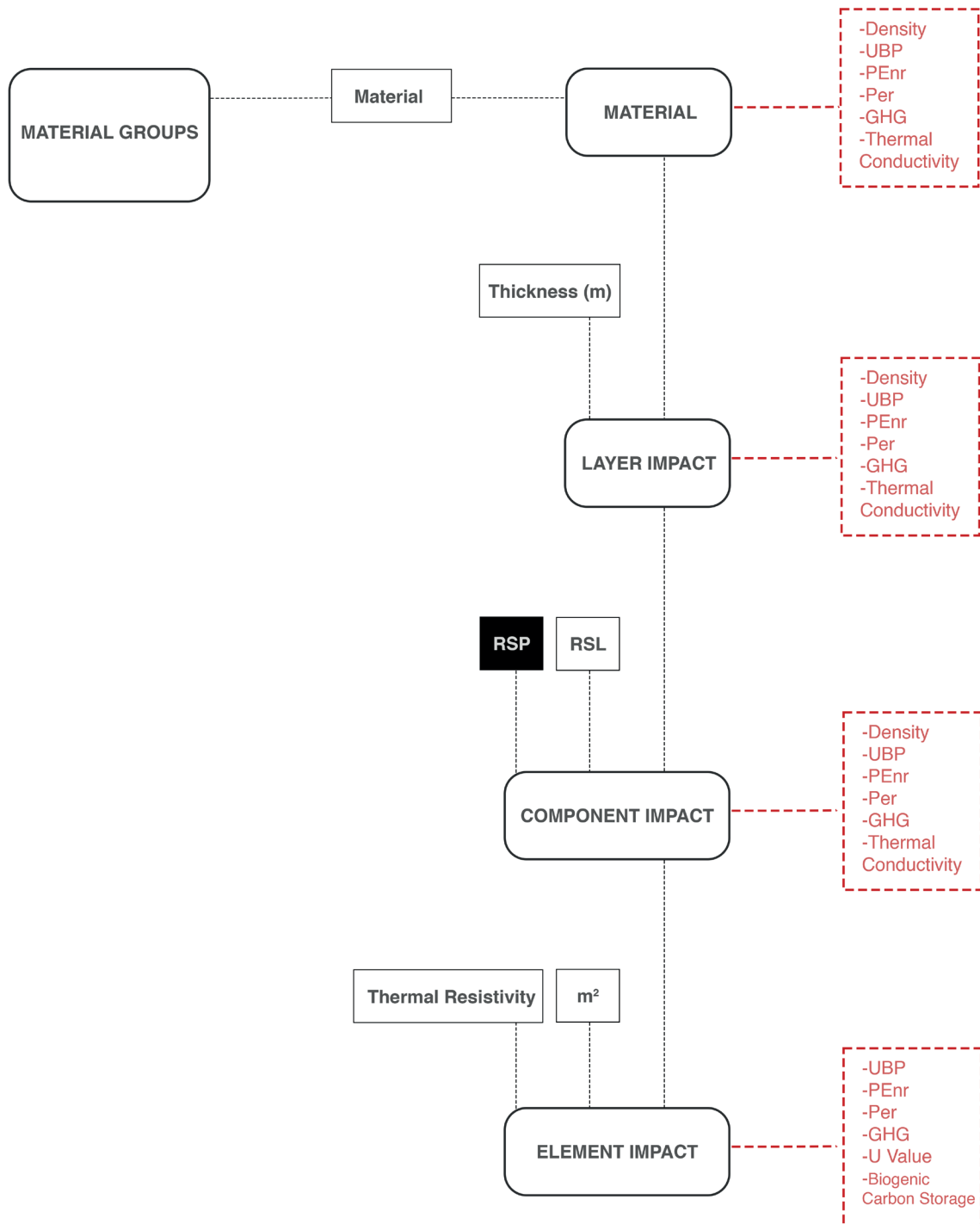


Figure 19 Building construction elements

All component properties, along with the thermal resistivity of the element (they defined inside of the Bombyx tool as external wall, slab, roof, etc.) and the surface area of the element derived from the general building parameters, are incorporated into the calculation to determine the impact of each element.

The impact categories that can be observed in this phase include UBP (Umweltbelastungspunkte), PEnr (Primary Energy nonrenewable), Per (Primary Energy renewab-

le), GHG (Greenhouse Gas), U Value and Biogenic Carbon Storage.

It is important to mention that the U-Value can be observed in this step, and it can help interpret the U-Value in line with the assessment's intention.

The impacts of all building elements intended for LCA evaluation are generated using the aforementioned steps. To obtain the building's impact, the properties of all elements are included in the calculation.

Step 4: Embodied emissions

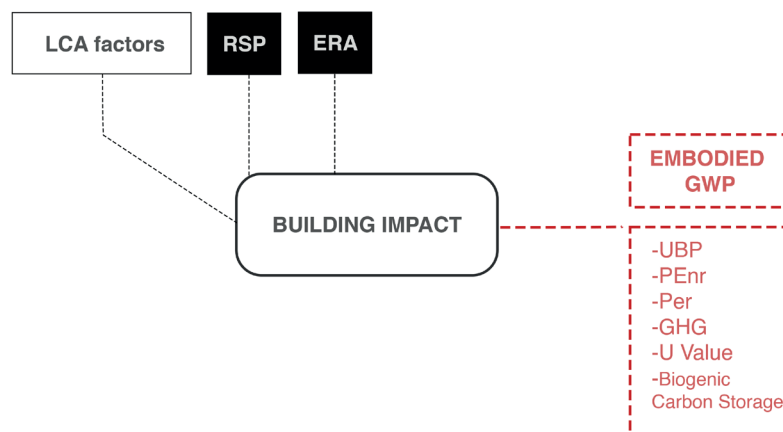


Figure 20 Embodied emissions

RSP value and Net Floor Area (NFA) are entered to determine the building's impact with the LCA factors that comes from element impact (as shown in Figure 20).

Global Warming Potential (GWP) is one of the impacts calculated in this phase, along with other impact categories. Embodied emissions originating from the building and systems are computed separately by following these steps.

Step 5: Hive Simulation

Embodied emissions which rise from building and system are calculated by using Bombyx tool; the Hive tool is incorporated for the operation emission results and it helps to simulate energy.

Hive set up consists of three main components; Hive Input Environment, Hive Input Building and Hive Input Energy Systems.

In Figure 21 the following process is illustrated; Hive Input Environment is a component that epw file, ground, context (trees, buildings etc.) and static shading are defined as meshes.

Hive Input Building consists of building volume (envelope), window and floor surfaces that comes from the building parameters. Inside of the component it is possible to



Rhino Environment

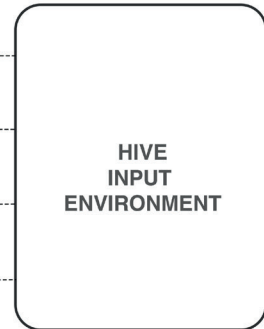


Weather File (epw)

Ground

Context

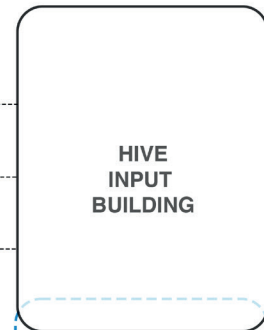
Static Shading



Building Volume

Windows

Floors

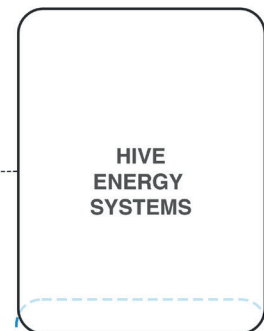


- Building Use Type
- Room Type
- Building Quality
- Building Construction Type

- Properties of Building Envelope (area, U-Value, g-Value etc.)



PV panels



- Properties of HVAC Systems

Figure 21 Hive main components

observe building envelope properties; wall, roof, slab and window features like U-value, g-value, emissions etc. These values are derived from the combined inputs to the Hive Building component.

Additionally, the building use type (residential, hotel, office, school etc.) , room type, building quality, building construction type can be selected.

The Hive Input Energy Systems component allows for the inclusion of HVAC systems. The technologies are added to the component by double-clicking, and it's important to note that only certain HVAC systems are defined for calculation in this version of Bombyx and Hive integration. The technologies currently included in the calculation are Chiller and ASHP (Air Source Heat Pump), and no other choices are available. The Bombyx team has suggested changing the efficiency of these technologies with the efficiencies considered in the design. Additionally, if PV systems exist, their total geometry on the building (as mesh) and their efficiency should be included in this component.

Additionally, the Rhino environment is also illustrated to demonstrate the impact of Hive definitions in the Rhino environment.

The data flow begins with the central distributor component (Hive Distributor), which is linked to these three component outputs.

Hive Distributer gathers all Hive inputs from outside the simulation core and outputs them independently based on their class type. The user can just enter all hive input items into the same node without regard for their forms (Waibel et al., 2021)¹² (Figure 22).

Outputs of Hive Distributer are connected with Hive Core which is component to calculate the energy demand inside. Additionally, it is possible to see **real time energy simulation** in the Grasshopper environment.



Figure 22 Hive Distributer

Step 6: Operational Emissions

In this step, Hive energy results are utilized to calculate operational emissions by incorporating Bombyx plugin components (as it is shown in Figure 23). The heating

¹² Waibel, C., Thomas, D., Elesawy, A., Hischier, I., Walker, L., & Schlueter, A. (2021). *Integrating energy systems into building design with Hive: Features, user survey and comparison with Ladybug and Honeybee tools*. Zurich, Switzerland: International Building Performance Simulation Association.

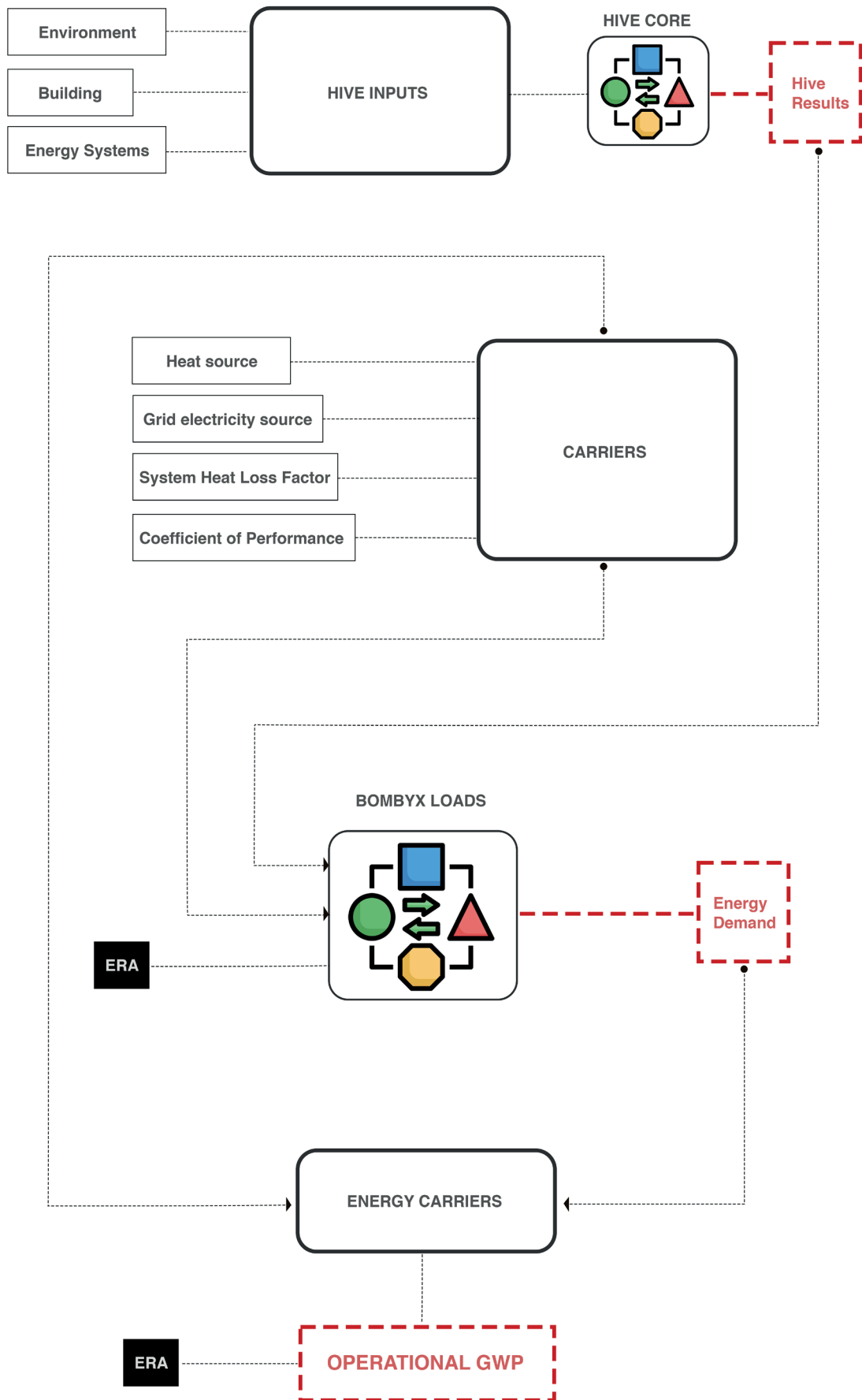


Figure 23 Operational emissions

system and grid electricity source are defined as sources.

In addition to that, the System Heat Loss Factor, which is the ratio of the surface area that can lose heat (the thermal envelope) to the floor area that gets heated ¹³, and the Coefficient of Performance, which is a measure of efficiency for HVAC systems based on their heating output ¹⁴, are inputted to the energy carrier component.

The data derived from Hive results, including Energy Reference Area (ERA), are combined with the data obtained from the carriers. This process transforms all data into a suitable form (energy demand), facilitating the calculation of operational emissions.

To calculate operational emissions, heating and electricity demands, along with their respective characteristics obtained from the carriers' output, are integrated into the calculation. Additionally, ERA is also incorporated into the operational emission calculation.

Step 7: Emissions Breakdown

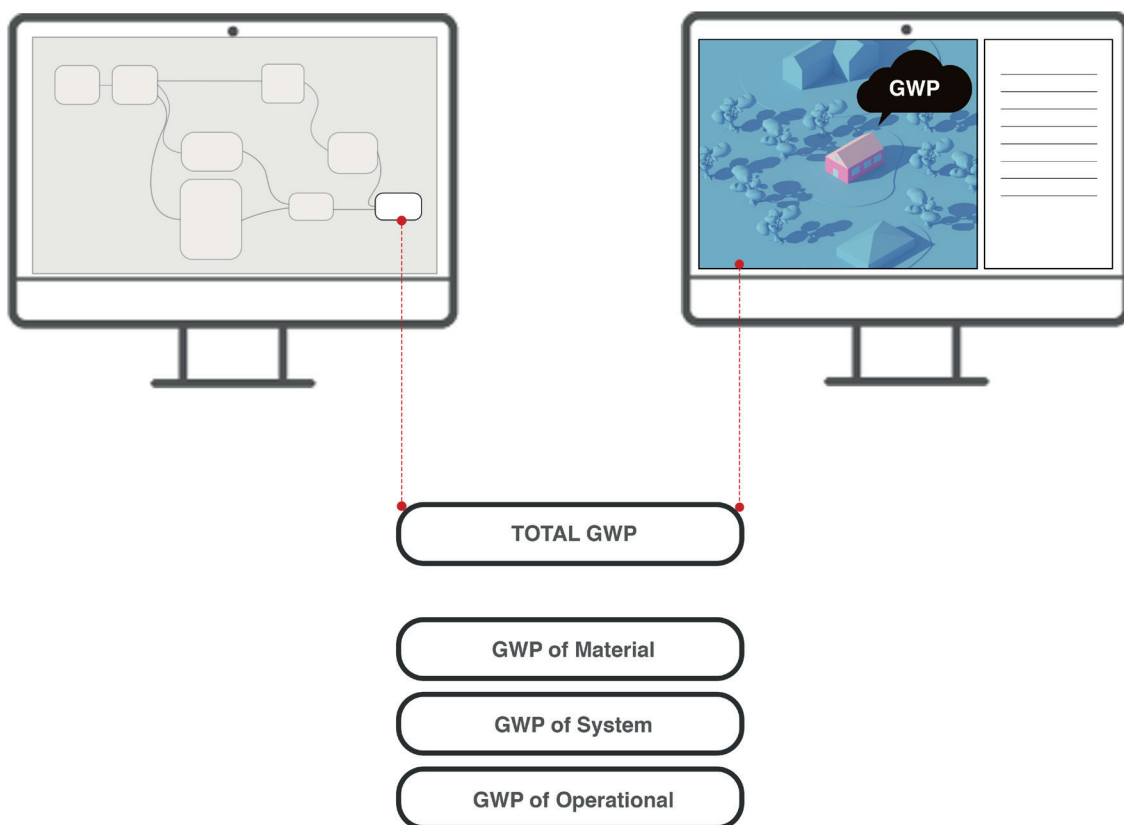


Figure 24 Emission breakdown

13 [https://www.greenspec.co.uk/building-design/heat-loss-form-factor/#:~:text=The%20Heat%20Loss%20Form%20Factor%20is%20the%20ratio%20of%20thermal,that%20gets%20heated%20\(TFA\).](https://www.greenspec.co.uk/building-design/heat-loss-form-factor/#:~:text=The%20Heat%20Loss%20Form%20Factor%20is%20the%20ratio%20of%20thermal,that%20gets%20heated%20(TFA).)

14 <https://dandelionenergy.com/resources/coefficient-performance-cop#:~:text=COP%20is%20calculated%20by%20>

As shown in Figure 24, embodied emissions; material embodied GWP and system embodied GWP and operational GWP can be illustrated separately and can be evaluated as total GWP according to the purpose of assessment. In addition, the results can be visualized in the Rhino and Grasshopper.

The entire workflow and all the components within the Grasshopper environment are depicted in Figure 25, summarizing the entire process.

Conclusion

The Bombyx allows modifications on the building features. The users can select alternative materials and construction systems, and quickly modify the geometry of the building while obtaining the calculated environmental impact in real-time (“A design integrated parametric tool”, 2019)¹⁵.

To be more specific, the building parameters (shape, orientation, window etc.), insulation materials (type, thickness, service life etc.), window types, PV systems (PV- Area, efficiency etc.), heating systems (oil, wood fibers, heat pump, CHP etc.) and more building features can be subject for creating an option to improve the design environmentally. Additionally, users can view the outcomes of their decisions instantly.

On the other hand, the Hive tool provides simple input and output user interface for low entrance barriers, real time impact visualization of design choices on building performance¹¹.

Certainly, with the Hive tool seamlessly integrated into the Bombyx tool, designers can visualize energy demand while also they calculate emissions stemming from materials, systems, and operations. **This integration empowers users to establish a connection between energy outcomes and emissions during the initial design stages.**

Additionally, these tools make the assessment process simpler and faster for users, particularly those who are not LCA experts, as they do not require extensive understanding of the Rhino/Grasshopper software.

The workflow of the thesis is illustrated in Figure 26. The thesis aims to select a case study for the application of parametric Life Cycle Assessment (LCA). The case study brief defines research subjects, helping to establish design strategies for the initial design proposal (referred to as “solution 0”). Research subjects also play a role in identifying specific needs for the design proposal, which can serve as a foundation for potential improvements.

Following the formation of the design proposal through conventional design methods, LCA parameters are determined while considering the boundaries set by the Bombyx and Hive tools. The design proposal is then enhanced by implementing a parametric LCA approach. In this process, parametric LCA tools are used as decision-making

¹⁵ *A design integrated parametric tool for real-time Life Cycle Assessment– Bombyx project.* (2019). Zurich, Switzerland: IOP Publishing.

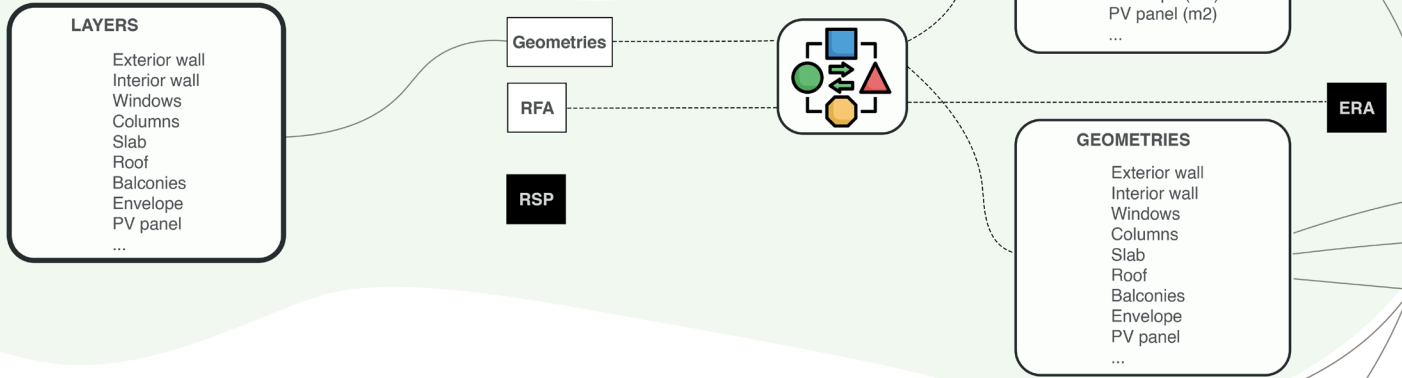
tools to achieve a well-balanced design in terms of emissions and energy demand.

The specific needs of the design define potential modifications for design improvement. All modifications are applied within the parametric Grasshopper environment, allowing real-time feedback on the results of these changes.

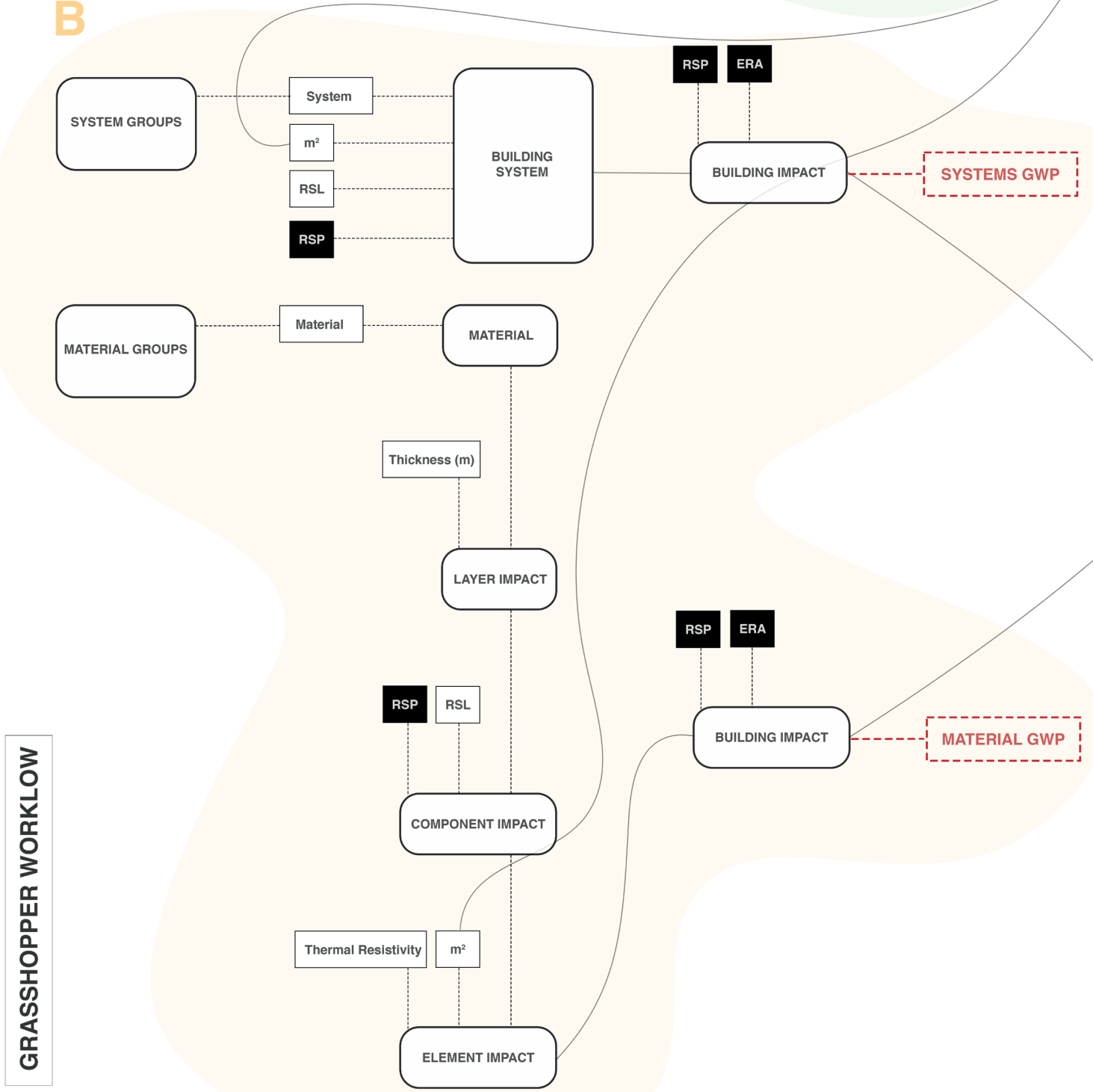
After all the optimum design solution between the Solution 0,1,2 is chosen in order to prepare for the final design.

Ultimately, the optimal design solution is selected among Solution 0, Solution 1, and Solution 2 to proceed with the final design.

A

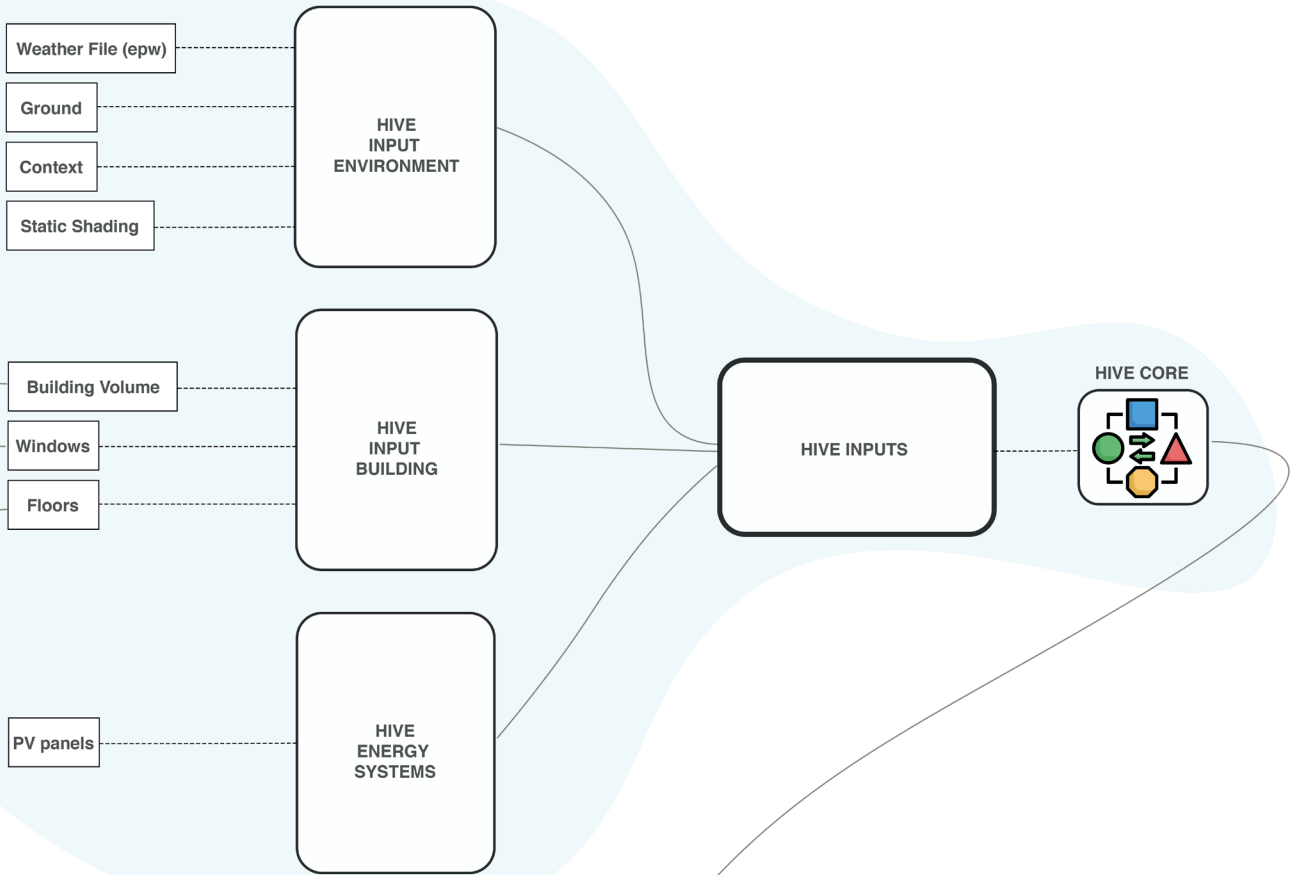


B



GRASSHOPPER WORKFLOW

C



D

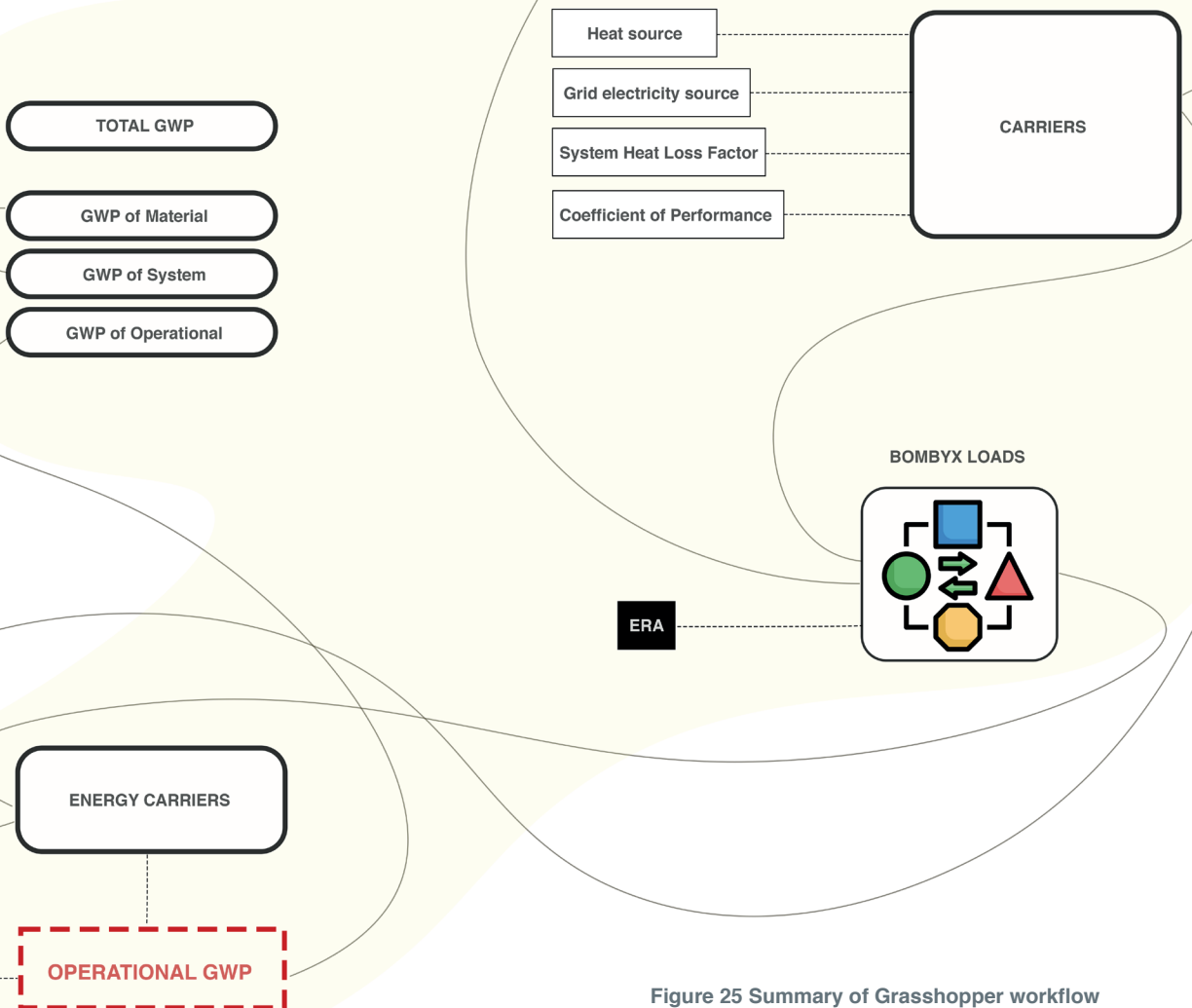


Figure 25 Summary of Grasshopper workflow

THESIS WORKFLOW

Conventional Approach:
WHICH design solution will be proposed?

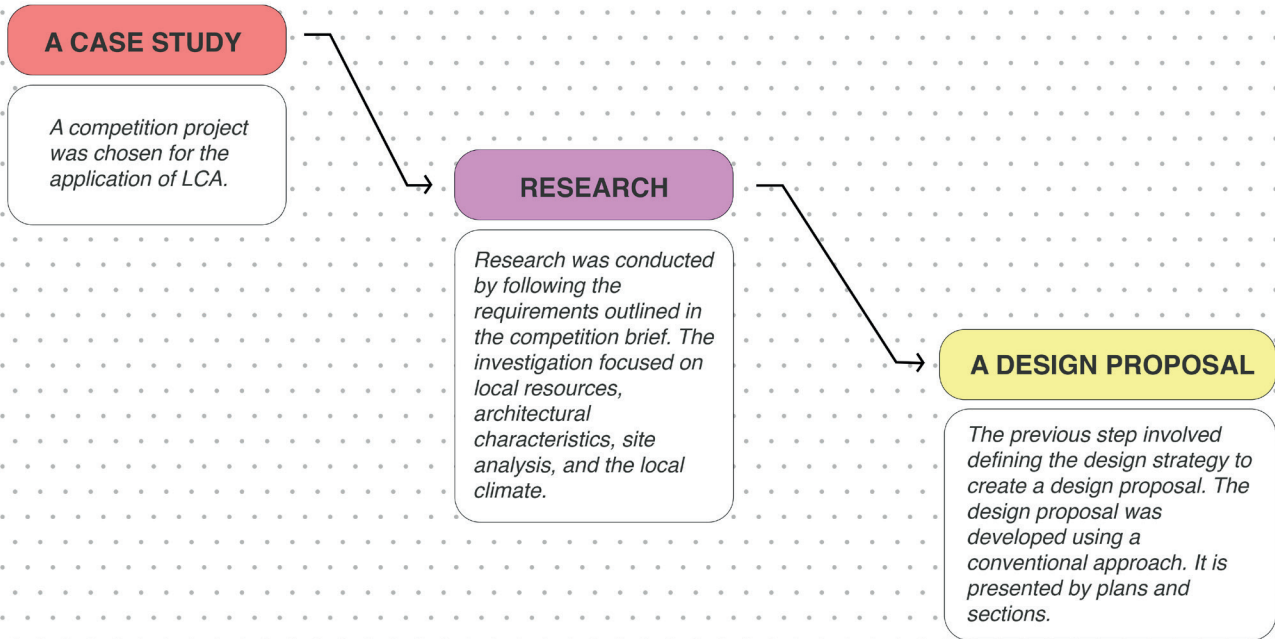
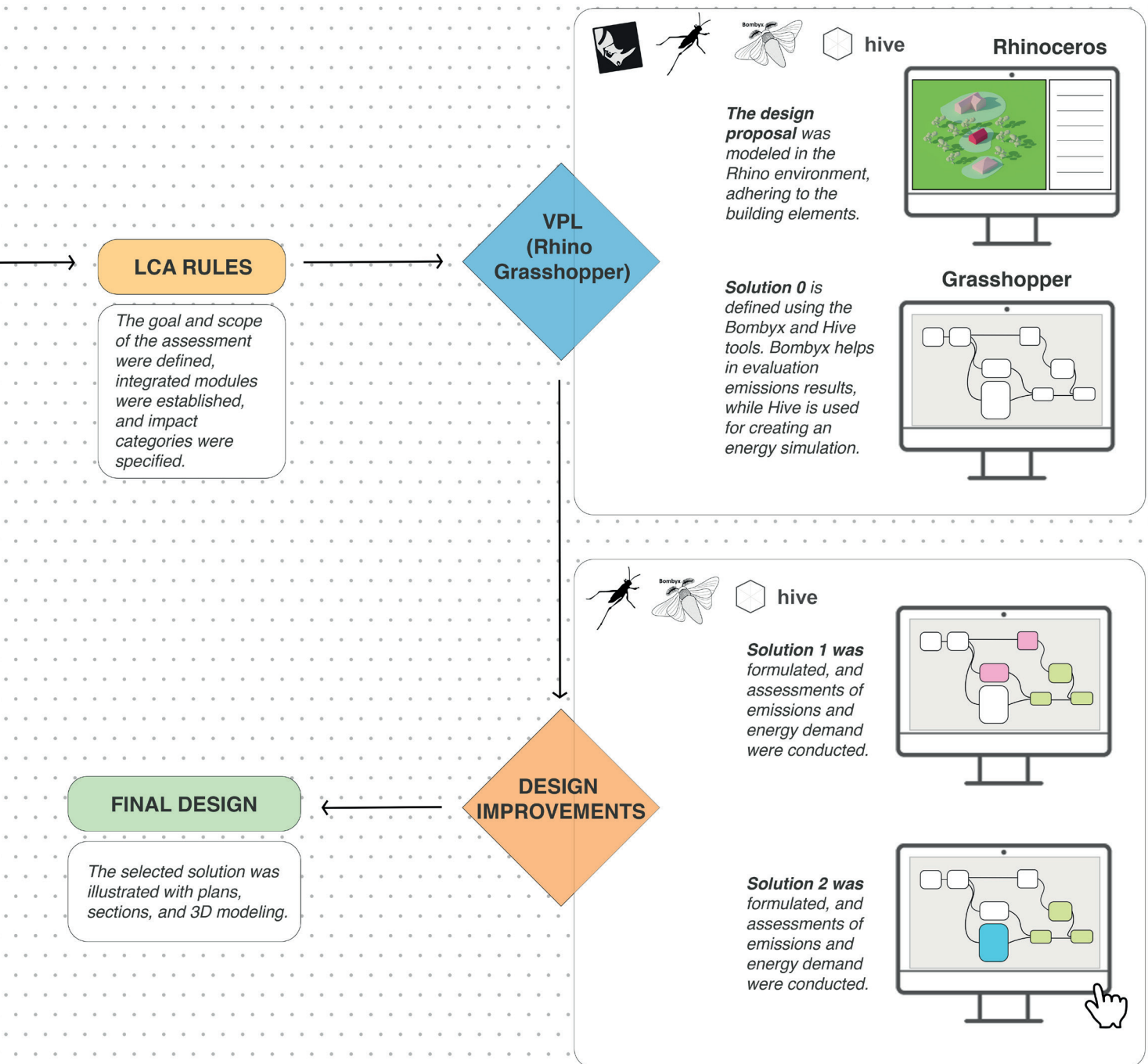


Figure 26 Thesis workflow

Parametric approach:

HOW can the design proposal be improved from an environmental perspective?



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<https://dandelionenergy.com/resources/coefficient-performance-cop#:~:text=COP%20is%20calculated%20by%20>

[https://www.greenspec.co.uk/building-design/heat-loss-form-factor/#:~:text=The%20Heat%20Loss%20Form%20Factor%20is%20the%20ratio%20of%20thermal,that%20gets%20heated%20\(TFA\).](https://www.greenspec.co.uk/building-design/heat-loss-form-factor/#:~:text=The%20Heat%20Loss%20Form%20Factor%20is%20the%20ratio%20of%20thermal,that%20gets%20heated%20(TFA).)

<https://www.renewableenergyworld.com/energy-efficiency/embodied-carbon-vs-operational-carbon-whats-the-difference-and-why-does-it-matter/#gref>

<https://www.rhino3d.com/>

www.eebguide.eu/eeblog/?p=430

Background

In order to implement parametric LCA methods in the early design phase, a competition project was chosen. The project's requirements and prominent components on the project are used to create the research subjects. The answers that are taken from the researches will be brought together to propose a design. The outcomes of each research topic can be located in their respective sections.

Background includes information that might be the inputs for screening LCA of design proposal. Furthermore, the findings are essential for determining which design enhancements can have a significant impact on the chosen case study.



Figure 1 Competition area, source: Google Earth Pro

3.1. The case study of a design competition: Yoga House in the Latvian Bog

Competition Brief

The competition project is conducted by architecture competition organizer Buildner Website. The aim is to design the yoga guest house in the Latvian bog which is surrounded by forest and is a few hundred meters from Baltic Sea Beach (Figure 1).

In the brief, Latvian natural features are underlined; especially with its wide beaches, rich biodiversity, and vast green forest.

‘Latvia is increasingly becoming a sought-after tourist destination, particularly for those looking for sustainable tourism locations. Moreover, while tourism generally is catching up after the pandemic, it is accelerating in Central-Eastern Europe, where it has grown by 18% since 2020¹.

It may be argued that the background for this competition to engage in sustainable tourism practices is being set by this increased interest.

The yoga house is considered an eco-tourism hotspot in the competition brief, eco-tourism and opportunities in Latvia is expressed;

‘Ecotourism places a strong emphasis on conservation, education, traveler responsibility and community participation. In addition to eco-tourism and sustainable travel trends being huge with contemporary tourists, and green building practices are be-

¹ *Yoga House in the Latvian Bog*. Buildner. <https://architecturecompetitions.com/yogahouseinthebog/brief> (accessed 05 16, 2023).



Figure 2 Slitere National Park, source: <https://www.getalper.com/slitere-national-park/>

ming more and more vital. Furthermore, Latvia, one of Europe's greenest nations, is the optimal location for designing a sustainable, eco-friendly yoga guest house ².

Connection between the competition area and Kolkasrags which is known in English as Cape Kolka is highlighted; Cape Kolka is a cape near the entry of the Gulf of Riga and it is the point at where the Gulf of Riga and Baltic Sea meet. There is one-hour drive distance between competition area and this important junction point. Traditional fishing villages, unspoiled wilderness hiking routes, and, for the truly daring, the opportunity to sail to an old-fashioned lighthouse built in 1875, are all available to visitors to Kolkasrags ².

For the Yoga House in the Bog competition, participants are asked to design **sustainable, eco-friendly, iconic yoga house design**. When user needs are taken into account; guests should **experience and connect with nature** during their stay, and while they **need shelter and protection from the elements** – high temperatures in summer and strong winds, rain and snow in the winter – the yoga house should make them **feel a part of the environment**, not separated from it.

Functional requirements are; unobstructed open space included for guests to practice yoga- the yoga space should function as a shared living space and communal area (25-30 sqm), two en-suite bedrooms for overnight guests, a kitchen, showers and toilets, storage space/s. These are the minimum requirements; as well as the building program is adaptable and can be changed.

In technological point of view, **cost-effective, environmentally responsible construction**, and **minimal or any excavation** are desirable in the construction process; in addition to these, a finished structure should be Low maintenance in terms of effort and costs, **resistant to rain and wind, environmentally responsible**.

2 Brief document: Architecture Competition, Yoga House in the Latvian Bog Competition Conditions. (2023). Buildner.



Figure 3. Cape Kolka, source: https://en.wikipedia.org/wiki/Cape_Kolka#/media/File:Kolkas_rags

3.2. Local Resources in Latvia

Considering the competition area's forested surroundings, the initial research focus was on the **forest and its products**. Latvian forests are outstanding feature of country, they cover 52 % of the country's territory (Erele et al., 2017)³.

This approach aids in defining **local materials** within the region, emphasizing the importance of minimizing the environmental impact of the design, in line with the primary research objective, since the cost of transportation can be reduced by using locally available materials, and it would be easier to locate labor to finish the construction work⁴.

Forest and Wooden Industry

The forestry and wood processing industry has a long tradition in Latvia since it was easily accessible and workable material. Traditional wooden building systems continue to exist today and are being improved using new technologies. For centuries, carpenters passed on the tradition of wood construction from one generation to the next, and even without the buildings surviving, wood construction skills were maintained. Today, industrial production of wooden structures creates an opportunity to implement standard and unique projects by saving time and resources (Viluma, 2020)⁵.

*“ Latvia has a well-developed wood processing industry as a result of its extensive **forest resources, and timber and wood products are among the country's most important exports**. Latvian wood processing firms are major players in a variety of European sectors.”*

-Iwaskiw (1995). Edited by Walter R. *Federal Research Division Library of Congress*. Estonia, Latvia, and Lithuania country studies.

Forest sector companies play a vital role in Latvia, providing significant employment opportunities, especially in rural areas. In the timber processing industry, only 20% of jobs are located in the capital city, Riga. Across Latvia, there is a presence of timber processing companies in every parish, making them essential employers in these regions. These companies often serve as the primary support for the local economy and its residents (Bekeris, 2016)⁶.

3 Erele I., Vālja H., Klauss K. (2017). *Overview of Baltic Forest and Wood Industry*. 23. Internationales Holzbau-Forum IHF 2017. Riga.

4 *10 Ways To Reduce The Carbon Footprint of a Building*. n.d. <https://www.re-thinkingthefuture.com/rtf-fresh-perspectives/a728-10-ways-to-reduce-the-carbon-footprint-of-a-building/> (accessed 09 16, 2023).

5 Viļuma, A. (2020). *Wooden Structures in Latvian Architecture*. Riga: Riga Technical University.

6 Chief Editor: Mr. Pauls Beķeris (2016). Developed by, Balti Group Ltd. *Forest Sector in the 25 Years of Independence of Latvia*. Association Zaļās mājas.



Figure 4 Forest and wooden industry in Latvia, source: <https://eng.ism.lv/article/economy/economy/21.07.2023-latvias-wood-product-trade-falling-rapidly.a517250/>

When the value of the forest industry is taken into account, the forestry laws in Latvia are among of the tightest in Europe, strictly restricting the harvesting of wood. Every five years, an estimate is conducted to determine the maximum felling volumes that can be harvested in state forests during final felling. This estimation is crucial for the development planning of the forest sector, as it helps determine the theoretically available timber resources (Kobuszynska, 2016) ⁷.

The forest areas in Latvia as they exist today began developing approximately 14-16 thousand years ago, following the retreat of the glaciers from the Ice Age. This development saw the growth of tree species like pine and birch in Latvia as the climate became milder (Kobuszynska, 2016) ⁷. **The predominant forest species in Latvia are: pine 34,3%, birch 30,8%, spruce 18%, grey alder 7,4%, aspen 5,4%, black alder 3%, ash 0,5%, oak 0,3% and other species 0,3%** (Erele et al., 2017) ³. The number of stands of young birch trees and white alder has increased rapidly in the past few years (Kobuszynska, 2016) ⁷.

It should be noted that forests also contribute social environments for use by the general population beside the wooden industry. **Berry and mushroom picking** remain a crucial secondary use of forests and continue to serve as a vital source of food and income for a considerable portion of the Latvian population (Ikauniece et al., 2017) ⁸. Further, nearly all forests in Latvia are publicly accessible that is why the most widespread pastimes of the population are picking bilberries, cranberries, mushrooms, and other bounties of the natural environment (Bekeris, 2016) ⁶.

⁷ Kobuszynska M., Agricultural Specialist (2016). *Wood Sector in Latvia*. Global Agricultural Information Network.

⁸ Ikauniece S., Priede A., Kļaviņa E., Jātņieks J. (2017). Editor in chief: Sandra Ikauniece. *Protected Habitat Management Guidelines for Latvia Forests*. Sigulda.



Figure 5 Old Pine Tree in Latvia, source: <https://www.turpravda.org/lv/blog-487070.html>



Figure 6 Mushrooms in the competition area, source: competition brief documents

In Figure 6, The presence of mushrooms in the competition area underscores the significance of this activity. Considering its importance, the design proposal can also incorporate features that cater to this activity, **making it a convenient stopover for mushroom pickers.**

Wooden Products

Timber and processed timber products are very widely used. Traditionally they are used for fuel, in construction and furniture production, as well as in the pulp industry (Ikauniece et al.,2017) ⁸.

The “Low Carbon Economy” concept in Europe aims to reduce GHG emissions by 80-95% compared to 1990 levels in EU countries. The forest sector plays a crucial role by absorbing CO₂ and storing carbon in trees and timber products. Increased use of timber products in various industries helps **reduce CO₂ levels** in the atmosphere, slowing down **global warming** (Kobuszynska, 2016) ⁷. Additionally, it requires **less embodied energy** than other materials so from harvest right through to use and disposal. Hence, forests have an important role in regulating the climate and circulation of water (Ikauniece et al.,2017) ⁸.

*“ Today, wood export is an important part of the economy; Latvia is the 3rd place in World exporting countries of **OSB** producers and 2nd in Europe. According to the plywood production export rates, the **birch plywood** Latvia is in 2nd place in Europe and in World in 4th place. In terms of **energy pellet production** Latvia is in 1st place in Europe and 3rd in World. The availability of these materials locally can offer **cost-effective** design opportunities.”*

- Erele I., Vālja H., Klauss K. (2017). *Overview of Baltic Forest and Wood Industry*. 23. Internationales Holzbau-Forum IHF 2017. Riga.



Figure 7 Industrial production of wood pellet, source: <https://www.balticpelletsenergy.com/en/home/>

Conclusion

Considering Latvia's long tradition in wooden construction and its well-developed wood processing industry, proposing a **timber structure** for a design proposal can offer several advantages. This includes easy access to a skilled labor force and suitable materials in the region. Additionally, taking into account Latvia's abundant timber resources, **pine** can be considered as a primary material for the structure.

The connection between **human activities and the forest** is essential, as well as the construction and forest. In the context of the competition area and the presence of mushrooms, it's important to consider **potential pickers** in the design of the yoga house guest area, as this could affect the building's circulation.

Beyond the structure of the yoga guest house, the choice of materials for finishing and covering is also crucial in a local context. Materials like **OSB and birch plywood** can be integrated into the design proposal. Not only are these materials local, but they are sourced from sustainable wood and offer carbon capture features, leading to **lower embodied emissions** and a more **environmentally friendly solution**.

Furthermore, considering the **accessibility and cost-effectiveness**, proposing an **energy pellet production system** for the design can be a valuable addition.

3.3. Architectural Characteristics in Latvia

The items that contribute to the distinctive architectural features to design are searched in order to gain deeper understanding of **what ‘iconic design’ means in Latvia**. Throughout this process the **cost effective and environmentally responsible construction methods** are in mind.

Closely examining both traditional and contemporary architectural practices in Latvia, attention was given to understanding **the essence of iconic design**. Furthermore, emphasis was placed on the selection of materials, geometries, and elements from these designs that could inform **established construction methods** in the region. These considerations were made in light of their alignment with nature, following a similar approach to the yoga house design, promoting an **immersive connection with nature**, and incorporating **eco-friendly** architectural principles.

Vernacular Architecture

“ Vernacular architecture can be defined as a type of local or regional construction, using traditional materials and resources from the area where the building is located.

*Vernacular architecture serves as a valuable starting point for gaining a **deeper understanding of the location**, enabling the study of architectural characteristics that **excel in the local climate**. ”*

-What is Vernacular Architecture? n.d. <https://www.archdaily.com/951667/what-is-vernacular-architecture> (accessed 09 16, 2023).

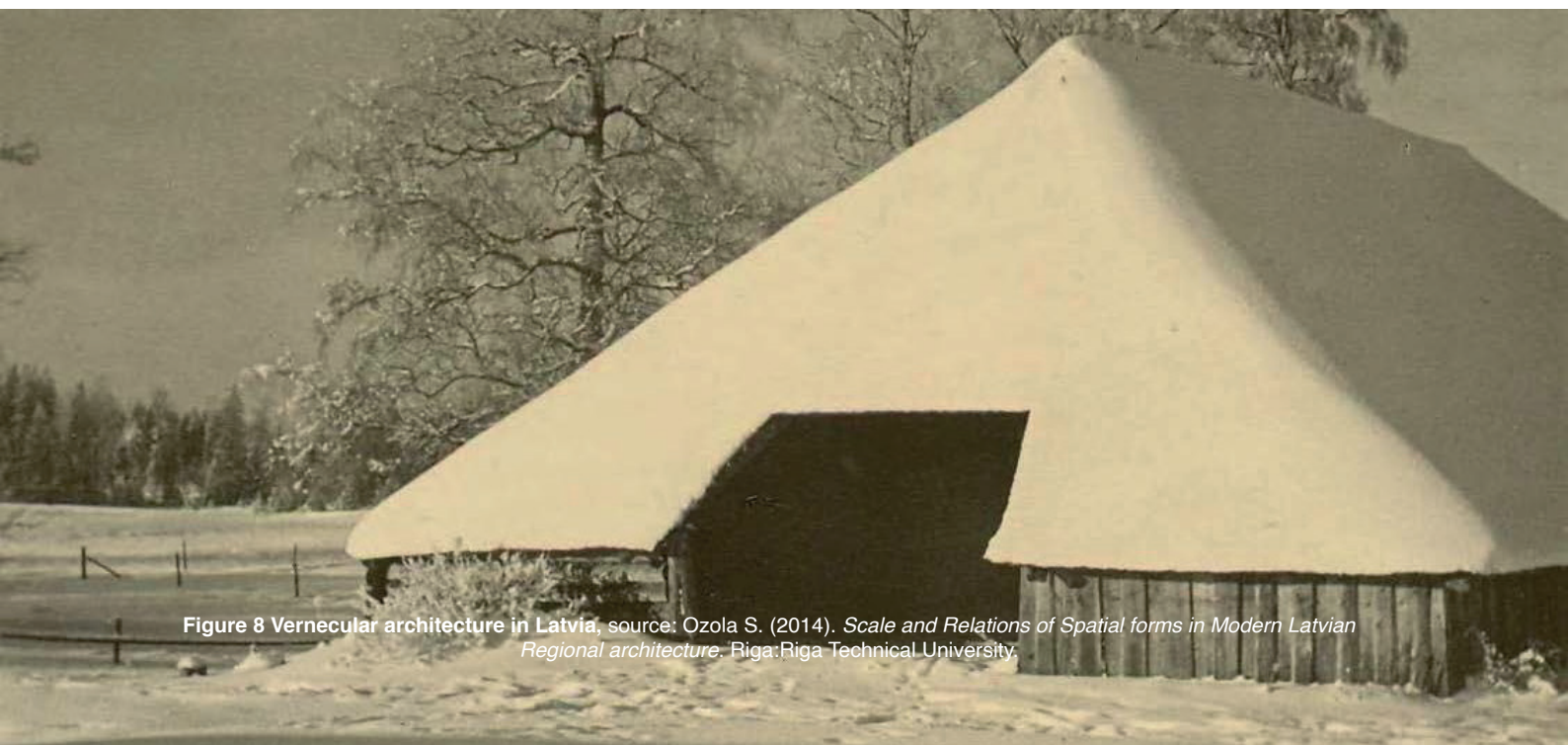
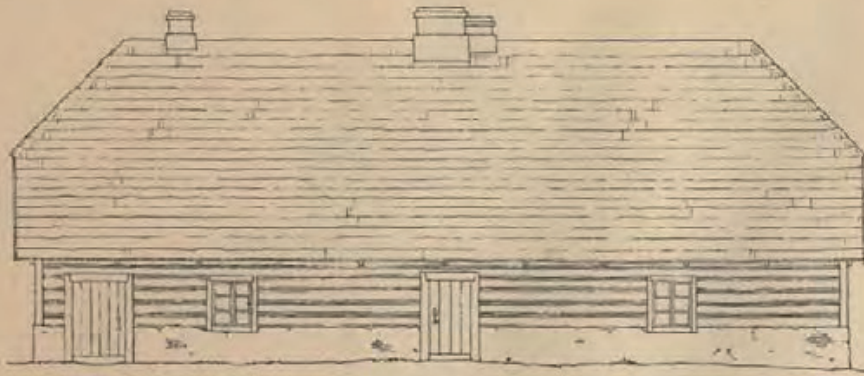
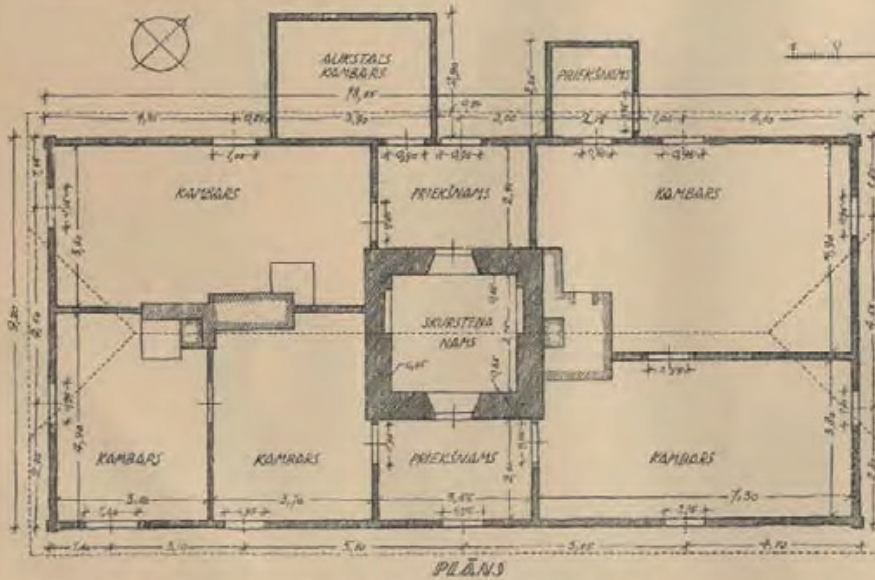


Figure 8 Vernacular architecture in Latvia, source: Ozola S. (2014). *Scale and Relations of Spatial forms in Modern Latvian Regional architecture*. Riga: Riga Technical University.



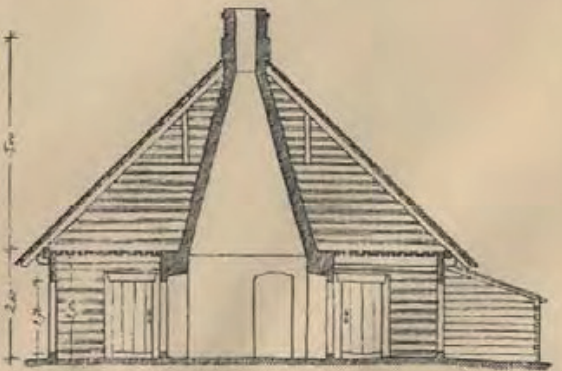
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PLĀNS



ŠĶĒRSGRIEZUMS

DZĪVĪJAMĀ ĒKA ĶĪRKOS, ĀRLAVAS PAG. TALSU APR.

UZMĒROJIS 1921. G. STUD. ARCH. H. KUNDZIŅŠ

Figure 9 Residential building in Vernacular architecture in Latvia, source: Ozola S. (2014). *Scale and Relations of Spatial forms in Modern Latvian Regional architecture*. Riga:Riga Technical University.

The origins of regional architecture formation in Latvia are linked to wooden houses built by Baltic tribes. The Latvian regional architecture was handled with its materials, scales and shapes in the article of Ozola, 2014⁹.

According to the article, the oldest buildings in Latvia were constructed of a natural building material - wood, whose constructive possibilities and sizes - cover span, length of horizontal beams, or straddle height - as well as the characteristics - **sensitivity to humidity, precipitation**, long-horned beetles, and fire - were taken into account when building wooden houses in different ages and countries in the corresponding climatic zones.

Timber frame, log building, and strut or lattice construction were the most common types of wooden construction buildings. The environment had a great impact, and local traditions were reflected in the construction of the structures. This approach was

9 Ozola S. (2014). *Scale and Relations of Spatial forms in Modern Latvian Regional architecture*. Riga:Riga Technical University.

aided by social structure, climate conditions, local building material availability, logic, and a desire for simplicity in construction and decoration.

The roof played an essential role in construction; the roof pitch required for country buildings could also be reached in urban wooden construction, demonstrating the influence of national building traditions on urban wooden architecture.

The proportions of the building's walls and the height of the roof were crucial.

Traditionally, **the roof has taken center stage** in building construction, accounting for roughly two-thirds of overall structure height. Buildings were covered with a tent roof, a double pitch roof, or a double pitch roof with hip ends. Roofing materials such as **straw**, reed, and shakes were employed.

In the Figure 9, the residential building is shown. It has two-part or three-part planning with **a communicating central part of the building**, a massive barn with an **open porch**, as well as a horseshoe-type or angled stockyard, where under one roof different rooms connected with cattle breeding were joined together.

Contemporary Architectural Case Studies in Latvia

Modern buildings in cities can be found with similar approaches to conventional architectural features, such as building elements, geometries, construction techniques, material selections, and so forth. Architects respect to traditional practices and preserve the human scale in the environment while placing an emphasis on harmonious landscape integration.

The examined case studies are selected based in Latvia, and each of them prioritizes **a connection with natural elements**, as they are situated within natural environments. Efforts have been made to establish a similarity with the competition site from an environmental perspective. Furthermore, the purpose of reviewing three different projects is to identify decisions that align with one another, as well as to uncover any contrasting choices, if they exist. It has also proven to be valuable, as it was not possible to access comprehensive architectural details for a single project. Compiling these details has expanded the scope of research into architectural characteristics.

The first case study is **Family Home in Paviļosta** which is designed by **Open AD Architecture** in Latvia in 2019.

The second project name is **8 Blacks** from **NRJA** architectural office in Latvia; the project was built in 2011.

The final project is called as **Bridge House** which was designed by Nomad Architects in 2021 in Latvia.

Family Home in Pāvilosta

Architects: Open AD

Year: 2019

Location: Pāvilosta, Latvia



Figure 10 Family home in Pāvilosta - Open AD Architecture, source: https://www.archdaily.com/957042/family-home-in-pavilosta-open-ad/602ac4ecf91c819a5c000083-family-home-in-pavilosta-open-ad-photo?next_project=no

The House in Pāvilosta is inspired by **local construction traditions**, with a distinctive **triangular shape, timber cladding**, narrow front windows, and a **wood shingle roof**. The timber cladding is **Siberian larch** which will take on a light grey hue to match the choppy Baltic sea and northern skies on a cloudy day.

Besides the traditional approach, new approaches in construction was applied; the home was built off-site as a custom prefab, allowing for a more seamless delivery and less inconvenience for surrounding neighbors ¹⁰.

¹⁰ Open AD Architecture. n.d. <https://www.openad.lv/project/4958/> (accessed 04 20, 2023).

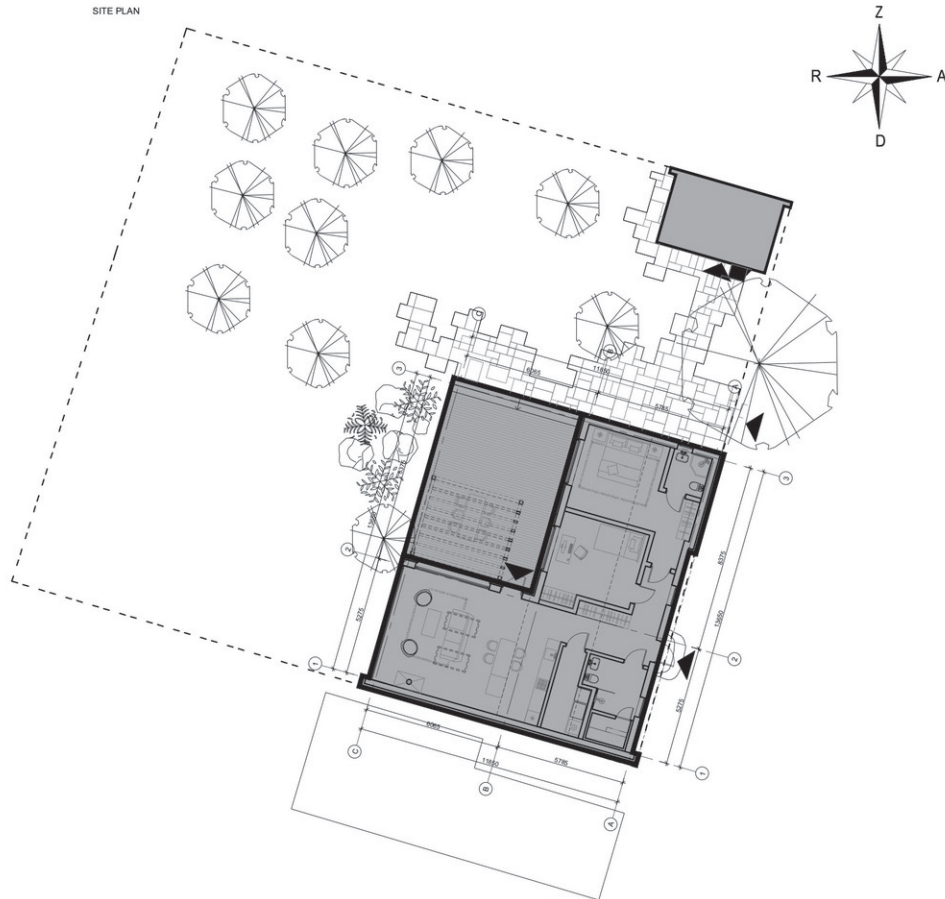


Figure 11 Family home in Paviļosta site plan, source: <https://www.archdaily.com/957042/family-home-in-pavilsta-open-ad/602ac2cbf91c819a5c00007d-family-home-in-pavilsta-open-ad-site-plan>

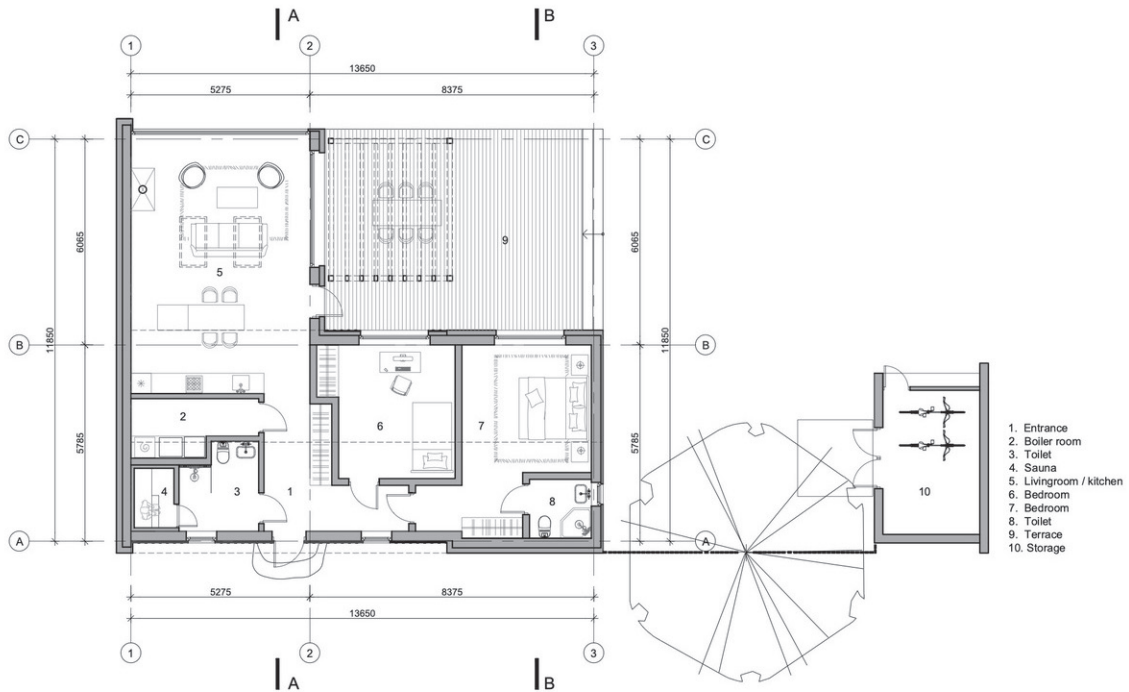


Figure 12 Family home in Paviļosta floor plan, source: https://www.archdaily.com/957042/family-home-in-pavilsta-open-ad/602ac2cdf91c8158bf000085-family-home-in-pavilsta-open-ad-floor-plan?next_project=no

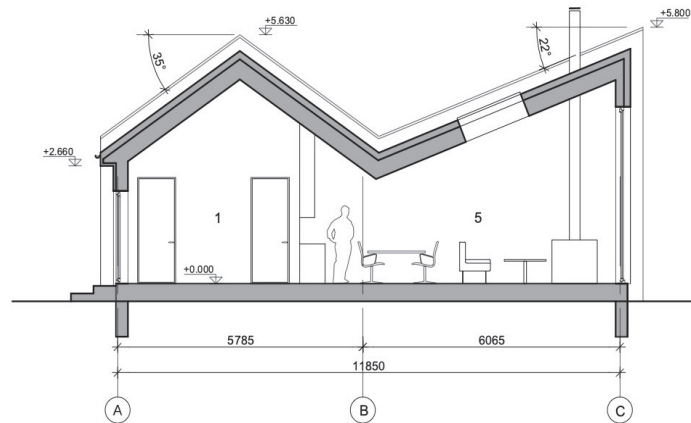


Figure 13 Family home in Paviļosta section A, source: https://www.archdaily.com/957042/family-home-in-paviļosta-open-ad/602ac2f5f91c8158bf000088-family-home-in-paviļosta-open-ad-section?next_project=no

The home has been filled with natural light despite of the weather, thanks to the big, west-facing windows at the back of the house and **skylights** over the kitchen and living room space. **A terrace**, divided into two zones by the addition of a **pergola**, separates the indoor area from the garden¹².

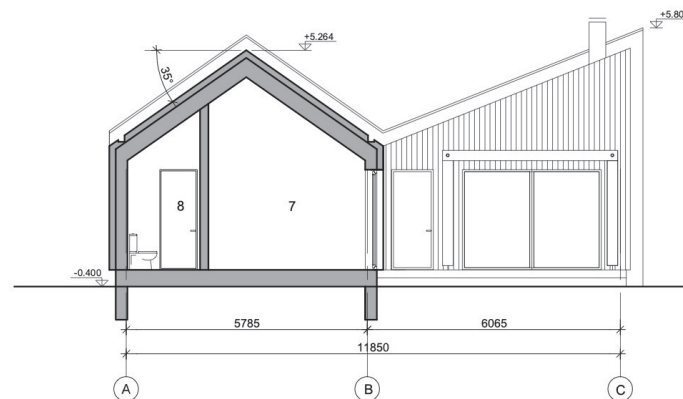


Figure 14 Family home in Paviļosta section B, source: https://www.archdaily.com/957042/family-home-in-paviļosta-open-ad/602ac2fbf91c8158bf000089-family-home-in-paviļosta-open-ad-section?next_project=no

In the interior, the architects **framed the view of nature** with a big windows and let it inside of the house. In addition, **craftsmen work** and **wooden stove** was used as traditional elements with a modern approach.



Figure 15 Family home in Pavilosta - Exterior and interior connection,
source: <https://www.archdaily.com/957042/family-home-in-pavilosta-open-ad/602ac541f91c8158bf000094-family-home-in-pavilosta-open-ad-photo>

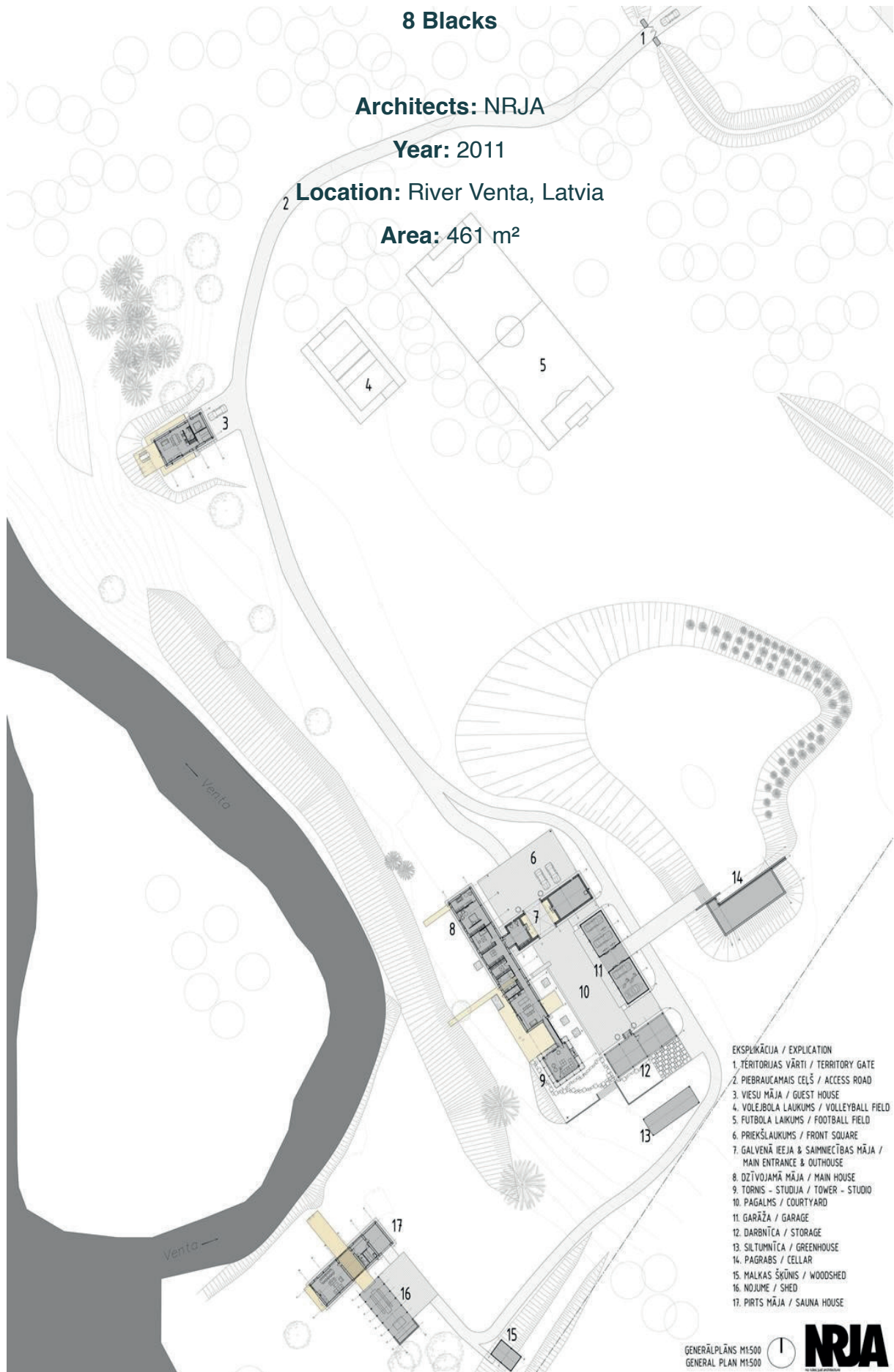


Figure 16 8 Blacks - Site plan, source: https://www.archdaily.com/124290/8-blacks-nrja/5013e26628ba0d3b450002a3-8-blacks-nrja-site-plan?next_project=no



Figure 17 8 Blacks - NRJA, source: https://www.archdaily.com/124290/8-blacks-nrja/5013e1cf28ba0d3b4500027c-8-blacks-nrja-photo?next_project=no

The second case study is composed of several units. The project name is **8 Blacks** from NRJA architectural office in Latvia; the project was built in 2011 and it is located in Venta River, Latvia.

8 black painted wood planking buildings forming as a complex. It consists of main entrance-outhouse, main house, guest house, tower-studio, green house, sauna, shed and cellar. Apart from these main areas, it includes storage areas, woodshed, garage, and sport fields.

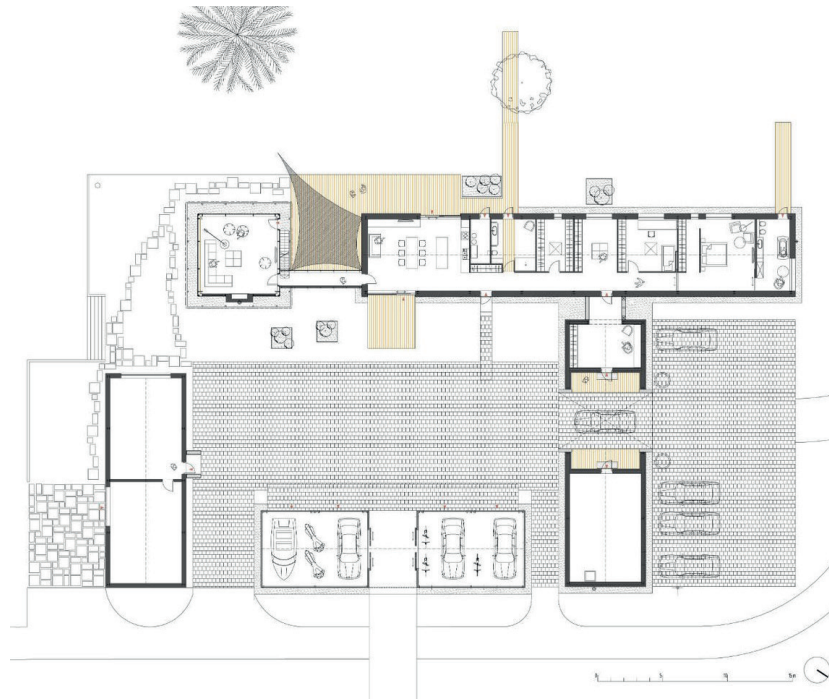


Figure 18 8 Blacks - Main house, studio, main entrance, garage and storage plan, source: https://www.archdaily.com/124290/8-blacks-nrja/5013e25a28ba0d3b4500029f-8-blacks-nrja-plan?next_project=no

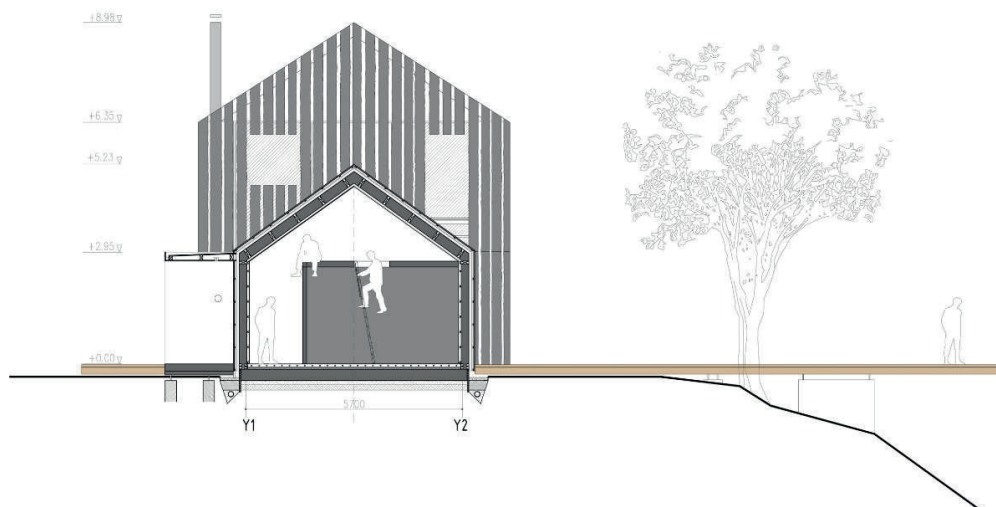


Figure 19 8 Blacks - Main house section and studio view, source: https://www.archdaily.com/124290/8-blacks-nrja/5013e26328ba0d3b450002a2-8-blacks-nrja-section?next_project=no

The private courtyard which creates **center of gravity** for the complex is surrounded by buildings, while some of them were located far spot in the area.

Architects defined the **minimalist form** of buildings with the **triangular shape**; they **do not compete with nature** since expressive nature of the terrain. In section and elevations, it can be seen that using one material for both – walls and roofs – **homogenous look of the building** is achieved; surface texture and details are reached by the



Figure 20 8 Blacks - Main house and studio, source: https://www.archdaily.com/124290/8-blacks-nrja/5013e1c728ba0d3b45000279-8-blacks-nrja-photo?next_project=no



Figure 21 Blacks - Main house and studio elevations, source: https://www.archdaily.com/124290/8-blacks-nrja/5013e25228ba0d3b4500029c-8-blacks-nrja-elevations?next_project=no

finish of **raw wood planking**.

Narrow and long **terraces** which can lead to view the nature along the site are one of the distinct feature of complex. Large windows of the buildings provide a **visual link** with the surroundings; the terraces of various sizes offer an opportunity to go out while being in the house ¹¹.

¹¹ *8 Blacks* / NRJA. n.d. <https://www.archdaily.com/124290/8-blacks-nrja> (accessed 04 20, 2023).

BRIDGE HOUSE

Architects: Nomad Architects

Year: 2021

Location: Baltezers, Latvia

Area: 80 m²



Figure 22 Bridge House - Nomad Architects, source: <https://nomadarchitects.lv/bridge-house>

The final project is called as **Bridge House** which was designed by Nomad Architects in 2021 in Baltezers, Latvia. Architects explain their design with the words; 'The Bridge House is a family house extension with sustainable and affordable building mindset; the **low-impact** home prioritized **sustainable materials and construction processes**, while also planning for future adaptation and deconstruction.

The new addition is well-insulated and includes an entry, home office, living room, and bedrooms for the family of five. The project had a strict budget in order to **reduce material and environmental expenses as low as possible**

12

As stated in the project definition, the construction processes were explained comprehensively, making it easy to understand the wooden frame construction through the provided diagrams, even in the absence of plans and sections in the research process.

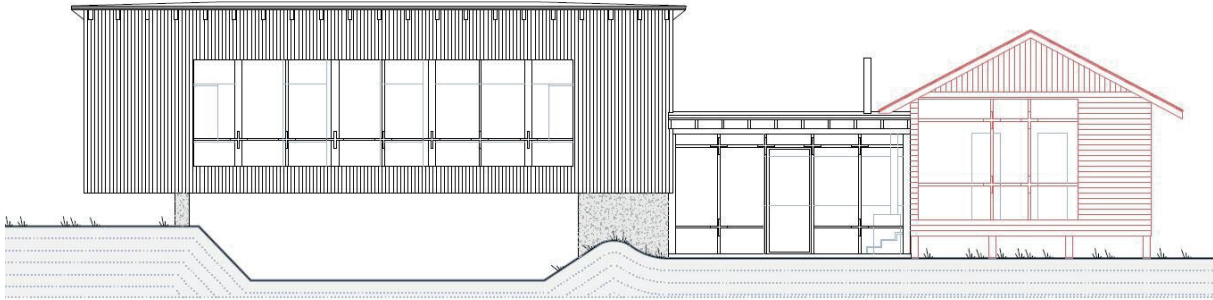


Figure 23 Bridge House - Elevation, source: <https://nomadarchitects.lv/bridge-house>

Natural materials were given special consideration. The entire construction is made of **wood** and insulated with **cellulose and wood fiber**. To eliminate the usage of membranes or foils, the vapor barrier was built with sealed internal **OSB**. Wind protection is provided behind the wooden ventilated facade by wood-fiber boards. All connections are mechanical and re-openable, allowing for simple repair as well as potential modifications or disassembly.

A simple shape and dark facade helps to **blend the house** in the forest setting. Besides, the functional wooden ornamentation gives a playful detailing to it.

This energy efficient home features **decentralized ventilation with heat recovery** and a **pellet stove** for domestic hot water and space heating. The pellets used in this type of heating system, are typically **wood pellets** made from wood chips and sawdust or sometimes straw¹³.

¹² *Sustainable homes*. n.d. <https://ecoedition.net/bridge-house-by-nomad-architects/> (accessed 04 21, 2023).

¹³ *Bridge House*. n.d. <https://nomadarchitects.lv/bridge-house> (accessed 04 21, 2023).

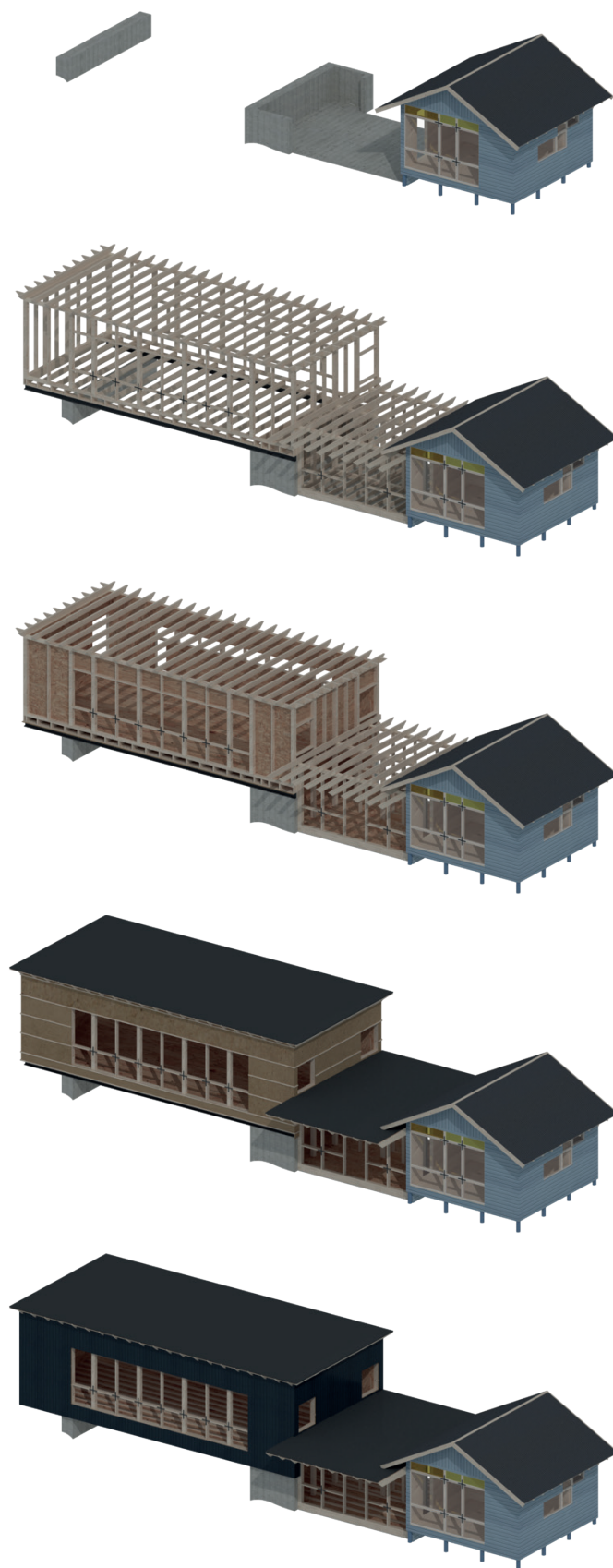


Figure 24 Bridge House - Some of the steps on the construction process, source: <https://nomadarchitects.lv/bridg>



Figure 25 Bridge House construction work, source: <https://nomadarchitects.lv/bridge-house>

Conclusion

The climate analysis is a crucial aspect of the design process, and seeking inspiration from vernacular architecture can provide valuable insights for addressing location-specific climatic challenges. Factors like humidity and precipitation are carefully considered in vernacular architectural case studies. **Timber frame houses** have historically evolved to address these climatic issues.

One of the most recognizable and effective design decisions in vernacular architecture is the roof's form. **A pitched roof** not only helps manage humidity and precipitation but also creates **a central focal point** inside the building. The proportion between the roof and the walls is considered **iconic** in design.

In addition to the roof, the layout of the plan is integral to vernacular architecture. All functions within the building are often connected to the central area, and elements like open **porches** are commonly incorporated.

To gain a broader perspective, contemporary architectural case studies are also examined. This helps in understanding current design approaches in Latvia and establishes a connection between contemporary and vernacular architecture.

In the first case study, various building elements such as **skylights, pergolas, and terraces** are observed. Materials like **Siberian larch**, used as timber cladding, can be considered as an option in the design proposal. **The triangular shape** is also a prominent geometric feature in this study. Additionally, **a wooden stove** can be incorporated inside the yoga guest house as part of the design.

In the second case study, the concept of the **center of gravity** is highlighted, and since a similar approach is found in vernacular architecture, it can be applied to the design proposal. **Minimalist geometric forms**, particularly triangular shapes, can serve as a starting point for the design. The use of the same material for both wall and roof elements, creating **a homogenous facade look**, is an inspiring aspect of this study.

The final case study emphasizes materials like **OSB and cellulose insulation** for cost-effective design while also considering environmental benefits. In terms of energy solutions, this study focuses on **decentralized ventilation with heat recovery** for cooling and **a pellet stove** for domestic hot water and space heating. This approach aligns with the forest surroundings and offers practical and sustainable solutions for the design proposal.

3.4 Site Analysis

*The competition brief highlights **eco-tourism activities**, and the yoga house will play a role in these activities with its offerings. Therefore, a study of activities in the vicinity of the site was conducted to identify **potential users** beyond the yoga house's own guests. This research encompassed a broad perspective, while also viewing the site's primary resources with a more detailed examination. The aim of examining the site's main resources is to gather information about existing **energy sources** to make a selection of technical equipment for the LCA.*

Eco-tourism activities

Due to the presence of biodiversity-rich areas such as forests, grasslands, wetlands, and Baltic marine and coastal regions in Latvia, numerous options are available for green tourism. They consist of activities such as hiking, biking, driving, climbing and bird watching while having an experience natural and cultural objects of Latvia. Figure 26 shows some hiking activity routes that pass over competition area and also Cape Kolka; these routes connect the Baltic states (Estonia, Latvia, Lithuania). Participants have the chance to see natural, historical and cultural sites and monuments; sandy beaches, open air museums, millenarian objects, pine forests, bird watching places and lighthouses as viewing platforms¹⁴.

Figure 27 focuses connection competition area and Cape Kolka. The site is located in a village called Jaunupe connected with Ventspils city in Latvia. The Ventspils-Kolka road and route for beach walk are main connections; and villages between Ventspils and Kolka were shown on the map. Bird watching places and lighthouses are represented as highest points; and the natural reserve areas are marked in Oviši, Ances Swamps and Forests, Slītere National Parks. In addition to these, the competition area is marked on the map.

Given the close relationship between the competition site and the routes, the design of the yoga house proposal is intended to welcome not only its own guests but also **visitors traveling along the routes**.

¹⁴ Tours. n.d. <https://baltictrails.eu/en/coastal/tours> (accessed 04 18, 2023).

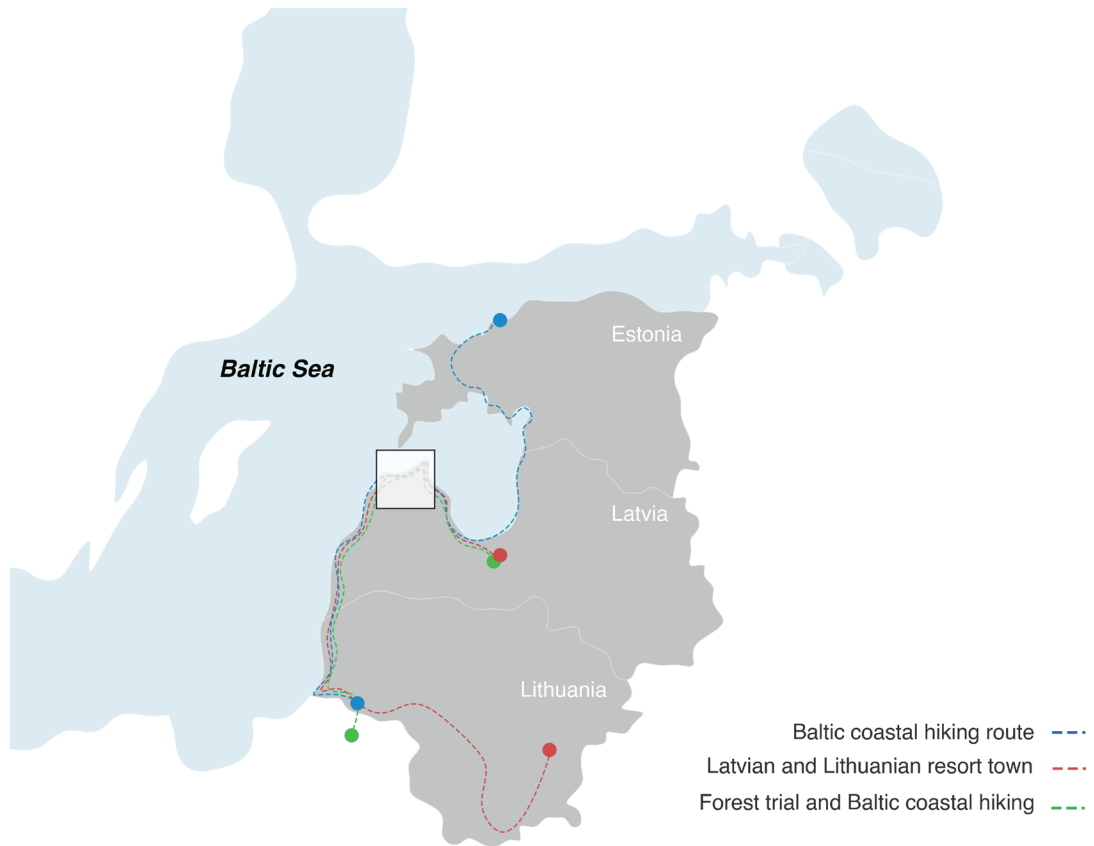


Figure 26 Baltic states hiking route map- scale 1.10.000.000,
 Google Earth Pro, <https://baltictrails.eu/en/coastal/tours> the source
 used to design map

0 100 200 500 km



● Natural reserve ⊙ Lighthouse □ Bird watching — Ventspils-Kolka road - - - Beach walk

**Figure 27 Connection between competition area and
 Cape Kolka- scale 1.500.000,** the source used to design map:
 Google Earth Pro, <https://baltictrails.eu/en/coastal/tours>,
<https://www.birdingplaces.eu/en/birdingplaces/latvia/lake-kanieris>,
<https://www.ibiblio.org/lighthouse/lva.htm>

0 5 10 25 km

Main resources of the site

As it is represented in the Figure 28, Baltic sea and beach, flat terrain, forest, Ventspils-Kolka road, secondary roads, agricultural fields and water between these fields compose the surroundings of the competition area.

When examining the area on a larger scale, Jaunupe stream, which is situated below ground level in the competition area, and the primary forest paths for vehicles can be observed as depicted in Figure 29. The relation between the resources can be more observable with the section on the Figure 30.

The Jaunupe stream, located underground near the area, becomes visible as it flows through to the Baltic Sea. Figure 31 illustrates the connection between the stream and the Baltic Sea in proximity to the competition area.

The area for the competition site is highlighted in the Figure 32. The closest point of the competition site to Baltic Sea is almost 250 meters far from North-West, and Ventspils-Kolka road is in 1250 meters' distance from this point; furthermore, the site is in 19-meter height and is around 14.500 sqm.

Furthermore, regarding the surroundings, the area has infrastructure for both electricity and water in accordance with shared information in the competition website. The source of the electricity grid is not found after researches; Nevertheless, efforts were made to gather information to facilitate assumptions.

There are Ventspils thermal power station as a cogeneration center and they use coal and biomass; Pope wind farm in Ventspils¹⁵; moreover there are renewable plants like hybrid - solar and wind power plant, solar power plant and wind power plant that are located near to Ventspils city¹⁶.

In overall, 53% of heat consumption meet by renewable sources and 60% of electricity demand meet by electricity generated from renewables in Latvia¹⁷.

Heat energy is produced in boiler houses and co-generation stations (CHP plants) in Latvia. Fuel-wood and natural gas are fuels which are mainly used in the production of heat energy from boiler houses. It is essential that the share of **local and renewable energy (fuel-wood)** increases each year, reducing the proportion of natural gas¹⁸.

The electricity produced by CHP plants has constituted more than a half of the total electricity produced in the country for the past ten years (except for 2012 and 2017), and in 2021 the share reached 51 %. Hydropower is the main suppliers for electricity generation and natural gas is following it¹⁸.

15 *List of power stations in Latvia*. n.d. https://en.wikipedia.org/wiki/List_of_power_stations_in_Latvia (accessed 06 27, 2023).

16 *Connections to the Transmission Grid*. n.d. <https://www.ast.lv/en/content/connections-transmission-grid> (accessed 06 26, 2023).

17 *Latvia*. n.d. <https://www.iea.org/countries/latvia> (accessed 06 27, 2023).

18 *Official statistic portal*. n.d. <https://stat.gov.lv/en/statistics-themes/business-sectors/energy/press-releases/8690-activities-chp-plants-2021> (accessed 09 17, 2023).

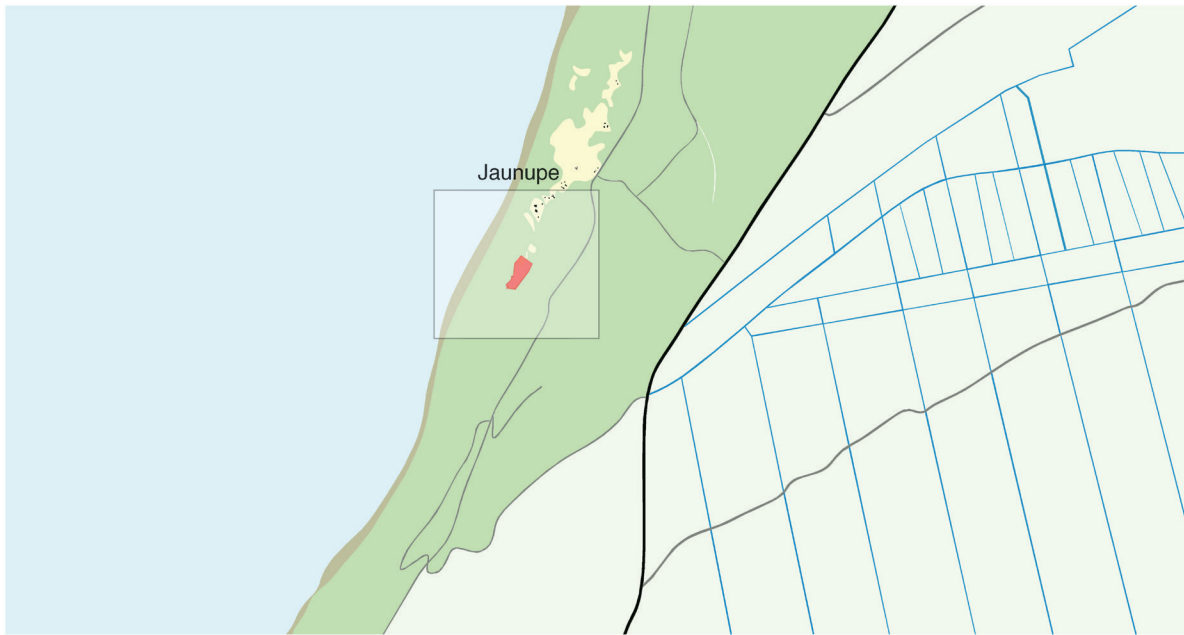


Figure 28 Resources around the competition area plan 1:50.000

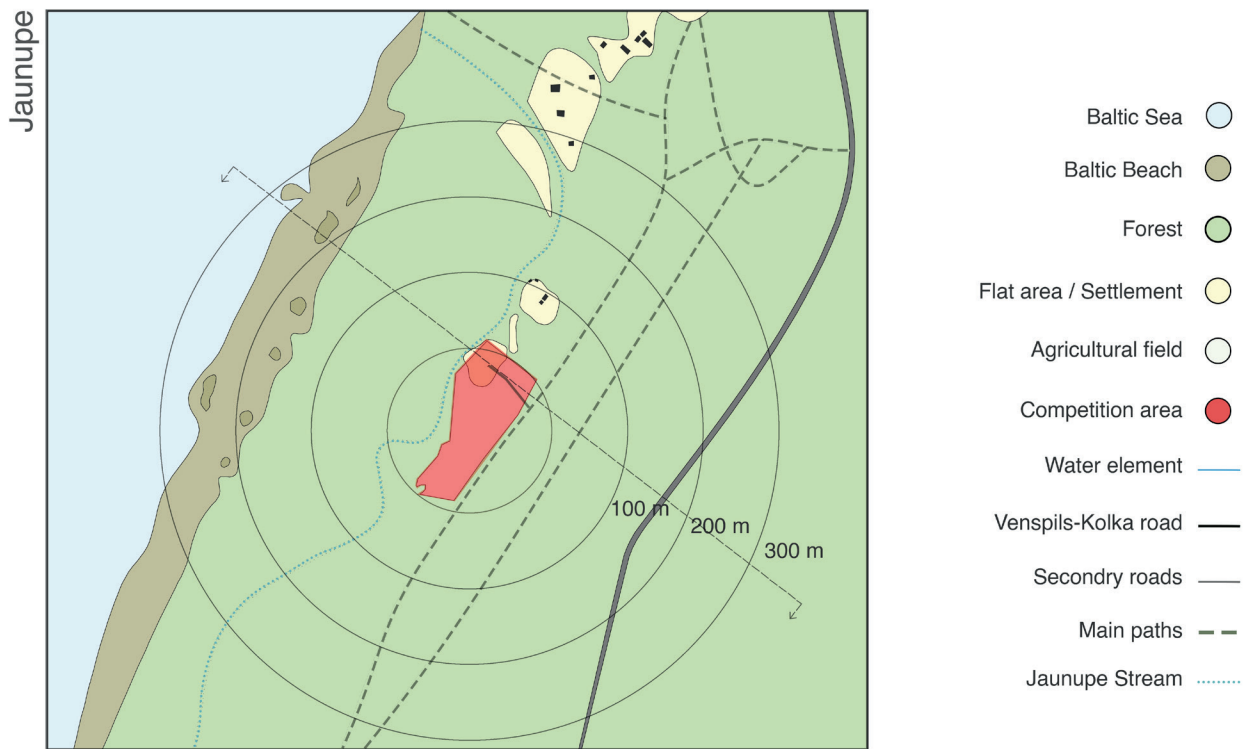


Figure 29 Resources around the competition area plan 1:10.000



Figure 30 Resources around the competition area section 1:10.000, the sources used to design maps (for Figures 28-29-30): Google Earth Pro, <https://www.mapbox.com/>





Figure 31 Jaunupe stream in the context, source: Competition files, competition website brief: <https://architecturecompetitions.com/yogahouseinthebog/brief>



Figure 32 Competition site plan- scale 1.1000



Conclusion

The competition area's proximity to hiking routes means that the design should accommodate travelers using Baltic Sea roads or the main Ventspils-Cape Kolka road. The yoga guest house could serve as a resting place for these **travelers**, and this consideration necessitates a **smooth circulation** plan to avoid disturbing yoga activities inside the guest house.

To facilitate this, it's important to provide a proper path connecting the Baltic Sea and the competition area for both travelers and yoga house users. Additionally, there's a small settlement nearby, and paths between these settlements can also be included in the design.

Regarding infrastructure, although there's existing electricity grid and water infrastructure, assumptions must be made for their sources. For the design proposal, it's worth considering **combined heat and power (CHP) plants, potentially using wood**, in Ventspils. Green energy solutions like PV panel technology should also be kept in mind, with a final evaluation to be made after conducting research on the local climate conditions.

3.5. Local Climate

Latvia is located in the temperate climate zone; relatively flat terrain, the proximity to the sea and air masses from the Atlantic Ocean influence climate in the country. **Climate is mild and humid** with four explicit seasons ¹⁹.

The competition site is located in Ventspils city, therefore **epw file** of the Ventspils city is used to analyse the climate conditions in the Grasshopper Software by using **Ladybug tool**.

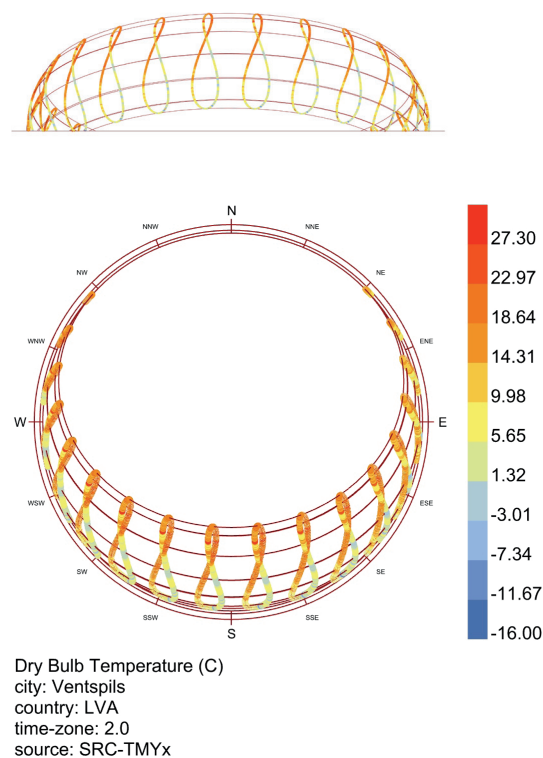


Figure 33 Sun path diagram- Temperature in Ventspils, source: Ladybug tool, Grasshopper

In Figure 33, the graph illustrates the sun's positions throughout the year in Ventspils. The graph also shows the minimum and maximum temperatures in a year in conjunction with the solar altitude. It's evident that the solar altitude angle remains low throughout the year, particularly during the winter months. In winter, the sun is nearly parallel to the horizon, resulting in reduced sun exposure.

¹⁹ National circumstances relevant to adaptation actions. n.d. <https://climate-adapt.eea.europa.eu/en/countries-regions/countries/latvia#:~:text=Latvia%20is%20located%20in%20the,humid%20with%20four%20explicit%20seasons.> (accessed 04 08, 2023).

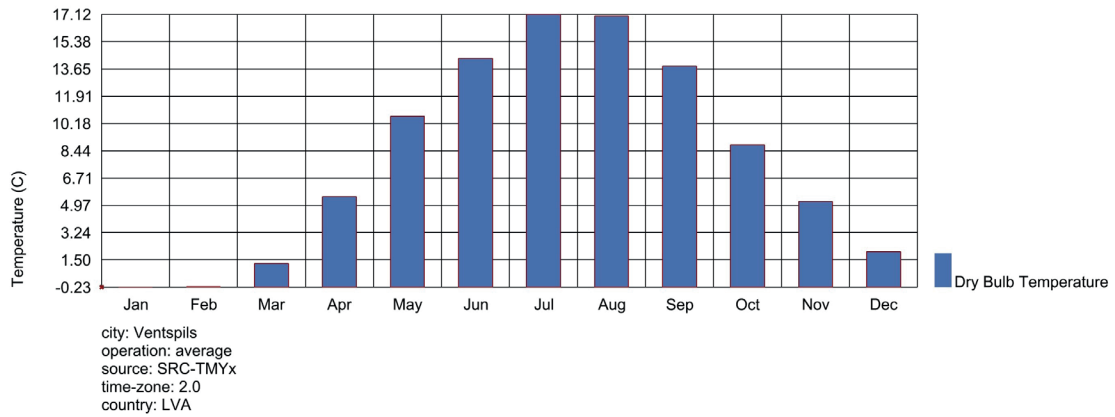


Figure 34 Average Monthly Temperature in Ventspils, source: Ladybug tool, Grasshopper

In Figure 34, an additional graph is provided to show the average monthly temperatures, creating a connection with the information presented in Figure 33. This graph makes it easier to identify and understand the monthly temperature variations in Ventspils, providing context for the solar position data in Figure 33.

Based on the graphs, July emerges as the warmest month of the year, with an average temperature of +17.1°C, while January and February stand out as the coldest months, both averaging at 0.2°C. During the months of April, May, September, and October, there is a **notable temperature difference** between daytime and night time hours. The highest recorded temperature in Ventspils so far is +27.3°C, while the lowest temperature observed is -18°C.

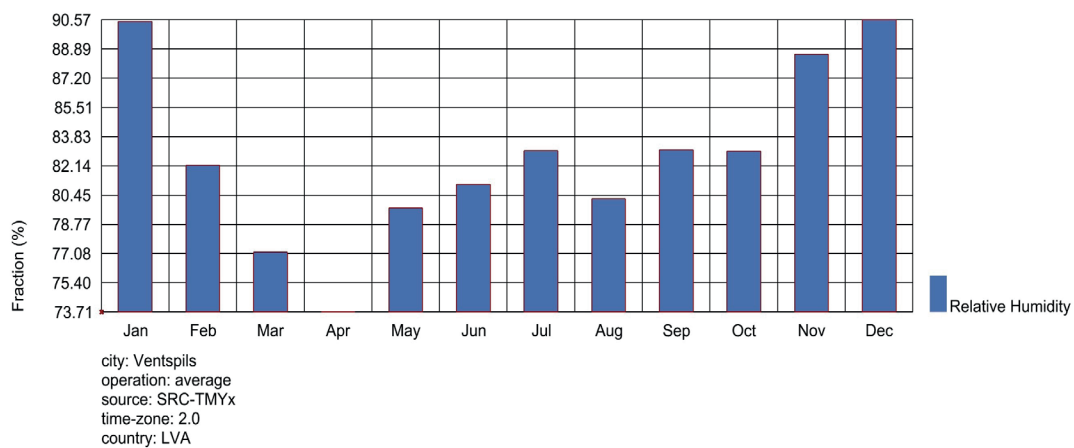
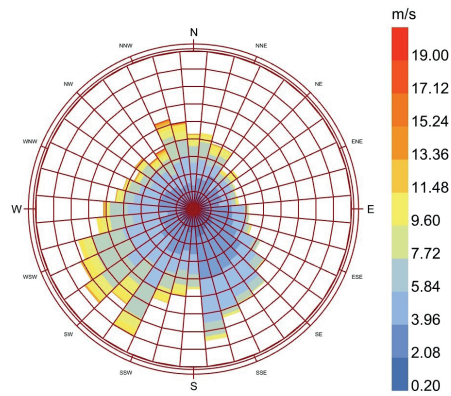


Figure 35 Average Relative Humidity in Ventspils, source: Ladybug tool, Grasshopper

In Figure 35, it is evident that **Relative Humidity exhibits high values**. December stands out as the month with the highest relative humidity at 90.6%, whereas April has the lowest relative humidity at 73.7%.



Wind Speed (m/s)
 city: Ventspils
 country: LVA
 time-zone: 2.0
 source: SRC-TMYx
 period: 1/1 to 12/31 between 0 and 23 @1
 Calm for 2.16% of the time = 189 hours.
 Each closed polyline shows frequency of 0.6% = 50 hours.

Figure 36 Wind Speed in Ventspils, source: Ladybug tool, Grashopper

The wind graph in the Figure 36, illustrates wind speeds and direction. **The strong wind comes to area from South, mainly from South-West.** To accurately assess wind speed, the Beaufort Wind Force Scale is included in the analysis. This scale provides a standardized and widely recognized way to describe wind intensity, aiding in the evaluation of wind conditions.

| Wind type | Wind speed | Wave height |
|------------------|------------|-------------|
| Calm | 0 m/s | 0 m |
| Light air | 0-2 m/s | 0 m |
| Light breeze | 2-3 m/s | 1 m |
| Gentle breeze | 3-5 m/s | 1 m |
| Moderate breeze | 5-8 m/s | 1-2 m |
| Fresh breeze | 8-11 m/s | 2-3 m |
| Strong breeze | 11-14 m/s | 3-4 m |
| Near gale | 14-17 m/s | 4-5 m |
| Gale, fresh gale | 17-21 m/s | 5-7 m |
| Severe gale | 21-24 m/s | 7-10 m |
| Storm whole gale | 24-28 m/s | 9-12 m |
| Violent storm | 28-33 m/s | 12-16 m |
| Hurricane force | ≥ 33 m/s | ≥ 14 m |

Figure 37 Beauford Wind Force Scale, source: <https://windy.app/blog/wind-speed-beaufort-scale.html>

Based on the Beaufort Wind Force Scale, it's evident that the dominant wind speed in the area is around 9.60 m/s, which corresponds to a “fresh breeze.” Additionally, the wind speed tends to reach higher levels, particularly in the west direction. This information helps in understanding the prevailing wind conditions in the region.

Additionally, an average of 180 days per year have precipitation in Latvia, 44 days have fog, and 72 days are sunny. The frost-free period remains 177 days, and there is continuous snow cover for 82 days²⁰.

In Ventspils, most rainy days are in January, October, November and December. On average, December is the rainiest with 18 days of rain/snow; and May is the driest month with 9 rainy days. The average annual number of rainy days is 164 (Average monthly rainy days in Ventspils²¹). Over and above, the number of days with **heavy and very heavy precipitation has grown** because of the climate change while **rise of air temperature** both in average and maximum and minimum values has been observed (Stāmure et al., 2021)²².

In terms of sunny days, the months from May to August have the sunniest days; with monthly averages between 28 to 30 days and the sun shines on average between 8 -10 hours per day. By contrast, in November, December and January, there are **less sunny days with less sunlight**; they are 10-12 days per month and the sun shines on average only 2-3 hours a day²³.

Conclusion

Considering the temperature levels and wind speed data, it can be interpreted that the competition area may have a cooler climate, especially outside of the summer months. Additionally, the lower sun angles in Ventspils suggest that the use of **PV panel technology should be evaluated** in terms of its emissions and its potential contribution to energy consumption.

The site's location within a forest introduces complexities when it comes to implementing green technology solutions, as they may have both benefits and drawbacks in this context. **Therefore, a careful assessment of the environmental impact is necessary.**

In addition to green technology, **passive strategies** like optimizing sunlight entry into the building and enhancing passive heating can be beneficial. Placing windows and doors to align with the dominant wind direction can improve passive ventilation, making the design **more energy-efficient** and comfortable for occupants.

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21 *Average monthly rainy days in Ventspils (Kurzeme)*. n.d. <https://weather-and-climate.com/average-monthly-Rainy-days,ventspils,Latvia> (accessed 09 17, 2023).

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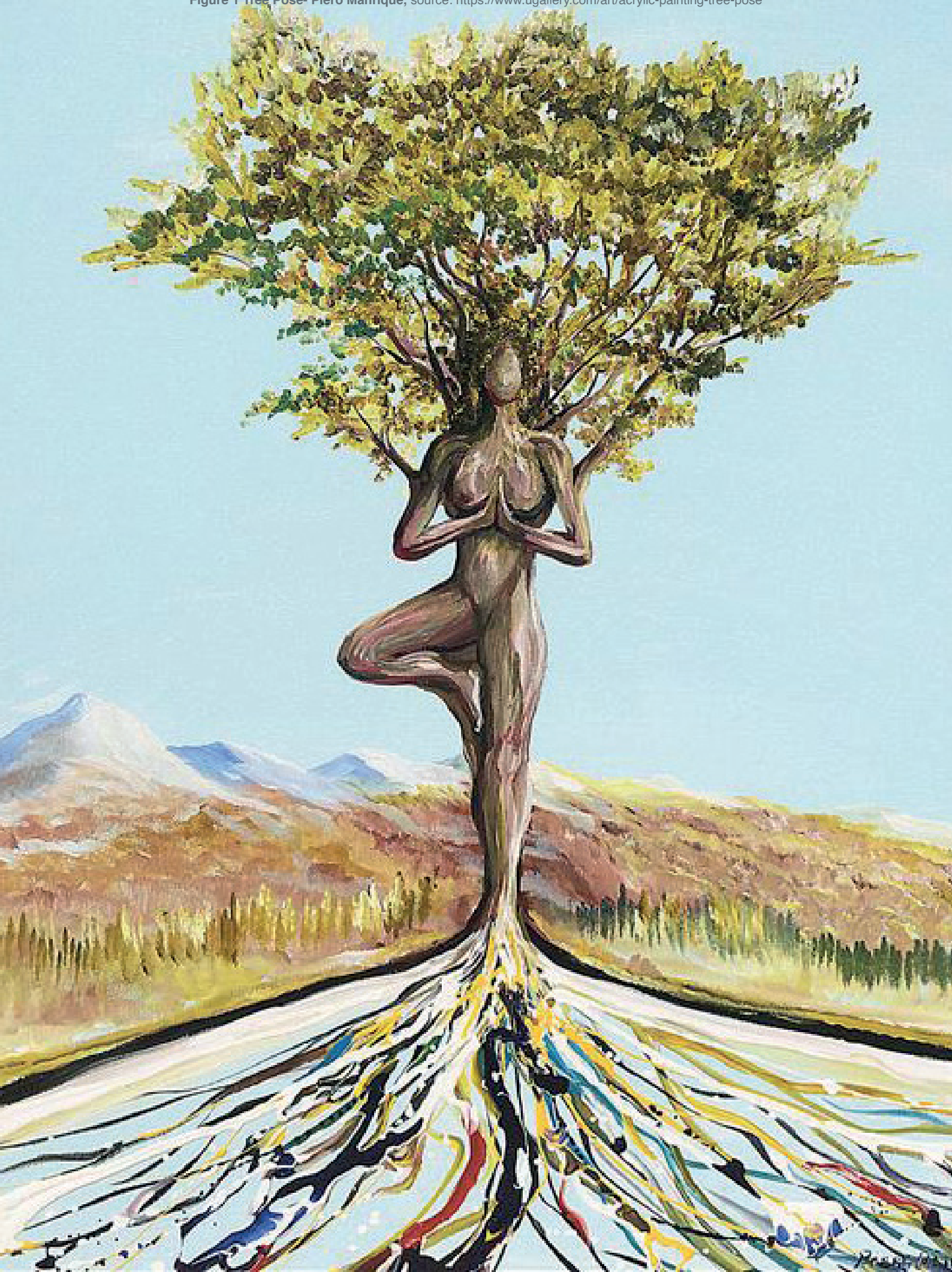
<https://windy.app/blog/wind-speed-beaufort-scale.html>

A case study: Yoga House in the Latvian Bog

The chapter primarily comprises a design proposal, its definition by integrating tools into the preliminary design process. Background data serves as the foundation for determining the design aspects of the yoga house proposal **(WHICH)**, while the methodology section outlines the approach for improving the design proposal during the early design process **(HOW)**.

To achieve this, the process begins with informing a design proposal using architectural drawings. Subsequently, the proposal is defined within the Rhino and Grasshopper environment to facilitate the application of LCA.

Figure 1 Tree Pose- Piero Manrique, source: <https://www.ugallery.com/art/acrylic-painting-tree-pose>



4.1. A design proposal

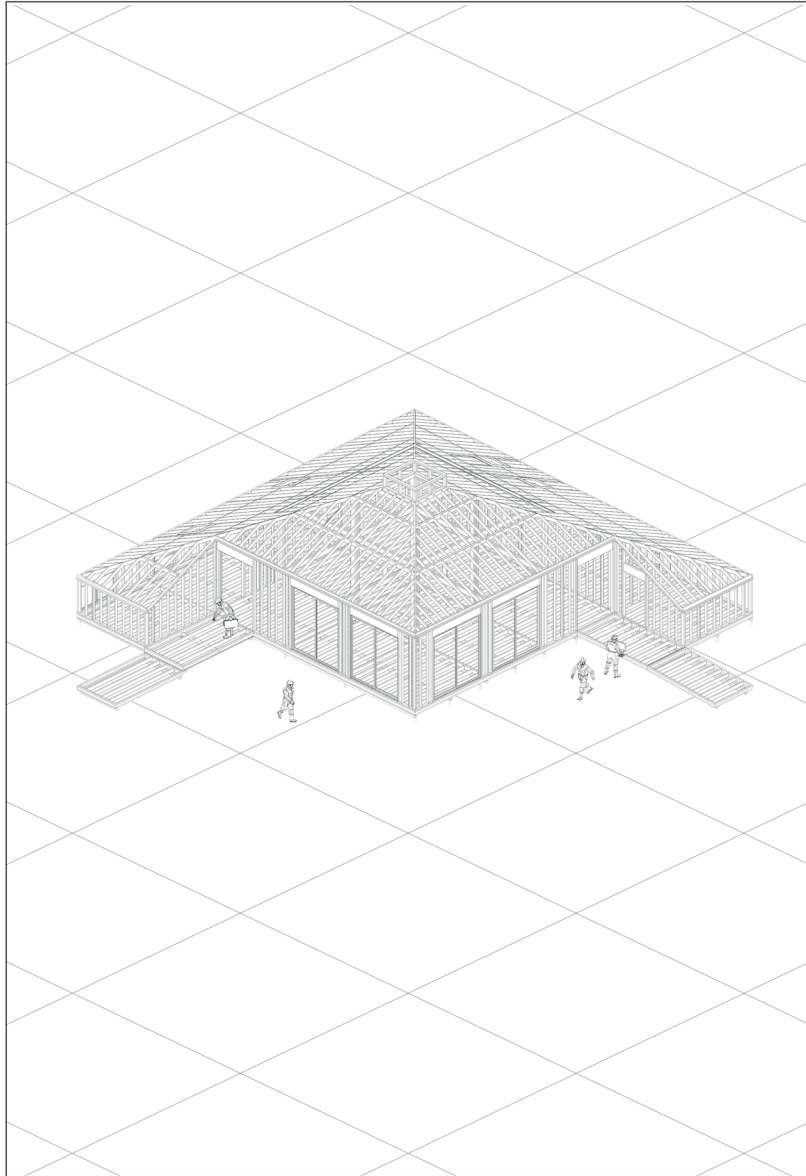


Figure 2 The design proposal diagram

The design strategies derived from background research have been organized under the titles provided on the previous page. Further design decisions and explanations are presented in the following sections while elaborating on the design proposal.

1. APPROACH

The design proposal aims to create a sustainable and eco-friendly design that focuses on the relationship between nature, both for users and the environment. It prioritizes providing opportunities for users to connect with and experience nature. Additionally, cost-effectiveness and environmental responsibility are essential considerations in the design process.

2. LOCATION

The location was primarily chosen to avoid tree felling. Subsequently, the design also incorporates passive strategies, including natural heating, ventilation, and natural lighting.

3. GEOMETRIES

The pyramid roof form is designed to rise at the center of the plan layout to withstand heavy snow and precipitation loads.

4. ELEMENTS

A timber frame construction approach is recommended for the design, with building elements like skylights, porches, and pergolas incorporated into the plan. These elements are strategically integrated to support passive lighting, heating, and ventilation.

5. MATERIALS

In the design proposal, dark Siberian larch is suggested for both the wall and roof materials. This choice aims to create a dark and homogenous facade that blends with the forest surroundings. Additionally, locally available materials like OSB panels and birch plywood are used. Cellulose insulation is also integrated to enhance the building's energy efficiency and insulation properties.

6. TECHNOLOGIES

Due to the substantial wood pellet production in Latvia, a pellet stove is recommended for heating and providing domestic hot water. Additionally, decentralized ventilation with heat recovery is incorporated into the design to ensure efficient ventilation while recovering and reusing heat, contributing to energy efficiency and sustainability.

Conceptual Approach

Yoga is an ancient practice focusing on breathing, flexibility and strength to boost mental and wellbeing. It is composed of a group of physical, mental, and spiritual practices or disciplines. The main components of yoga are breathing and postures (a series of movements designed to increase strength and flexibility). Asana is a term that is used to refer to the practice of physical yoga postures or poses¹.

Vrikshasana (Tree Pose) one of the Asanas that encourages you to simultaneously stretch high like the branches of a strong tree while pressing down and feeling rooted. The mythology behind the pose is that, the tree is defined as patient creatures; they live a long, quiet time, and they know how to stand firm through all the changes of day and night, climate and season².

The yoga guest house that is planned to settle inside of the pine trees as characteristic feature of Latvia can also host the idea of tree pose by imitating the connection of the tree with its surrounding. This approach **puts the human in the center**, and leads to **take root** to the earth and **reach to the sky** while also providing **views to the pine forest**. In the Figure 3, the concept of the design proposal is drawn in tree steps;

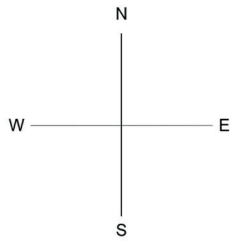
“At the outset, there is a pine forest. Then, through a convergence of directions, humans are drawn to the center, culminating in a form that elevates this central essence towards the sky. This transformation symbolizes humans becoming like pine trees, with roots as their connection to the earth.”

How the key decisions are made is depicted in Figure 4. There are essentially six phases to explaining them.

1. The settlement provides an explanation for the location of the yoga guest house in relation to the competition area.
2. The design’s structure is made clear by the simple grid layout.
3. The conditions for the design competition and the zoning between the functions are explained in functional units.
4. Movements elucidate the geometric formation of the building. Additionally, it is demonstrated how circulation works in both public and private spaces.
5. The building’s mass and path provide an explanation of its relationship to the surrounding area.
6. According to the related purposes, places of use are also explained by indoor and outdoor areas.

¹ *Explore the Ancient Roots of Yoga*. n.d. <https://artsandculture.google.com/story/explore-the-ancient-roots-of-yoga/rAKCRDI92CPuJg> (accessed 09 20, 2023).

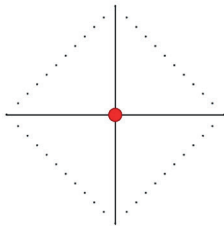
² *The Mythology Behind Vrikshasana (Tree Pose)*. n.d. <https://yogainternational.com/article/view/the-mythology-behind-vrikshasana-tree-pose/> (accessed 09 20, 2023).



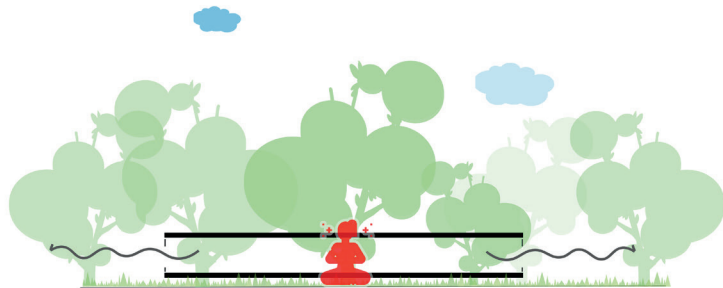
Competition Site



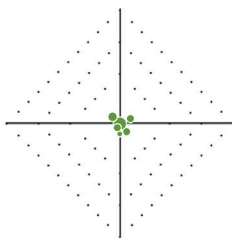
Pine Forest is a characteristic feature of Latvia.



The roof emphasizing the central layout with its pyramid shape, and the form becomes **iconic**.



Human is in the center with a **connection with the natural elements**.

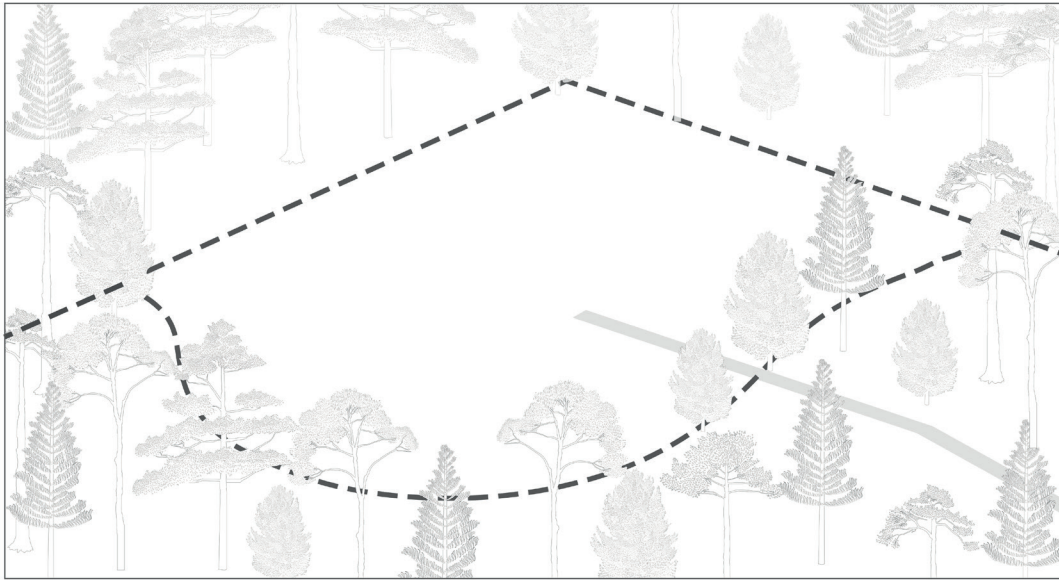


Central layout which takes the users in the middle creates connection between the all aspects.



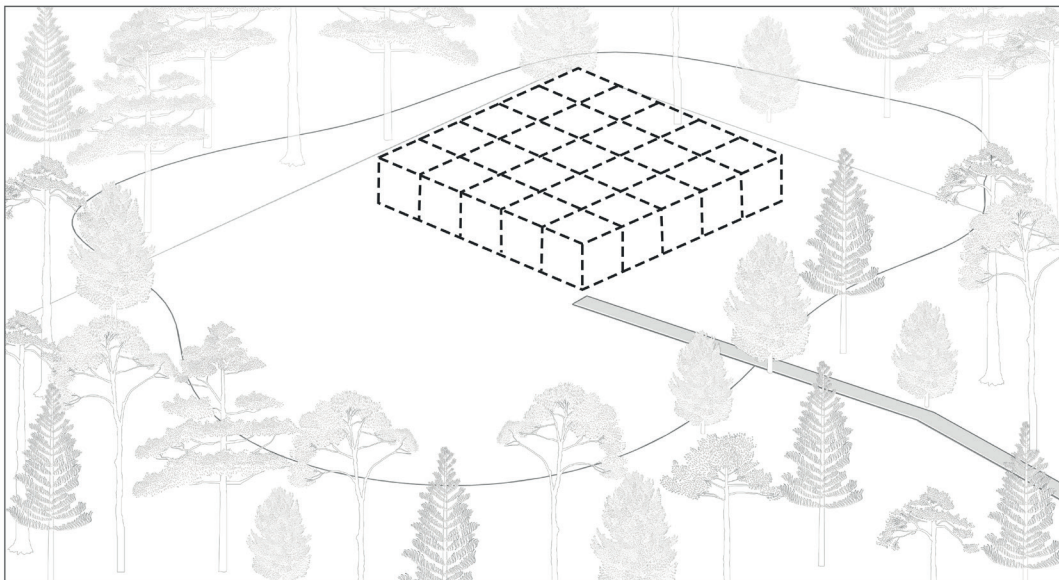
An **interior pine tree** symbolizes the human who roots to the earth and bloom to the sky.

Figure 3 Concept diagram



1. SETTLEMENT

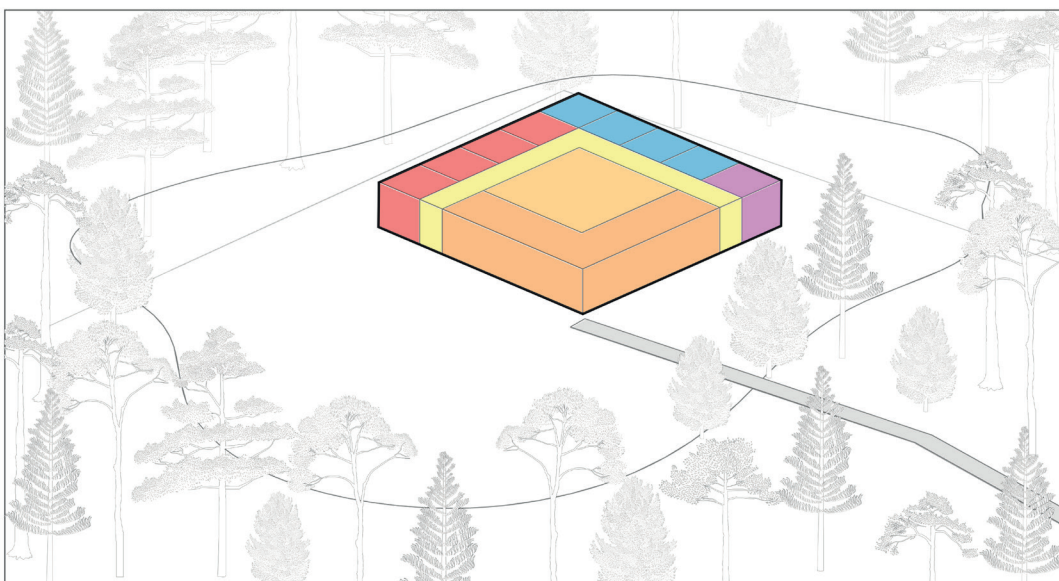
The site without any trees was selected to avoid tree felling and potential damage to the surrounding tree roots. This location allows the yoga guest house to receive more natural light, potentially providing passive heating as the building can capture sunlight effectively. Additionally, the integration of solar technology is being considered.



2. SIMPLE GRID LAYOUT

The building is designed using 360 cm cubic units, creating a simple and compact structure that enhances its resilience to climatic conditions. This design approach also ensures that the building harmonizes with and complements the natural environment rather than competing with it.

Additionally, this design approach facilitates a faster construction process.

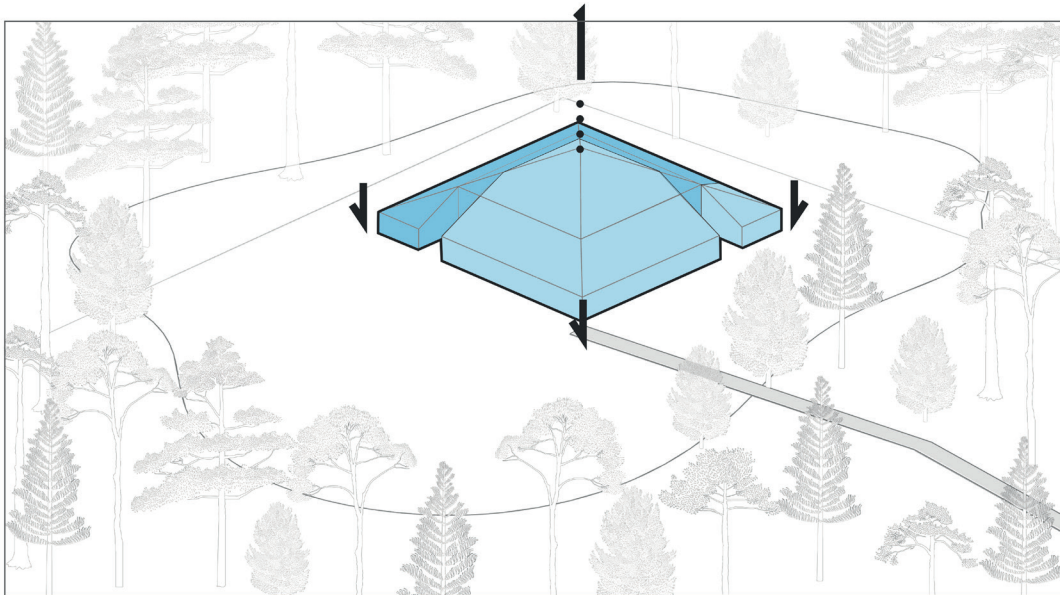


3. FUNCTIONAL UNITS

The organization is structured based on activities, which include practicing yoga, meditating, sleeping, and attending to basic needs. The design places the related spaces strategically to maximize natural light according to the specific requirements of each activity.

- Yoga space and kitchen
- Meditation porch
- Corridors
- En-suite bedrooms
- Service areas
- Storage

Figure 4 Main decisions diagram - Scale 1:500

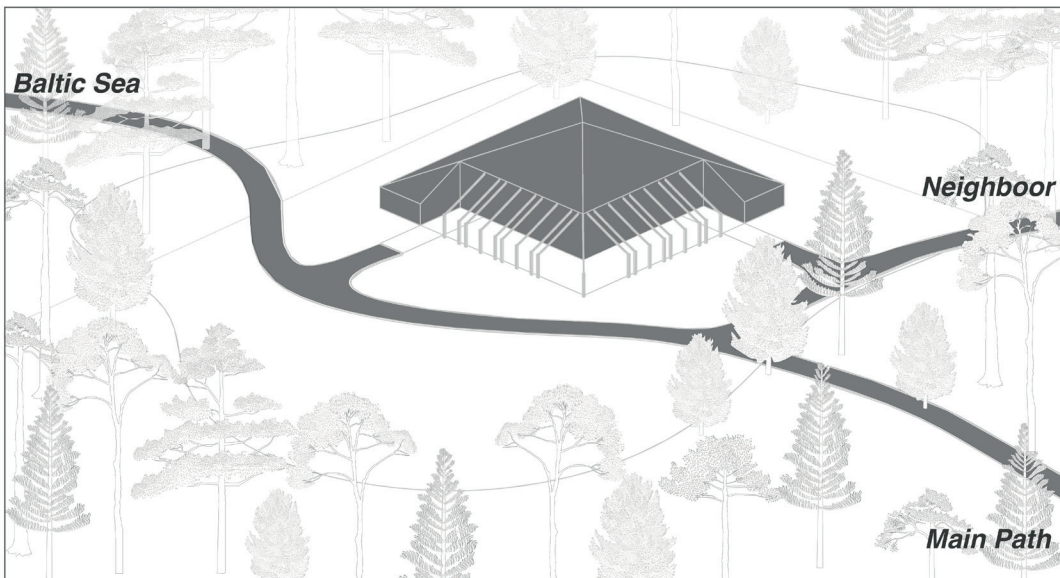


4. MOVEMENTS

To create an iconic shape for the building, the roof was raised, placing emphasis on the central layout. Simultaneously, the walls were reduced to increase the ratio of roof to wall, achieving integration with the forest on a human scale.

The areas are partitioned into public and private spaces, with consideration for potential guests in addition to the yoga house residents, taking into account the various activities in the surrounding forest.

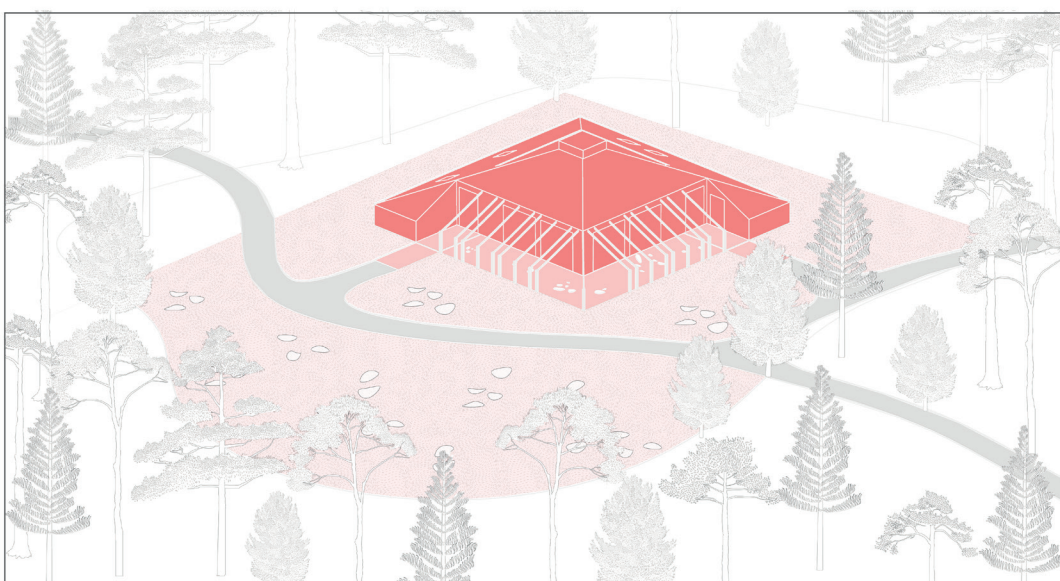
- Private
- Public



5. MASS AND PATHS

After finalizing the building-related decisions, the pathways on the site are planned to establish connections with the Baltic Sea and the neighboring area.

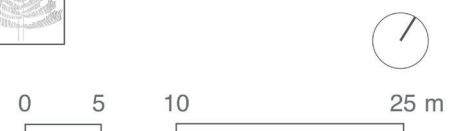
These pathways also help in delineating the outdoor areas based on their proximity to the Yoga Guest House and their intended use.



6. INDOOR - OUTDOOR

The Yoga Guest House is designed as a shelter, with the pergola featuring sunbreakers creating a semi-open space for the meditation porch. The remaining area is designated for various multipurpose activities, including outdoor yoga and meditation, gatherings around the fireplace, al fresco dining, and games.

- Close space
- Semi open space
- Open space



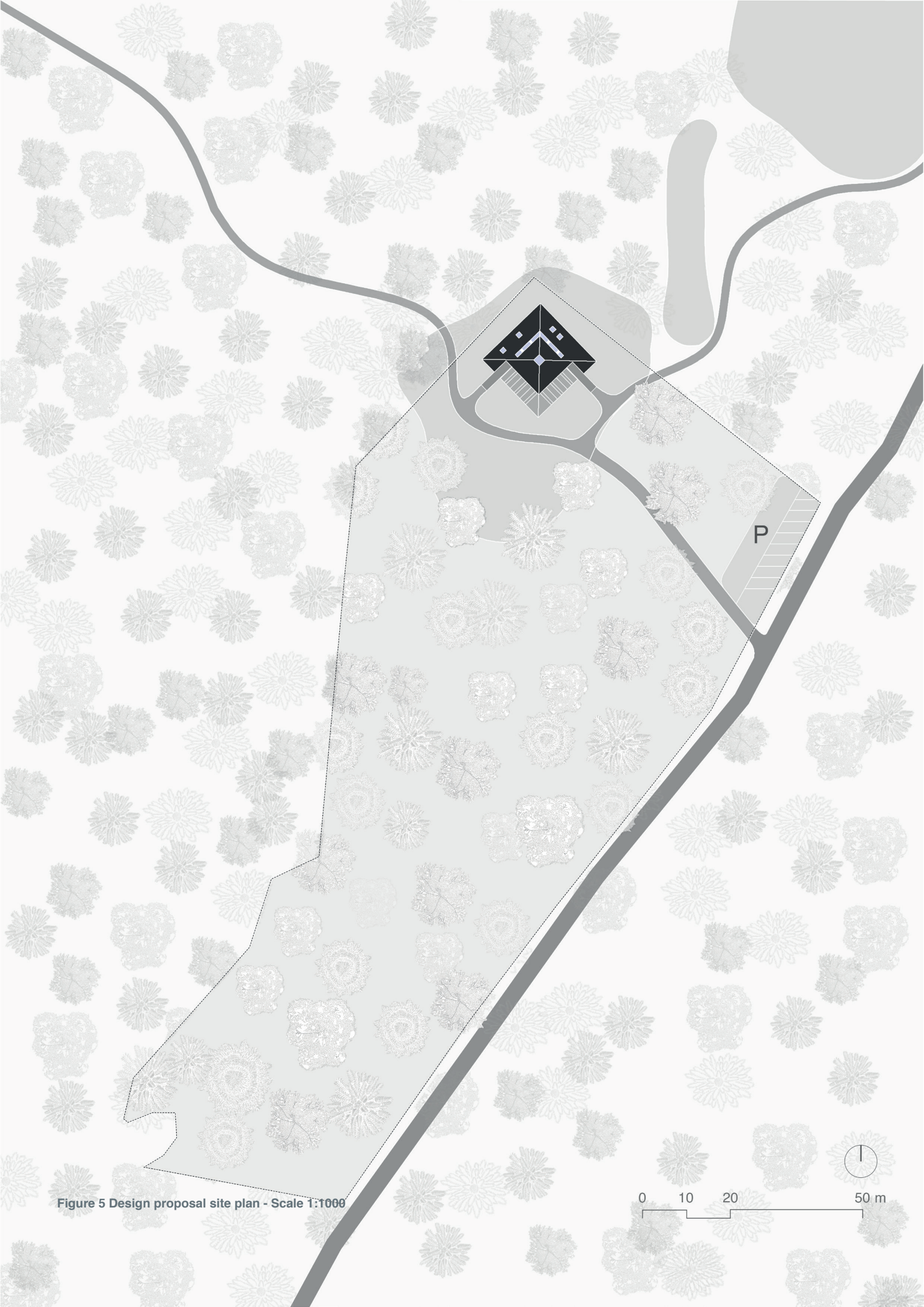


Figure 5 Design proposal site plan - Scale 1:1000

0 10 20 50 m

Figure 5 presents the site plan for the design proposal. It highlights the primary pathway and the routes connecting to the neighboring areas in the east and the Baltic Sea in the west. These pathways seamlessly integrate with the existing path within the competition area. Visitors to the yoga guest house have the convenience of parking their cars outside and taking a short walk to reach the destination.

The building has been strategically positioned within a forested area to maximize natural light, especially in the main spaces. This is achieved by placing the south facades at a distance from the trees, while the north facades are located closer to the trees. Furthermore, the northwestern facade runs parallel to the Baltic Sea and features ensuite bedrooms, while the service areas are situated in the northeastern part of the building.

Figure 6 displays the plan of the design proposal, allowing observation of the various areas as close spaces; bedroom, service areas (toilet, cabin and shower), storage, kitchen, multi-purpose yoga space and also meditation porch as a semi open space.

The functional spaces are placed by taking activities into account; yoga and meditation are the primary priorities; thus these spaces are situated on the South facade to receive the lightest during the day.

The kitchen and the main yoga space are interconnected to facilitate various activities that can be organized within the yoga area; the kitchen is elevated on a platform to create a functional separation. It can serve users who are not participating in the yoga activity via access from the corridor (**traveller and pickers**).

Furthermore, the presence of large glass sliding doors establishes a continuous connection between the main space and the meditation porch, offering a visual link to the forest. Additionally, they offer great natural ventilation because of their location against the predominant wind directions.

Within the main space, an **interior pine tree** is positioned at its center, illuminated by a sizable skylight.

As previously mentioned, there are two entrances—one in proximity to the bedrooms, and the other near the service areas. The interconnected corridors associated with these entrances aid in segregating individuals based on their activities, while also enhancing the privacy of the yoga space. These corridors are equipped with long, narrow skylights to introduce natural light, ensuring well-lit circulation areas even during brief periods of sunlight.

Bedrooms have small kitchen and bathroom. Service areas have toilets, changing cabins and showers. In both functional spaces, the windows provide views of the forest and allow natural light to penetrate the interiors, complemented by skylights. Additionally, these skylights facilitate passive ventilation, particularly advantageous in addressing **high humidity** levels.

The presence of a simple grid system is particularly noticeable, with a grid spacing of 360 cm, predominantly evident in the bedrooms and service areas. These areas are supported by load-bearing walls. In the main space surrounding the interior pine tree, there are four columns measuring 20x25 cm that support the roof. Connected to these columns are beams measuring 15x20 cm, which distribute the loads to the walls and the all walls function as load-bearing walls.

In the Figures 7-8-9-10, the sections are drawn. The pitched roof element, resembling a pyramid shape, not only establishes a **center of gravity** but also emphasizes the interior pine tree. Beyond its symbolic value, this roof design enhances the proposal's **resilience to**

heavy rain and snow. Moreover, it aligns with Latvian architectural tradition, where the proportion between the roof and walls is considered iconic. To achieve this, exterior walls are intentionally kept shorter to increase the roof area, while maintaining a human-scale perspective.

The meditation porch is situated on the southern facades and is **shielded from the wind** by a pergola featuring sturdy shading elements. These elements not only offer sun protection in the yoga space but also shield from wind. The floor of the meditation porch is designed with earth and small stones to facilitate passive heating on days with significant temperature fluctuations between day and night.

Additionally, screw piles with a helical design are recommended for the foundation to prevent any harm to the tree roots.

Figure 11 and 12 depicts system details and materials. In addition to the local availability of wood products in Latvia, wood is a favorable choice due to its **lower embodied energy and carbon storage capabilities.** Furthermore, it is considered a preferred option in Latvia as it provides insulation against heat loss. These attributes render wood an environmentally responsible choice for the design. Hence, a **timber structure** is proposed as a lightweight construction method, with pine trees serving as the source of wooden elements in the design.

Since the all walls are load-bearing walls, the openings are created by reinforcing them with double studs on both sides of the open area, along with double headers (as it can be seen in Figure 12).

In addition, **minimal finishing materials** are utilized to achieve reduced emissions associated with construction materials. The design incorporates **dark Larch cladding, OSB panels, and Birch plywood** as finishing elements. After a thorough examination of practices in Latvia, **cellulose fiber insulation** is recommended for thermal insulation. The utilization of dark larch cladding on both the walls and roof aims to **blend** the design seamlessly within the forest surroundings, creating a sense of **homogeneity.**

The inclusion of **decentralized ventilation with planned heat recovery** for cooling is a key technical consideration. This technology enables the yoga house to draw in natural, fresh air from the outside, enhancing the indoor environment. This is particularly crucial for creating an optimal atmosphere, especially during yoga sessions, as the system helps minimize allergic reactions to pollen and dust. Moreover, it has the advantage of requiring minimal equipment installation, a small footprint, and reduced energy consumption.

For heating, the main space can be efficiently warmed using a wood stove, while radiators are provided for all functions. The plan includes the use of a pellet stove as a source for heating and hot water. Electricity is sourced from the grid to meet the electrical needs.

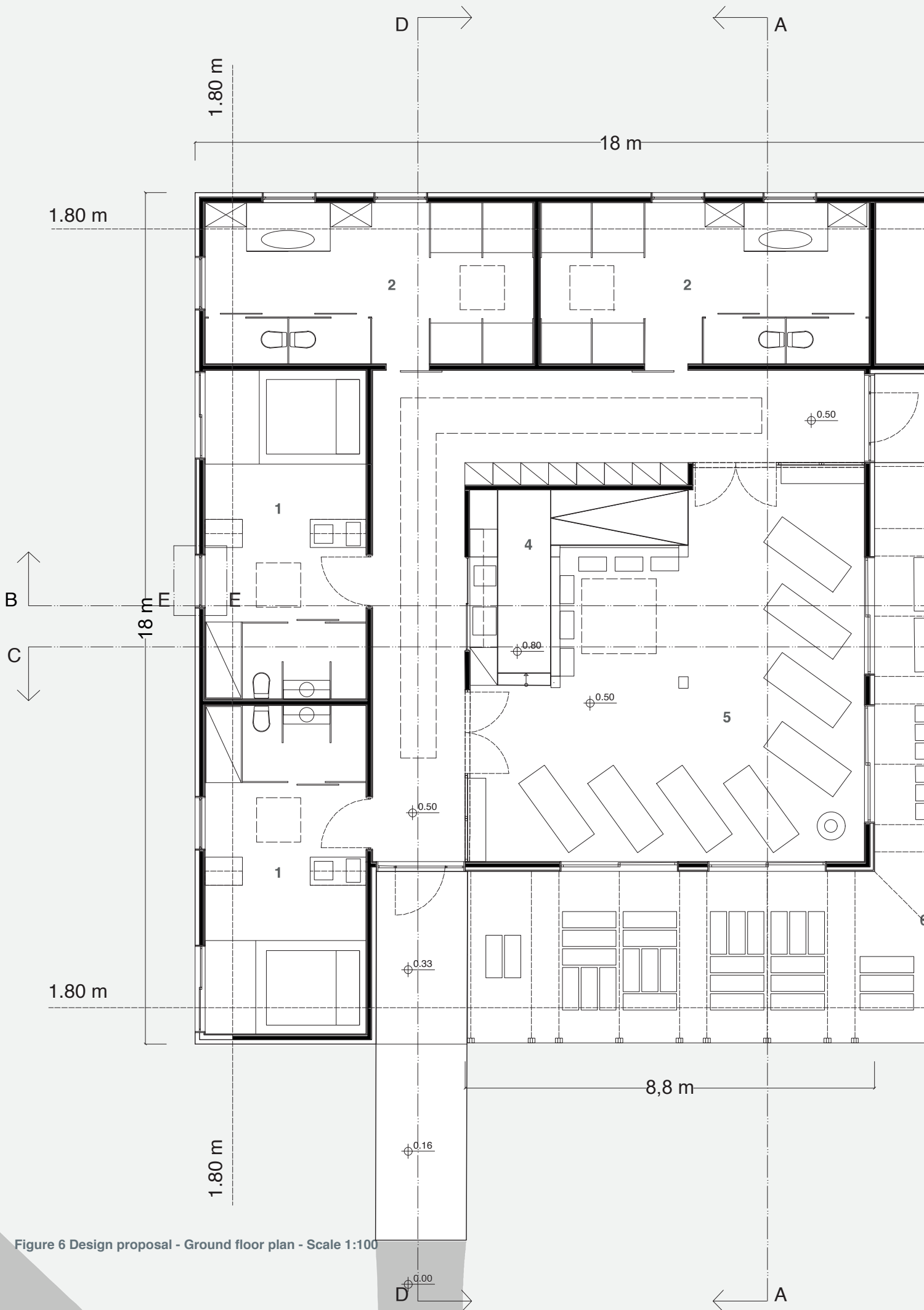
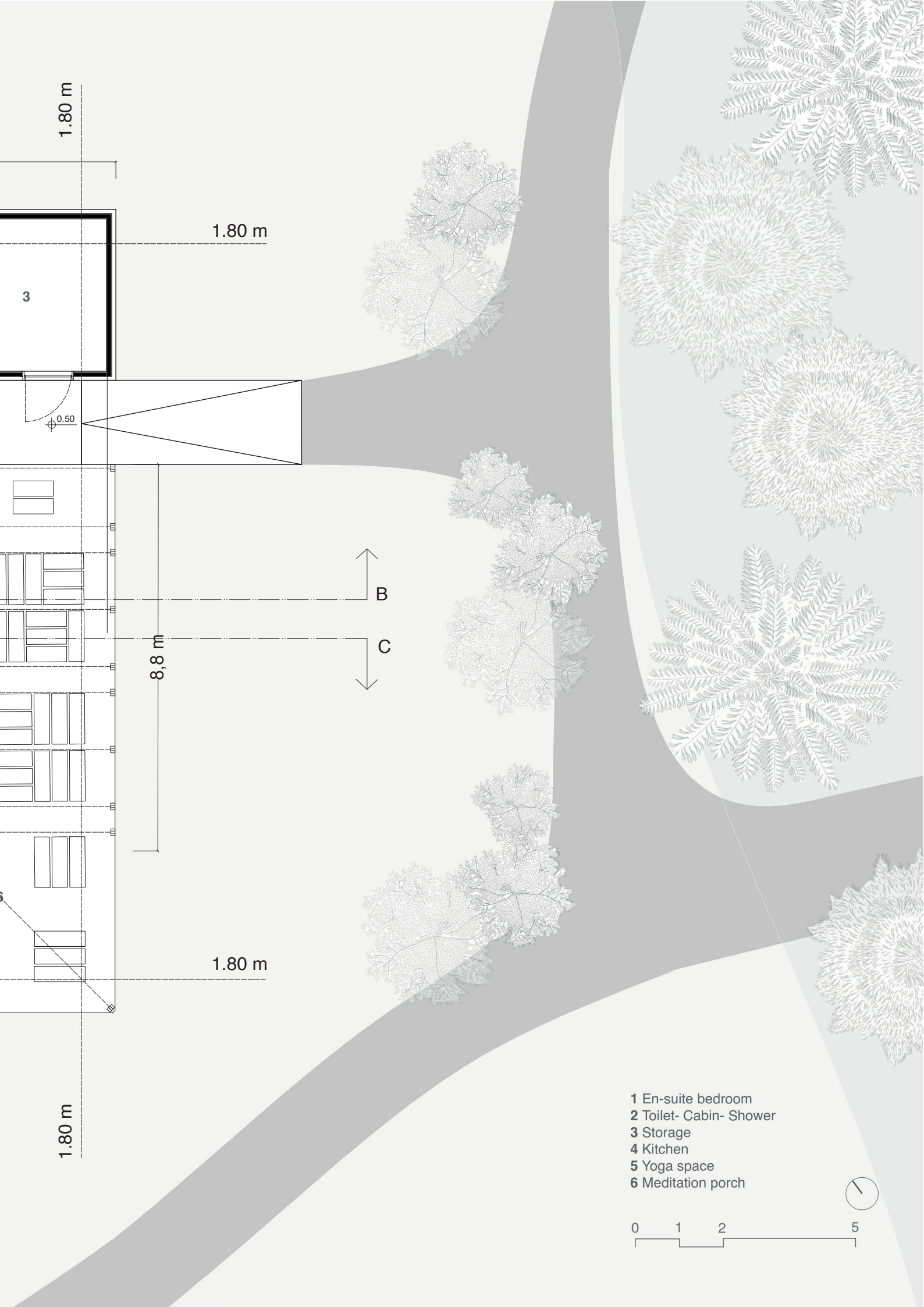
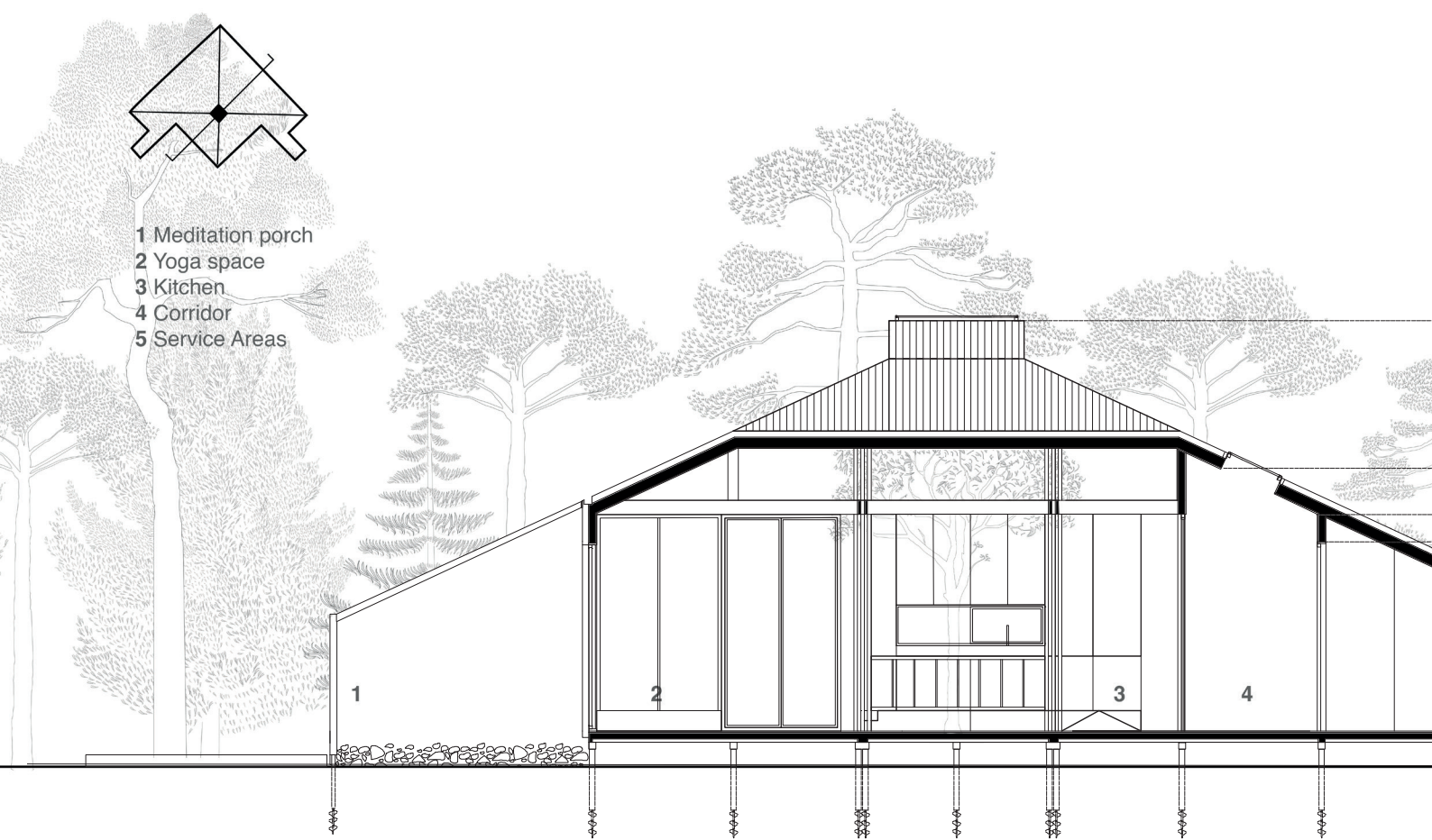


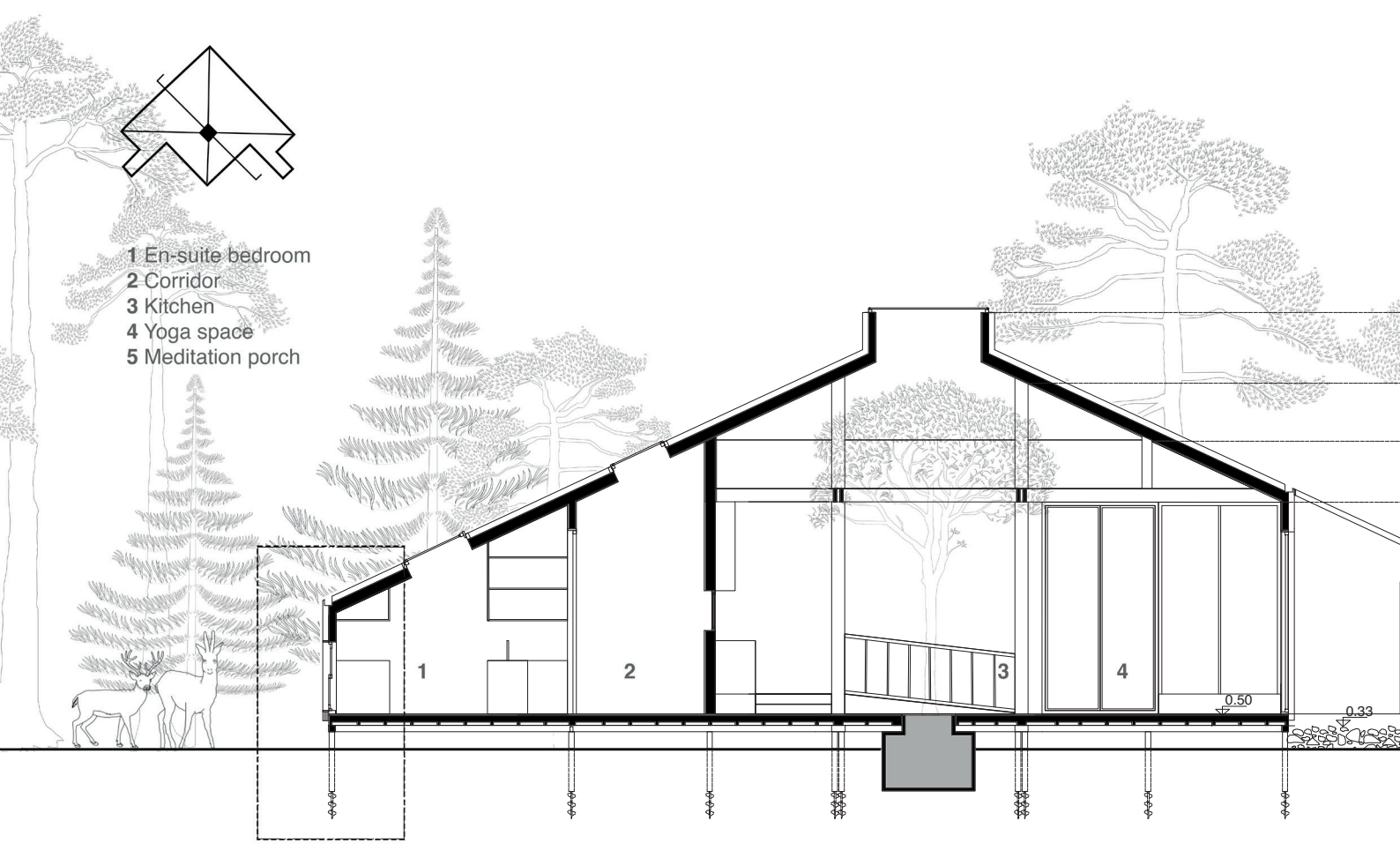
Figure 6 Design proposal - Ground floor plan - Scale 1:100





- 1 Meditation porch
- 2 Yoga space
- 3 Kitchen
- 4 Corridor
- 5 Service Areas

Figure 7 Design proposal section AA - Scale 1 1:100



- 1 En-suite bedroom
- 2 Corridor
- 3 Kitchen
- 4 Yoga space
- 5 Meditation porch

Figure 8 Design proposal section BB - Scale 1:100



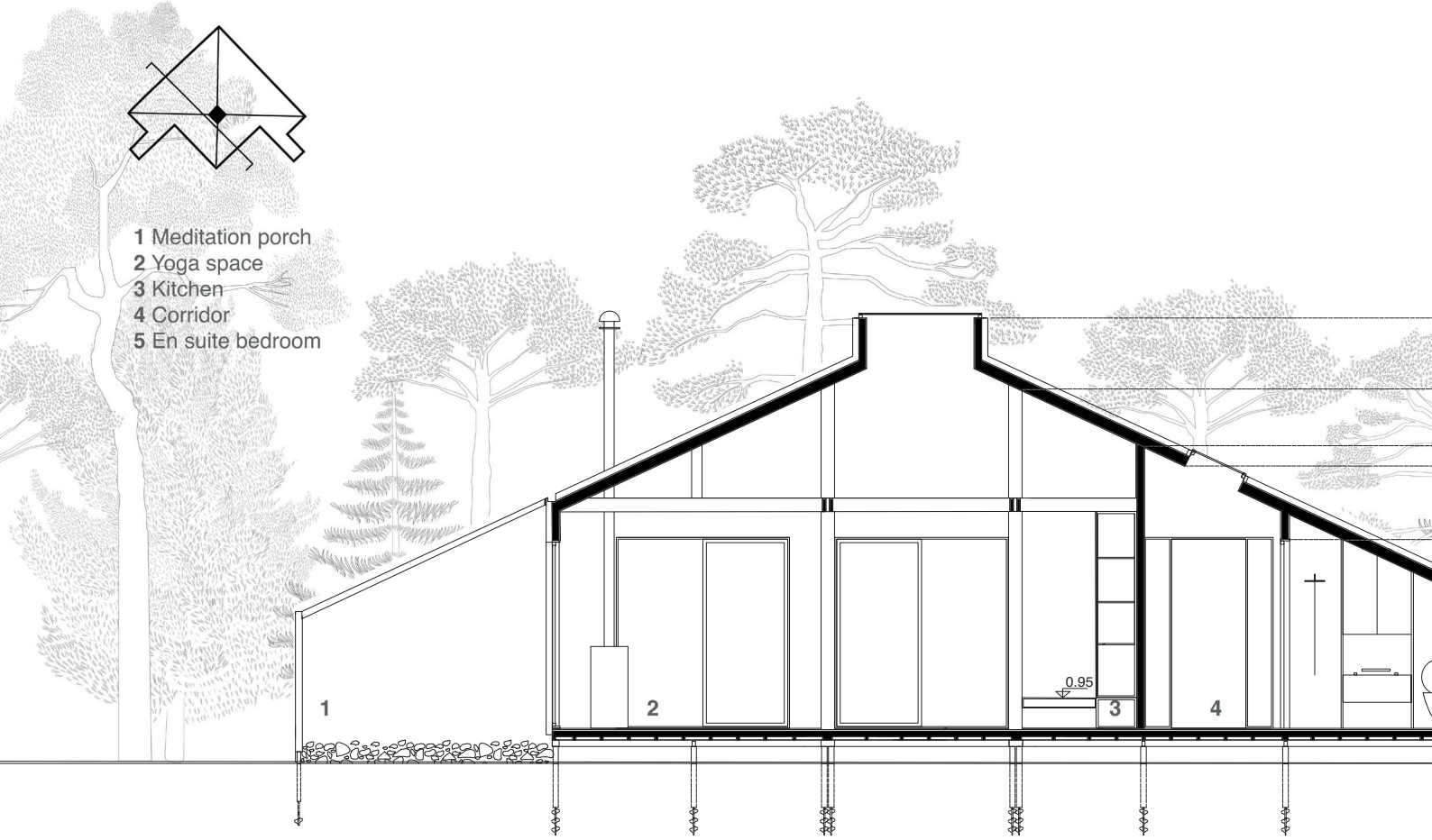


Figure 9 Design proposal section CC - Scale 1:100

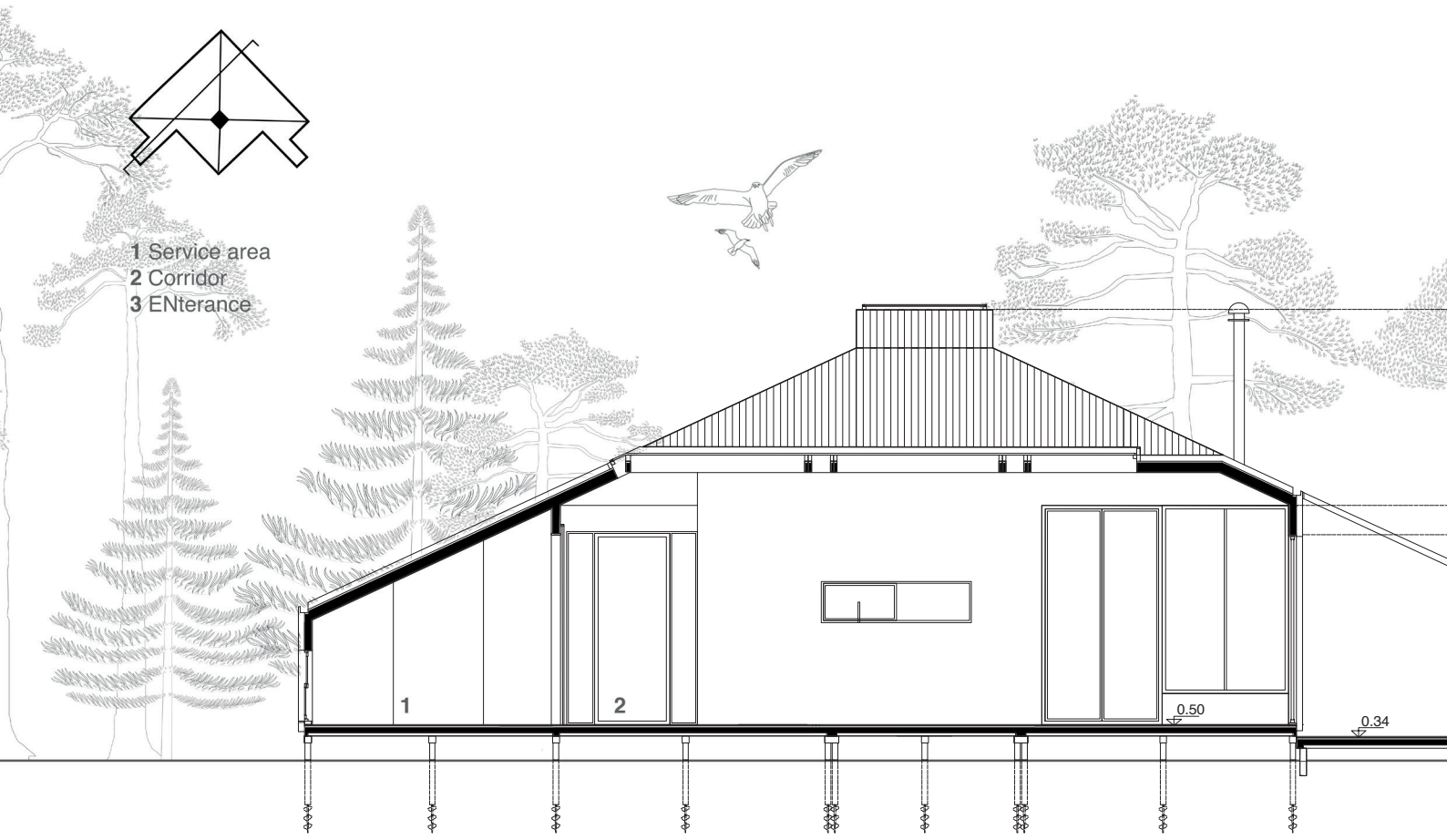


Figure 10 Design proposal section DD - Scale 1:100



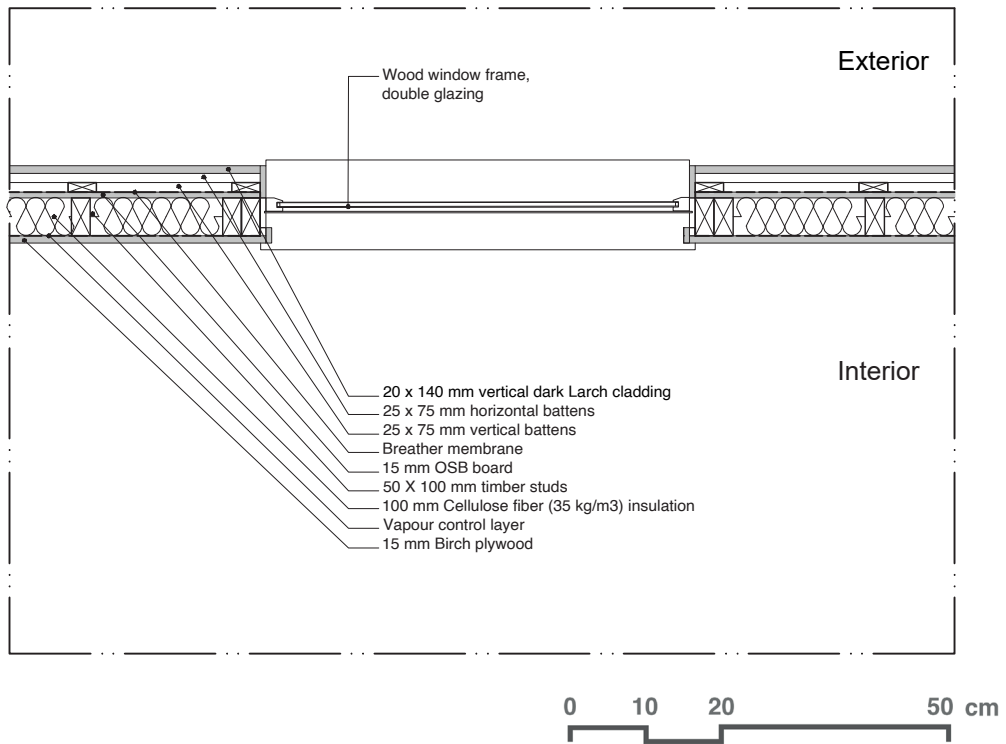
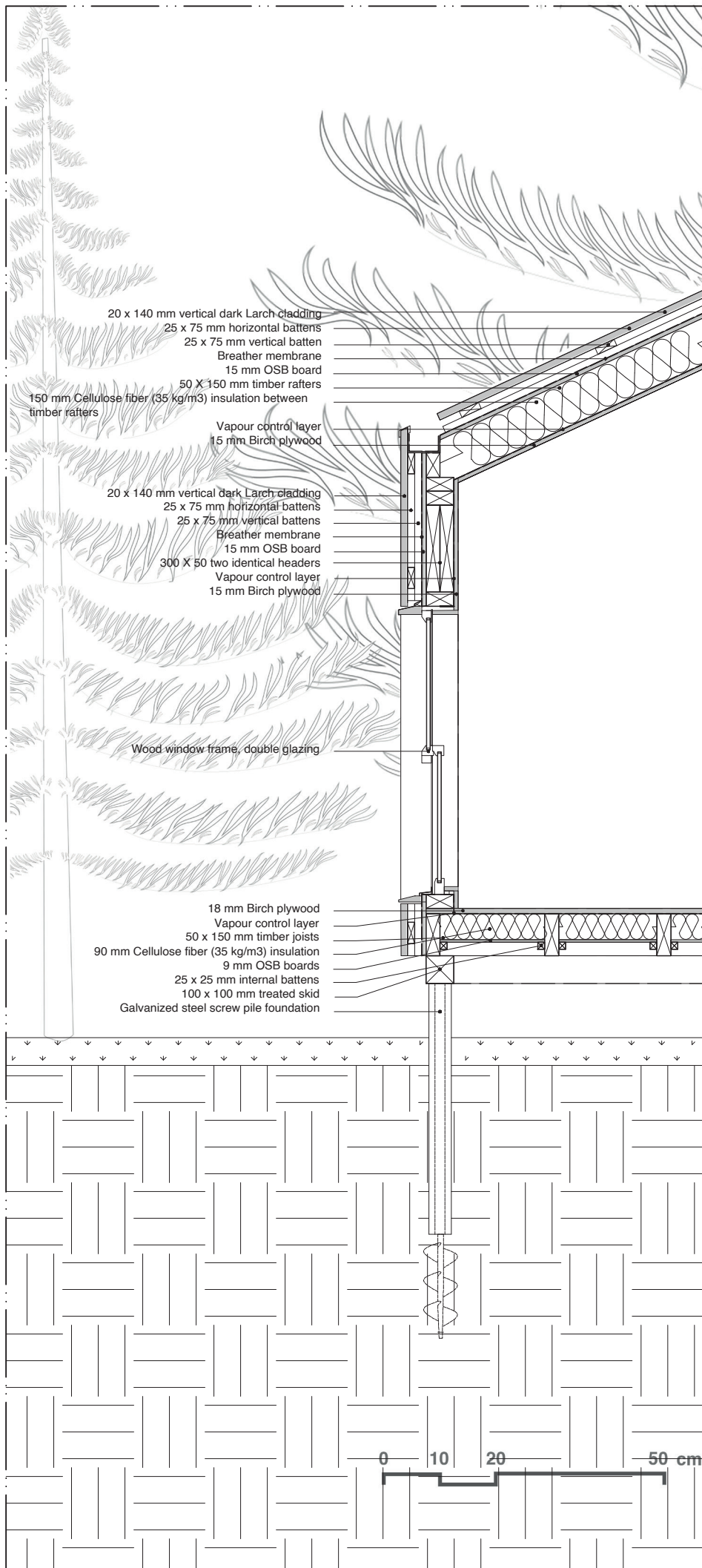


Figure 11 Design proposal detailed plan - Scale 1:20

Figure 12 Design proposal section EE - Scale 1:20



4.2. LCA Rules

GOAL & SCOPE

The primary objective is to find a design **balance between energy consumption and environmental impact**. This involves assessing emissions from materials, systems, and operational usage, with a focus on reducing **emissions and energy consumption**.

The assessment includes **A1-A3**, and **B6** modules; these components contribute to a substantial share (70-90%) of the environmental impact in residential buildings.

A reference service period of **50 years** has been decided upon.

LCI

The assessment includes various building elements such as the slab, exterior wall, windows, skylights, interior wall, columns, and roof. Foundations, terraces, shading devices, and doors are not included. The selection process for materials does not consider the breather membrane and vapor control layer.

In addition, building systems such as electrical, heating, and ventilation systems are also included in the assessment.

The databases used include Bauteilkatalog, Eco Komposit and KBOB.

LCIA

GWP - Green House Gas (GHG) emissions in kg CO₂-eq per m² per year, called as Global Warming Potential (GWP) is defined as impact category.

4.3. Definition of the design proposal via Bombyx and Hive Tools

In this section, the decisions made during the design proposal will be translated into the Rhino and Grasshopper environments to visualize the environmental impact of the design proposal. The goal is to establish a foundation for evaluating, enhancing, and refining these decisions, taking into account the Global Warming Potential (GWP) results.

The Bombyx and Hive tools provide the opportunity to conduct simplified LCA, even when the decisions regarding building materials, systems, and technologies are not fully defined or specific, these tools enable the assessment of results that closely approximate the final outcomes in the early design stages.

Before explaining the definition of the design proposal through the step-by-step process using Bombyx and Hive tools, it is essential to precisely outline the entire procedure. This explanation aims to enhance comprehension of the prerequisites before implementing the methodology, contributing to a clearer understanding of the requirements.

To initiate the methodology, the foundational model of the design proposal is first created as surfaces in the Rhino environment. The model is crafted based on the 2D plans and sections, incorporating the findings obtained through conventional approaches.

Subsequently, the study is conducted parametrically in the Grasshopper environment, and the parametric Life Cycle Assessment (LCA) approach is applied step by step, aligning with the integration process of Hive and Bombyx tools.

The architectural and technical features pertinent to the design proposal are then inputted, including:

- Materials and their thickness in meters for each building construction element included in the assessment (entered manually).
- Reference Study Period (RSP) of the design and Reference Service Life (RSL) for each building element (materials and systems, entered manually).
- Quantity of each building construction element (square meters), with this information derived parametrically from the building model.
- Technical equipment for HVAC systems (entered parametrically).
- Energy Reference Area (ERA) (entered manually).

The inputs are essential for calculating emissions originating from both building construction materials and building systems. Additionally, the inputs necessary for calculating operational emissions and energy consumption are integrated into the process. These include:

- Geometries of the environment and building, information derived parametrically from the building model.
- Building technologies (entered parametrically).
- Energy sources (entered parametrically).
- Energy Reference Area (ERA), entered manually.

Some of features are illustrated in the design proposal chapter, providing insights into the necessary information for defining the design parametrically in the Grasshopper environment.

The design proposal, as defined through the Bombyx and Hive tools, is explained by referencing the seven steps of the workflow in Grasshopper. This section is crucial for elucidating the process, as it involves showcasing the Grasshopper workflow to facilitate a comprehensive understanding of the application for the assessment. It is also crucial to comprehend the methodology, which has been explained schematically earlier.

Step 1: Building Model

Initially, the building elements targeted for evaluation are identified and introduced into Grasshopper as distinct layers, including slab, exterior wall, windows, skylights, interior wall, column, roof, shading elements, envelope, and PV panel (as shown in Figure 13). Concurrently, the design proposal is modeled in Rhino as surfaces, taking these layers into account (as depicted in Figure 14).

Subsequently, the layers generated in Grasshopper are integrated into the Rhino layers. Following this, the building elements in the model are aligned with the layers imported from Grasshopper (as shown in Figure 15). Notably, certain building elements such as the foundation, doors, terraces and pergola have been omitted and are not modeled within the Rhino and Grasshopper environment.

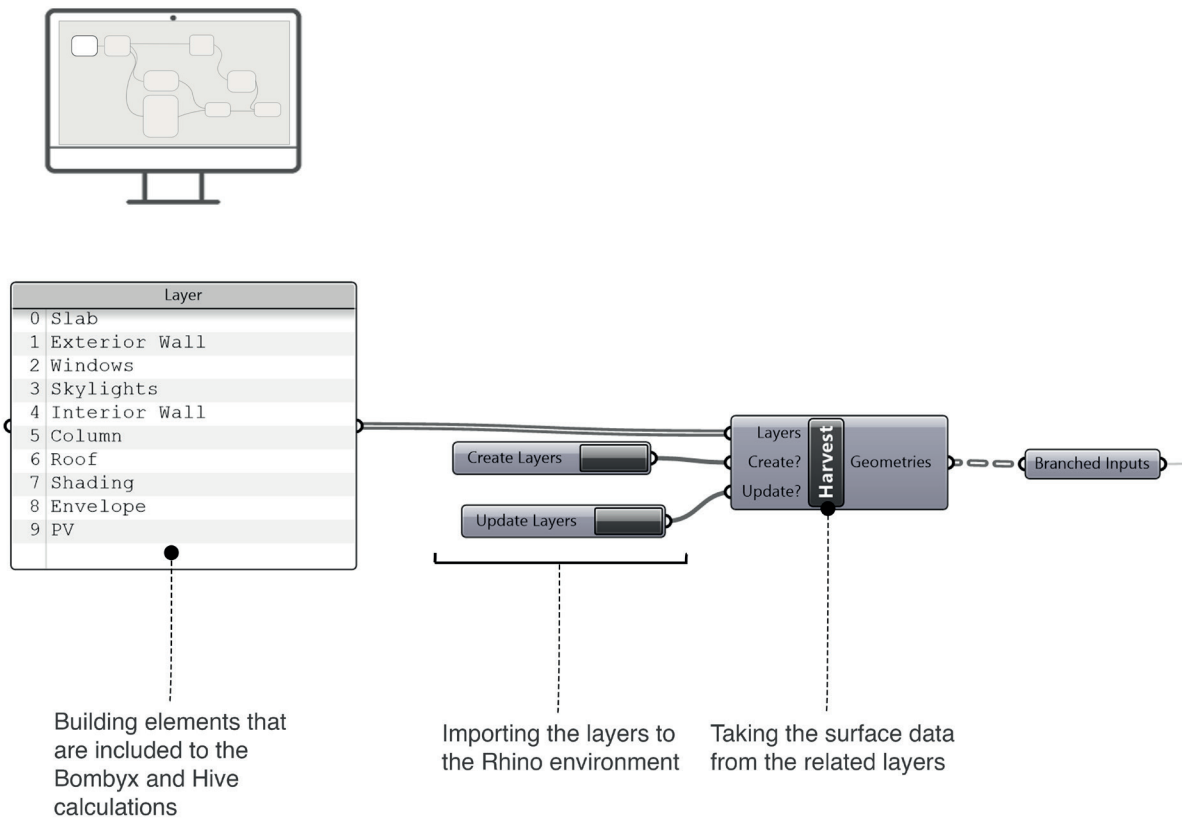


Figure 13 The introduction of building layers in Grasshopper

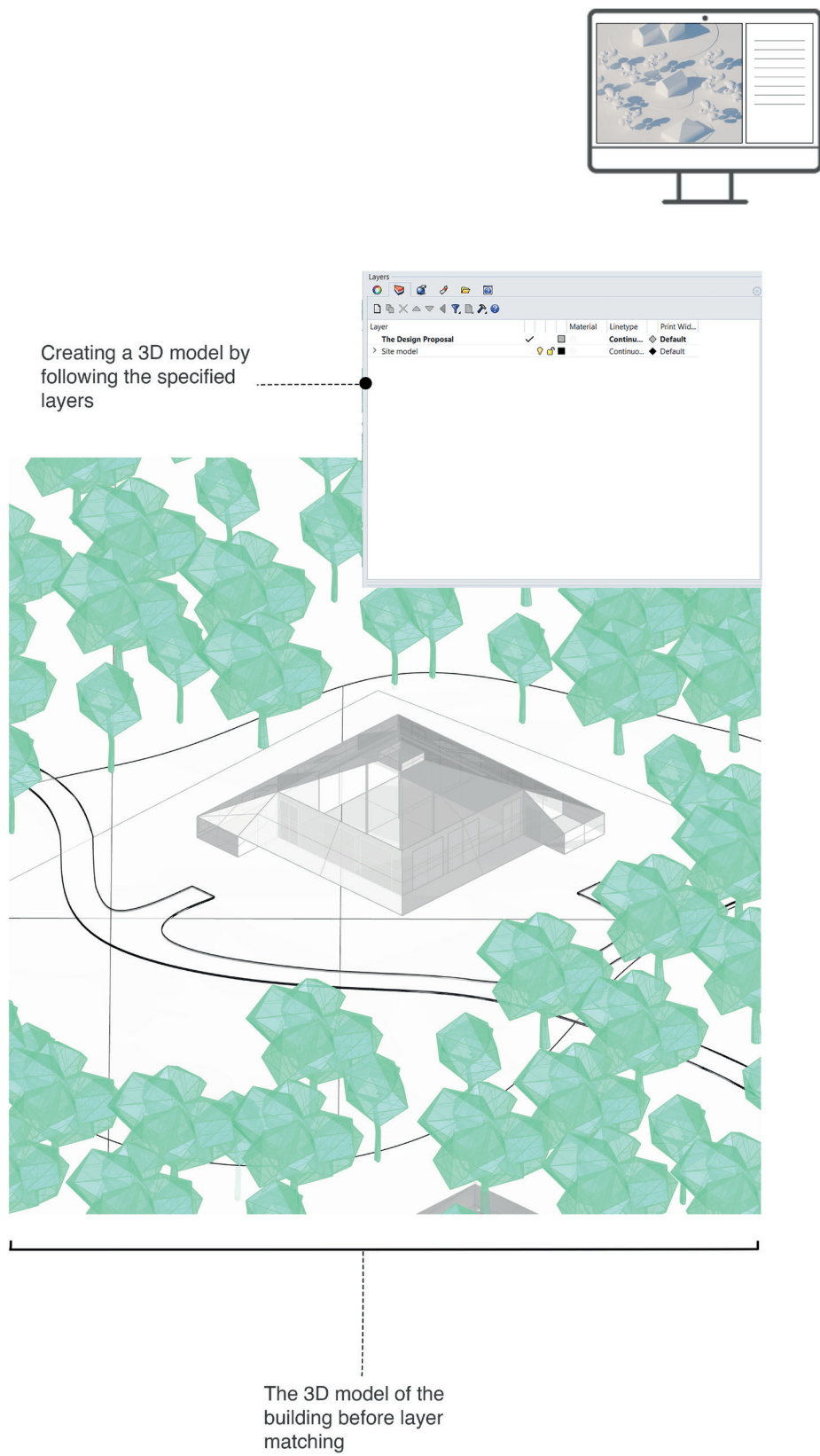


Figure 14 The design proposal 3D model in Rhino

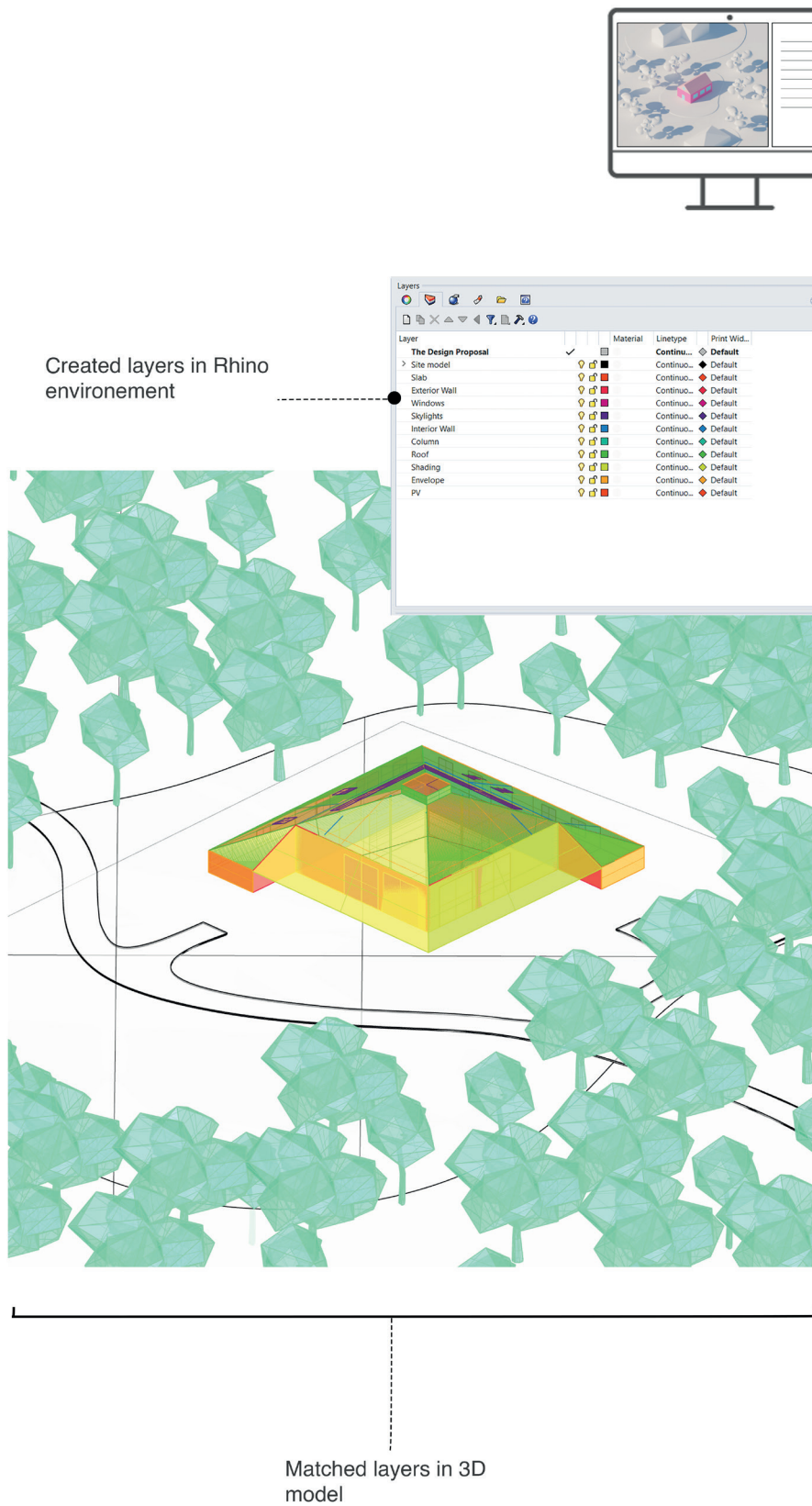


Figure 15 The design proposal 3D model in Rhino after importing the layers

Step 2: Building parameters

Following the establishment of the building definition, the building parameters are organized for use as areas in Bombyx and geometries in Hive (as illustrated in Figure 16).

During this phase, the Energy Reference Area Factor (ERA Factor) and the Reference Service Period (RSP) are introduced.

ERA Factor represents the proportion of the slab area that remains after deducting the wall area, and ERA is calculated by multiplying this factor by the slab area. Additionally, the RSP is set at 50 years in accordance with the Level(s) framework created by the European Commission. This framework serves as a common set of European indicators designed to address the life cycle environmental performance of buildings³.

³ About the project. n.d. [https://lifelevels.eu/about/#:~:text=Level\(s\)%20is%20a%20voluntary,performance%20in%20the%20built%20environment](https://lifelevels.eu/about/#:~:text=Level(s)%20is%20a%20voluntary,performance%20in%20the%20built%20environment). (accessed 09 22, 2023).

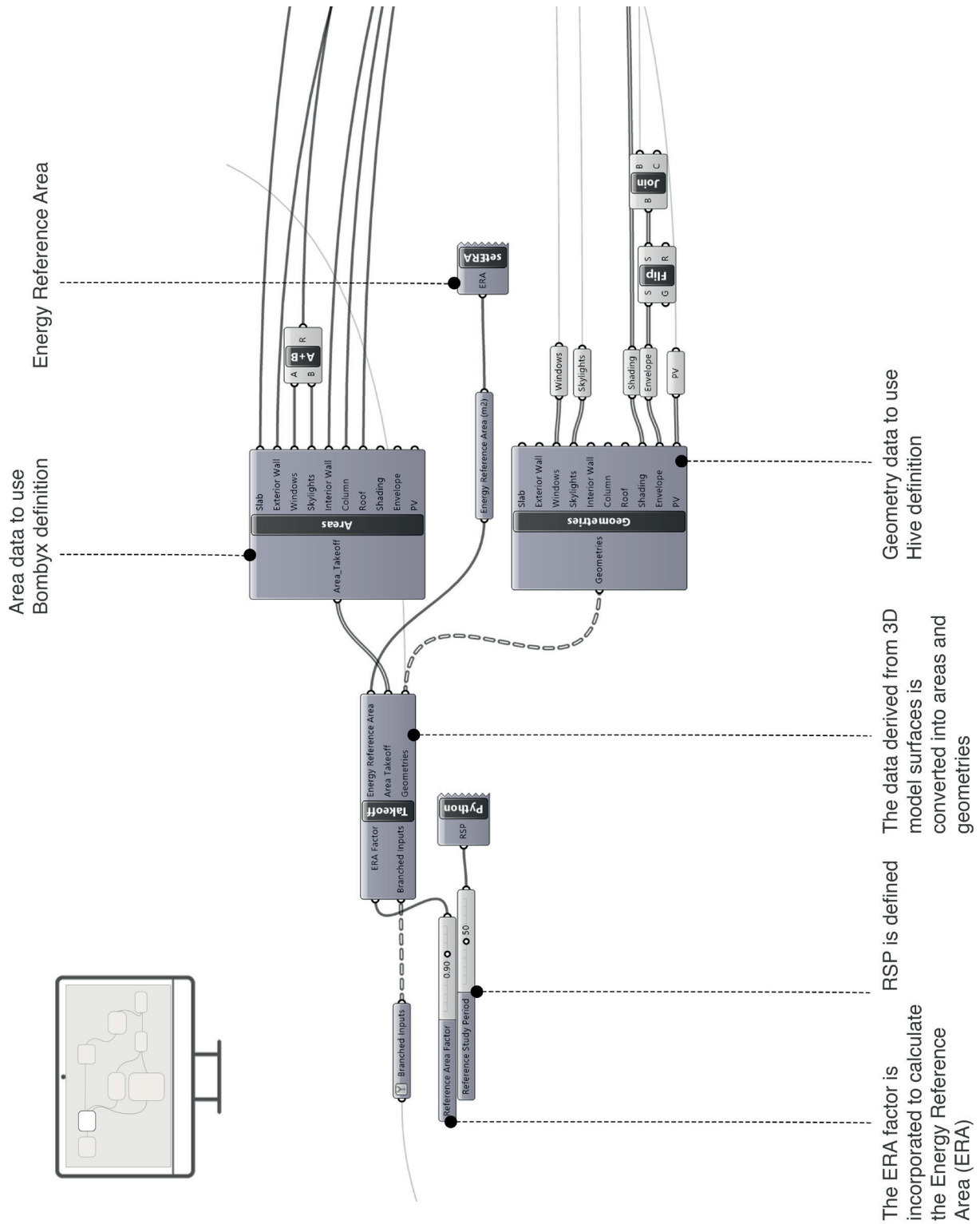


Figure 16 The building parameters

Step 3: Building elements

Step 3.1: Building systems

The building systems have been incorporated into this phase; system definitions are presented in Figure 17. The heating, ventilation, and electrical systems are implemented. Systems are chosen from the relevant system groups, and RSP and RSL values are inputted along with the ERA.

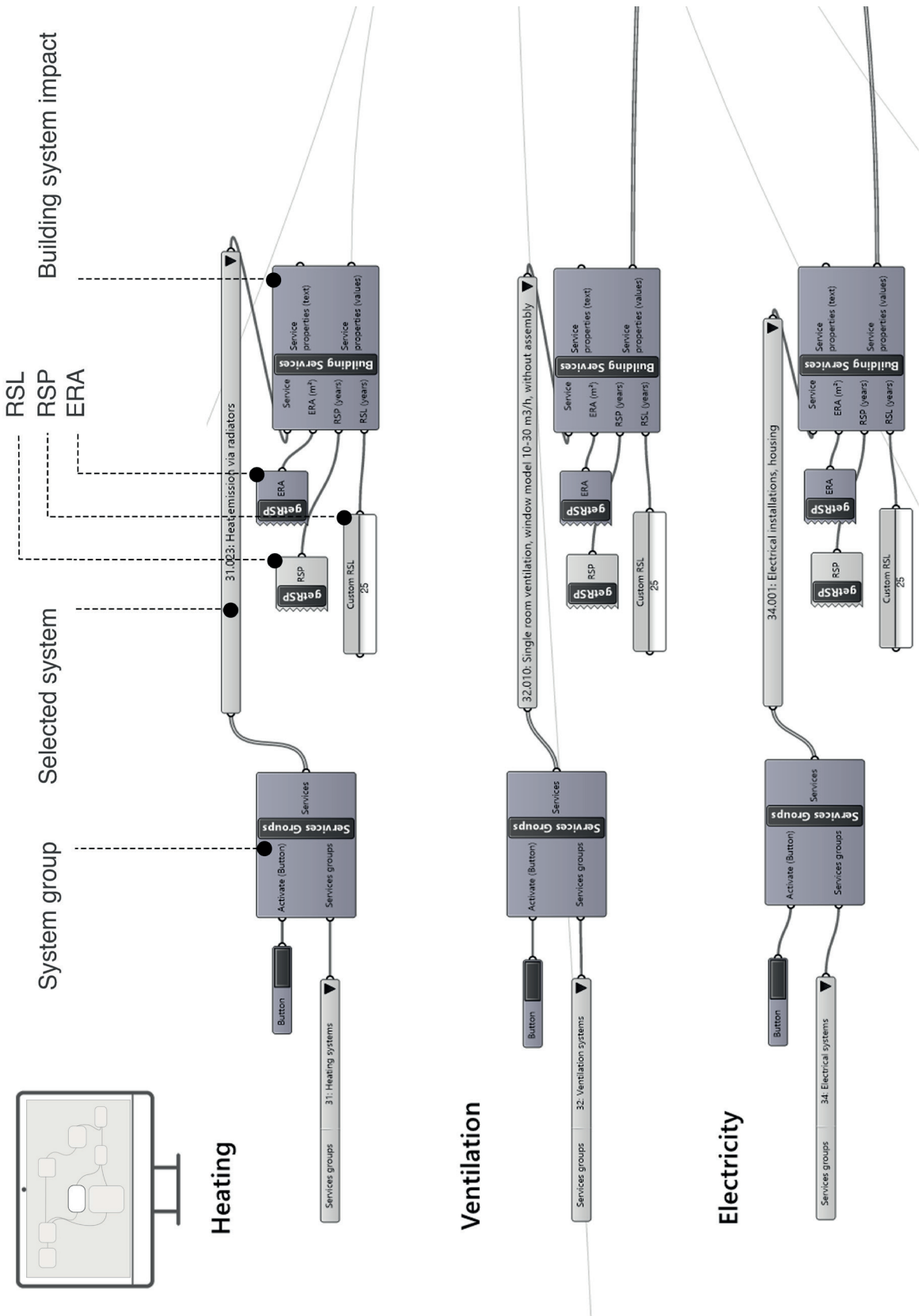


Figure 17 Building system definition by using Bombyx tool in Grasshopper

Step 3.2: Building construction elements

All elements, including the slab, exterior wall, windows and skylights, interior wall, column, and roof, are defined in accordance with the steps outlined in Figure 18. The organization of each building construction element can be observed in the figure. Figure 19 provides a detailed view of the one of the element (slab) within the Grasshopper surface, demonstrating how the element's impact is determined.

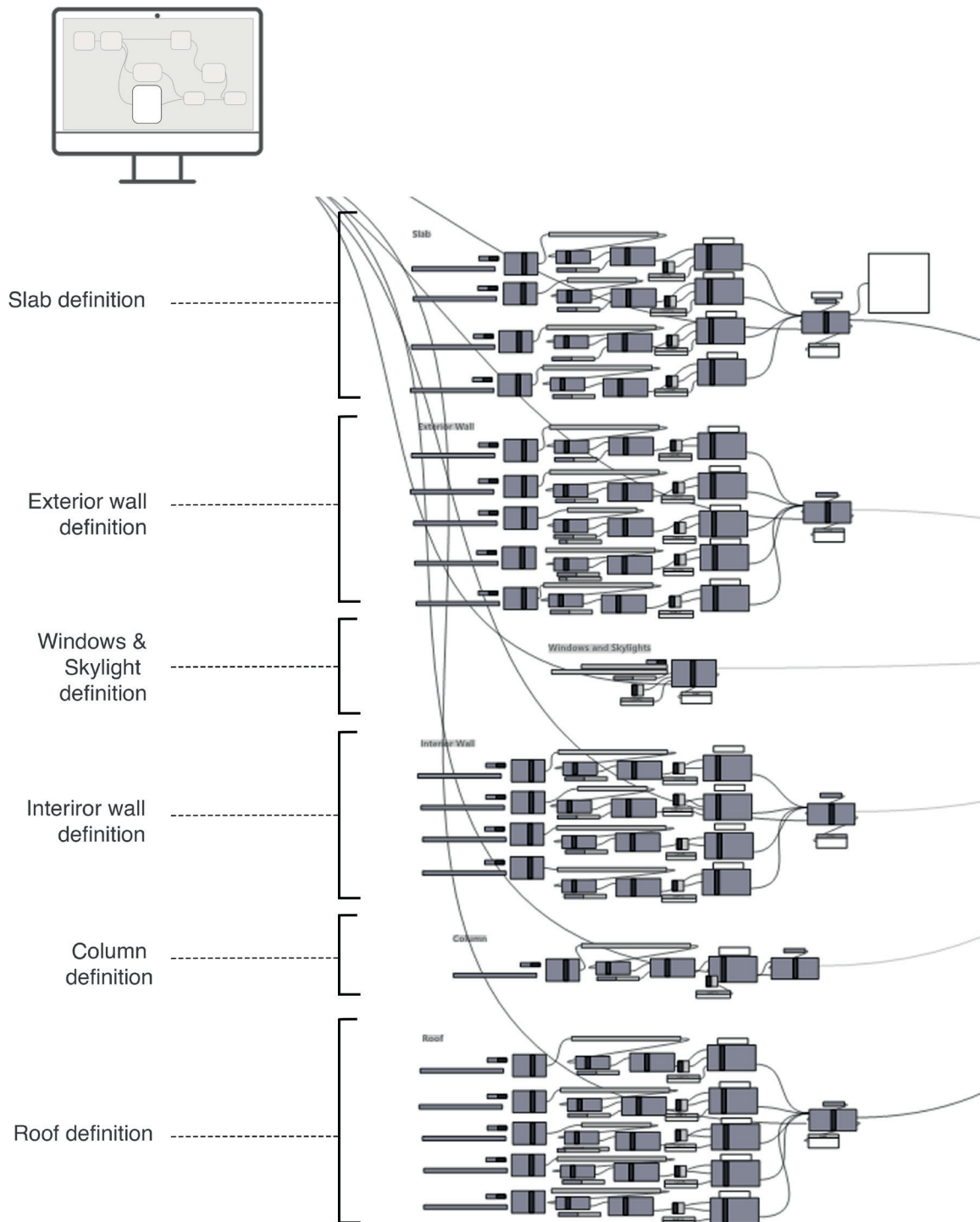


Figure 18 Building construction elements definition by using Bombyx tool in Grasshopper

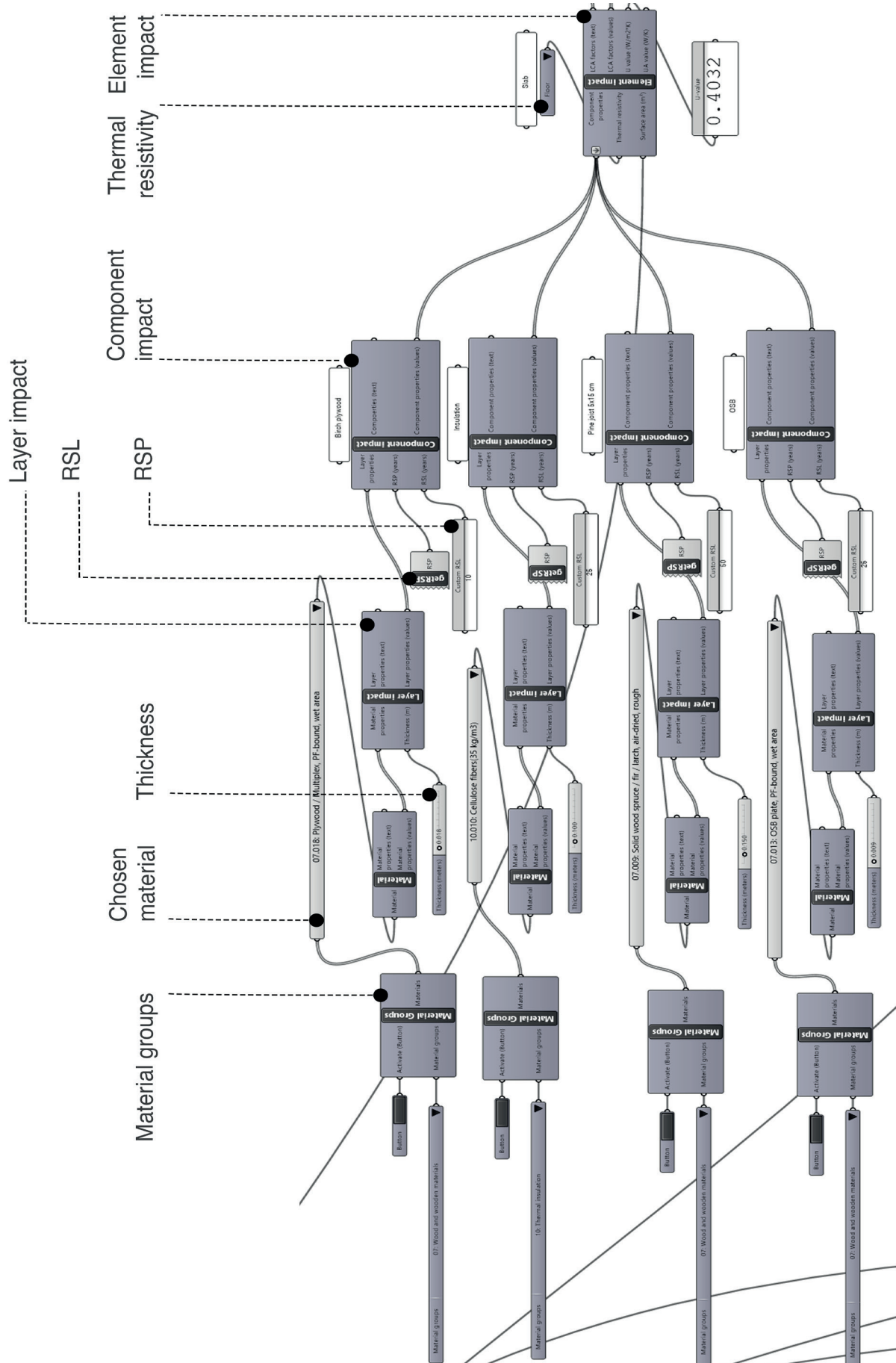


Figure 19 Building construction elements definition (slab) by using Bombyx

It can be observed that, following material selection from the material groups, thickness is inputted in meters. These inputs, at subsequent stages, define layer properties. After adding RSP and RSL values, the component impact is determined. This process is repeated for each component of every element to calculate element impacts. Additionally, to determine the element impact, thermal resistivity, defined in Bombyx as default, should be selected, and the square meters of the relevant element should be integrated from the building parameters.

Additionally, all the inputs used in the creation of building construction elements and building systems are presented in Figure 20.

As previously mentioned during the explanation of the Bombyx and Hive tools, users have the ability to define materials and systems from the Swiss LCA database; customization is not an option.

Consequently, materials and systems considered for use in the design proposal are highlighted in red to distinguish them from those that can be selected using the Bombyx tool.

It is noticeable that windows and skylights have distinct inputs because window impacts are presented as a specific component within the tool. This implies that there is no requirement to create a separate window component.

The Reference Service Life (RSL) is defined according to the European Organization for Technical Assessment (EOTA) technical guidelines.

“ The EOTA is a Europe-wide association of Technical Assessment Bodies for construction products established under the Construction Products Regulation (CPR) and it provides an independent Europe-wide procedure for assessing the essential performance characteristics of non-standard construction products. ”

-What is an ETA? n.d. <https://www.eota.eu/what-is-an-eta>
(accessed 09 25, 2023).

BILL of QUANTITY (BoQ)

Design proposal
material selection

Slab

Birch plywood

| Material group (Bombyx tool, default material database) | Material (Bombyx tool, default material database) | Layer Impact (thickness in meters) | Component Impact (RSP and RSL years) | Element Impact (Surface area in meters) |
|--|--|---------------------------------------|---|--|
|--|--|---------------------------------------|---|--|

| | | | | |
|---------------------------|--|-------|--------|-----|
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.018 | 50, 10 | |
| Thermal Insulation | Cellulose fibers (35 kg/m3) | 0.09 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/ larch, air-dried, rough | 0.15 | 50, 50 | 234 |
| Wood and wooden materials | OSB plate, PF-bound, wet area | 0.009 | 50, 25 | |

Exterior Wall

Birch plywood

Cellulose insulation

Studs from Pine wood

OSB

Larch cladding

| | | | | |
|---------------------------|--|-------|--------|-----|
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | |
| Thermal Insulation | Cellulose fibers (35 kg/m3) | 0.10 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.10 | 50, 50 | 110 |
| Wood and wooden materials | OSB plate, PF-bound, wet area | 0.015 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.020 | 50, 25 | |

Windows & Skylights

| | | | | |
|--|--|--|--------|----|
| Window frame: wood Window glazing: double glazing, Ug value: 1.1 W / m2K, thickness 24 mm Frame percentage, 10 | | | 50, 25 | 64 |
|--|--|--|--------|----|

Interior wall

Birch plywood

Cellulose insulation

Studs from Pine wood

Birch plywood

| | | | | |
|---------------------------|--|-------|--------|-----|
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | |
| Thermal Insulation | Cellulose fibers (35 kg/m3) | 0.10 | 50, 50 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.10 | 50, 50 | 150 |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | |

Column

Column from Pine wood

| | | | | |
|---------------------------|---------------------------------------|------|--------|----|
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.20 | 50, 50 | 42 |
|---------------------------|---------------------------------------|------|--------|----|



| Roof | | | | | |
|----------------------------------|--|---|--------------------------------------|--------|-----|
| Birch plywood | Wood and wooden materials | Solid wood spruce/fir/larch, air-dried, rough | 0.015 | 50, 50 | 246 |
| Cellulose insulation | Thermal Insulation | Cellulose fibers (35 kg/m ³) | 0.15 | 50, 25 | |
| Rafters from Pine wood | Wood and wooden materials | Solid wood spruce/fir/larch, air-dried, rough | 0.15 | 50, 50 | |
| OSB | Wood and wooden materials | OSB plate, PF-bound, wet area | 0.015 | 50, 25 | |
| Larch cladding | Wood and wooden materials | OSB plate, PF-bound, wet area | 0.020 | 50, 25 | |
| | | | | | |
| Design proposal system selection | | | | | |
| | System groups (Bombyx tool, default material database) | System (Bombyx tool, default material database) | Building Services (ERA, RSP and RSL) | | |
| Heating | | | | | |
| Radiators | Heating systems | Heat emission via radiators | 210 m ² , 50, 25 | | |
| Ventilation | | | | | |
| Decentralized ventilation | Ventilation systems | Single room ventilation, window model 10-30 m ³ /h, without assembly | 210 m ² , 50, 25 | | |
| Electricity | | | | | |
| Electrical installation | Electrical systems | Electrical installation, housing | 210 m ² , 50, 25 | | |

Figure 20 Design proposal - BII of Quantity

Step 4: Embodied emissions

The embodied emissions from building systems and building construction elements are shown separately in Figure 21.

All LCA results derived from the building elements are consolidated in the building impact component. Additionally, the RSP value and ERA factor are integrated to calculate the building impact. Various impact categories can be observed as outputs of this process.

As GWP is assessed in this study, each GWP result is highlighted. Construction materials have a GWP of **5.63 kg CO₂-eq/m²a**, whereas a system has a GWP of **2.53 kg CO₂-eq/m²a**.

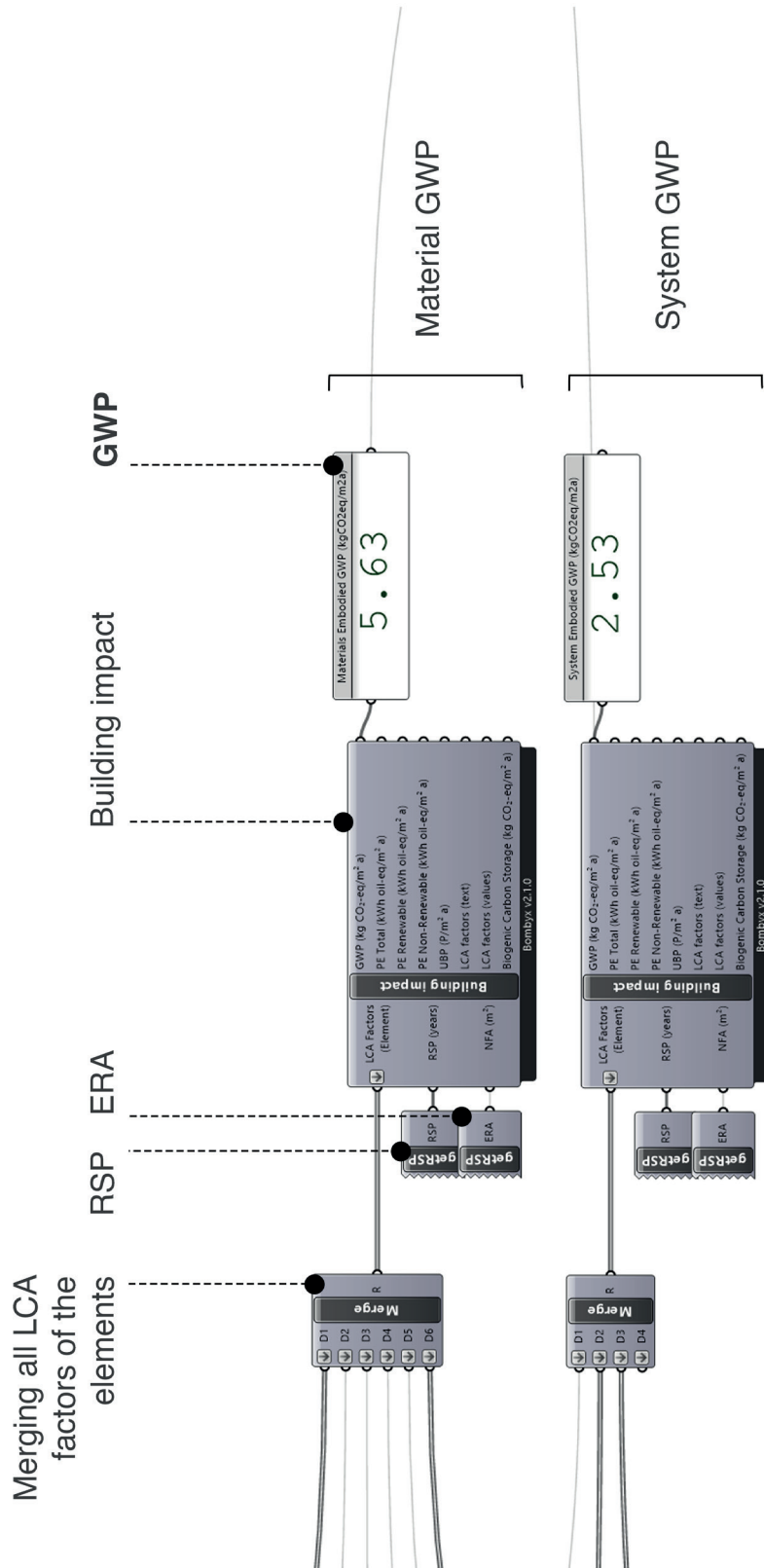
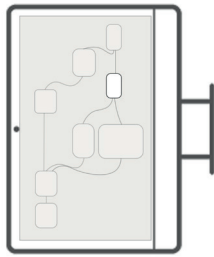


Figure 21 Design proposal - Embodied emissions that comes from the building construction materials and the building systems

Step 5: Hive Simulation

After the building definition is completed through Bombyx, the inputs are combined using the Hive tool to derive operational emissions.

Figure 22 provides an overview of the three primary components of Hive:

Ground (earth), Context (trees), and Shading device (pergola and sunbreakers). These are input as 'Obstacles,' along with the inclusion of the EPW file for Ventspils city in the **Hive Input Environment**.

Additionally, the building envelope (roof, exterior wall and slab), windows, and skylights are incorporated into the **Hive Input Building** as geometries.

Although the **Hive Input Energy System** initially operates with specific technologies (Chiller and ASHP - Air Source Heat Pumps), the names of the technologies remain the same while the efficiency ratios are adjusted in accordance with the recommendations from the Bombyx team.

For instance, even though Chiller and ASHP are selected within the Hive Input Energy System, their efficiencies are adjusted to match CHP (Combined Heat and Power/Cogeneration) for electricity demand and Boiler (Gas) for heating and DHW (Domestic Hot Water) demand, as suggested. Furthermore, default efficiency ratios are applied; 0.3 for CHP and 0.94 for DHW.

All these inputs are then consolidated within the **Hive Distributor** to facilitate data transformation for energy demand calculations.

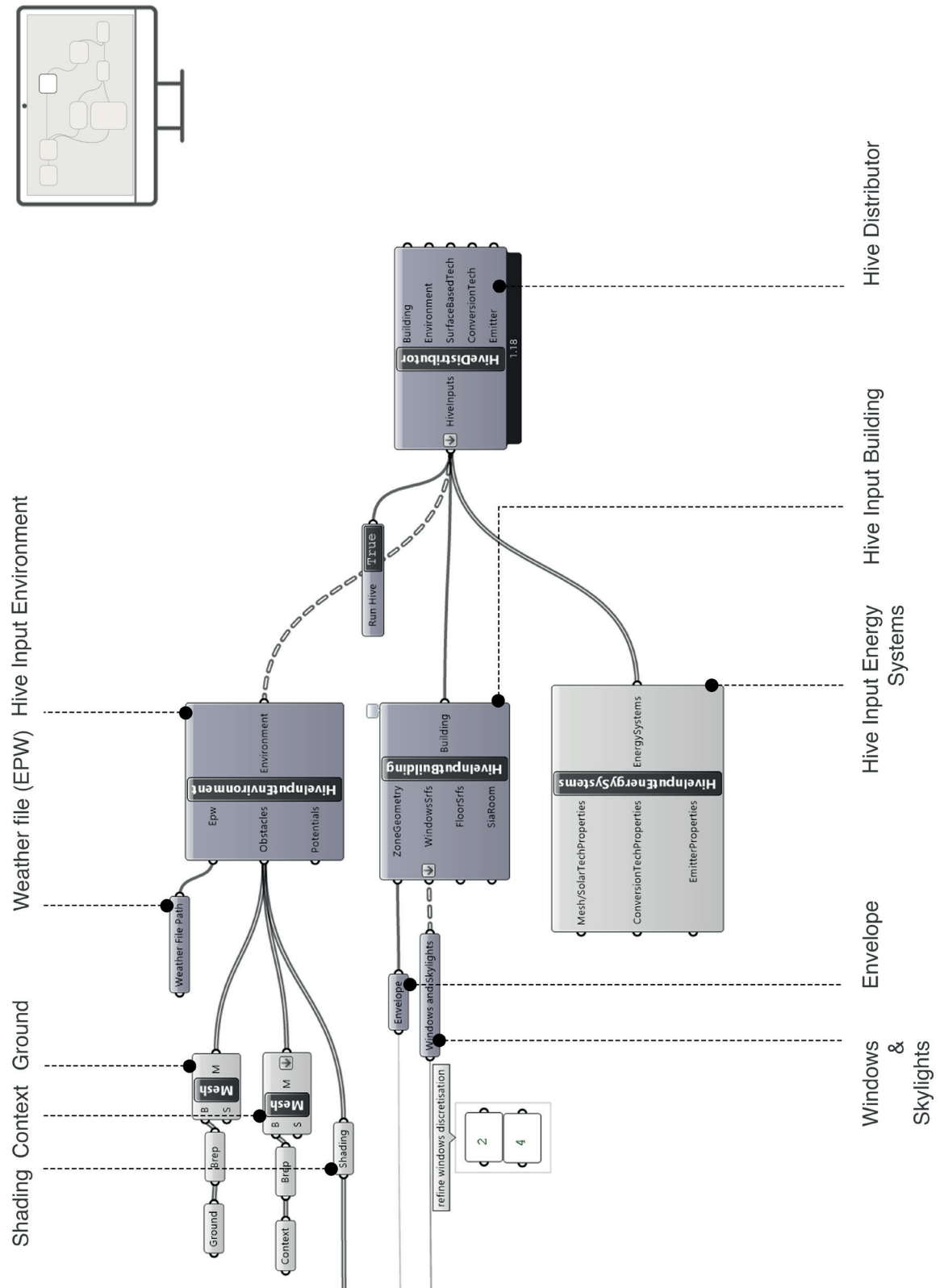


Figure 22 The design proposal- Hive Definition

The energy demand, as shown in Figure 23, can be monitored in real time, with an annual operational final energy consumption of **55.147 kWh/year**. In the chart, it is possible to observe heating, cooling, electricity and DHW consumption separately according to the each month.

Following this adjustment, the data derived from the geometry changes can be viewed within the Hive Building component. The areas for the floor, wall, window & skylights, and roof are displayed, along with the respective U-values for these building elements, as depicted in Figure 24.

Furthermore, additional features such as building use type, room type and construction type are specified, with “residential” , “multi family home” and “lightweight” being the chosen selections, respectively.

Figure 25 provides a visual representation of the workspace within Hive Input Energy Systems.

The highlighted sections in the figure denote different technologies. As mentioned earlier, the proposed technologies are achieved by altering the system efficiency, while the names remain constant, and their efficiencies are adjusted based on the choices made.

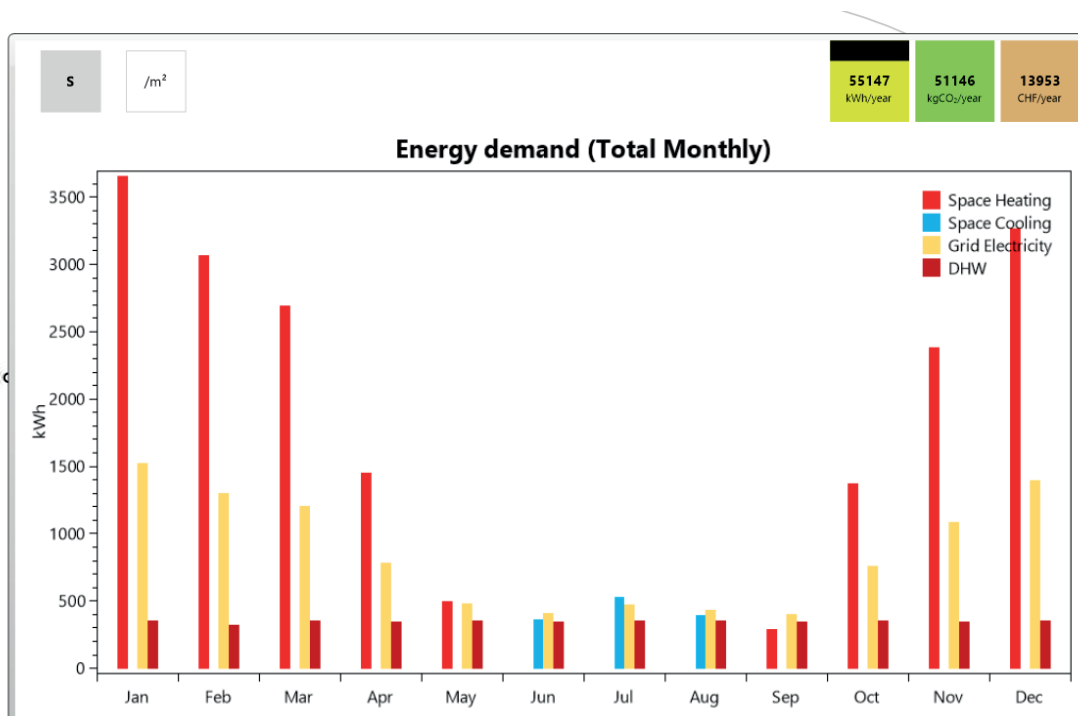


Figure 23 Annual operational final energy consumption, Chart in Grasshopper

Building use type, room type

Building construction type

U- values of the slab, wall, windows & skylights and roof

Building use type, room type

Area of the slab, wall, & skylights and roof

hizard | Building

Building use type: Residential
Room type: 1.1 Multi family home
Building quality: Standard value

Geo./Set-points: Envelope Internal Gains/Ventilation

Building construction type: lightweight
Capacity per Floor Area (Wh/m²K): 50.00

Wall

| |
|-----------------------------|
| lightweight |
| U-value (W/m²K): 0.45 |
| Emissions (kgCO2/m²): 63.00 |
| Cost (CHF/m²): 347.00 |

Floor

| |
|-----------------------------|
| lightweight |
| U-value (W/m²K): 0.40 |
| Emissions (kgCO2/m²): 63.00 |
| Cost (CHF/m²): 347.00 |

Roof

| |
|---------------------------------|
| lightweight |
| U-value (W/m²K): 1.75 |
| g-value (-): 0.50 |
| Emissions (kgCO2/m²): 64.00 |
| g-value with shading: 0.14 |
| Shading setpoint (W/m²): 200.00 |
| Cost (CHF/m²): 467.00 |

hizard | Building

Building use type: Residential
Room type: 1.1 Multi family home
Building quality: Standard value

Geo./Set-points: Envelope Internal Gains/Ventilation

| Geometry | Set-points | Adaptive? |
|-------------------------|---------------------|--------------------------|
| Floor Area (m²): 234.23 | Heating: 21.00 | <input type="checkbox"/> |
| Wall Area (m²): 115.78 | Cooling: 26.00 | |
| Win Area (m²): 64.44 | Heat Setback: 19.00 | |
| Roof Area (m²): 238.04 | Cool Setback: 28.00 | |

Figure 24 Hive Input Building, within the component itself

The screenshot shows a software interface titled "EnergySystemsInputForm" with two tabs: "Conversion" and "Emission". The "Conversion" tab is active, displaying a table with columns for Conversion, Source, and End Use. Below the table are input fields for Efficiency (Reference), Specific Embodied Emissions, and Embodied Emissions, each with a unit dropdown menu.

| Conversion | Source | End Use |
|-----------------------|------------------|--------------------|
| Cooling Exchanger | Air | Cooling demand |
| Chiller (Electricity) | Electricity Grid | Cooling demand |
| ASHP (Electricity) | Air | Electricity demand |

Below the table, the following input fields are visible:

- Efficiency (Reference): 0.94 (unit: (-))
- Specific Embodied Emissions: 364.00 (unit: (kgCO₂/kW))
- Embodied Emissions: 0.00 (unit: (kgCO₂))
- Capacity: 0.00 (unit: (kW))
- Specific Capital Cost: 1798.00 (unit: (CHF/kW))
- Capital Cost: 0.00 (unit: (CHF))

Annotations with dashed lines and dots point to the table and the input fields, labeled "Energy systems" and "System efficiency" respectively.

Figure 25 Hive Input Energy Systems, within the component itself

Step 6: Operational Emissions

To determine operational emissions, the Bombyx energy definition is established, as illustrated in Figure 26.

The heat source is selected as 'Boiler, pellet,' while electricity is sourced from the 'Cogeneration plant, wood.' In this phase, COP (Coefficient of Performance) is inputted manually as 0.94, since the selected entry uses electricity and does not contain the Coefficient of Performance in it. In addition, the System Heat Loss Factor is inputted as 0.10.

These inputs are incorporated into the carriers to generate data suitable for assessing energy demand, facilitating the determination of operational emissions.

Subsequently, all data from Hive results, Bombyx carriers, and ERA are merged to provide comprehensive energy demand data (as shown in Figure 27).

In the final stage, electricity and heating demands and data from the carrier are inputted to energy carrier component in order to calculate operational emissions (as it is seen in Figure 28). The resulting Global Warming Potential (GWP) arising from operational use is computed as **9.17 kg CO₂-eq/m²a**.

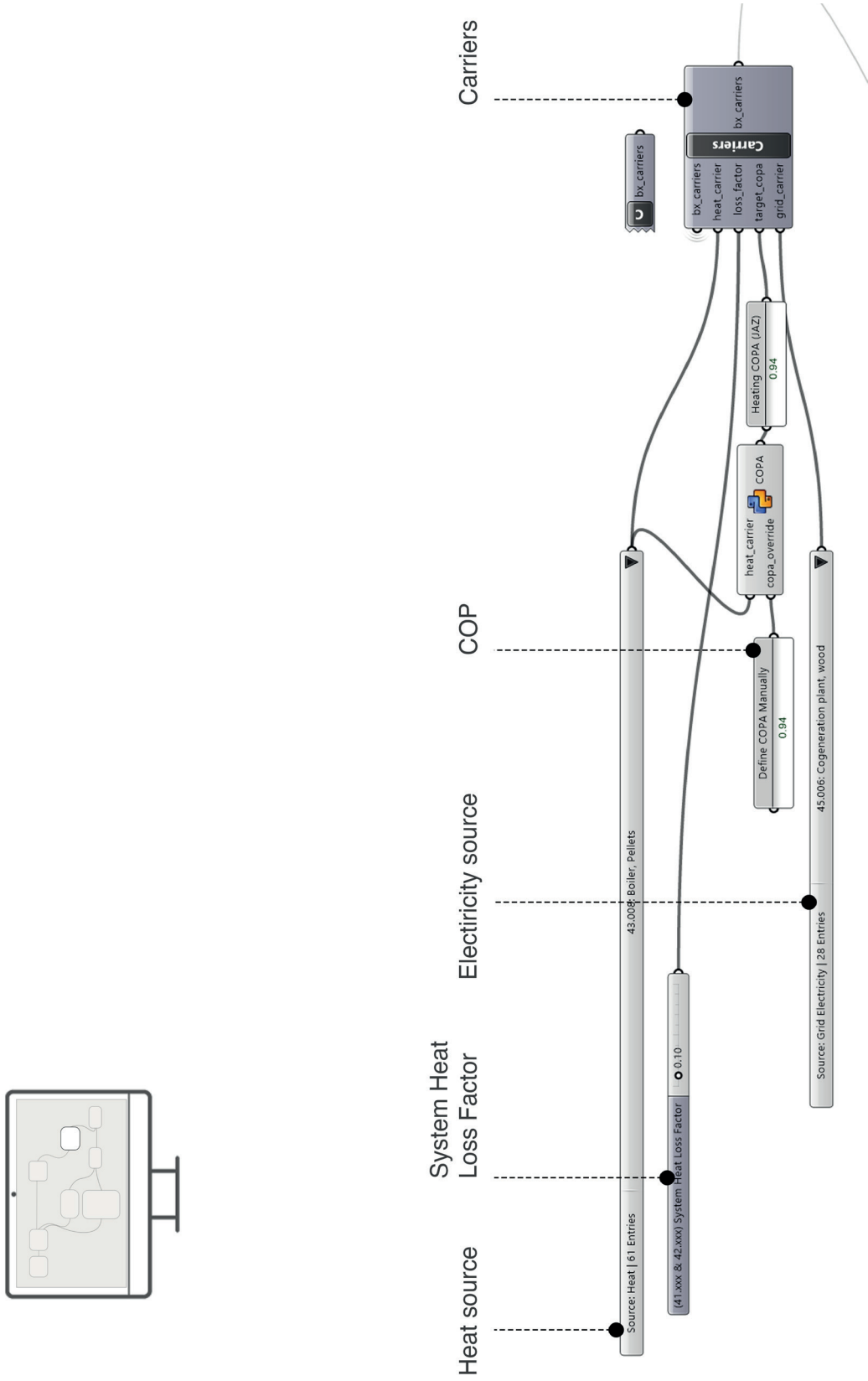


Figure 26 Energy source identification

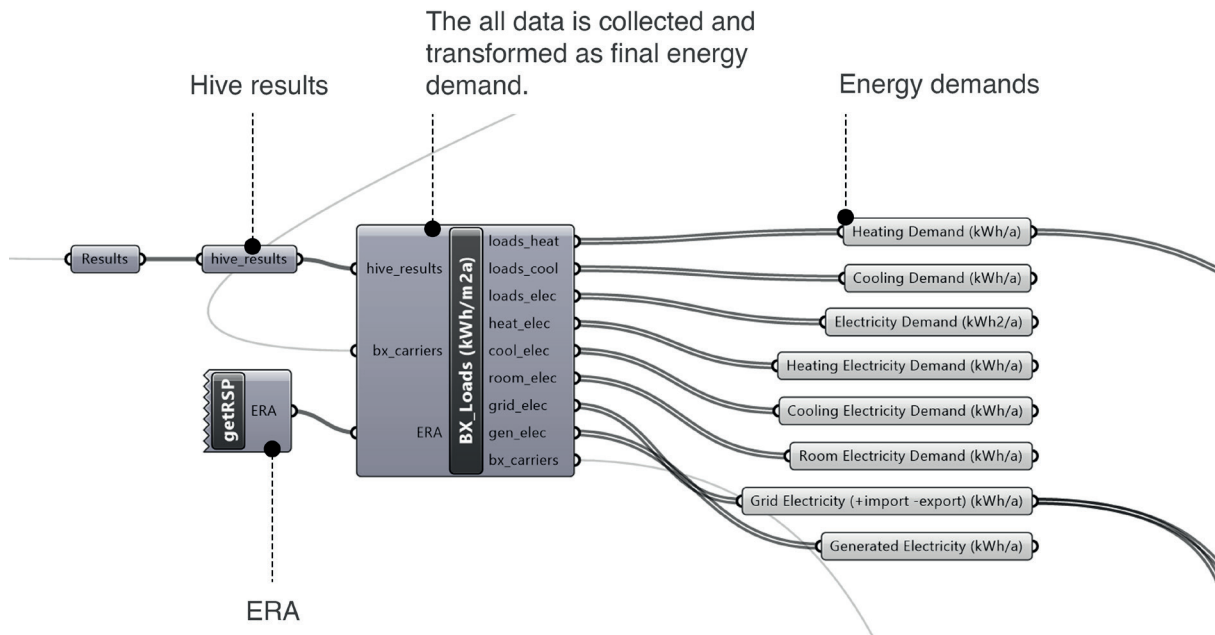


Figure 27 Energy demand to calculate operational emissions

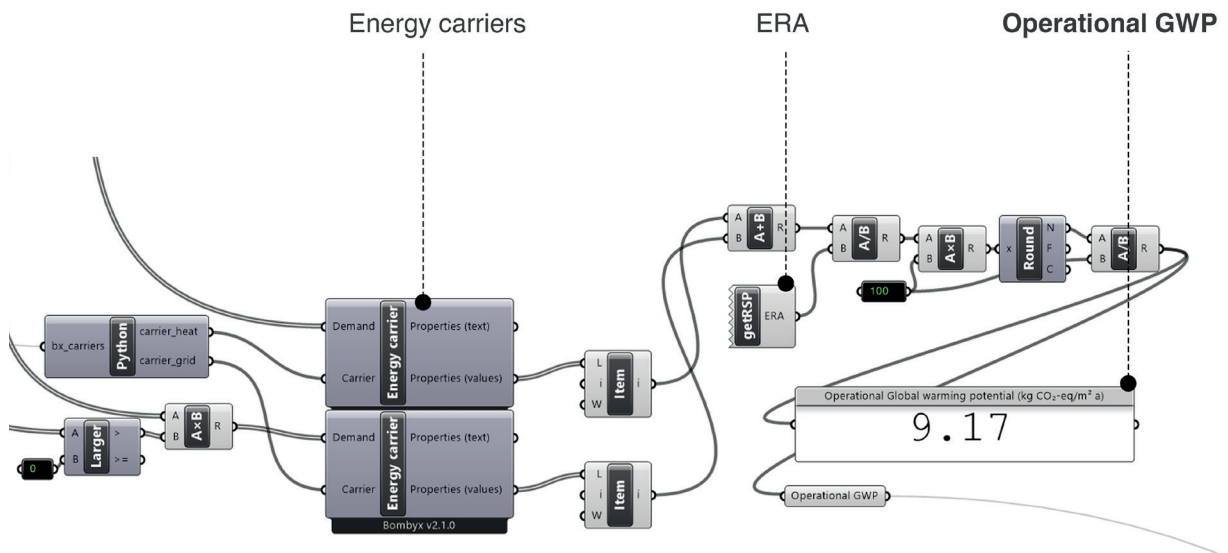


Figure 28 Design proposal - Operational emissions

Step 7: Emissions Breakdown

All GWP results are depicted in Figure 29, presented both individually and as a total (17.33 kg CO₂-eq/m²a). These results can be transformed into a chart within Grasshopper. Additionally, it is possible to view the results on the Rhino model (as displayed in Figure 30) and the all process in Grasshopper environment is shown in Figure 31.

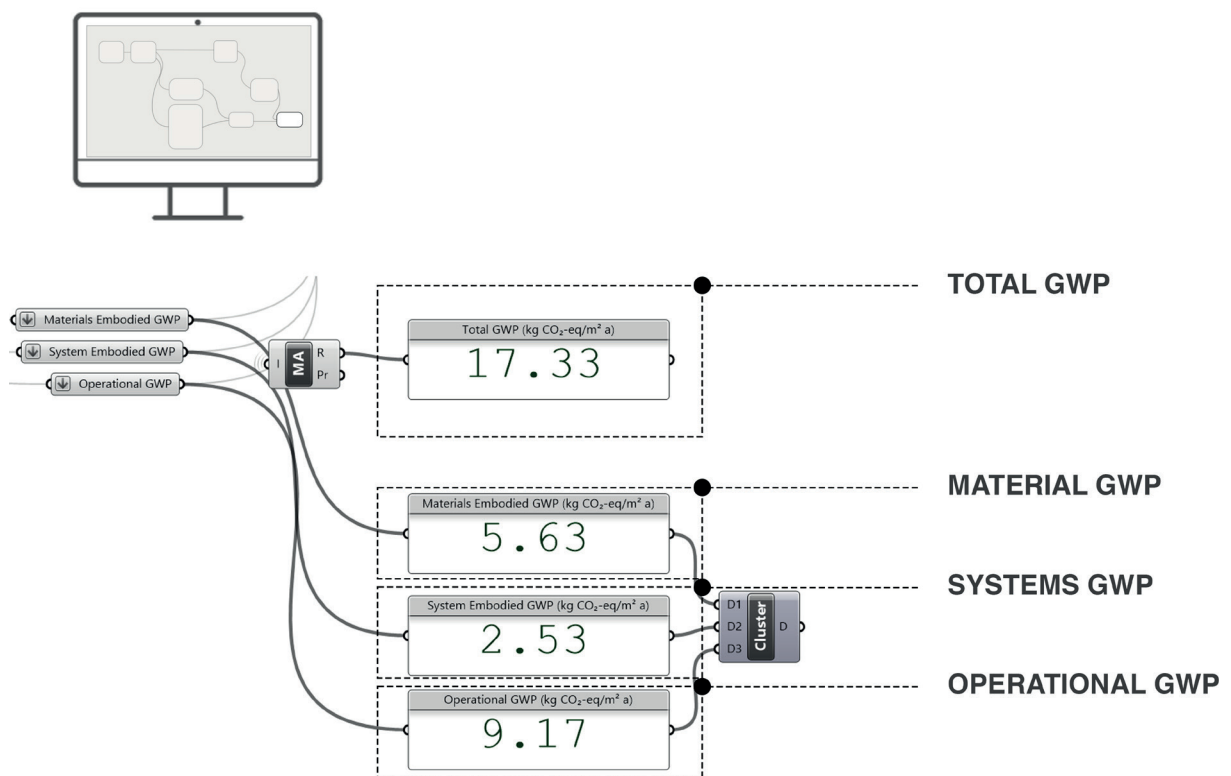


Figure 29 The desing proposal- Emissions breakdown

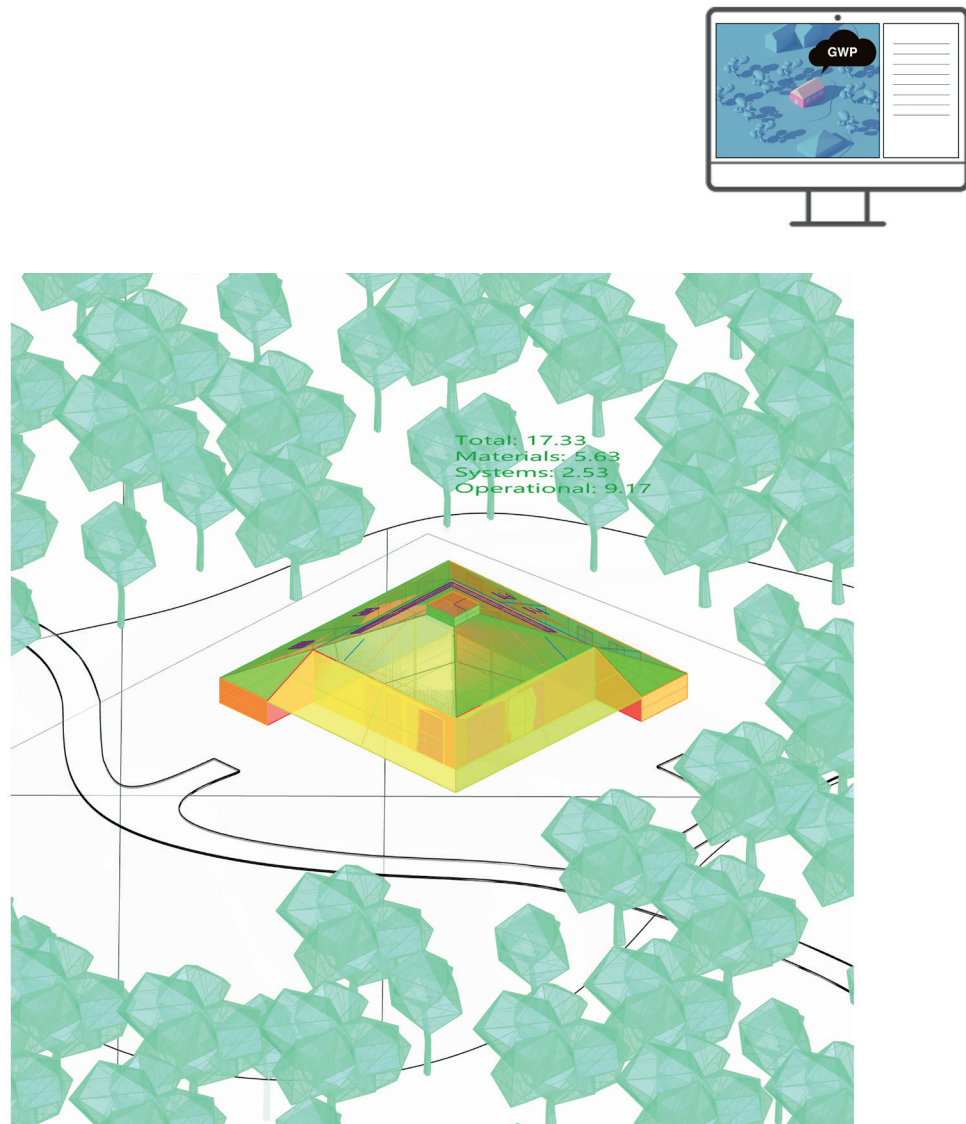


Figure 30 Design proposal - GWP results on Rhino model

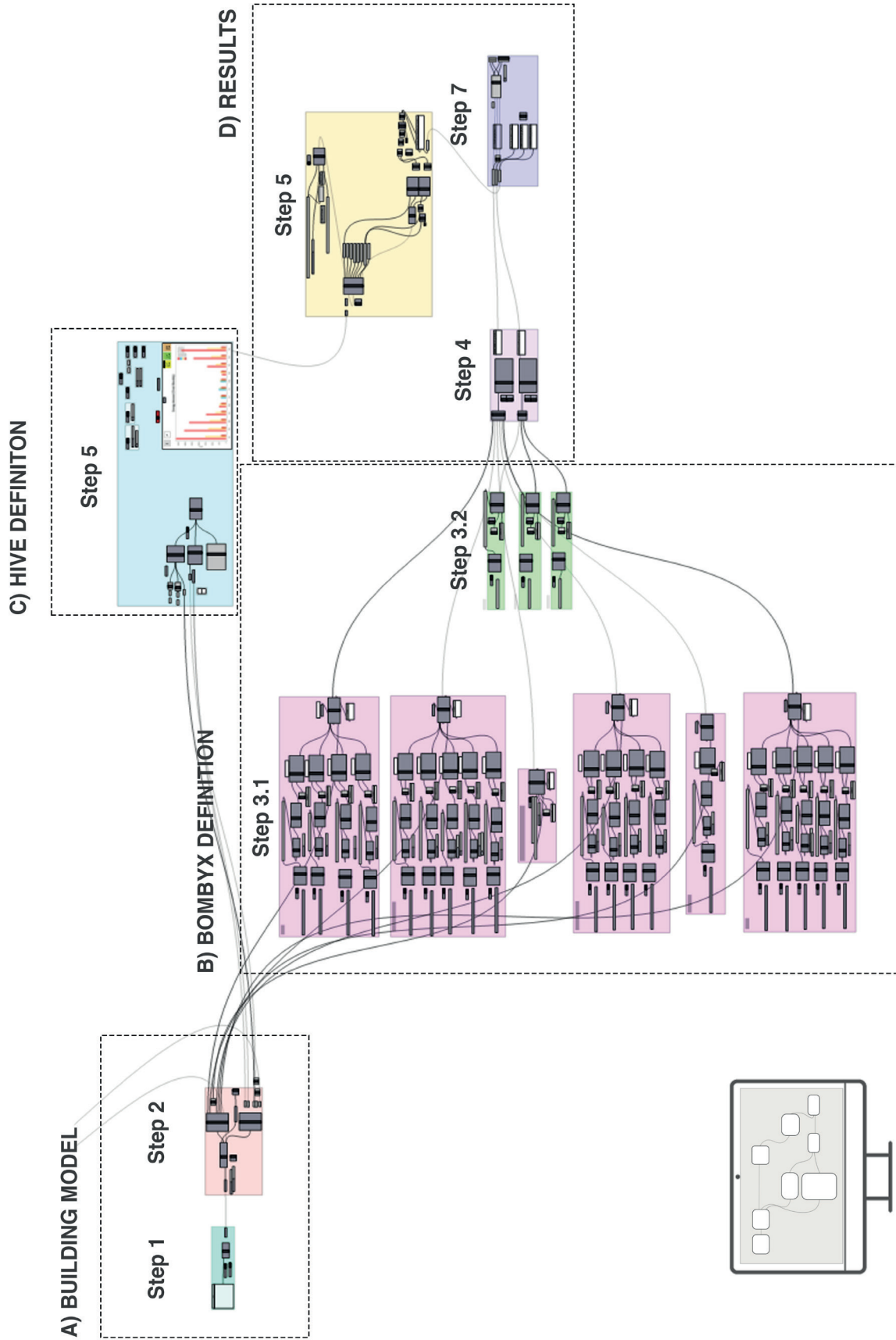


Figure 31 The design proposal - Definition via Bombyx and Hive in Grasshopper

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What is an ETA? n.d. <https://www.eota.eu/what-is-an-eta> (accessed 09 25, 2023).

Design Improvements

To begin the process of improving the design proposal, it is essential to first understand the specific needs and requirements of the yoga guest house project. This understanding will serve as the foundation for making informed design decisions.

Furthermore, a comprehensive grasp of how the Bombyx and Hive tools are integrated into the project workflow is crucial. This integration will provide insights into how environmental and energy-related factors are considered within the design process and can help identify areas for potential improvements in terms of **environmentally responsible design**.

As it mentioned in the previous chapters, the primary goal is to achieve **well-balanced design decisions** that strike an optimal equilibrium between energy consumption and environmental impact.

In this context, the design proposal introduced in the previous chapter is designated as **Solution 0**.

5.1. Solution 1 - PV Panel Integration

The goal of achieving a design with **fewer embodied emissions** in materials is realized by implementing design strategies outlined in Solution 0. This achievement is assessed and confirmed using the Bombyx tool. This process is fluid because each material choice can be easily evaluated based on U-values and the GWP results of materials.

The strategies are directly linked to the development of an environmentally responsible design, considering factors such as effort, cost, emissions, and indoor environmental quality. Therefore, it is crucial to implement improvements that align with these strategies.

In Solution 1, the focus turns to technological advancements, specifically integrating PV panels into the design, aiming to reduce energy demand in a specific climate and environment. The objective is to maintain the embodied emissions from construction materials at the same level while achieving a reduction in energy demand.

PV integration is considered a green solution that reduces energy demand during the usage phase, its potential contribution to emissions should be examined and assessed, particularly in a climate with limited sun exposure and within a forested setting.

For the next set of improvements, PV panels have been integrated into the South-East and South-West parts of the roof.

Figure 1 illustrates the integration of PV panels as a diagram, while Figure 2 displays improvements in Section EE. Given that there is no material difference, the detailed plan remains the same, but changes resulting from the improvement can be observed in the section. This is why only Section EE is displayed.

The Figure 2 provides a detailed section illustrating the roof integration, using 450 x 1200 mm solar roof tiles for the improvement.

Improvements on drawings

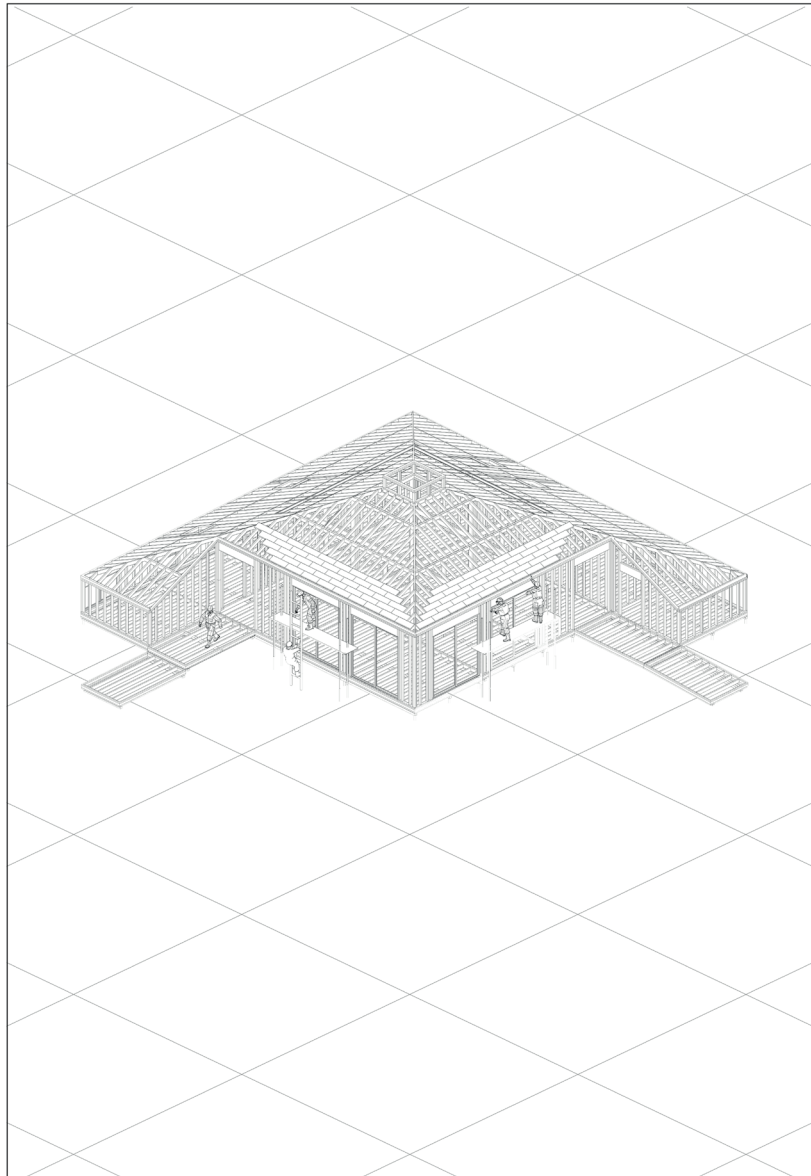


Figure 1 Solution 1 - PV Panel integration

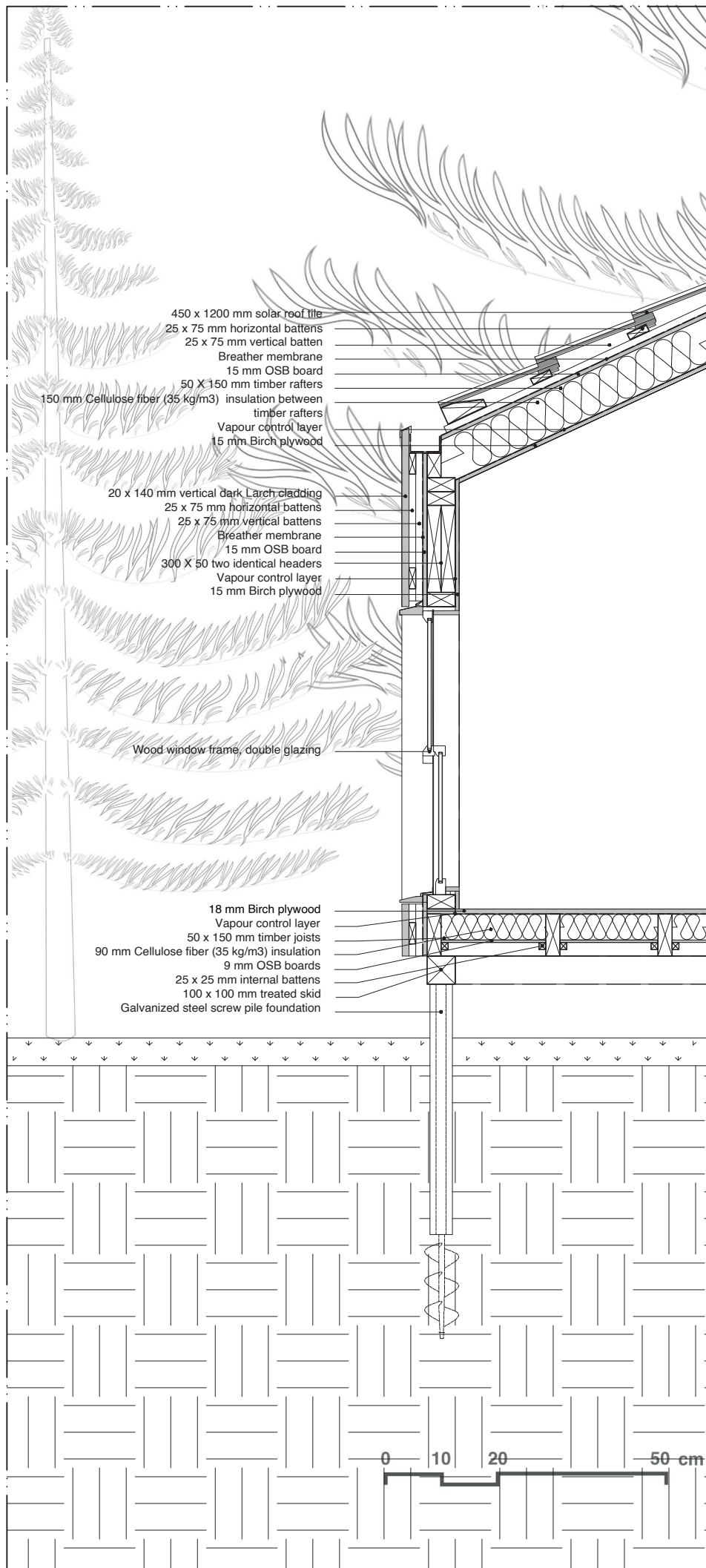


Figure 2 Solution 1 section EE - Scale 1:20

Improvements in Grasshopper Environment

As the improvements were decided, simultaneous adjustments were made in Grasshopper, and these modifications are depicted in the following figures.

To establish a clearer connection between the improvements and changes in the Grasshopper workflow, the modified tool components are highlighted.

Figure 3 illustrates that modifications in the Grasshopper environment are made in steps 3.2, and step 5. The changes in embodied and operational emissions, as well as the emission breakdown, are not highlighted, as it is understood that the modifications affect these values.

The PV system is incorporated as one of the building systems to assess its impact on embodied emissions. Additionally, the technological features are added to the Hive Input Energy Systems to comprehend their contribution to operational emissions and energy demand.

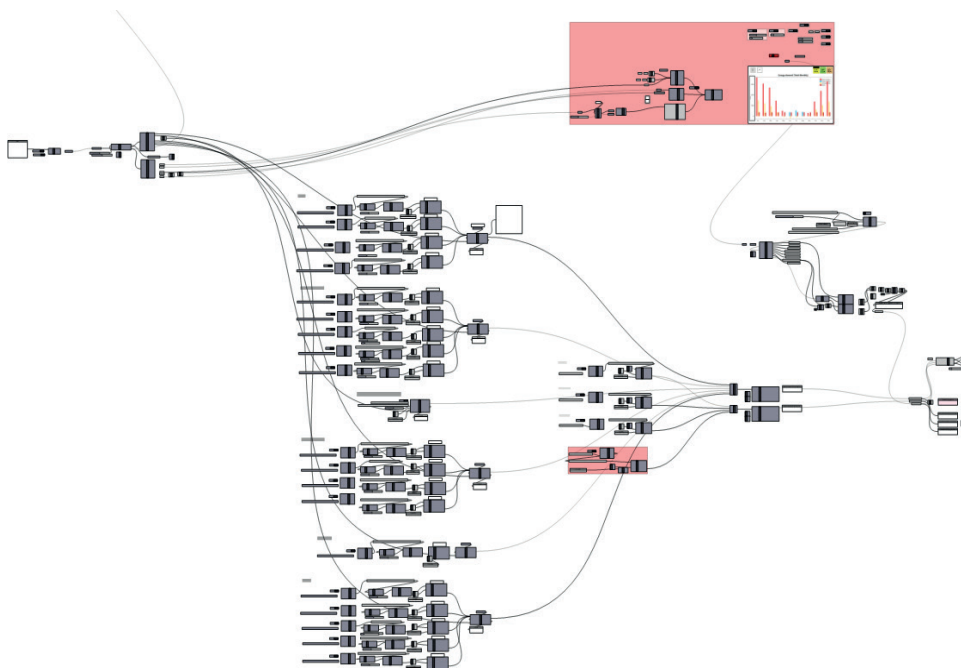


Figure 3 Solution 1, modified parts in Grasshopper environment

Upon closer inspection, Figure 4 illustrates the definition of the PV panel within the building system component.

The 'Electrical Systems' are selected from the 'Service Groups,' and the 'Photovoltaic installations on the sloped roof' system is chosen.

All inputs, including sizing (78 m²) value from the building parameters, RSP (50 years), and RSL (25 years), are integrated into the calculation to determine the embodied emission of the PV system. The output of the 'System properties' is inputted to building impact (for system) with the other systems.

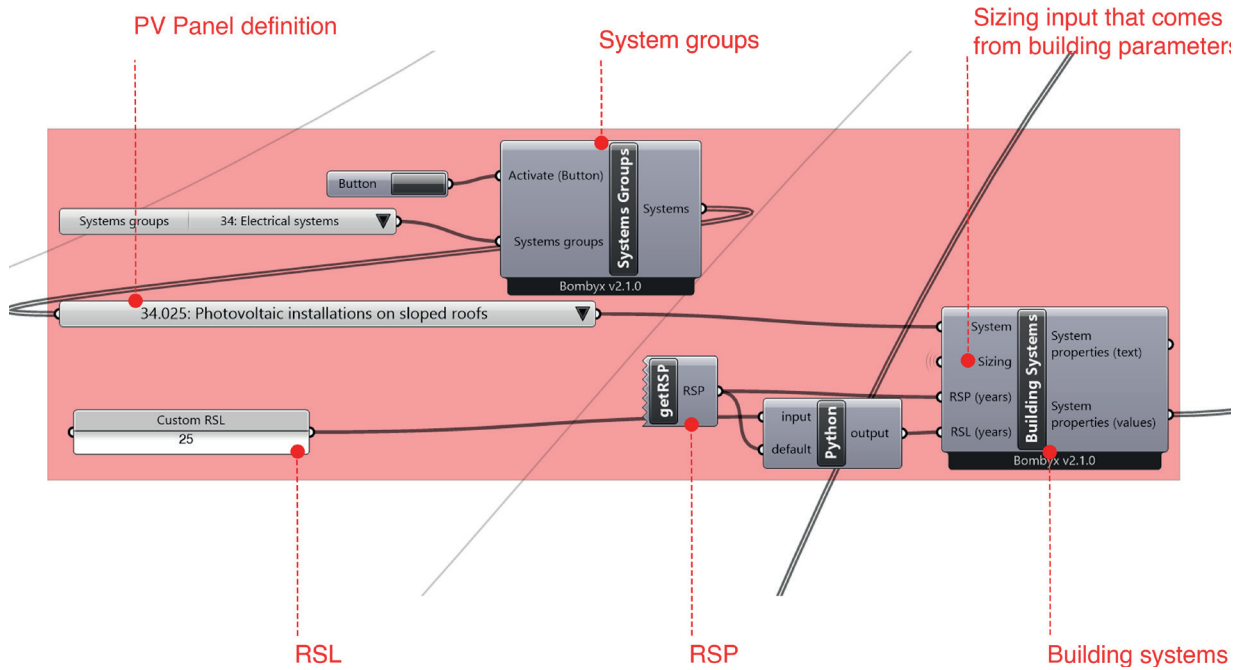


Figure 4 Solution 1, PV Panel definition via Bombyx tool (Step 3.2)

The surface of the PV panels is converted into a mesh and then incorporated into the ‘Hive Input Energy Systems’ component with the system efficiency. The ‘System efficiency’ value of 0.12 is included in this step, as illustrated in Figure 5.

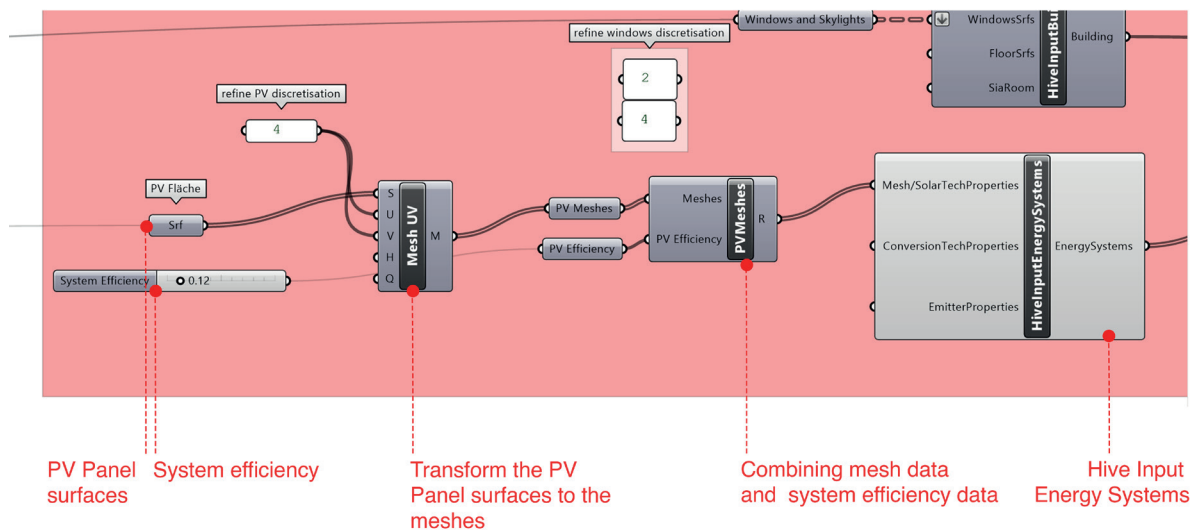


Figure 5 Solution 1, PV Panel definition via Hive tool (Step 5)

It is also possible to choose ‘Module Type Efficiency’ inside of the Hive component (which is Hive Input Energy Systems); however, the ‘System Efficiency’ includes all the inefficiencies of the PV system, and is lower than the value for the panel alone (it is mentioned in the Bombyx example file). Thus, the custom efficiency is applied to the PV technology instead of adjustment inside of the Hive component.

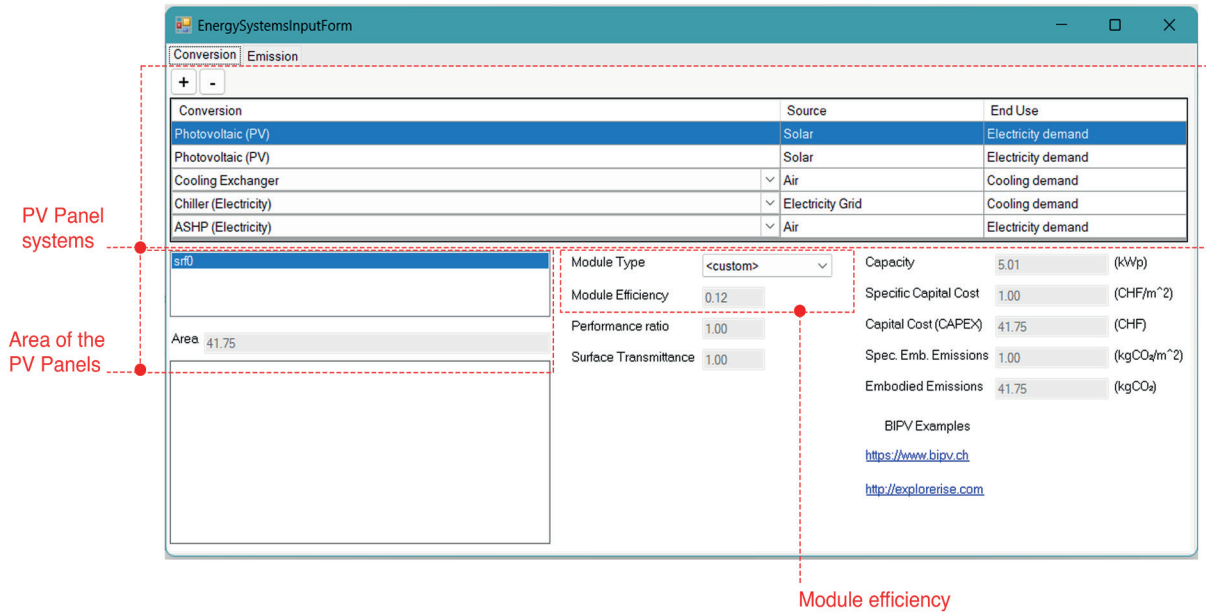


Figure 6 PV panel definition, within the component itself (Step 5)

The PV panel selection is automated after all inputs are integrated into the Hive Input Energy System component, as depicted in Figure 6. The system efficiency is directly adjusted within the component, and the PV panel area is also visible.

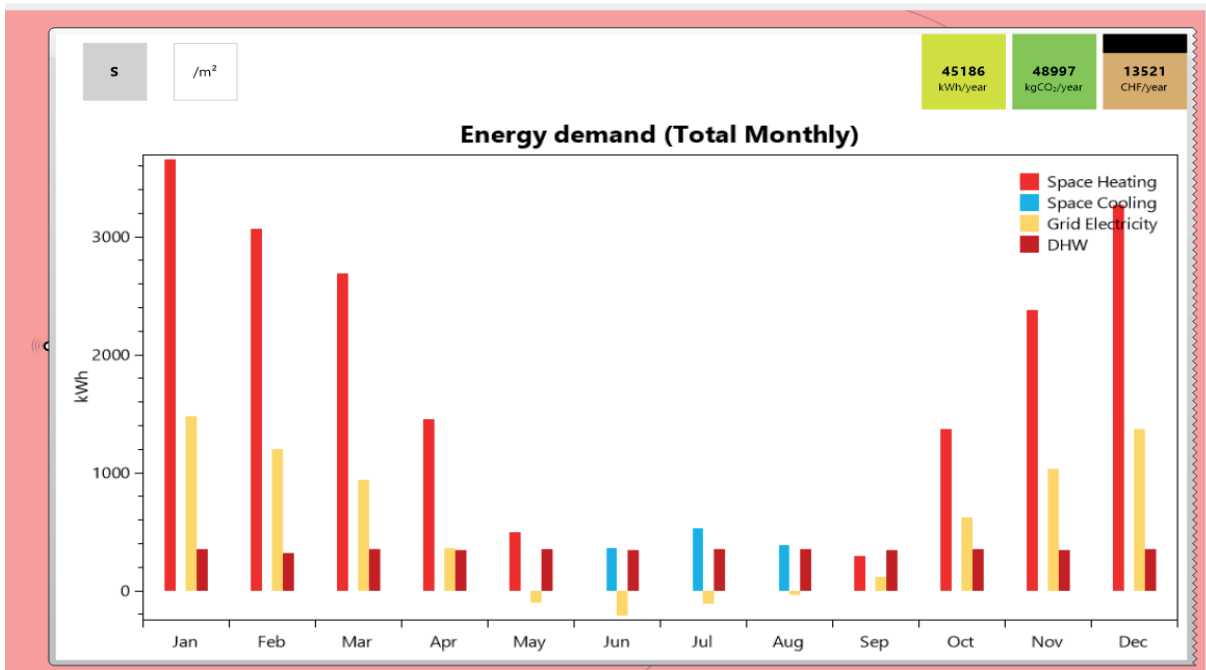


Figure 7 Solution 1 - Annual operational final energy consumption (Step 5)

Finally, the Grasshopper model presents the annual energy consumption for operations, allowing for a comprehensive view of the building's energy performance. The

chart in the Grasshopper environment can be seen in Figure 7.

After the integration of PV panels, the annual operational energy demand is reduced to **45.186 kWh/year**.

All modifications are carried out through Bombyx and Hive tools, and the resulting changes can be observed in the emission breakdown.

Figure 8 shows the final GWP results in Grasshopper environment after the PV panel integration. There are no changes in the GWP results of materials, but changes in the GWP results of the system and operational phases can be observed. GWP of system is increased to **17.32 kg CO₂-eq/m²a**, while also GWP of operational is decreased to **8.38 kg CO₂-eq/m²a**. Hence, the total GWP (Global Warming Potential) results have increased to **31.48 kg CO₂-eq/m²a**.

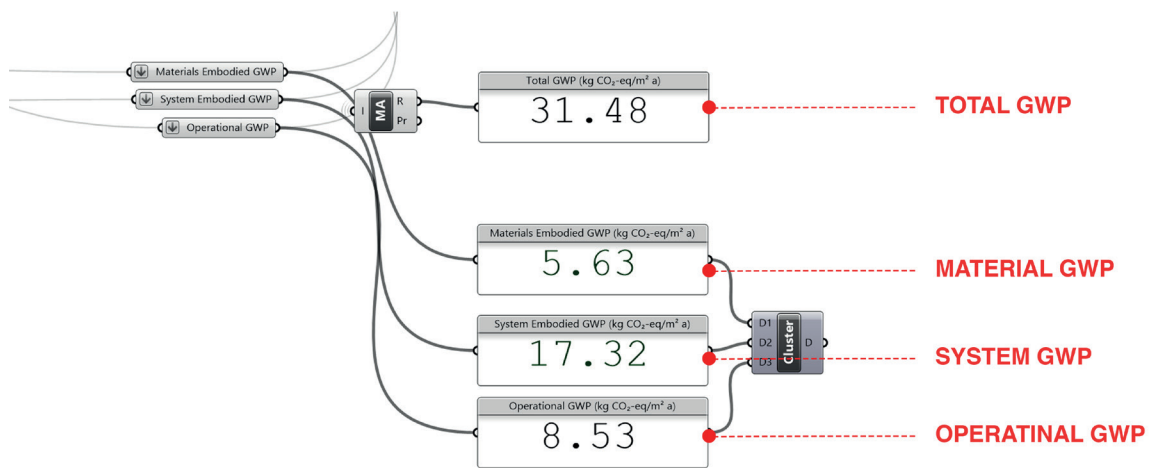


Figure 8 Solution 1 - Emissions breakdown (Step 7)

Modifications in BoQ

As there are no material changes, adjustments to the Bill of Quantities (BoQ) are made in the building systems.

In Figure 9, it can be observed that the PV panel system is selected from the default Bombyx system definitions.

| Solution 1 System selection | System groups (Bombyx tool, default material database) | System (Bombyx tool, default material database) | Building Services (ERA, RSP and RSL) |
|--------------------------------|---|--|---|
| ● Heating | Heating systems | Heat emission via radiators | 210 m2, 50, 25 |
| ● Radiators | | | |
| ● Ventilation | Ventilation systems | Single room ventilation, window model 10-30 m3/h, without assembly | 210 m2, 50, 25 |
| ● Decentralized ventilation | | | |
| ● Electricity | Electrical systems | Electrical installation, housing | 210 m2, 50, 25 |
| ● Electrical installation | | | |
| ● Electricity | Electrical systems | Photovoltaic installations on sloped roofs | 78 m2, 50, 25 |
| ● PV Panel installation | | | |

Figure 9 Solution 1 - System selection

Interpretation

To interpret the improvement, a comparison is made between Solution 0 and Solution 1. Figure 10 illustrates the GWP of materials, systems, and operational while Figure 11 shows the comparison between the annual energy consumptions based on the results.

The material emissions remain the same as there are no changes at the material level; therefore, **achieving lower embodied emissions from materials is still an accomplishment.**

It is evident from the results that the installation of PV panels on the roof has resulted in a **significant increase in system emissions.** However, there has been a **notable reduction in energy consumption** thanks to PV panel integration. The reduction is primarily achieved in electricity consumption.

It is also observed that there is a **slight reduction in operational emissions** associated with the decrease in energy consumption.

It is considered that a solution, which can simultaneously reduce energy consumption and maintain emissions at a lower level, should be pursued in the following section.

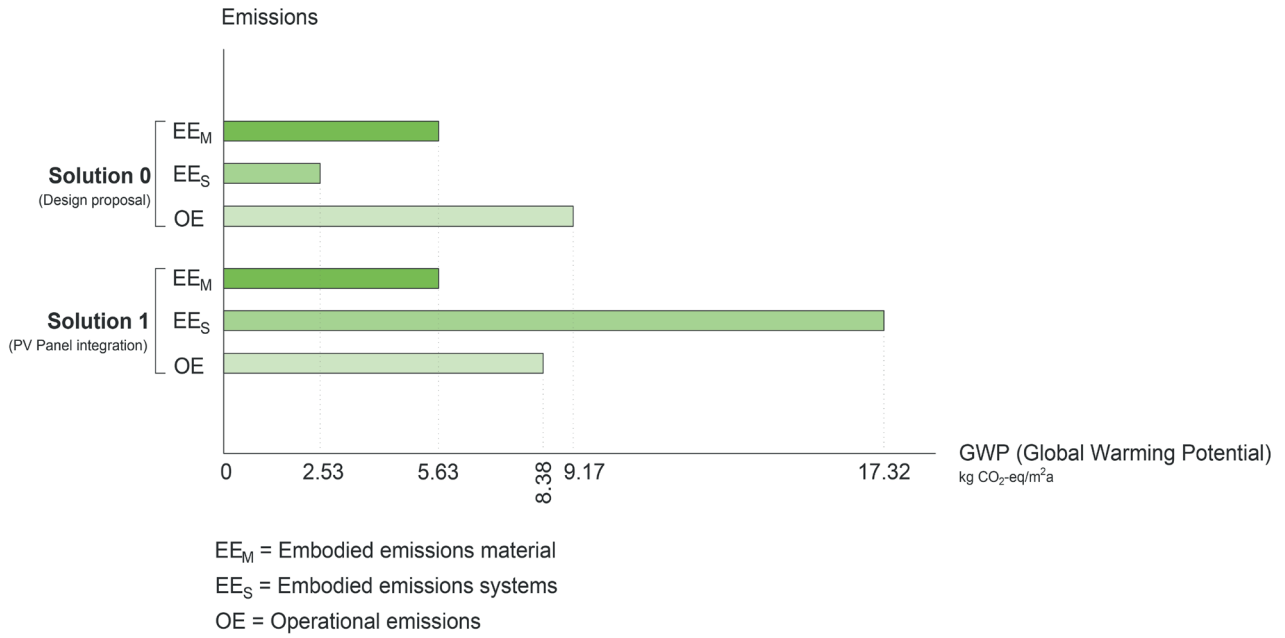


Figure 10 Comparison the results of emissions between the Solution 0 and Solution 1

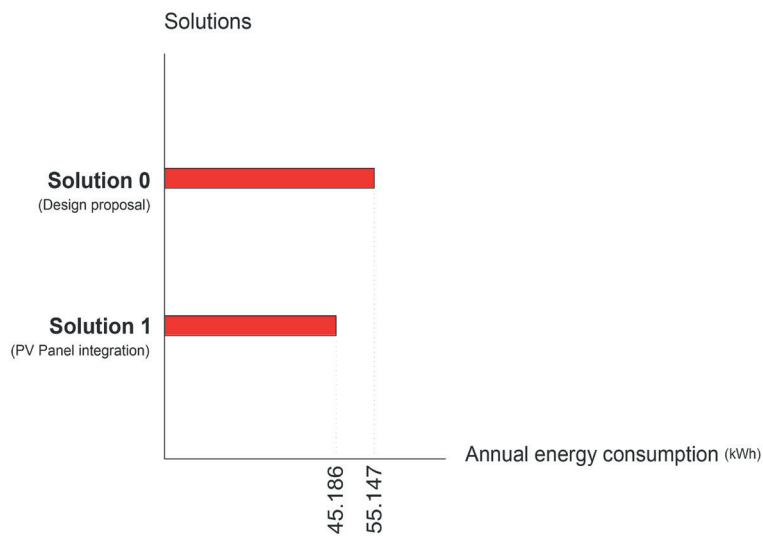


Figure 11 Comparison the results of annual energy consumption between the Solution 0 and Solution 1

5.2. Solution 2 - Modication on materials

Given that the construction materials selected for Solution 0 (design proposal) already have lower embodied GWP results and are confirmed within Bombyx's list of materials.

On the other hand, Solution 1 leads higher embodied GWP results while it has reduction on energy consumption.

In Solution 2, improvements are made at the material level, aiming to reduce energy consumption while also maintaining lower emissions.

This is accomplished by increasing the U-Values of building elements, and the resulting impacts on energy consumption and GWP results are observed. This solution entails various alterations to the building construction elements, including changes to their types and thicknesses.

The modifications are divided into four stages:

1. Addition of insulation layers to the exterior wall
2. Addition of an insulation layer to the roof
3. Introduction of different window and skylight materials
4. Evaluation of insulation materials based on their contribution to energy reduction

1. Addition of insulation layers to the exterior wall:

In this stage, in addition to the insulation between the timber rafters, internal and external insulation materials are applied in the structural system. For external insulation, 50 mm rock wool (30 kg/m³) provides the best solution when considering energy consumption and contributions to embodied emissions. For internal insulation, cellulose fiber insulation (35 kg/m³) remains the same, with the addition of a 50 mm internal insulation layer.

2. Addition of an insulation layer to the roof:

In this stage, an additional insulation layer is applied to the roof using 50 mm cellulose fiber insulation (35 kg/m³).

3. Introduction of different window and skylight materials:

In this stage, the window and skylight types are changed. Glazing is replaced with insulating glazing triple with a U_g value of $0.6 \text{ W/m}^2\text{K}$ and a thickness of 40 mm. Additionally, the window frame is changed to wood-aluminium.

4. Evaluation of insulation materials based on their contribution to energy reduction:

After all modifications are completed, the same process used for choosing external insulation material is applied to the cavity and the internal insulation material (cellulose fiber insulation).

A final check is conducted to identify the insulation material that provides the best energy reduction while maintaining a low contribution to embodied emissions. Based on the evaluation conducted by the Bombyx tool, Glass wool, Isover (20 kg/m^3) insulation is identified as the optimal solution.

Figure 12 illustrates the modifications on materials as a diagram. Figure 13 and 14 displays the all improvements on detailed plan and Section EE.

Improvements on drawings

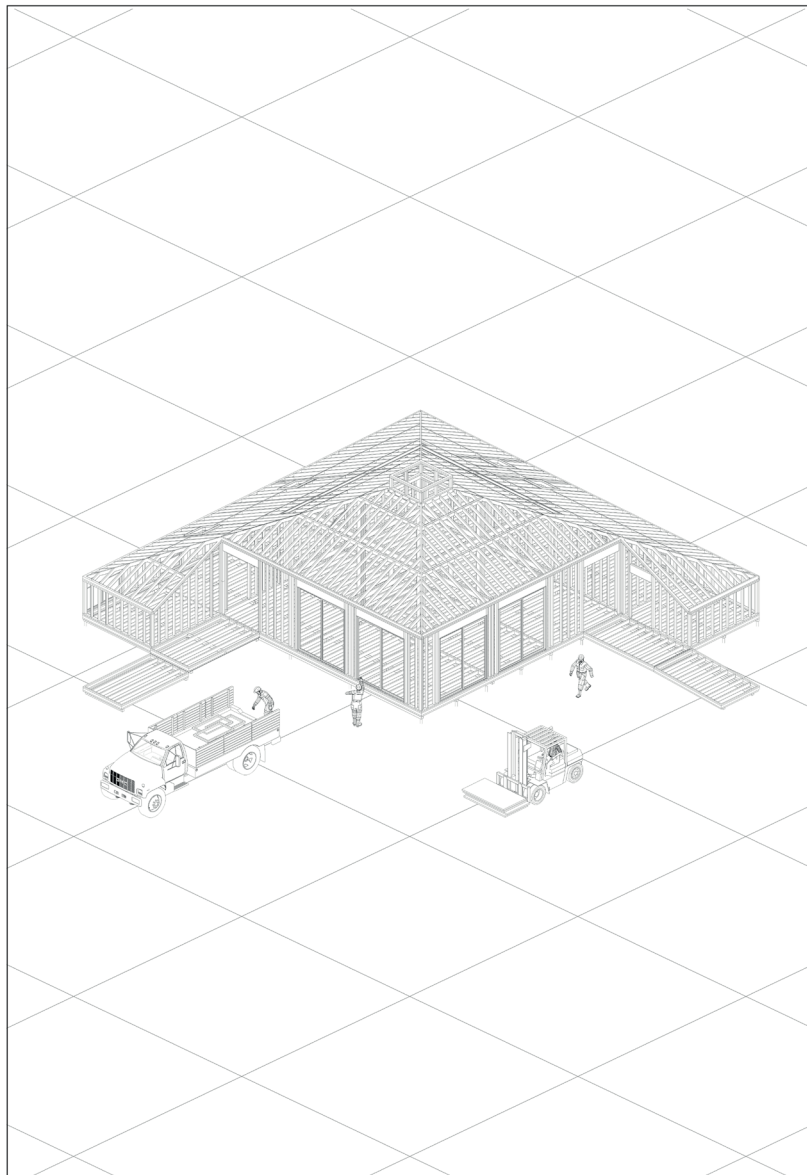


Figure 12 Solution 2 - Modification on materials

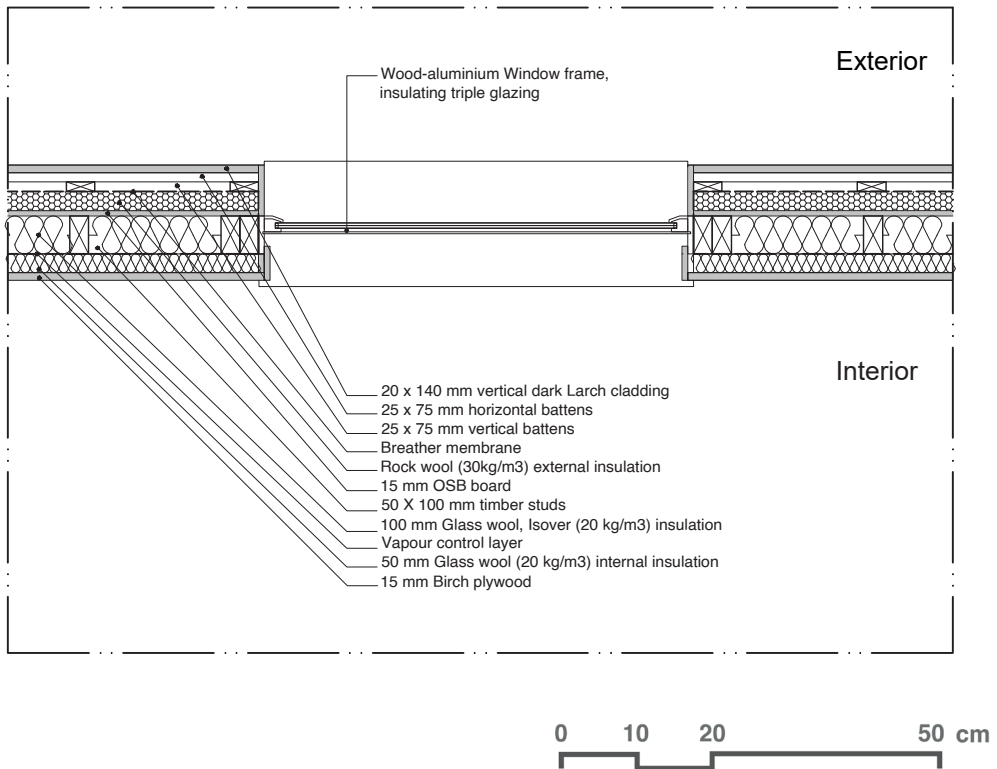


Figure 13 Solution 2 - Detailed plan, Scale 1:20

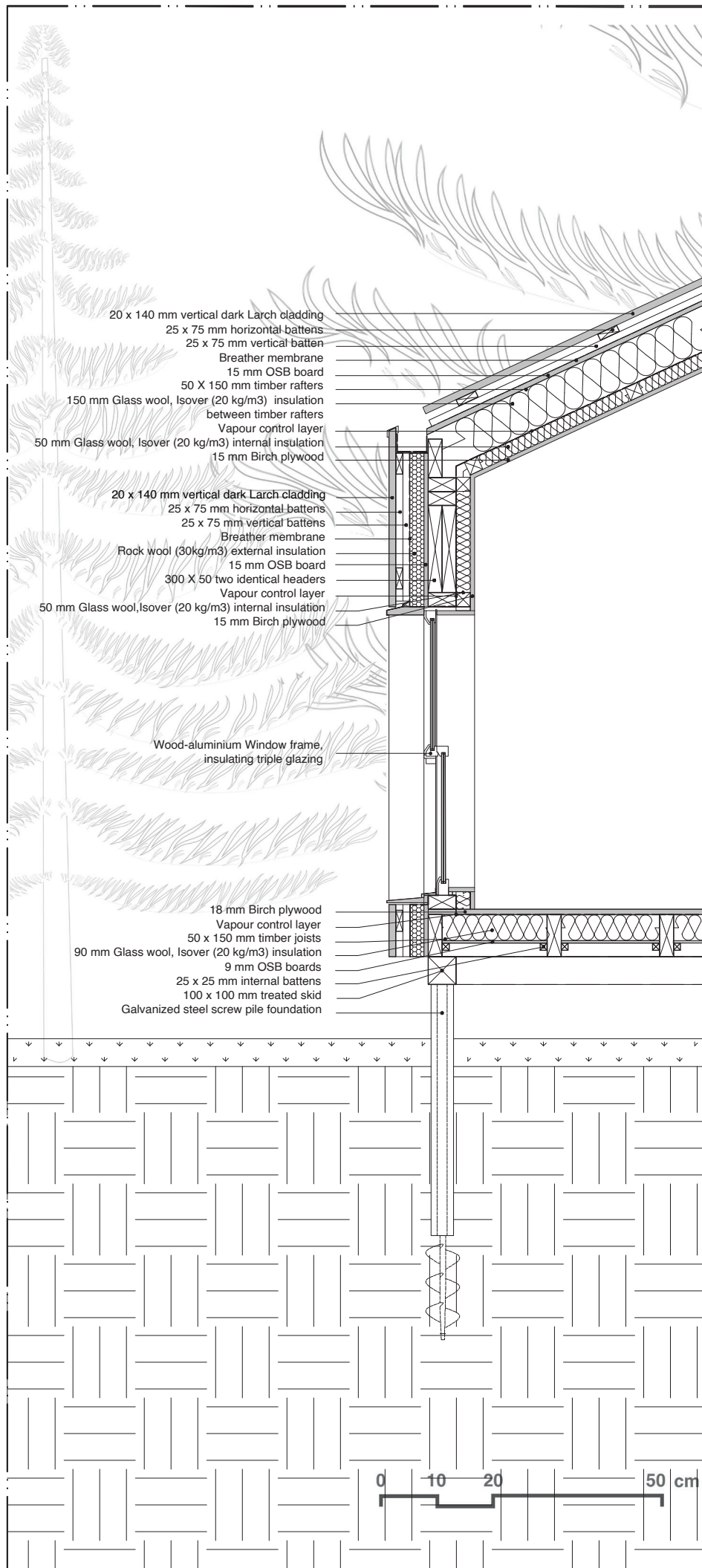


Figure 14 Solution 2 - Section EE, Scale 1:20

Improvements in Grasshopper Environment

As the improvements were determined, concurrent adjustments were implemented in Grasshopper, and these modifications are depicted in the following figures.

To establish a clearer connection between the improvements and changes in the Grasshopper workflow, the modified tool components are highlighted.

In Figure 15, it is evident that modifications in the Grasshopper environment are made in step 3.1. The changes in embodied and operational emissions, as well as the emission breakdown, are not highlighted, as it is understood that the modifications impact these values.

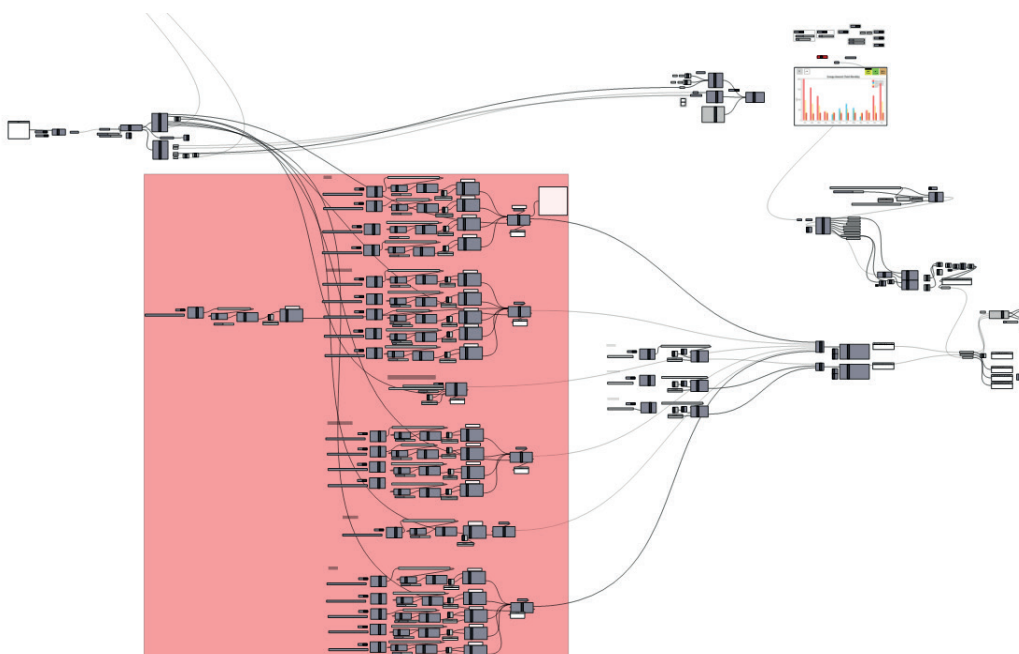


Figure 15 Solution 2, modified parts in Grasshopper environment (Step 3.1)

The initial step involves the application of external and internal insulation layers to the external wall. Figure 16 provides a close observation of the modification. 50 mm internal cellulose fiber insulation (35 kg/m³) is included in addition to the cavity insulation between the timber studs. To do this, the existence thickness of the thermal insulation is increased from 0.1 meters thickness to the 0.15 meters thickness.

In addition to that, the definition of 50 mm external rock wool (30 kg/m³) is made in this stage (as it is shown in Figure 17). The material is created in a modular way, similar to the other materials.

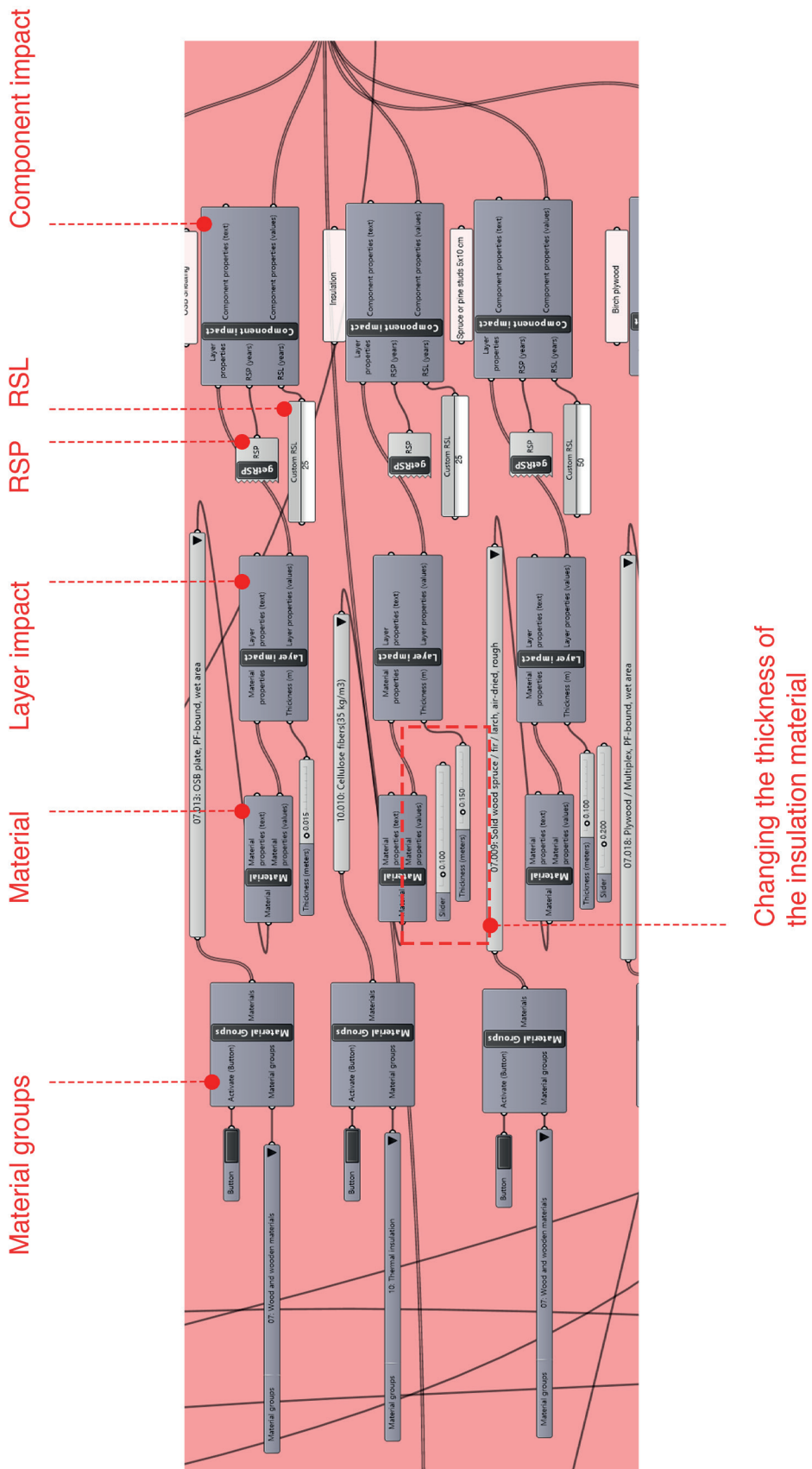


Figure 16 Addition of internal insulation material to the external wall (Step 3.1)

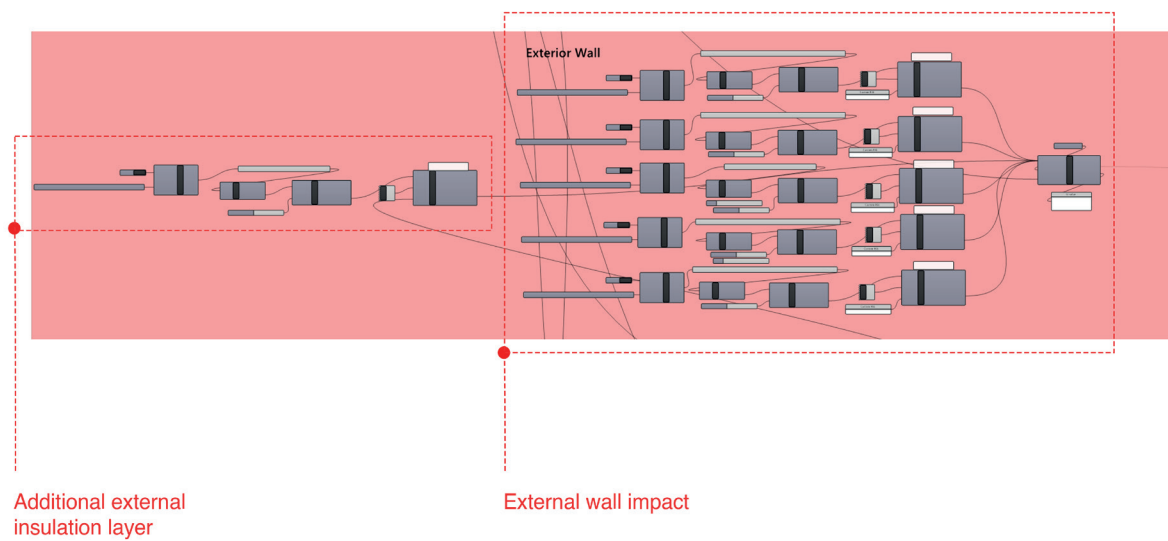


Figure 17 Addition of external insulation layer to the external wall (Step 3.1)

In the second step, an additional insulation layer is added to the roof. This internal insulation uses the same material as the cavity insulation, and the thickness of the thermal insulation layer is increased from 0.15 meters to 0.2 meters (as it is shown in Figure 18). Since the modification process is similar to the modification of the external wall, the figure is illustrated in a smaller size.

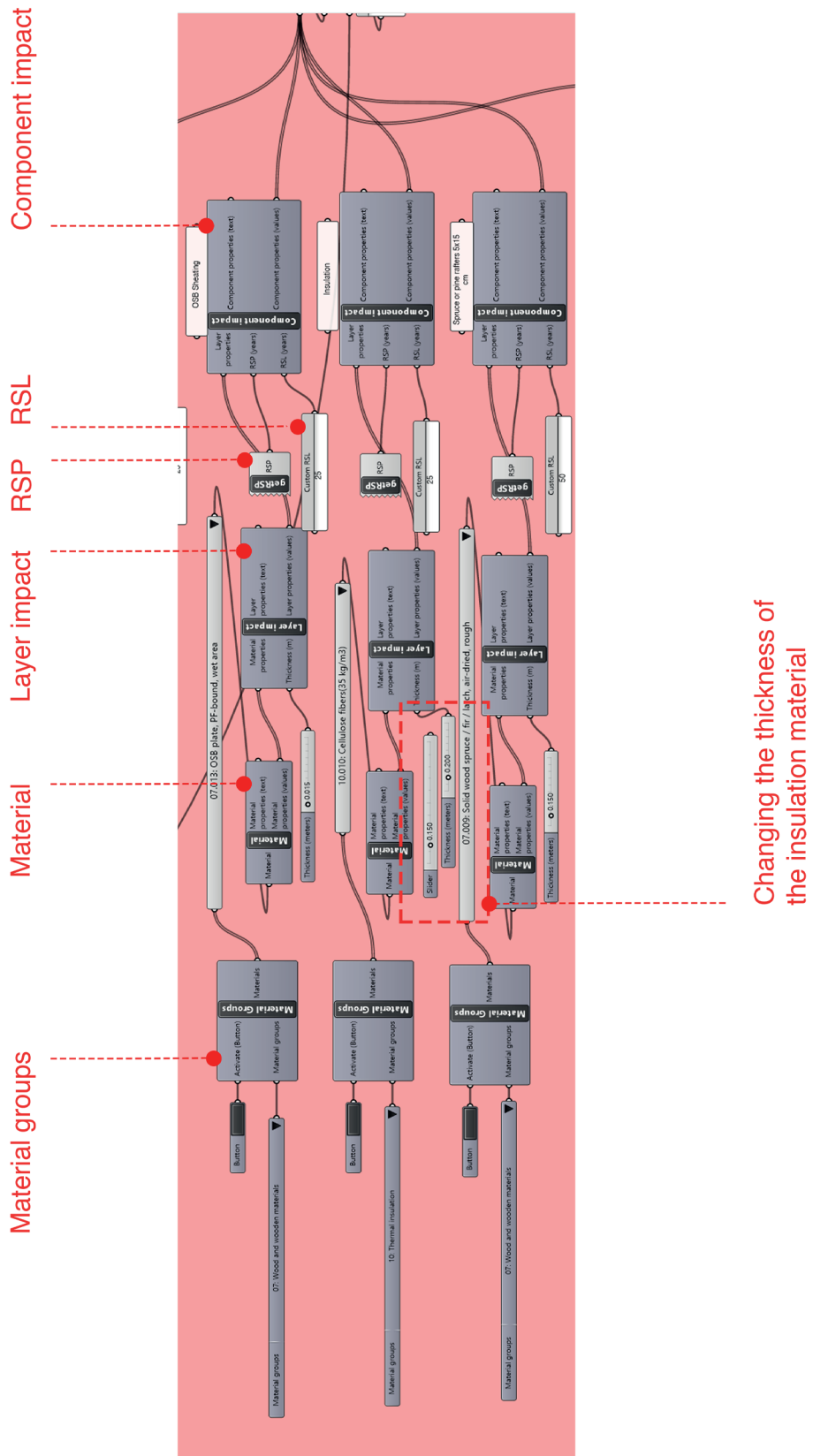


Figure 18 Addition of internal insulation layer to the roof (Step 3.1)

In addition to these modifications, the materials of windows and skylights are changed; 'Insulating glazing triple, Ug value 0.6 W / m2K, thicknesses 40 mm' is defined as glazing; and 'window frame wood-aluminium' is inputted as window frame. In Figure 19 these changes can be seen.

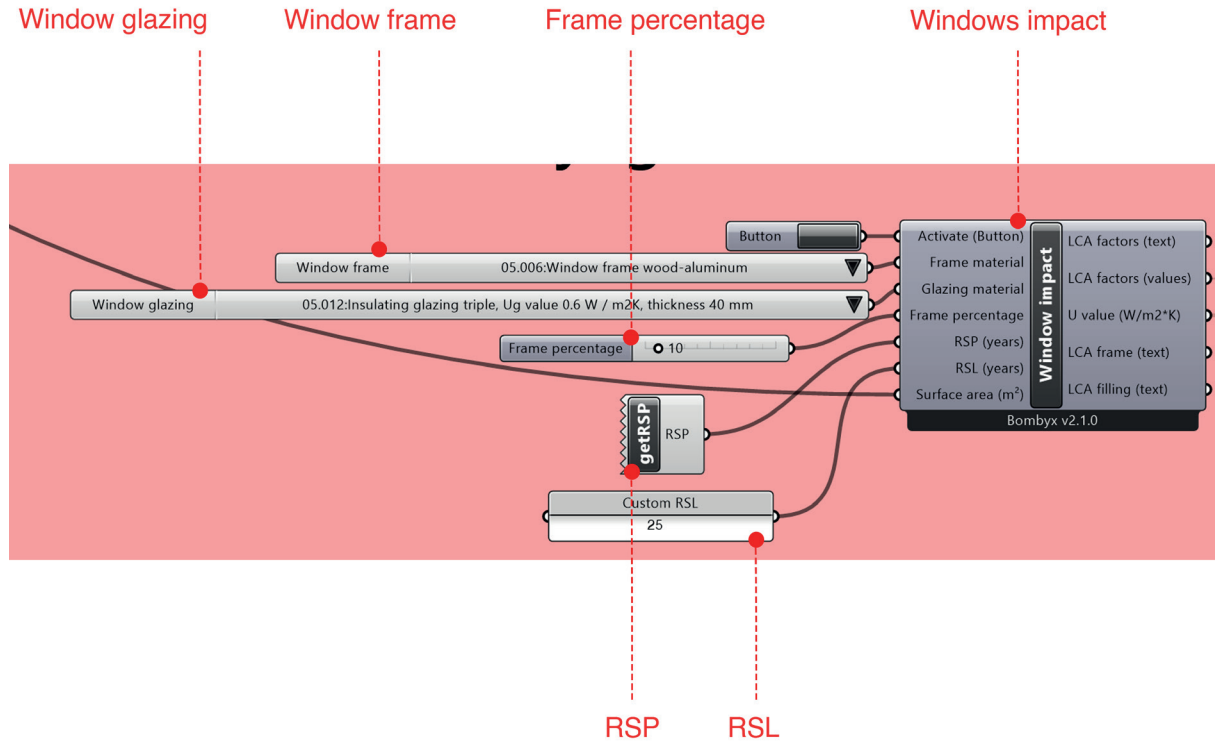


Figure 19 Introduction of different window and skylight materials (Step 3.1)

As the final step, various insulation materials are tested from the material groups. The streamlined process facilitates a quick execution. After each selection of different insulation materials, the results, including U-value, GWP, and energy consumption, are illustrated within the Grasshopper environment. Through a rapid comparison of the results, the option that presents an optimal solution in terms of energy consumption and embodied emissions is chosen. In this regard, Glass wool, Isover (20 kg/m3), is selected for application throughout the entire structure.

In Figure 20, the thermal insulation selection process can be seen.

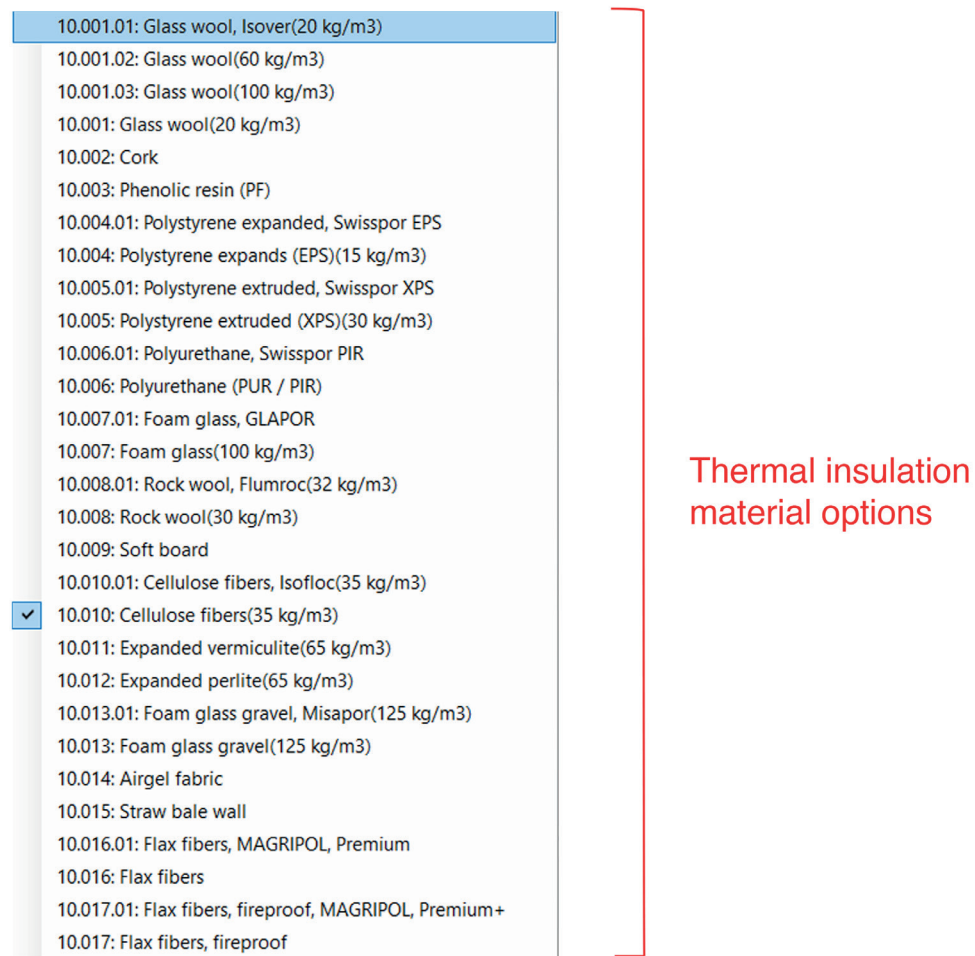


Figure 20 Evaluation of different insulaton materials (Step 3.1)

After the all modification the results are changed on energy simulation and emission breakdown.

Figure 21 shows the the annual operational final energy consumption chart in Grashopper environment. It has been reduced to **37.335 kWh/year** and the reduction is made mainly on heating.

Figure 22 shows the emission breakdown; GWP of total, material, system and operational can be seen.

Compared with Solution 0, the GWP of materials has increased to **6.2 kg CO₂-eq/m^{2a}**, while the GWP of operations has decreased to **5.53 kg CO₂-eq/m^{2a}**. The GWP of systems remains unchanged. Consequently, the total GWP results amount to **14.26 kg CO₂-eq/m^{2a}**.

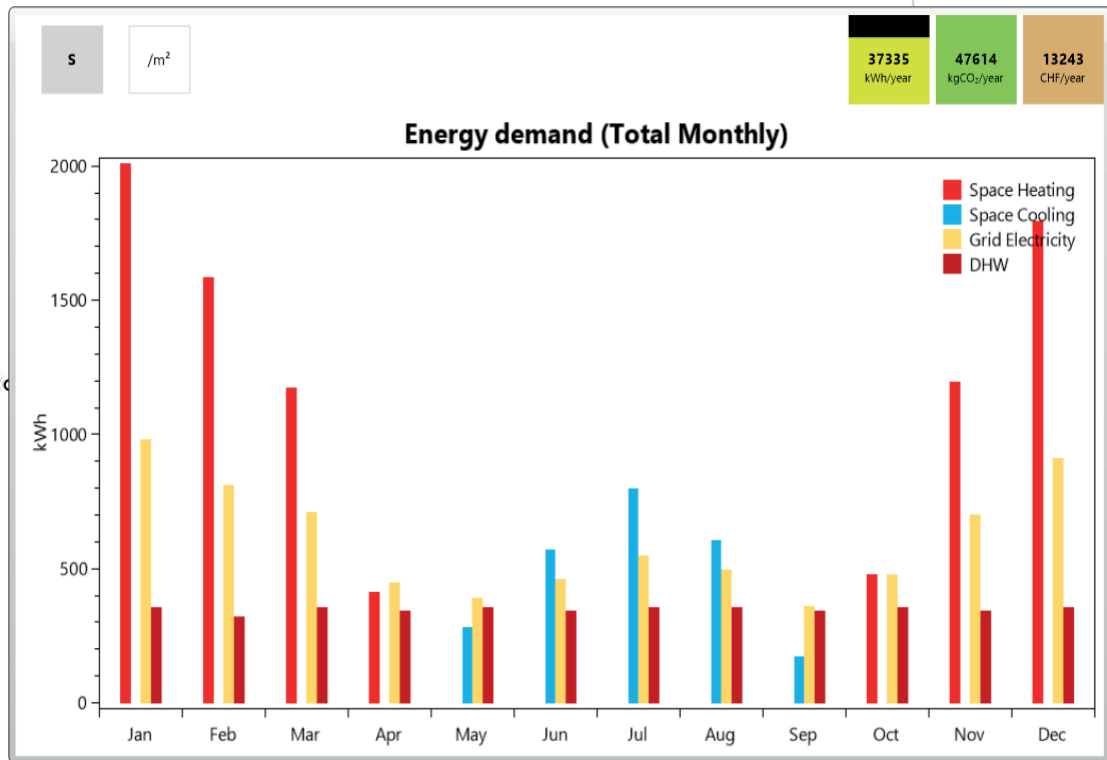


Figure 21 Solution 2 - Annual operational final energy consumption (Step 5)

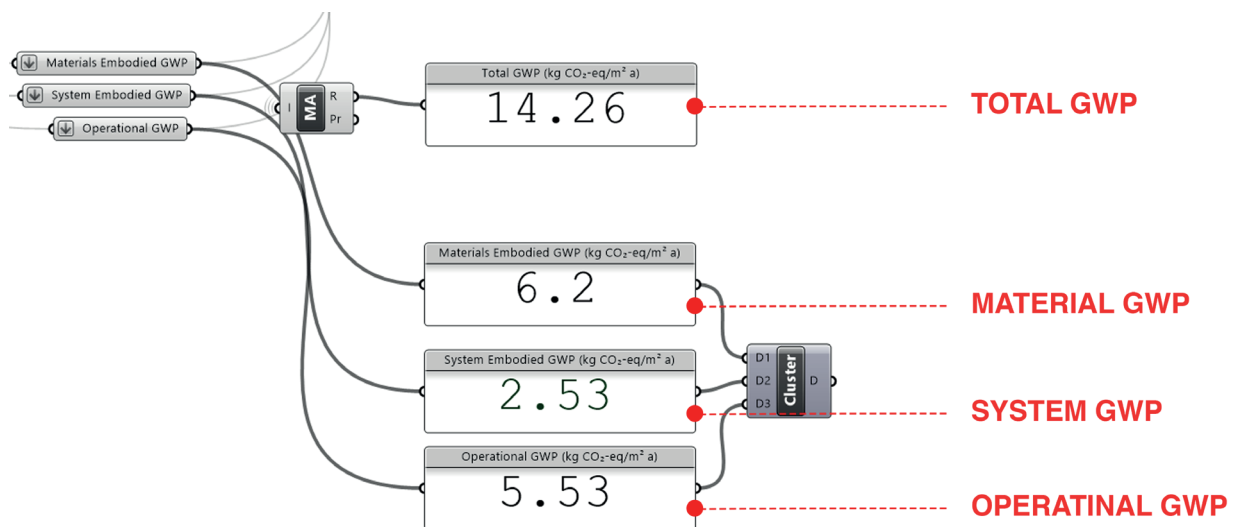


Figure 22 Solution 2 - Emissions breakdown (Step 7)

Modifications in BoQ

In Solution 2, there are material changes, and there are no system changes; therefore, the modification reflects in the material selection in the BoQ. The new materials are shown in Figure 23.

BILL of QUANTITY (BoQ)

Solution 2
material selection

Slab

Birch plywood

Glass wool

Joists from Pine wood

OSB

Exterior Wall

Birch plywood

Rock wool

Glass wool

Studs from Pine wood

OSB

Larch cladding

Windows & Skylights

Interior wall

Birch plywood

Glass wool

Studs from Pine wood

Birch plywood

Column

Column from Pine wood

| Material group (Bombyx tool, default material database) | Material (Bombyx tool, default material database) | Layer Impact (thickness in meters) | Component Impact (RSP and RSL years) | Element Impact (Surface area in meters) |
|---|--|---------------------------------------|---|--|
| <hr/> | | | | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.018 | 50, 10 | 234 |
| Thermal Insulation | Glass wool, Isover (20 kg/m3) | 0.09 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/ larch, air-dried, rough | 0.15 | 50, 50 | |
| Wood and wooden materials | OSB plate, PF-bound, wet area | 0.009 | 50, 25 | |
| <hr/> | | | | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | 110 |
| Thermal Insulation | Rock wool, (30 kg/m3) | 0.05 | 50, 25 | |
| Thermal Insulation | Glass wool, Isover (20 kg/m3) | 0.15 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.10 | 50, 50 | |
| Wood and wooden materials | OSB plate, PF-bound, wet area | 0.015 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.020 | 50, 25 | |
| Window frame: wood-aluminium Window glazing: insulating triple glazing, Ug value: 0.6 W / m2K, thickness 40 mm Frame percentage, 10 | | | 50, 25 | 64 |
| <hr/> | | | | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | 150 |
| Thermal Insulation | Glass wool, Isover (20 kg/m3) | 0.10 | 50, 50 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.10 | 50, 50 | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | |
| <hr/> | | | | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.20 | 50, 50 | 42 |



| Roof | | | | | |
|------------------------|---------------------------|---|-------|--------|-----|
| Birch plywood | Wood and wooden materials | Solid wood spruce/fir/larch, air-dried, rough | 0.015 | 50, 50 | 246 |
| Glass wool | Thermal Insulation | Glass wool, Isover (20 kg/m3) | 0.20 | 50, 25 | |
| Rafters from Pine wood | Wood and wooden materials | Solid wood spruce/fir/larch, air-dried, rough | 0.15 | 50, 50 | |
| OSB | Wood and wooden materials | OSB plate, PF-bound, wet area | 0.015 | 50, 25 | |
| Larch cladding | Wood and wooden materials | OSB plate, PF-bound, wet area | 0.020 | 50, 25 | |

Figure 23 Solution 2 - Material selection

Interpretation

Before comparing Solution 0 and Solution 2, the contribution of each implementation (four stages) to the design proposal is shown in the following figures. The goal is to understand the contribution of each application in terms of the emissions and annual energy consumption. In Figure 24, this relationship is illustrated.

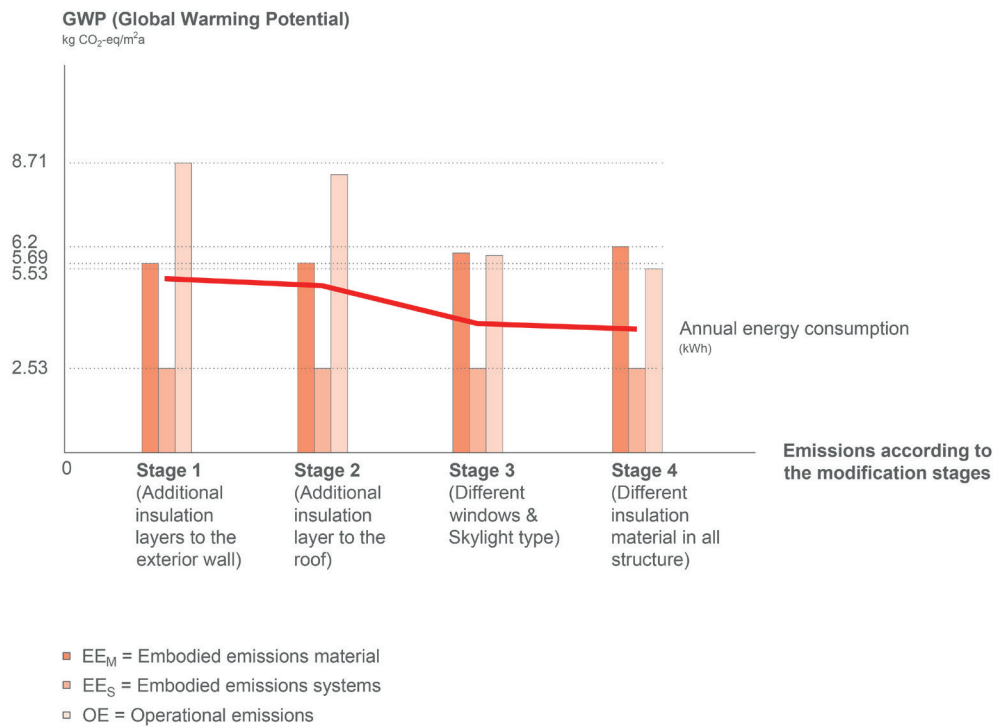


Figure 24 Solution 2 - Contribution of each modification stages

According to the figure, the individual impact of each modification stage can be observed. Only the initial and final results for each type of emissions are added as numerical values.

The modification made to windows and skylights has the greatest impact on annual energy consumption and, relatively, operational emissions.

System emissions remain the same since there is no modification to building systems.

Since Solution 2 includes a reduction in U values of building construction materials, the increase in material emissions can be observed. To better understand, the comparison between the U values in Solution 0 and Solution 2 is illustrated in Figure 25.

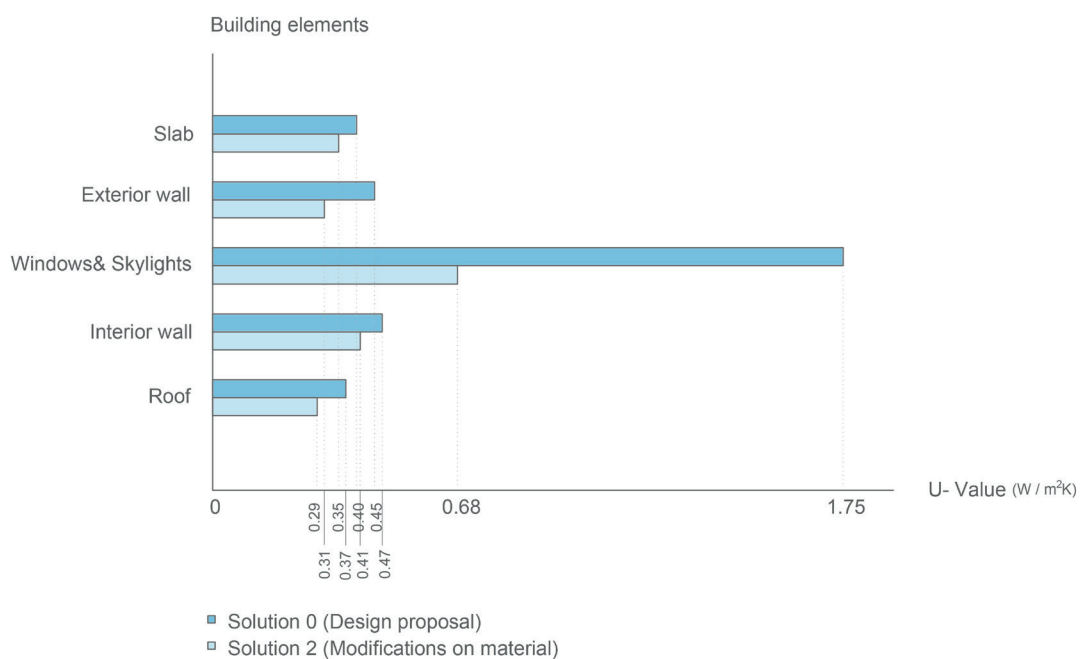


Figure 25 Comparison of U-value of Solution 0 and Solution 2

It can be observed that the most significant reduction in U-Value is achieved by applying different material types to window and skylight building elements. It should be noted that the reduction of U-Value on the interior wall does not affect operational emissions, as only the building elements included in the envelope are calculated to determine operational emissions. The contribution of the interior wall is only for material emissions. Therefore, the interior wall can be considered separately.

To interpret the improvement, a comparison is made between Solution 0 and Solution 2. Figure 26 illustrates the GWP of materials, systems, and operations, while Figure 27 shows the comparison between the annual energy consumptions based on the results.

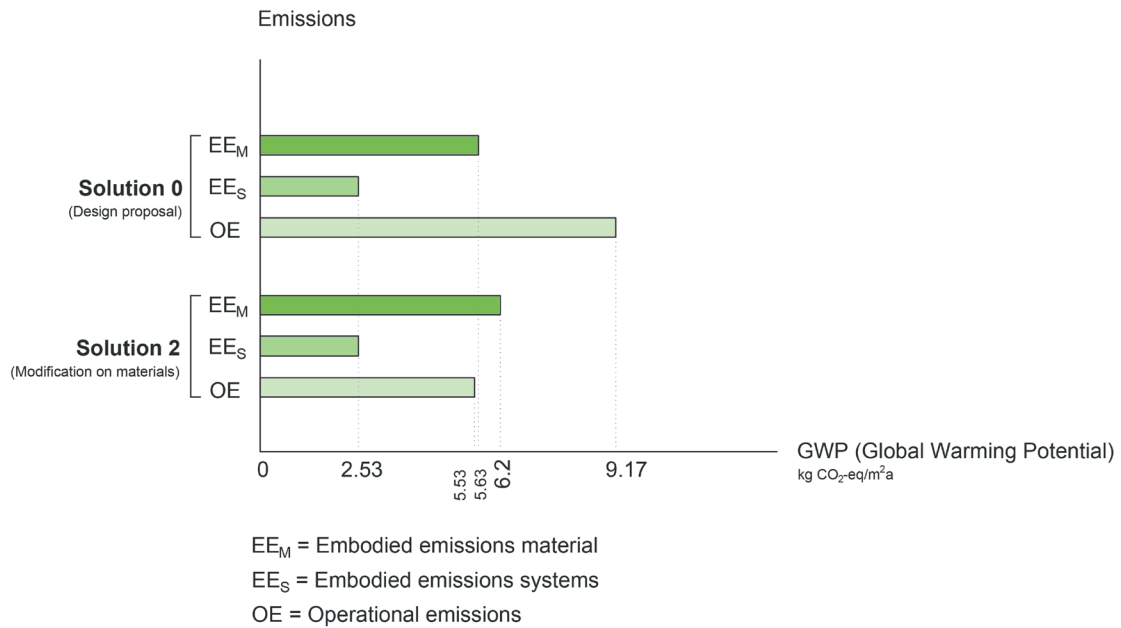


Figure 26 Comparison the results of emissions between the Solution 0 and Solution 2

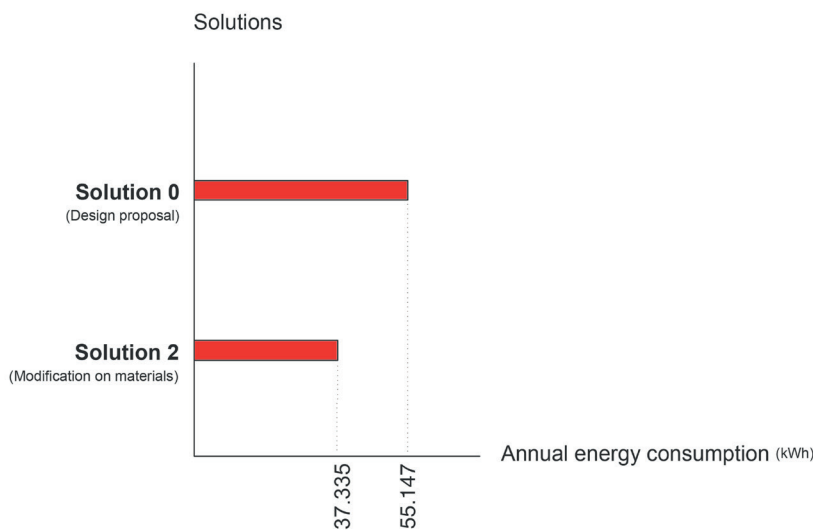


Figure 27 Comparison the results of annual energy consumption between the Solution 0 and Solution 2

According to the figures, in comparison to the Solution 0, there is a reduction in the total GWP, and a decrease in energy consumption has been accomplished.

While the emissions from materials show a small increase, operational emissions experience a significant decrease, being the primary reason for the reduction in total GWP results. It can be concluded that the main energy reduction is achieved thanks to the application of different materials on windows and skylights.

Conclusion

The results of all solutions are compiled in Figure 28 and Figure 29 before selecting the optimal solution.

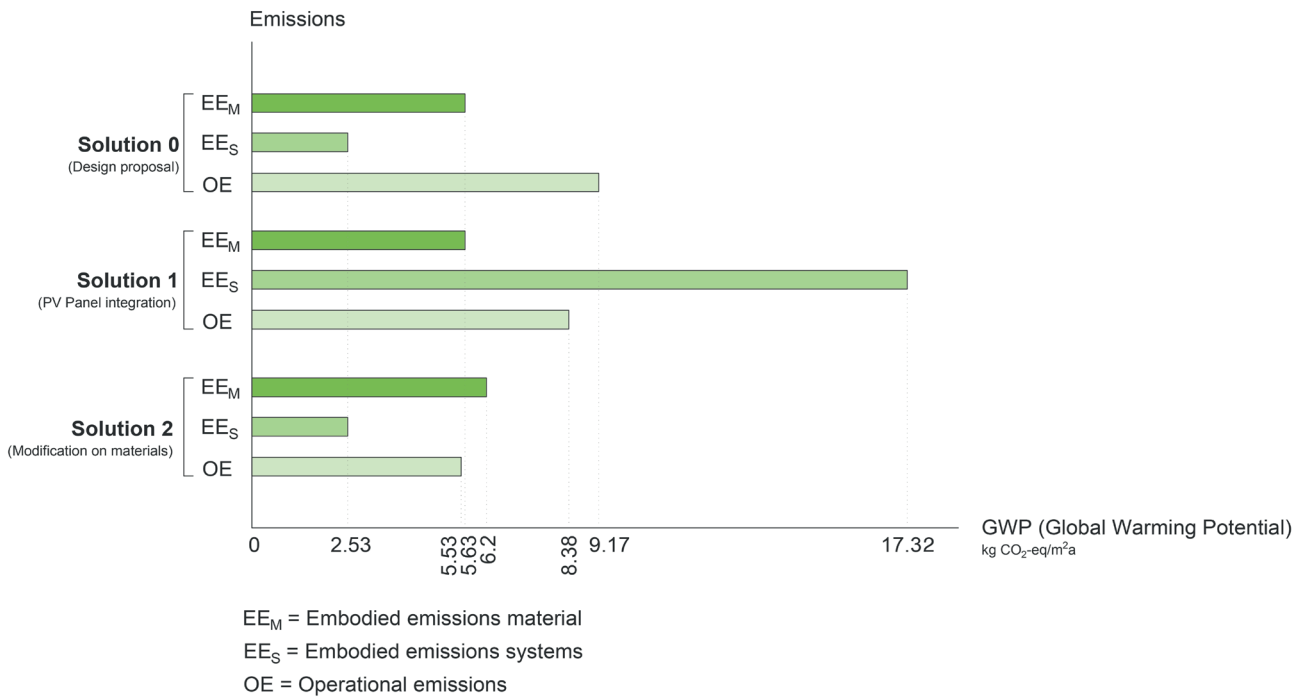


Figure 28 Comparison the results of emissions between the Solutions 0 - 1 - 2

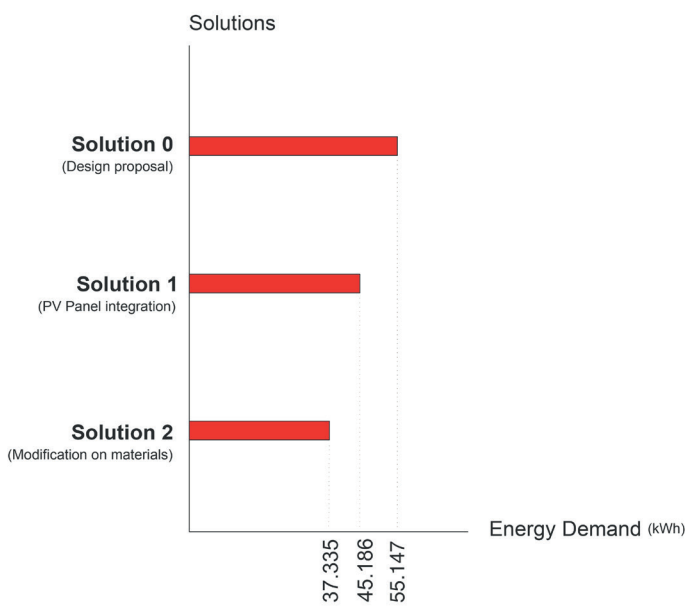


Figure 29 Comparison the results of annual energy consumption between the Solutions 0 - 1 - 2

In this study, **achieving both lower emissions and reduced energy consumption is crucial.**

According to the results it can be seen that **Solution 2 has the lower environmental impact while also it leads lower energy consumption annually.**

Although the combination of both improvements can be another solution, it can lead to a significant reduction in energy consumption, it can also result in higher emissions.

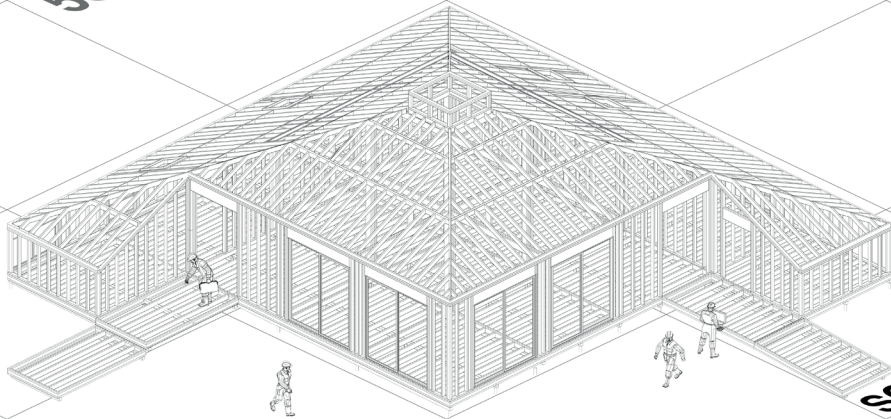
Therefore, the design proposal (Solution 0) is improved by making adjustments to the design proposal materials (Solution 2) to find **a optimum solution** between emissions and also annual energy consumption; the **Solution 2** is implemented to improve design decisions.

Figure 30 illustrates the entire process of design improvement diagrammatically.

DESIGN ALTERNATIVES

17.33 CO₂-eq/m²a

55.147 kWh/year



SOLUTION D

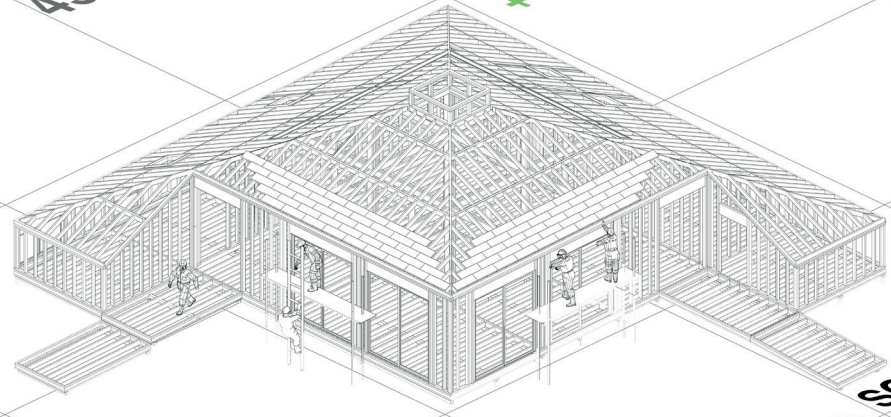
Figure 30 Design alternatives - All Solutions

31.48 CO₂-eq/m²a

45.186 kWh/year



+ PV PANEL TECHNOLOGY



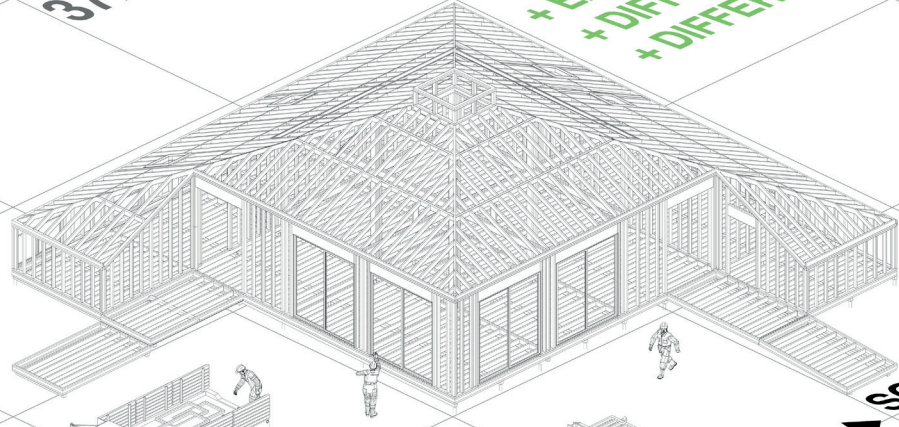
SOLUTION 1

14.26 CO₂-eq/m²a

37.335 kWh/year



+ EXTRA INSULATION LAYER
+ DIFFERENT INSULATION MATERIAL
+ DIFFERENT WINDOW TYPE



SOLUTION 2



Final Design

This chapter presents the design that was initially developed through a conventional approach, followed by the application of solutions for improvement using a parametric LCA approach.

After a thorough methodology application and interpretation, **Solution 2** was chosen to achieve **lower emissions while considering energy consumption**.

The following sections introduce the selected solution through 2D and 3D drawings presented in Figures.



Figure 1 Final design - Kitchen and dining place

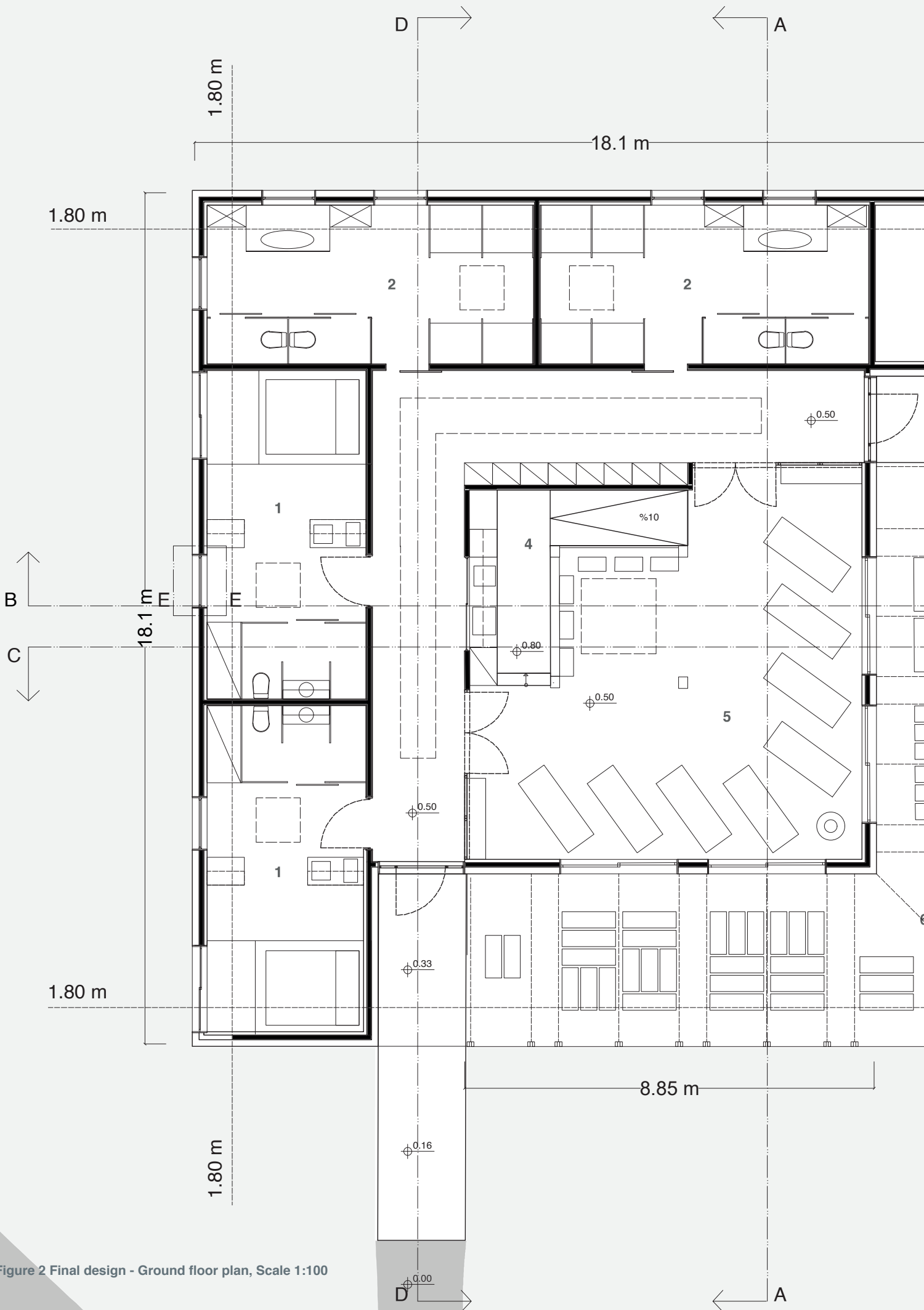
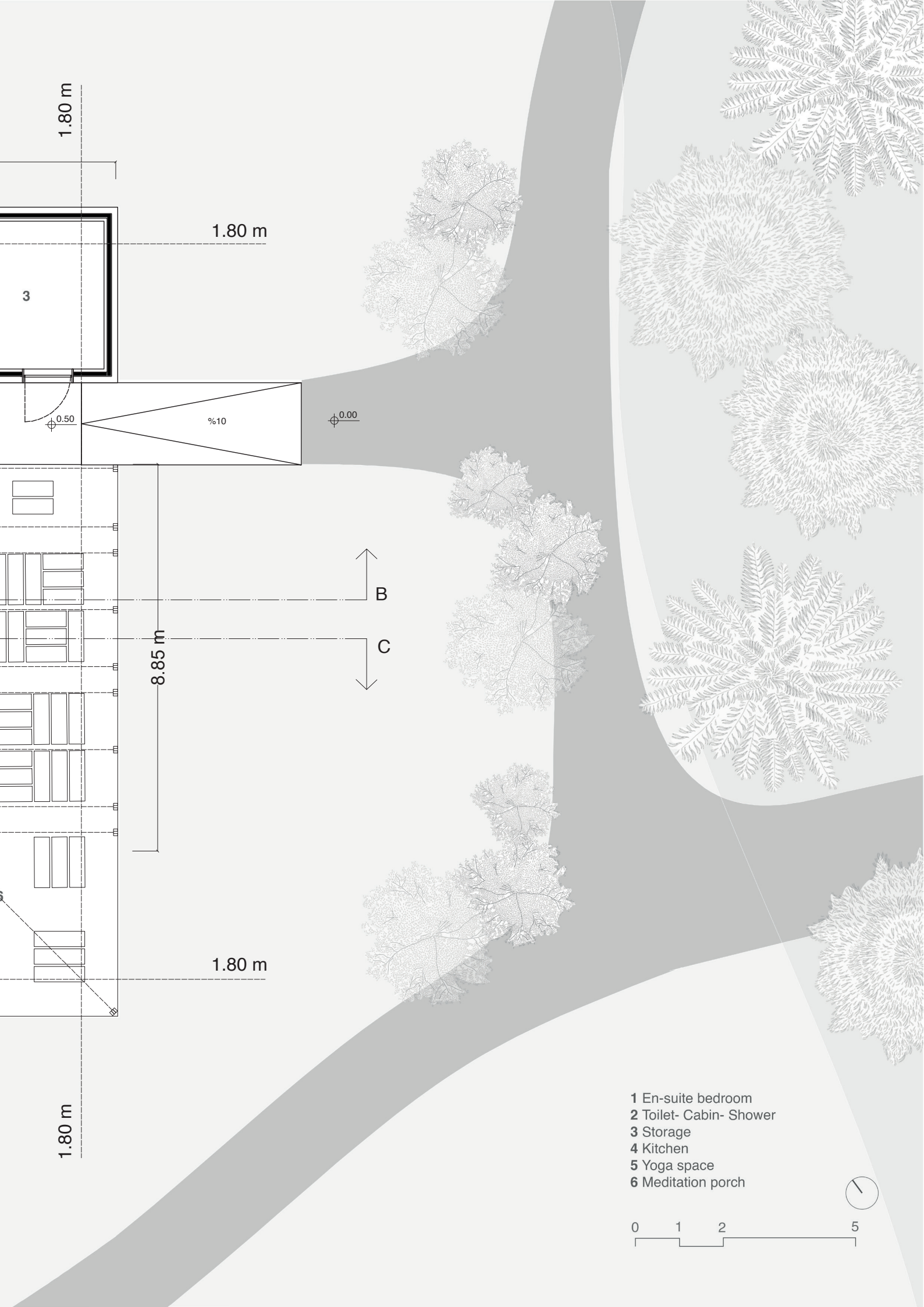


Figure 2 Final design - Ground floor plan, Scale 1:100



1.80 m

1.80 m

3

0.50

%10

0.00

8.85 m

B

C

1.80 m

1.80 m

- 1 En-suite bedroom
- 2 Toilet- Cabin- Shower
- 3 Storage
- 4 Kitchen
- 5 Yoga space
- 6 Meditation porch



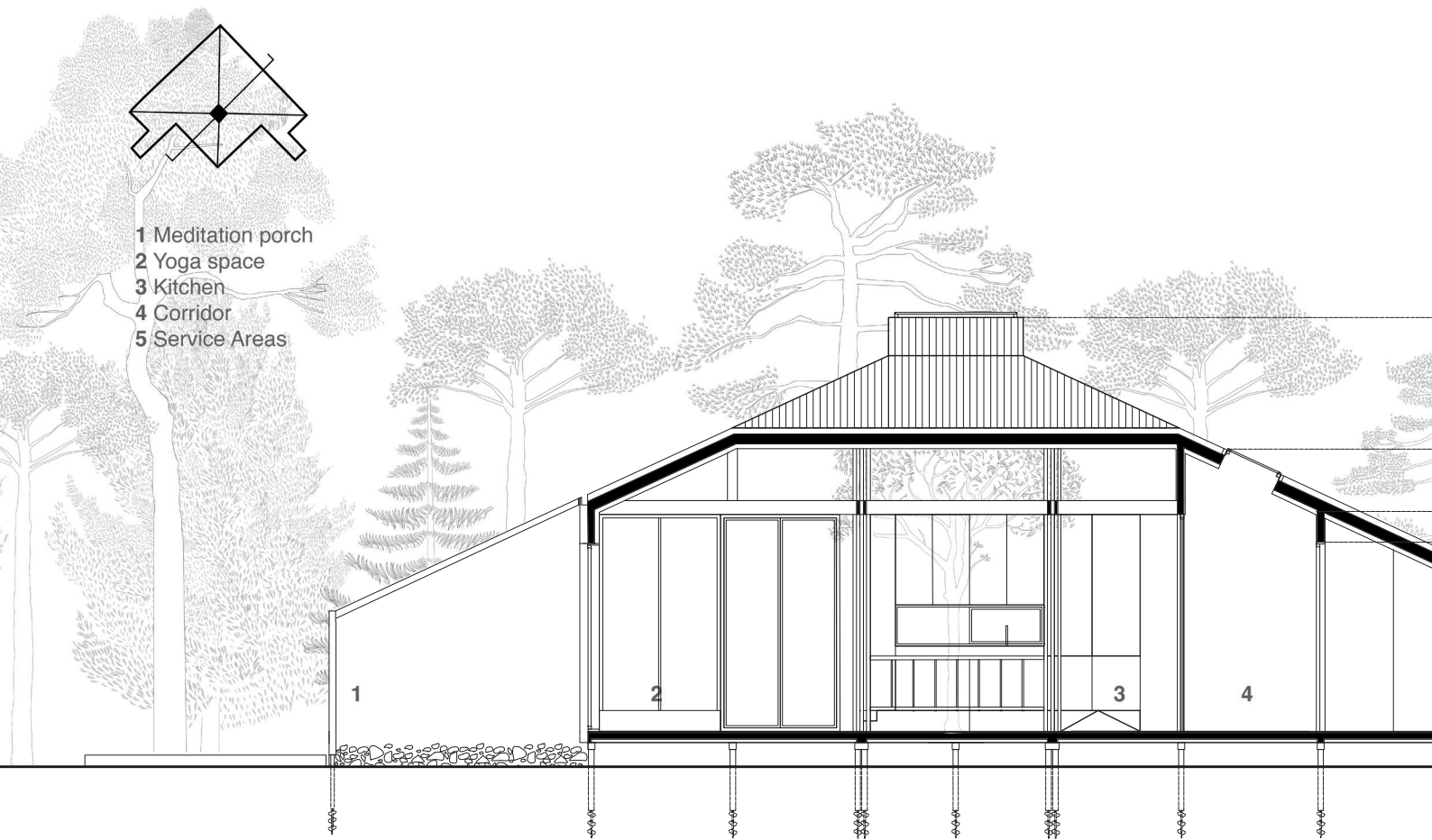


Figure 3 Final design - Section AA, Scale 1:100

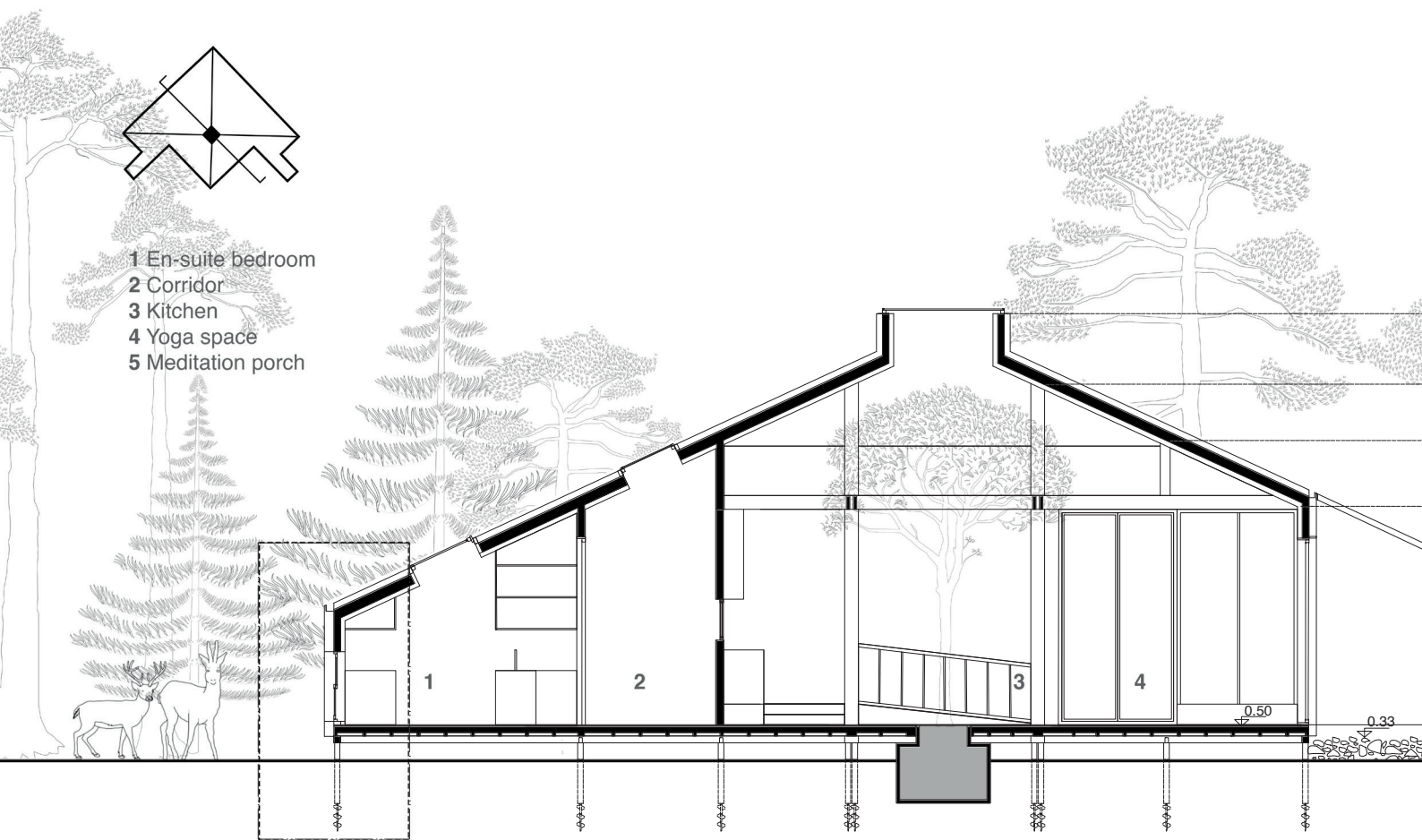


Figure 4 Final design - Section BB, Scale 1:100



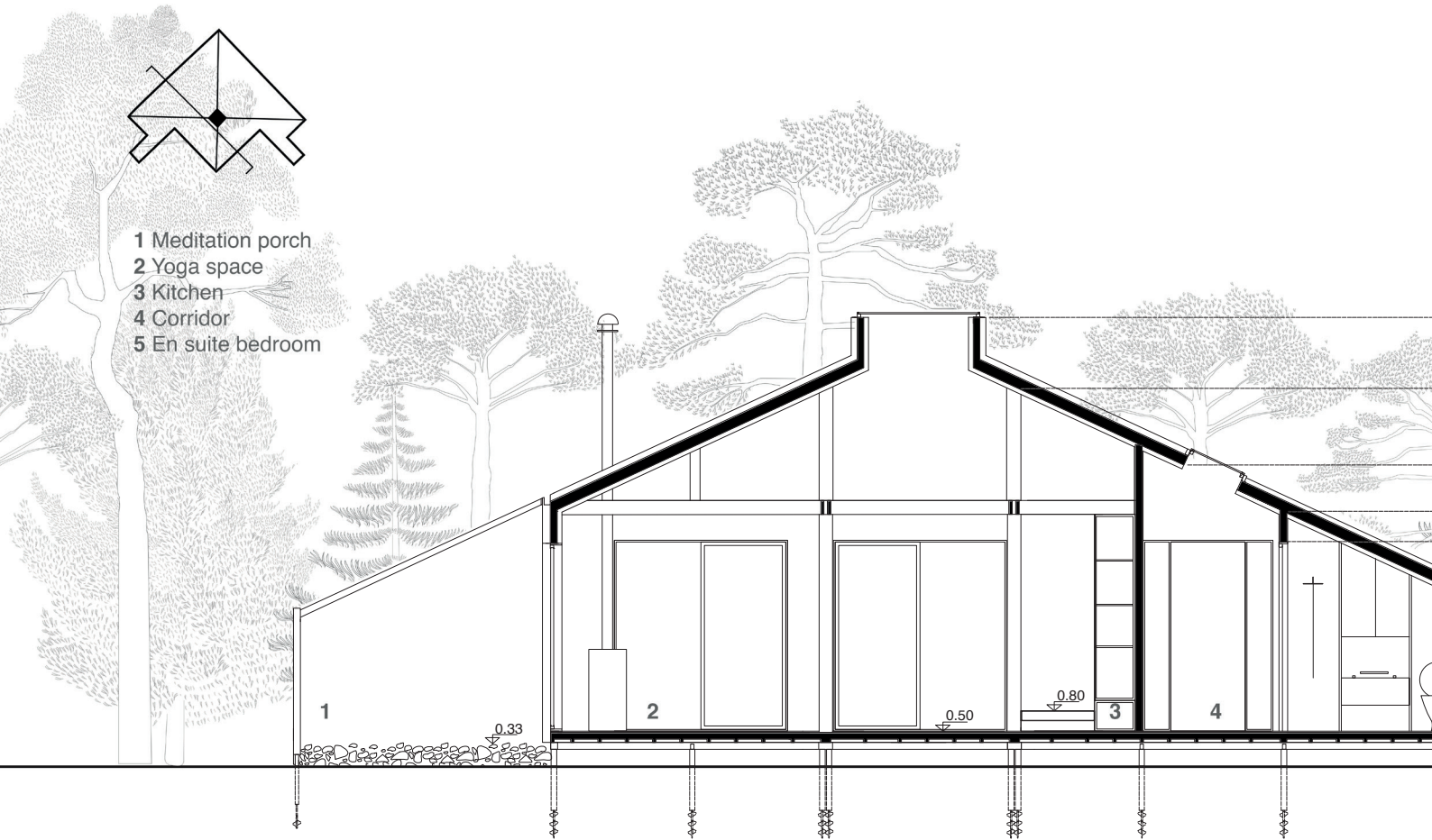


Figure 5 Final design - Section CC, Scale 1:100

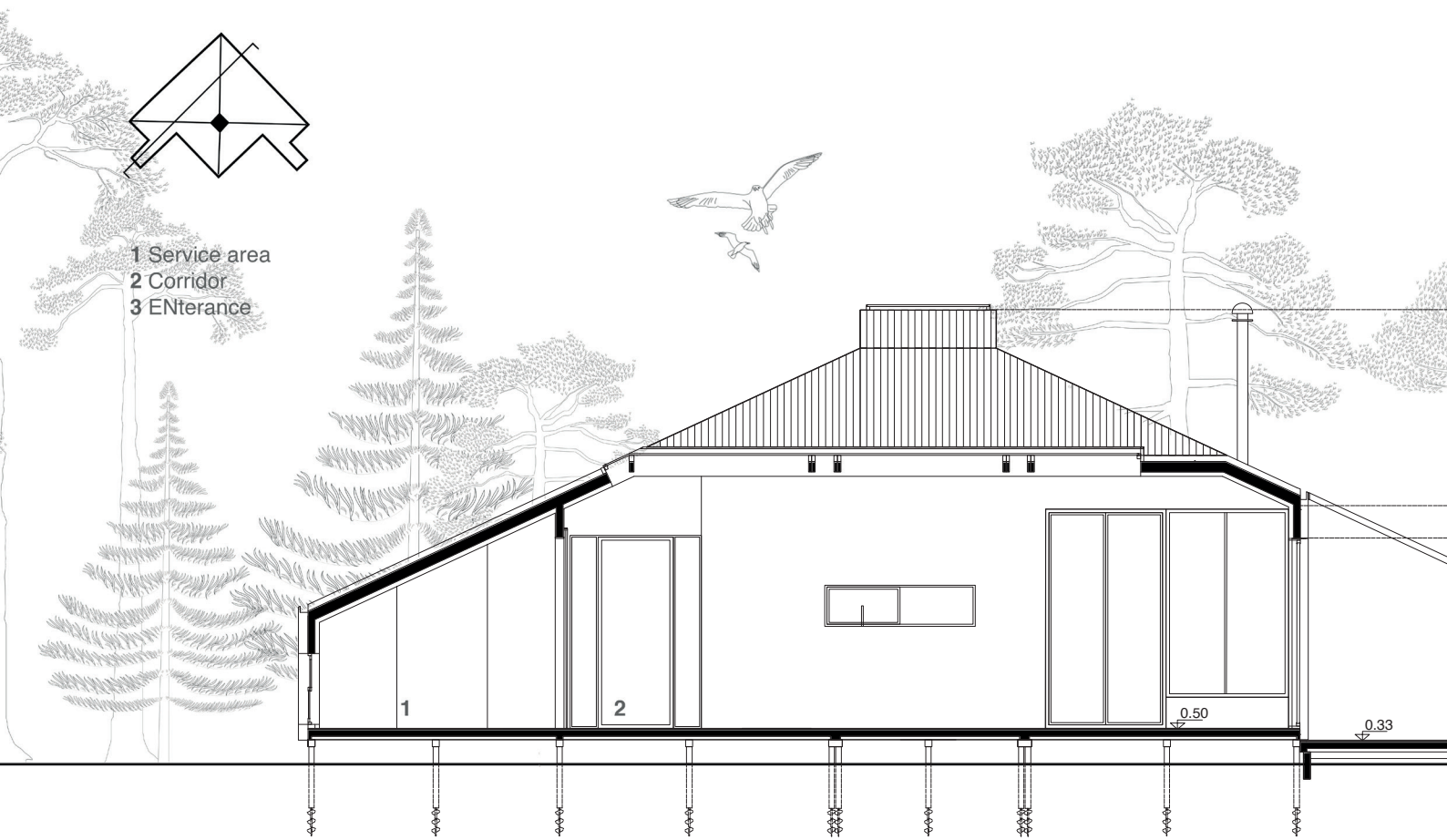


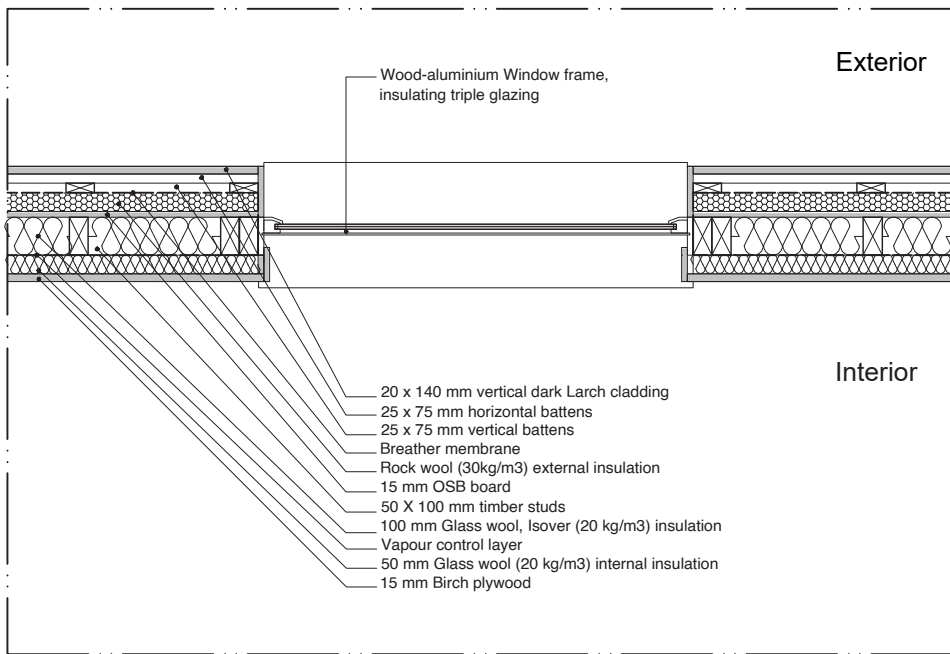
Figure 6 Final design - Section DD, Scale 1:100



Figure 7 Final design - Detailed view, Scale 1:20



Figure 8 Final design - Detailed plan, Scale 1:2



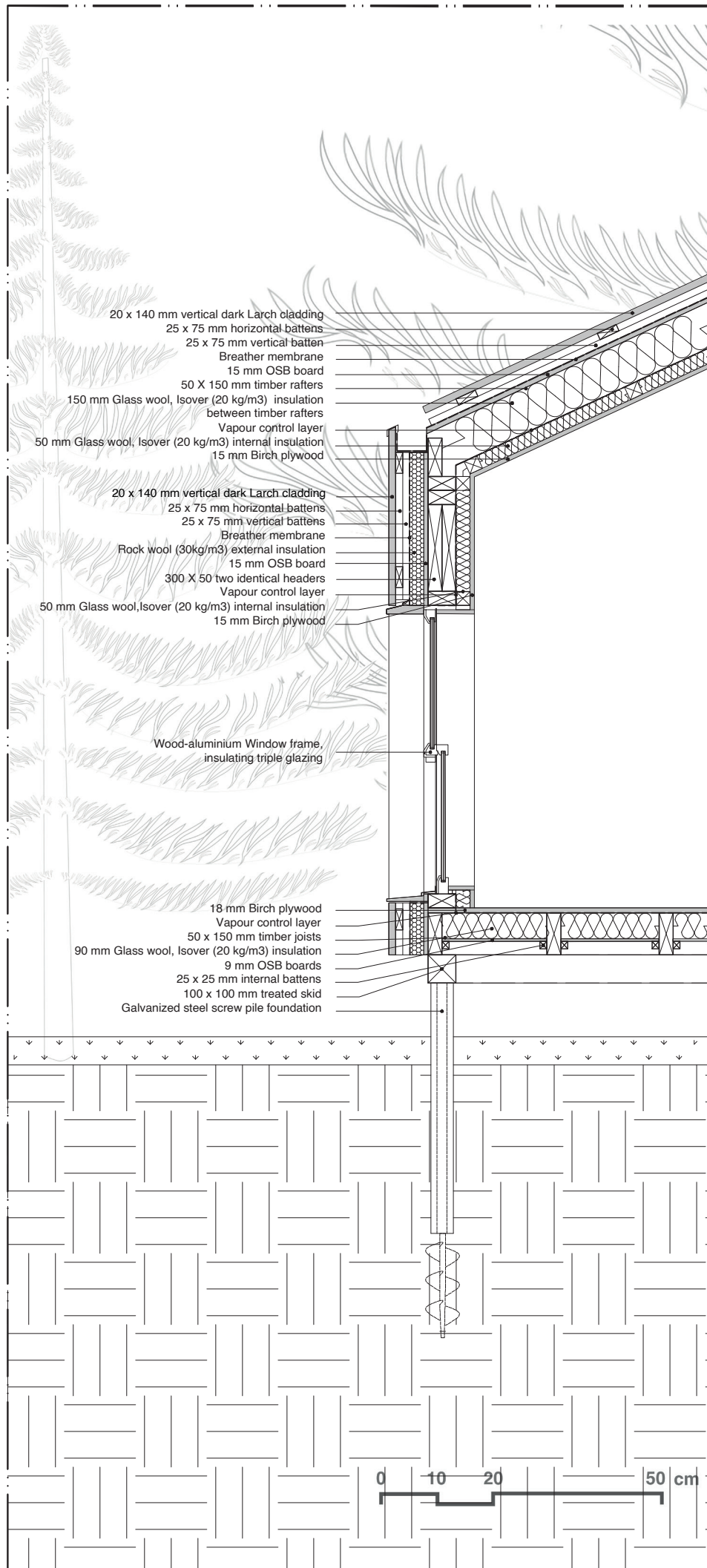


Figure 9 Final design - Detailed section EE, Scale 1:20

BILL of QUANTITY (BoQ)

Final design material selection

Slab

Birch plywood

Glass wool

Joists from Pine wood

OSB

Exterior Wall

Birch plywood

Rock wool

Glass wool

Studs from Pine wood

OSB

Larch cladding

Windows & Skylights

Interior wall

Birch plywood

Glass wool

Studs from Pine wood

Birch plywood

Column

Column from Pine wood

| Material group (Bombyx tool, default material database) | Material (Bombyx tool, default material database) | Layer Impact (thickness in meters) | Component Impact (RSP and RSL years) | Element Impact (Surface area in meters) |
|---|--|---------------------------------------|---|--|
| <hr/> | | | | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.018 | 50, 10 | |
| Thermal Insulation | Glass wool, Isover (20 kg/m3) | 0.09 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/ larch, air-dried, rough | 0.15 | 50, 50 | 234 |
| Wood and wooden materials | OSB plate, PF-bound, wet area | 0.009 | 50, 25 | |
| <hr/> | | | | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | |
| Thermal Insulation | Rock wool, (30 kg/m3) | 0.05 | 50, 25 | |
| Thermal Insulation | Glass wool, Isover (20 kg/m3) | 0.15 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.10 | 50, 50 | 110 |
| Wood and wooden materials | OSB plate, PF-bound, wet area | 0.015 | 50, 25 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.020 | 50, 25 | |
| <hr/> | | | | |
| Window frame: wood-aluminium Window glazing: insulating triple glazing, Ug value: 0.6 W / m2K, thickness 40 mm Frame percentage, 10 | | | 50, 25 | 64 |
| <hr/> | | | | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | |
| Thermal Insulation | Glass wool, Isover (20 kg/m3) | 0.10 | 50, 50 | |
| Wood and wooden materials | Solid wood spruce/fir/larch, chambered, planed | 0.10 | 50, 50 | 150 |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.015 | 50, 10 | |
| <hr/> | | | | |
| Wood and wooden materials | Plywood/Multiplex, PF-bound, wet area | 0.20 | 50, 50 | 42 |



| | | System groups (Bombyx tool, default material database) | System (Bombyx tool, default material database) | Building Services (ERA, RSP and RSL) | |
|---|---------------------------|--|--|---|-----|
| Roof Birch plywood Glass wool Rafters from Pine wood OSB Larch cladding | Wood and wooden materials | Solid wood spruce/fir/larch, air-dried, rough | 0.015 | 50, 50 | 246 |
| | Thermal Insulation | Glass wool, Isover (20 kg/m3) | 0.20 | 50, 25 | |
| | Wood and wooden materials | Solid wood spruce/fir/larch, air-dried, rough | 0.15 | 50, 50 | |
| | Wood and wooden materials | OSB plate, PF-bound, wet area | 0.015 | 50, 25 | |
| | Wood and wooden materials | OSB plate, PF-bound, wet area | 0.020 | 50, 25 | |
| | | | | | |
| <i>Final design system selection</i> Heating Radiators Ventilation Decentralized ventilation Electricity Electrical installation | | | | | |
| | Heating systems | Heat emission via radiators | 210 m2, 50, 25 | | |
| | Ventilation systems | Single room ventilation, window model 10-30 m3/h, without assembly | 210 m2, 50, 25 | | |
| | Electrical systems | Electrical installation, housing | 210 m2, 50, 25 | | |
| | | | | | |

Figure 10 Final design - BoQ

Materials

SIBERIAN DARK LARCH CLADDING



Siberian Larch is a popular, durable, and cost-effective cladding material especially in the cold regions.

It's resistant to weather, pests, and diseases, making it an ideal choice for outdoor use. Its stability and affordability make it a practical option for many projects.

OSB



Latvia is a significant global exporter of OSB (Oriented Strand Board), ranking 3rd worldwide and 2nd in Europe.

OSB is a strong, durable, cost-effective, and environmentally friendly construction material, made from sustainably sourced wood. It is resistant to moisture, making it suitable for outdoor projects, and is easy to install and work with.

ROCK WOOL



Rock wool is the preferred insulation material for external applications in Bombyx tools due to its excellent performance in achieving low U values and minimal contributions to the Global Warming Potential (GWP).

Exterior wall insulation is crucial for improving energy efficiency, reducing CO2 emissions, and cutting heating or cooling costs, as exterior walls are where heat loss or gain is most common in buildings.

PINE WOOD



Pine, the most common tree type in Latvia, is a vital component of the wooden industry. It is a renewable resource known for its cost-effectiveness, strength, and durability.

Additionally, pine is easy to work with and boasts an aesthetic, natural design

GLASS WOOL



Glass wool is the preferred choice for cavity insulation in Bombyx tools, thanks to its emphasis on low U values and reduced Global Warming Potential (GWP).

It is made from recycled glass and sand, making it fire-resistant, resistant to vermin and rot, and resistant to moisture absorption. Its exceptional thermal properties also help reduce heating and air-conditioning costs.

BIRCH PLYWOOD



Latvia has experienced a rapid increase in the number of young birch trees stands. The country is the second-largest exporter of birch plywood in Europe, highlighting the prominence of birch as a fine-grained, easy-to-work-with wood with excellent strength and water-resistant qualities, making it suitable for both interior and exterior projects.

Figure 11 Final design - Building construction materials

LCA Results

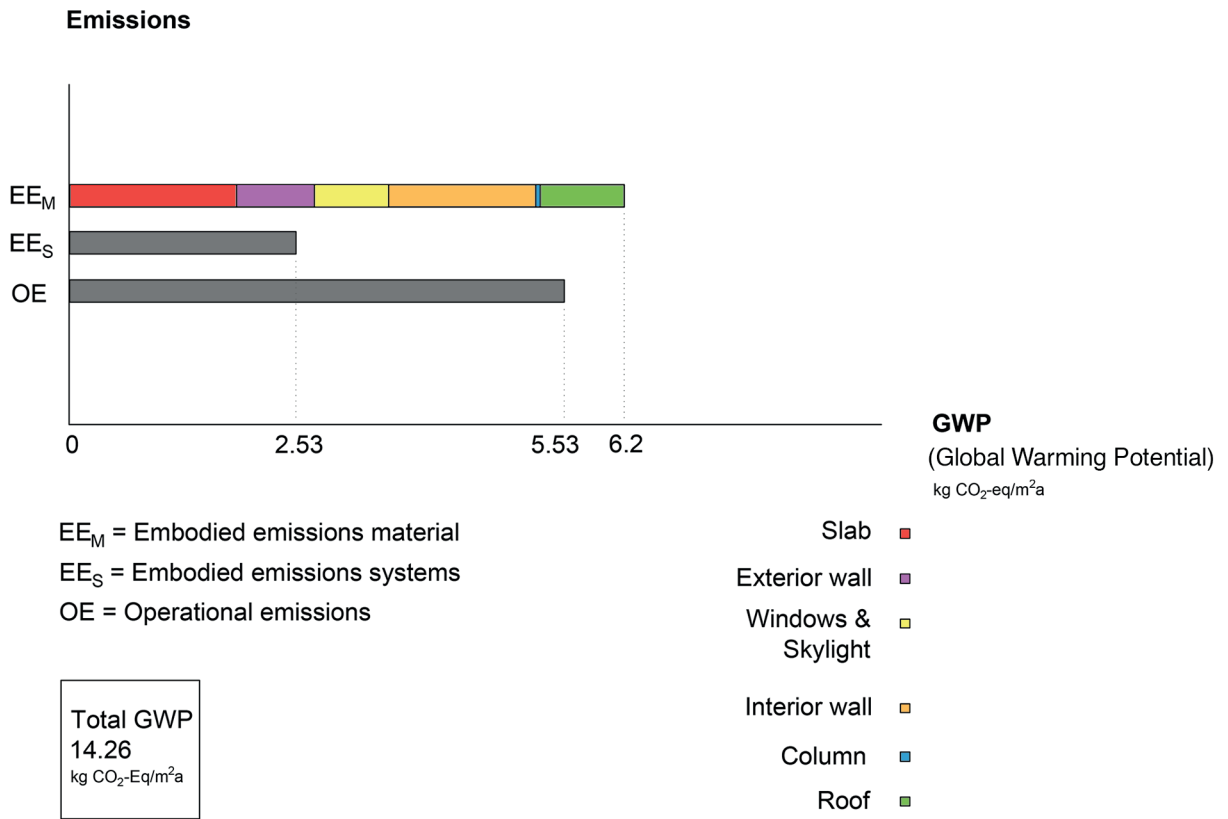


Figure 12 Final design - LCA results

Annual Energy Consumption

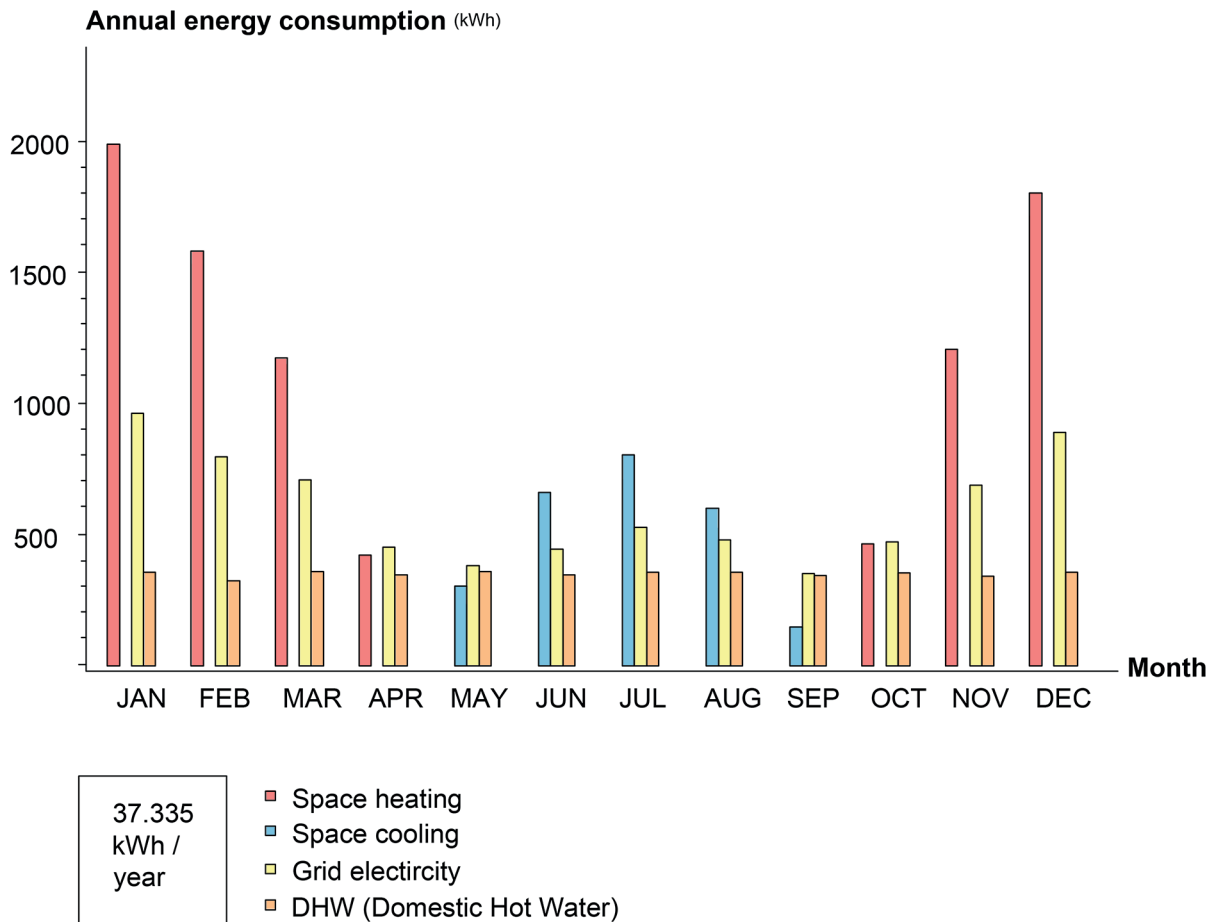


Figure 13 Final design - Annual energy consumption

Construction Process and Emissions

The construction process and the associated embodied emissions resulting from building construction materials are visually depicted in the following Figures.

Figures 14 through 18 introduce all stages of the construction process. Additionally, Figure 19 consolidates these stages, explaining each one's contribution to the embodied emissions arising from materials.

The first four phases detail the step-by-step contributions of timber frame structure and insulation materials to emissions. The final step elucidates the contributions of windows & skylights materials, as well as finishing materials (OSB, dark larch cladding, birch plywood), to the overall emissions.

The construction process illustrates the gradual progression leading to the final emissions, showcasing each step in detail.

The calculation of emissions excludes entrance terraces, doors, pergolas, and foundations.

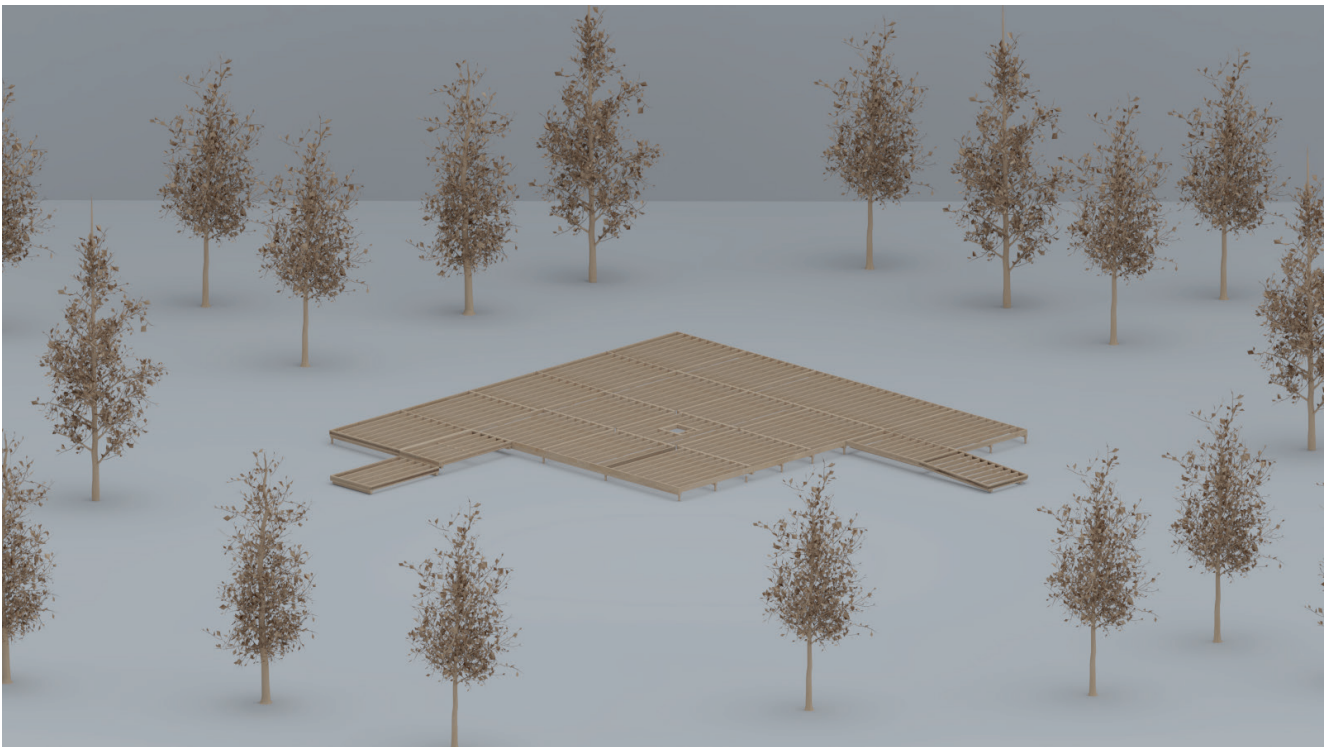


Figure 14 Construction Stage 1, slab frame

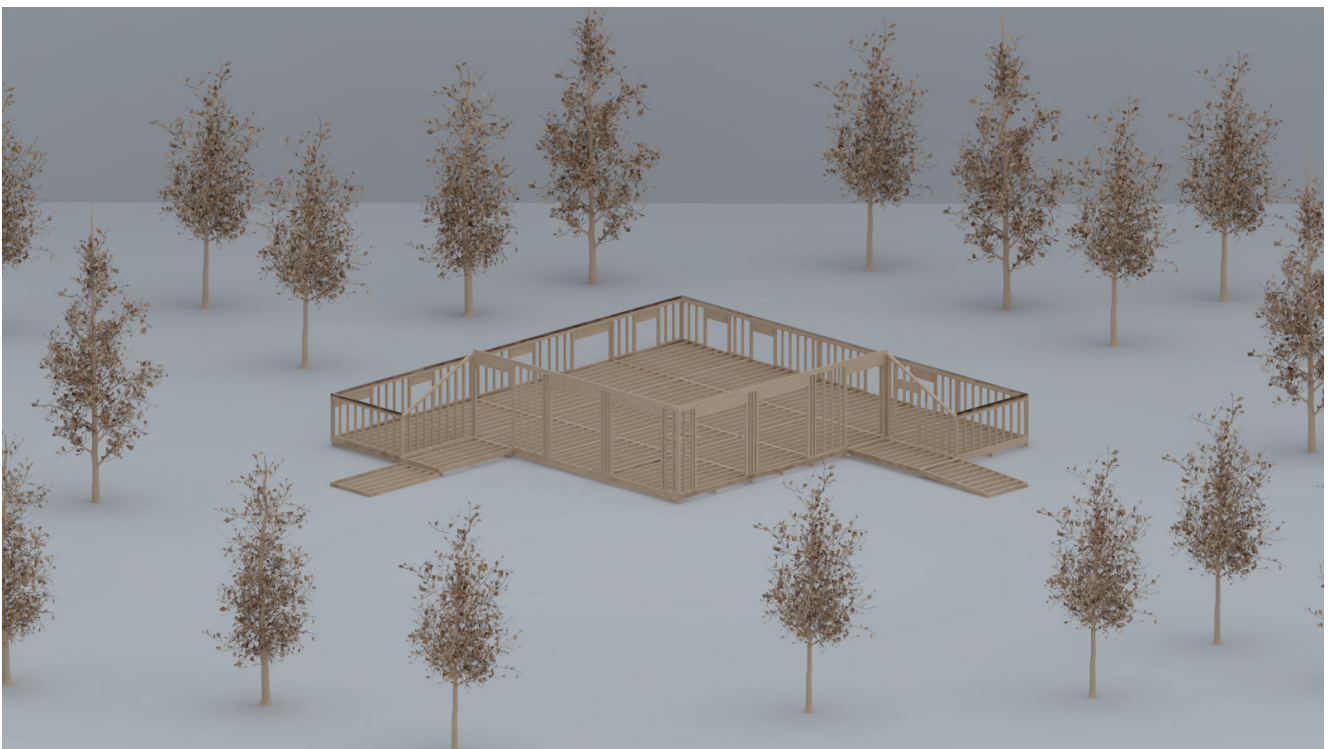


Figure 15 Construction Stage 2, addition of exterior wall frame

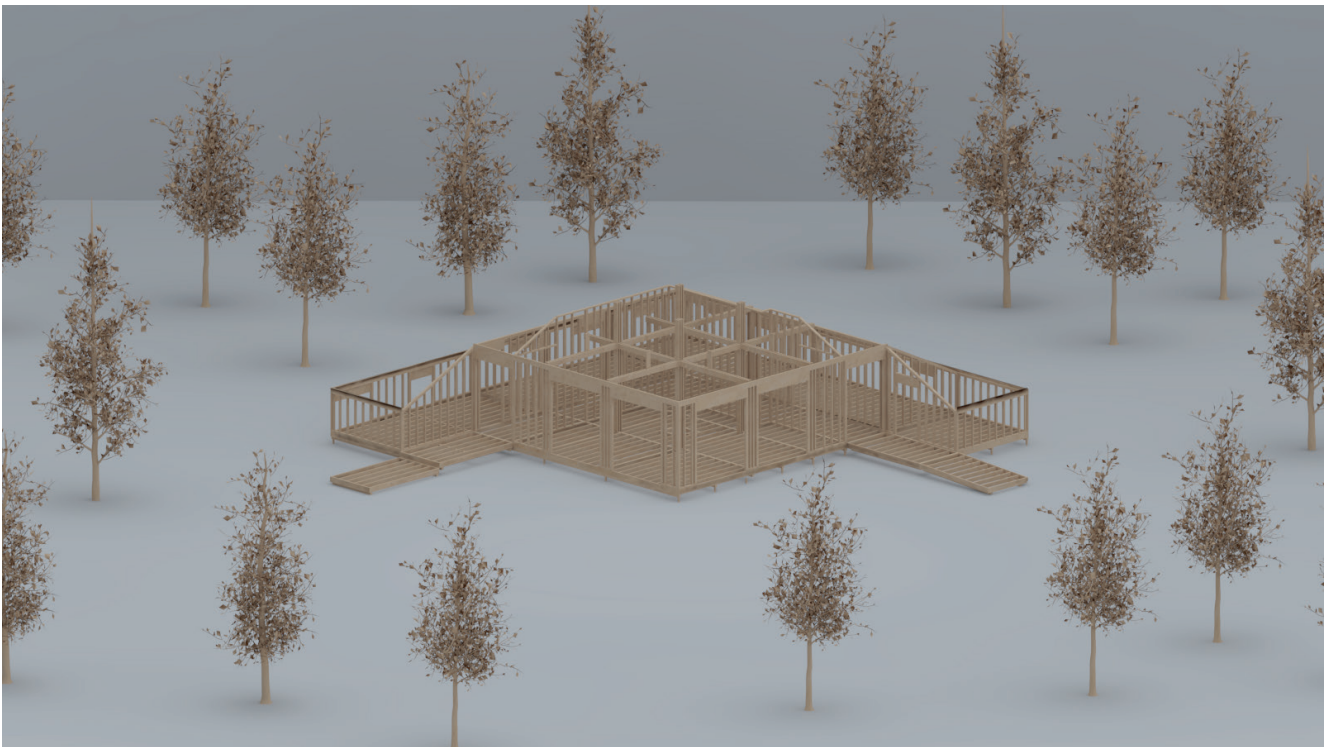


Figure 16 Construction Stage 3, addition of interior wall frame and column element



Figure 17 Construction Stage 4, addition of roof frame

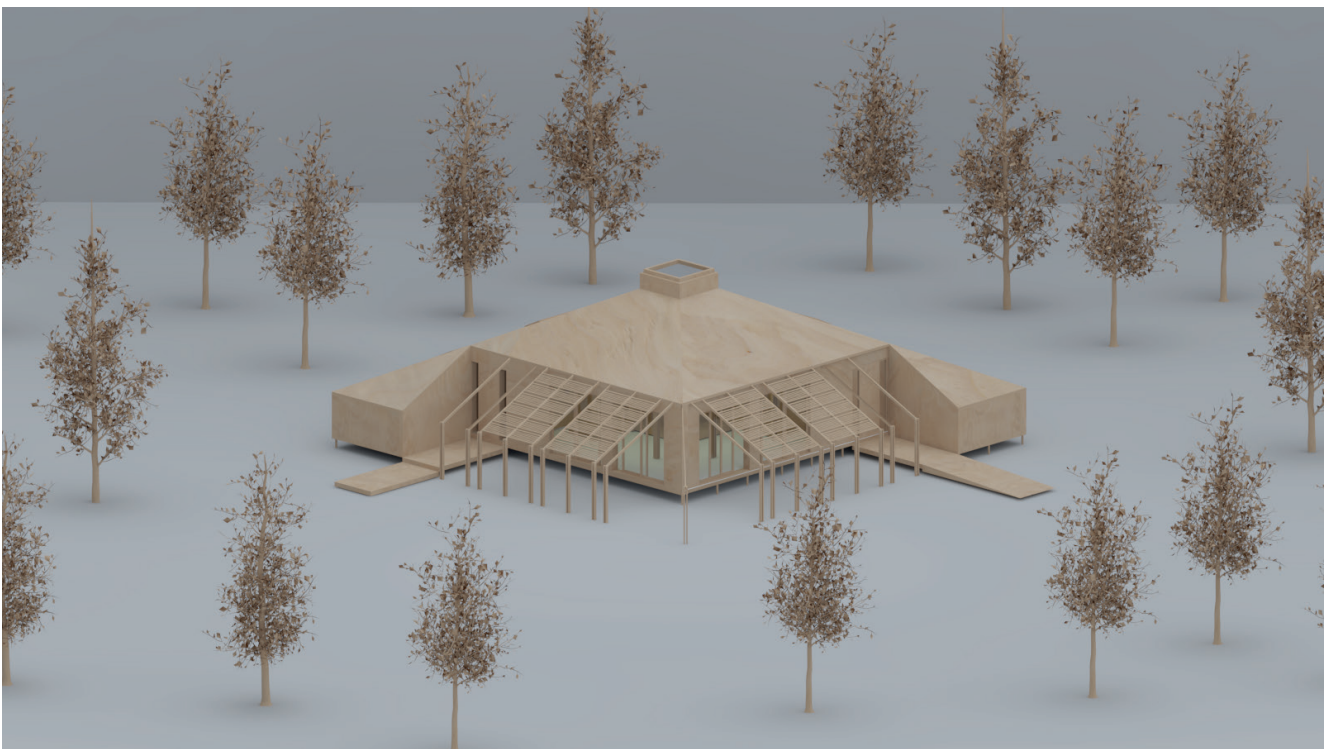
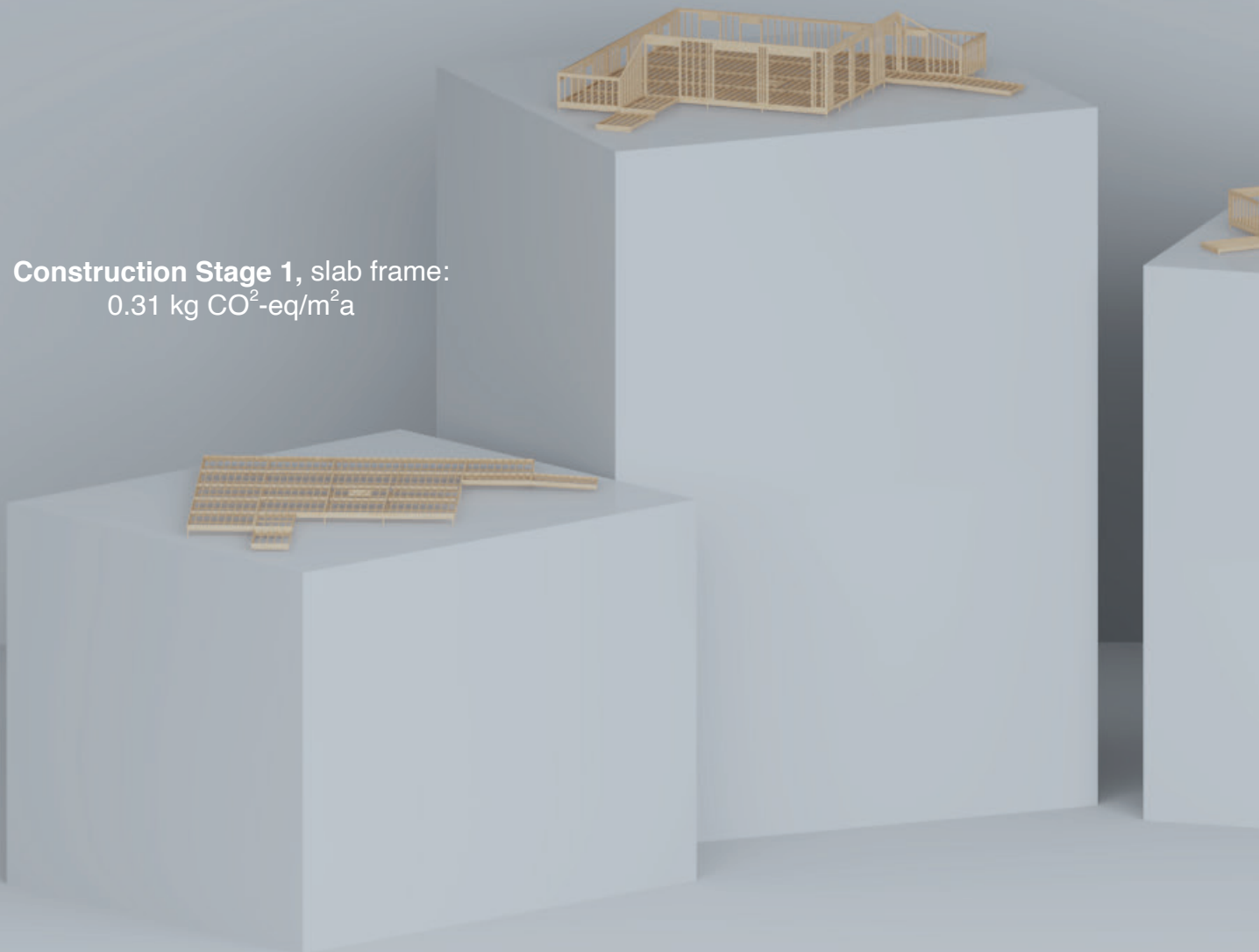


Figure 18 Construction Stage 5, addition of windows & skylights and finishing materials

Construction Stage 2, addition of
exterior wall frame:
0.47 kg CO²-eq/m²a

Construction Stage 1, slab frame:
0.31 kg CO²-eq/m²a



Construction Stage 4, addition of
roof frame:
1.05 kg CO²-eq/m²a



Construction Stage 3, addition of
interior wall frame and column:
0.65 kg CO²-eq/m²a



Construction Stage 5, addition of
windows & skylights and finishing
materials:
6.2 kg CO²-eq/m²a



Addition of windows & skylights:
1.88 CO²-eq/m²a

Addition of finishing materials:
6.2 kg CO²-eq/m²a



Figure 20 Final design - South West Facade, meditation porch



Figure 21 Final design - Dining and yoga space

Results

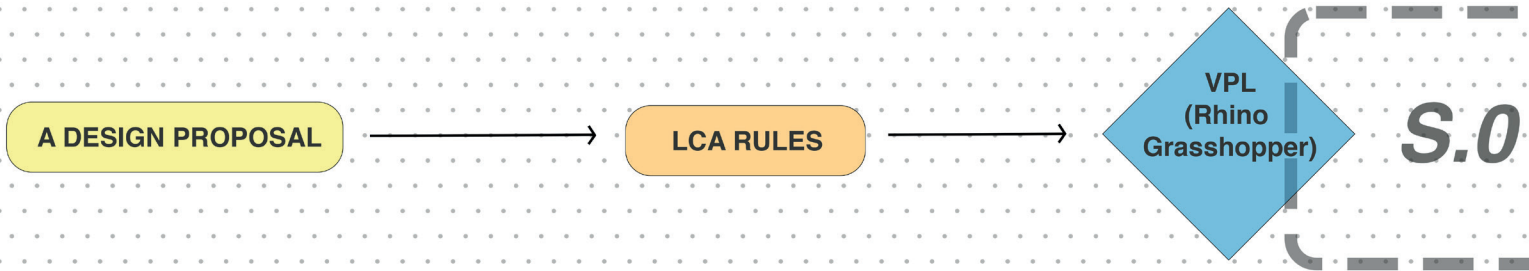
Bombyx and Hive are instrumental in conducting LCA to develop environmentally responsible design, a crucial requirement in this case study. These parametric tools facilitate **a quick and straightforward assessment** while adhering to LCA principles, allowing for the definition of the case study and the exploration of alternative solutions. Rhino software is utilized for 3D model creation, while Grasshopper provides essential parametric environment for the application of parametric LCA tools.

The integration of these tools in the early stages of design enhances design solutions by exploring alternatives and observing real-time results, encouraging the transformation of the case study into an environmentally responsible project. This integration addresses the central question of the thesis: **"How can LCA analysis be incorporated into the early stages of the conventional design process?"**

The methodology chapter illustrates the workflow followed throughout the thesis study, aiming to answer questions such as **"Which design solution is proposed?"** and **"How can a design proposal be improved from an environmental perspective?"**.

Upon proposing a design solution, alternatives are presented to create a design with **lower emissions and energy consumption**. Figure 1 depicts the outcomes of the design proposal and the provided alternatives, with a specific emphasis on LCA and energy consumption results. The application of LCA, the enhancements achieved through LCA, and the progression towards the final design can be closely observed.

Solution 0 is initially proposed, and after defining LCA rules, it is implemented in Rhino and Grasshopper environment with the application of Bombyx and Hive tools. The results indicate low embodied emissions, specifically material and system emissions, aligning with the design proposal strategies. However, **the goal is to maintain these emissions while reducing energy consumption.**



Question to reach the GOAL:

How can a design proposal be improved by considering less emissions and lower energy consumption?



Figure 1 Results on Thesis Workflow

GWP:
17.33
kg CO²-eq/m²a

**Energy
Consumption:**
55.147 kWh/year

SOLUTION 0
(DESIGN PROPOSAL)

Improvements on Technology:
PV Panel Integration

Improvements on Materials:
Additional and different
insulation materials, different
windows & skylights materials

**DESIGN
IMPROVEMENTS**

SOLUTION 1

GWP:
31.48 kg CO²-eq/m²a

Energy Consumption:
45.186 kWh/year

SOLUTION 2

GWP:
14.26 kg CO²-eq/m²a

Energy Consumption:
37.335 kWh/year



In Solution 1, the integration of PV panels as green technology is explored. The results show a reduction in energy consumption but an increase in emissions due to their contribution to system embodied emissions. To address this, **Solution 2 involves modifications to materials in four stages, focusing on additional insulation layers and alternative windows and skylights.** This approach increases material U Values, reducing energy consumption without changes to system emissions.

While Solution 2 shows a slight increase in embodied emissions, it achieves a reduction in operational emissions and a decrease in annual energy consumption compared to Solution 1. Consequently, **Solution 2 is selected as the final design**, successfully achieving the LCA goal of "lower emissions and lower energy consumption" through material modifications in Solution 0. The emissions (embodied + operational) decrease, and annual energy consumption is significantly lowered, with a detailed evaluation indicating changes in embodied and operational emissions.

When examining the final design LCA results individually, it is evident that materials contribute the most to emissions, with operational and system emissions following. The results also highlight the varying impacts of each building construction element, with **slabs and interior wall elements showing the most significant effects.**

Additionally, a detailed breakdown of emissions at each construction stage emphasizes finishing materials as the leading contributors. Further analysis using the Bombyx tool reveals that **Birch plywood has the highest impact**, surpassing dark larch cladding and OSB material. This result is attributed to the greater thickness of plywood in the slab and the presence of a double layer in the interior wall, making their emissions contribution more pronounced compared to other building construction materials.

Conclusion

In conclusion, the exploration of alternative design solutions aims to comprehend potential improvements and their impacts on the environment and energy consumption. Before settling on a design, it is crucial to create and assess various options, taking into account materials, systems, and operational impacts specific to the design climate and local features. This approach provides a holistic perspective, considering diverse viewpoints rather than focusing solely on one aspect of adjustments.

The review and comparison of these options play a vital role in shaping the approach to design improvements for specific projects. The obtained results reinforce the idea that each improvement idea should be observed within the context of a specific design, considering its unique characteristics and requirements.

In addressing the question of **‘How can LCA analysis be integrated into the early conventional design process?’** a parametric approach to LCA, employing tools like Bombyx and Hive, is proposed. The study aims to demonstrate a method for applying parametric tools in the early stages of conventional design, providing a procedural guide for architects in their decision-making processes. It is believed that integrating this procedure can bring about a significant difference in design approaches, fostering an awareness and responsibility for architects’ decisions from an environmental perspective.

To apply parametric LCA effectively, a thorough understanding of the parametric tools (Bombyx and Hive in this study) is essential, requiring proficiency in Rhino software and Grasshopper. However, the study emphasizes that, unlike traditional LCA methodologies that may demand expert-level knowledge, parametric tools make this knowledge more accessible. The application process becomes less complicated after acquiring knowledge about Rhino software and Grasshopper.

