FROM AN EXISTING BUILDING COMPLEX TO A REGENERATIVE SYSTEM

Design strategies to transform an existing architectural project towards ecological regeneration

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From an existing building complex to a regenerative system. Design strategies to transform an existing architectural project towards ecological regeneration
Written Report Master´s Thesis

Profile
Building design and transformation for sustainability

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Finally, I must offer a special thanks to the architect Ken Yeang, a pioneer in combining architecture with ecology. His theories were the foundation of this thesis topic, and it was an honor to benefit from his conversation and invaluable advices.

ABOUT ME

I'm Andrea Rodriguez, an Ecuadorian architect, that started working in the construction industry for about three years where I saw first-hand the role of this industry and the housing mass-production in the environmental global crisis. Therefore, I decided to change paths and started looking for a way to propose solutions that sustain and repair our footprint in the planet.

I began by studying Building Sciences in the UNAM in Mexico, exploring sustainable materials in some incubator project hubs, and working for Arch-Bio, an architectural office that has bioclimatic approaches. Finally, I discovered environmental design and climate-responsive architecture applied to real world practices. However, the knowledge was not enough, and there I decided to pursue my Master, to learn more about these design approaches.
There is when I got the Scholarship for Global Professionals from the Swedish Institute that sponsored my studies in Architecture and Planning Beyond Sustainability at Chalmers University of Technology in Sweden.

This thesis is a reflexion of my current knowledge, a challenge to my role as architect and an ambitious way to explore how I can contribute to the world within my professional expertise. And from now, I cannot be more sure about the path I choose to continue developing solutions into the field and eager to continue learning.

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ABSTRACT

This thesis aims to be part of the solution of the environmental challenges of the construction industry nowadays by moving beyond impact reduction toward architecture as an active contributor to ecological health.

It starts with an existing project, Housing and Beyond, an academic exercise that works with the transformation of a school in Tynnered, Gothenburg, into a residential complex focus on community development. The present thesis explores how this project can be transformed to support and become an active contributor to its closer ecosystem through regenerative practices.

Regeneration in architecture is defined as an holistic design approach that aims to create projects that works as systems capable not just to sustain themselves, but restoring and revitalizing their specif site. That is, to use the elements and conditions of a project as resources that can enhance and improve the environment, not only offering what is necessary to fulfill human needs but providing a balance between human activities and ecological processes.

For that, architects needs multidisciplinary knowledge to be applied since the conception of the project, understanding how the sites´s characteristics can contribute to propose solutions that supports the environment. Therefore, this thesis project presents an exploratory exercise, with a design - based research methodology, where regenerative principles will guide the on-site interventions to transforms Housing and Beyond into a regenerative project.

The ecological aspects of regenerative theoretical frameworks are the central focus of this research. In other words, address basic elements of the built environment such as energy, water, and carbon emissions, enriched with biological and ecosystemic approaches. The proposal develop an early stage design, where the strategies respond to specific site conditions and the needs of the existing building complex.

The systemic hypothesis will be generated through the analysis and interpretation of datasets, relevant literature review, and expert consultation. However, to generate a final proposal, the system is designed, modeled, and evaluated using computational tools such as Rhino, Grasshopper, Revit, QGIS, and Excel. This approach enables early-stage interaction, allowing changes and adaption during the design process.

In summary, this research project explores how an existing architectural proposal can be transformed into a regenerative one using multidisciplinary knowledge and existing resources from the site, through specific design strategies aligned to regenerative principles. It proposes to rethink the role of architects and designers as integrators of theories and practices from different fields, managing complexity and translating them into design decisions. In the same way, it explores how existing computational design tools support these processes, their limits and their influence into early-design stages of design.

1. INTRODUCTION

The global population has reached 8 billion, a dramatic increase from 1.6 billion a century ago, placing immense pressure on the planet's ecosystems. This growth has led to widespread habitat fragmentation, biodiversity loss, and environmental degradation. Human activities, such as construction, pollution, overexploitation of resources, and the introduction of invasive species, have accelerated extinction rates to 100–1,000 times the natural level (Pimm et al., 2014). Habitat destruction alone is being a primary threat for approximately 80% of threatened species, with construction being a major driver (WWF, 2020), affecting the essential services that the ecosystems provide to sustain life such as clean water, aire, soil fertility, climate regulation, etc. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019), 75% of the Earth's surface has been significantly altered, 85% of wetlands have been lost, and 32 million hectares of primary forests disappeared between 2010 and 2015. Today, 25% of plant and animal species are threatened, with 1 million species facing extinction.

As mention, the construction industry plays a significant role in this crisis, contributing 37% of global greenhouse gas emissions and 30% of global energy consumption, and also it is a major contributor to global greenhouse gas emissions, accounting for 37% of emissions when considering its entire life cycle. At the building scale, structures alone represent 30% of total energy consumption related to operation and maintenance (Global Alliance for Buildings and Construction, 2019). Addressing these challenges is critical to preserve the health of the ecosystems, and sustain human life.

However, achieving this goal requires a shift in the way humankind is inhabiting the planet. The human practices must transition across all sectors into practices that not just has low impact in the environment, but actively contributes to subsane the damage generated by conventional ones, and even more, to go beyond, contributing positively with the environment. In that sense, the concept of sustainability becomes obsolete and new paradigms need to be adopted.

1.1. Sustainable vs Regenerative design

Emanuele Naboni, in his conference "Regenerative Design with Climate Change," (2024) argued that a sustainability mindset focused solely on being "less bad" is insufficient. He challenged the idea of minimizing environmental footprints, urging instead to ask, "What can a building provide to the ecosystem?" This shift calls for projects that actively contribute to their surroundings, encouraging a symbiotic relationship between the built environment and nature. But why is sustainability not enough anymore?. As defined by Cole R. (2012) sustainability is about reducing environmental impacts where the focus is just to minimize. This practice, in essence, means to use resources in a way that future generations can also benefits from them, that is, to meet present needs without compromising the ability of future generations to meet their own. However, this mindset can be leading humanity into a "evolutionary dead end" due to flawed assumptions such as the infinite resources to fulfill the needs of a growing population (Du Plessis, 2012).

Regenesis group, one of the leader organizations in the regenerative field, introduces the term of "regenerative development" in 1995. It is defined as an holistic design approach that create systems that not only sustain themselves but actively restore, renew and revitalize their own health. It is consider as a step forward sustainability improving environments, communities, and organizations, creating resources.
That means regeneration goes beyond neutrality, aiming to make positive environmental,

cultural, and social contributions. A good example already exist in nature: biological ecosystems, with their self-generating, self-regulating, and evolving capacities, serving as models for regenerative systems, demonstrating efficient energy dynamics and structural setups that can inspire sustainable design.

Sustainability relies on healthy ecosystem services to provide the resources necessary for human life, emphasizing the need for a balance between human activities and ecology. As contrast, regenerative practices aim not only to sustain but to enhance and restore the environment, offering a proactive response to the climate crisis. Fig. 1
Therefore, to implement regeneration within architectural practices is necessary to understand the function of earth systems, that are the ones aiming to be sustain. To integrate their characteristics into design the influence and interrelation between the parts must be considered. With that, the link between the built and the natural environment in a complementary manner become essential (Reed, 2007).

However, the current practices still relies in isolated solutions, with a fragmented and limited approach, focusing mainly in aspects such as energy efficiency overlooking other important problems as resource depletion or pollution. (Santini T. 2020). To combine these aspects and propose solutions with biodiversity awareness, carbon consciousness, resource use, waste and water management, among others, it is important to understand the interrelationships between the place and each system. This increase the complexity of the project, and architects should assume the role of integrators of multidisciplinary knowledge during the initial design phases of a project.

Data analysis helps architects to comprehend different kind of site-specific dynamics and propose informed solutions that work in synergy with the environment. This approach not only supports creativity but also addresses uncertainties inherent in early design phases. Moreover, it allows to visualize and assess the impacts of decisions and adjust quickly based on real-time data feedback thorough performance visualization. (Quiñonez - Gómez et al, 2025). While data-driven design depends on the accuracy of its data and interpretation (Naboni & Havinga, 2019), traditional design remains largely assumption-based, relying on intuition, precedent, or detached best practices. Therefore, they are poorly suited for multidisciplinary design approaches such as regenerative design, which requires deeply informed and integrated decision-making.

This thesis explores how to translate environmental data into architectural and landscape design with available computational tools, using regenerative principles applied in an existing sustainable project, in early phases of design.

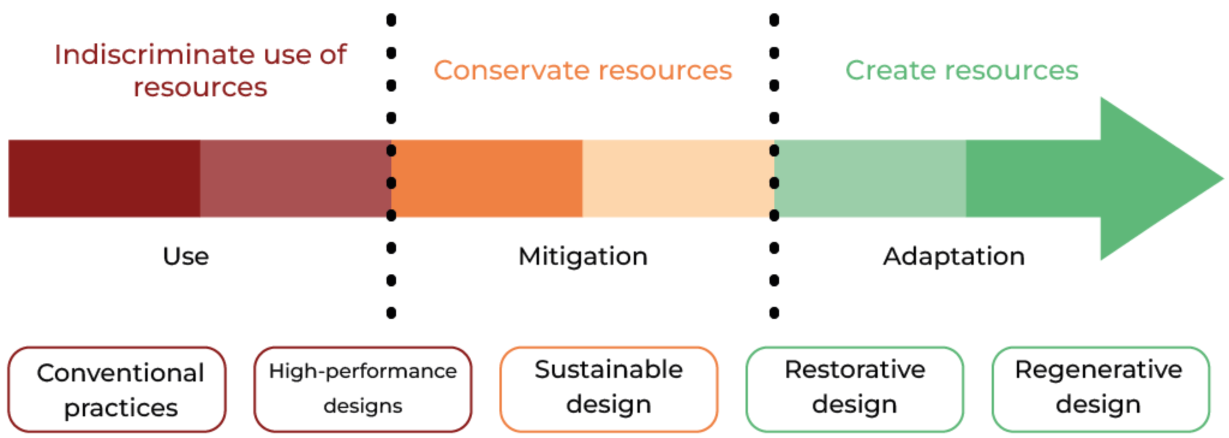


Figure 1. Concept of Regenerative design. (Naboni & Havinga, 2019)

1.2. Problem description

Contemporary architectural practice remains inadequate to address the escalating environmental crisis. Prevailing sustainability approaches are often fragmented and technocentric, relying on generic, add-on solutions applied without meaningful contextual analysis (Reed, 2007). Despite the growing availability of ecological data and computational tools, design decisions continue to be driven by assumption, precedent, or detached best practices (Quiñonez-Gómez et al, 2025) rather than being systemically informed by site-specific dynamics. This methodological gap is increased by the difficulty of integrating multidisciplinary environmental data into conventional architectural workflows, discouraging its consideration during the whole process of design, specially first stages.

Regenerative design proposes a holistic alternative, promoting an interconnected, systemic approach that actively restores and co-evolves with local functions (Reed, 2007). However, its application remains largely theoretical; a significant lack of practical, scalable methodologies make more difficult its adoption. (Pavez et al, 2024) Consequently, interventions in architecture that aims for sustainable solutions are often isolated or symbolic, lacking the rigorous systems-thinking required to combine buildings within their surrounding, thus failing to contribute meaningfully to ecosystem restoration or climate resilience. This thesis addresses this gap by applying a regenerative design framework to go beyond sustainability, as an example to empowers architects to synthesize multidisciplinary complexity into purposeful, informed design strategies.
Therefore, this exploration begins with a project whose core aim was to transform an existing building complex into a sustainable proposal. This research uses the results as a foundation to explore what is missing to reach regeneration.

1.3. An existing building complex

Housing and Beyond

The school Ängås F-6 in Tynnered was schedule to be demolished in the incoming years. The course Integrated Sustainable Building Design at Chalmers University of Technology planned an alternative for demolition, as an exercise of transformation. The objective of the studio was to propose sustainable housing transforming and adapting the existent.

As a result, the proposal Housing and Beyond was developed in a group of four people, from the analysis of site and existing building, to the ideas for the modification and adaptation to the existent structure. The final project included two residential typologies: row houses and apartments (2, 3 and 4 rooms) with indoor and outdoor communal spaces that integrates the users of the project with the existing residents in the area, reinforcing community sense.

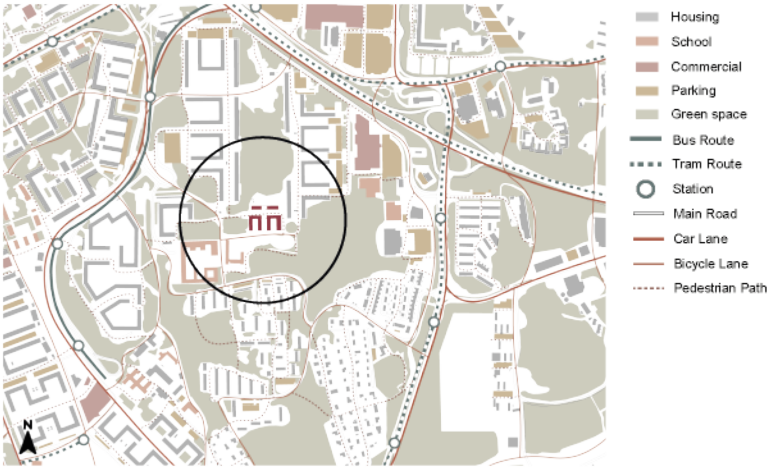
That proposal aimed for minimal changes in the buildings, and even thought a new floor is added as expansion, the materials were selected with low carbon emissions, and good thermal performance. The connection with the site is solved prioritizing the pedestrian existing network and adding a new pedestrian flow from north to south, connecting the communal outdoor areas.

Designed in alignment with established sustainable practices, the new expansion of Housing and Beyond exhibits a primary energy demand below Swedish standards, as shown by its life cycle assessment

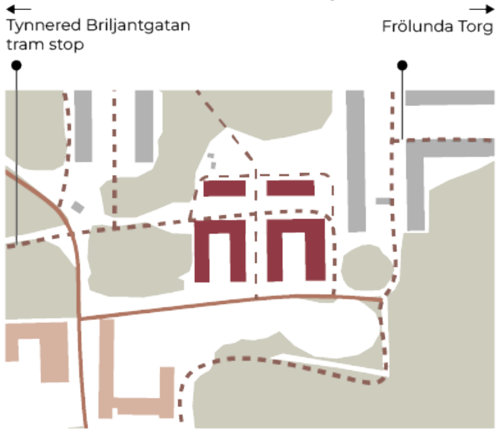
This thesis starts as a continuation of Housing and Beyond, a step further offering a hypothesis on architectural and landscape design beyond sustainability, where the proposal is going to be improved through regenerative design strategies.

TOTAL BUILT AREA:
5303 m²

GROUND FLOOR:
3109 m²
SECOND FLOOR (EXPANSION):
2194 m²



Pedestrian pathways



Site plan

1. Kids playground
2. Café / Playroom
3. Row houses (11 units)
4. Outside sitting area
5. Individual gardens
6. Communal gardens
7. Apartments (22 units)
8. Terrace
9. Row houses (11 units)
10. BBQ area
11. Outdoor gym
12. Sports area

Figure 2. Housing and Beyond site plan

AXONOMETRY

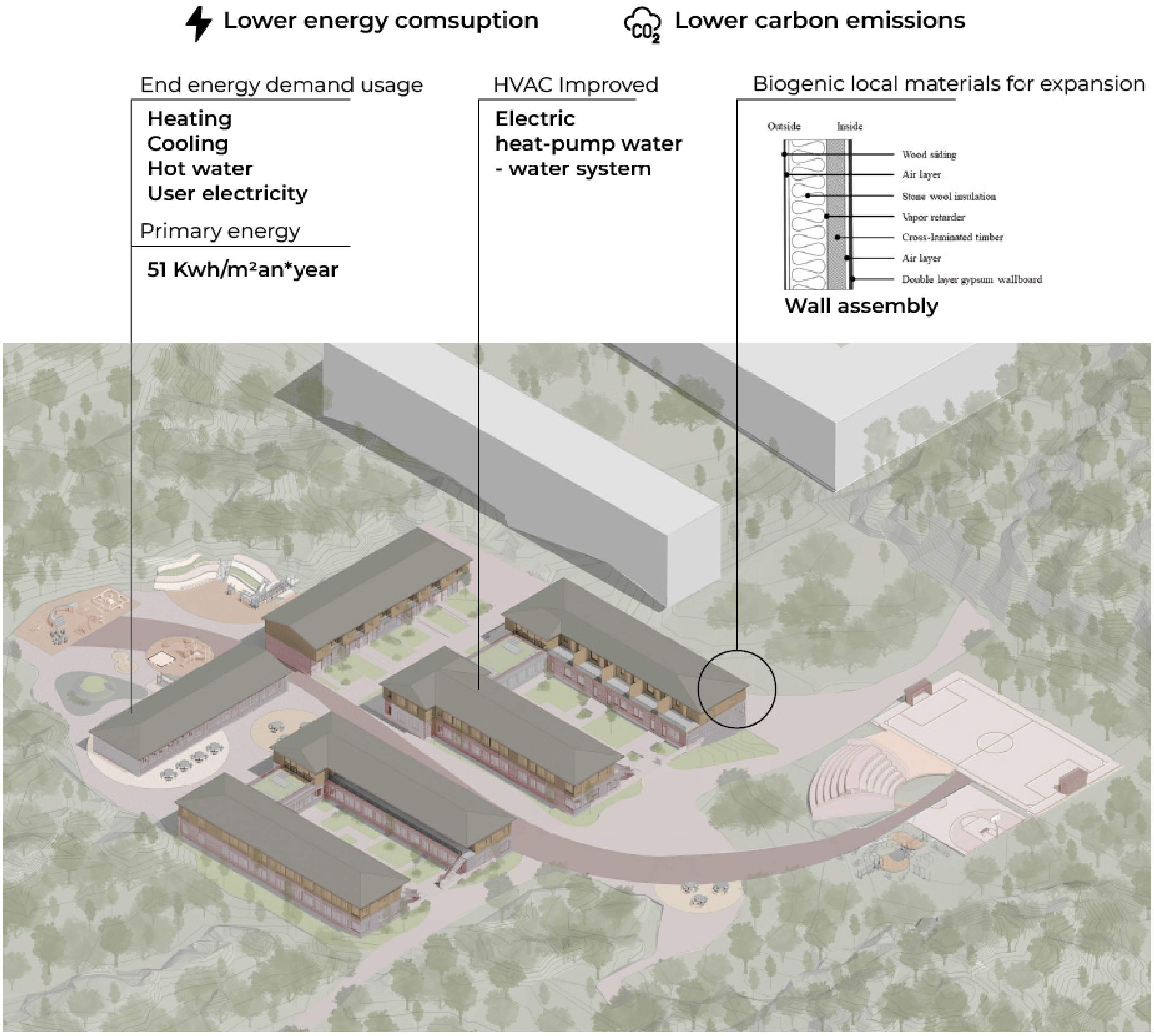


Figure 3. Housing and Beyond axonometry with characteristics.

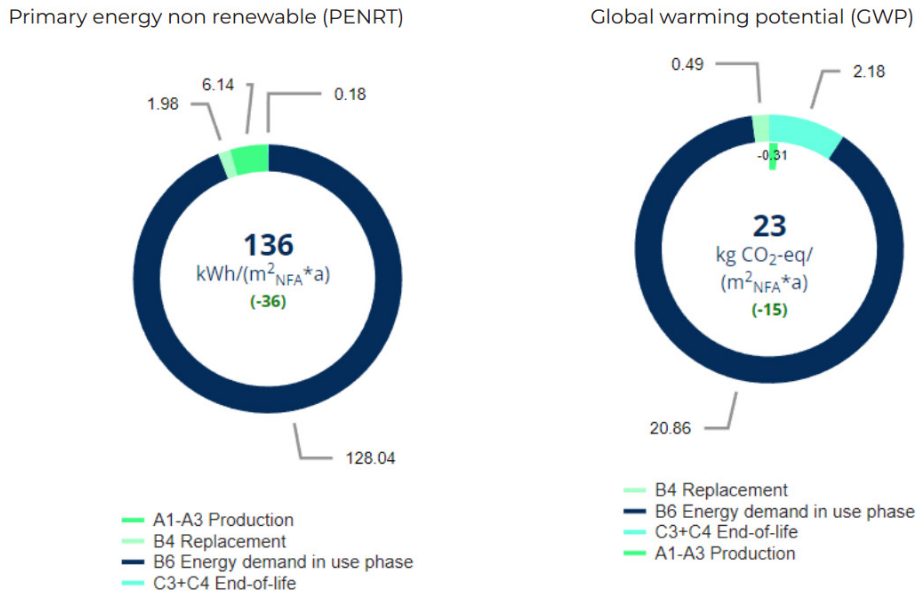


Figure 4. Housing and Beyond LCA analysis in CAALA

1.4. Aim of the investigation

This research is guided by the central question of the methods required to transform conventional sustainable building projects into one that actively contributes to and enhances its local natural environment.
To address this inquiry, the thesis has a clear aim: to demonstrate the transition from sustainable into regenerative design.
The primary goal is to translate theoretical regenerative principles into integrated, context-specific spatial strategies applicable to an existing conventional sustainable project.

The development of the project involves the application of computational design tools, supported by both literature reviews and consultation with relevant experts, which are decisive for a more precise, evidence-based approach. The toolkit will facilitate the:

- **Context-Based Analysis:** To conduct a comprehensive assessment of the site's unique ecological and spatial conditions, and identify problems and design constraints.

- **Decision making:** To model and test the efficacy of various design strategies to select the more feasible for the project objectives and the site

- **Systemic proposal:** To compare and evaluate proposed strategies, identifying the most effective synergistic combinations, how the strategies are working together.

The main intention of this work is to advance architectural practice beyond the mitigation of environmental harm. The final goal is to demonstrate, through digital workflows, that the built environment can be designed as a interactive and regenerative system, with a clear, actionable framework for its implementation in an early stage design project.

1.5. Objectives

- Identify and synthesize regenerative design principles and translate them into spatial strategies grounded into the ecological and spatial context of the project site.

- Apply computational design tools and workflows to test and develop site-specific spatial solutions.

- Assess the performance and regenerative potential of the ecological strategies through comparative simulations, evaluating their capacity to work together as an integrated system

1.6. Research questions

- How can the ecological components of regenerative design principles be translated into site-responsive, interconnected spatial design strategies to transform an existing sustainable architectural project into a regenerative one?

- Which computational tools and workflows can support the application of regenerative design strategies to transform an existing sustainable architectural project?

The thesis **will**

- Use established research frameworks and regenerative design theories to develop a holistic approach for simulating the transformation of an existing project into a regenerative one.

- Use Housing and Beyond project in Tynnered, Gothenburg, as a start point to apply regenerative principles translated into design strategies.

- Analyze the current conditions of the specific site to identify problems and conditions that can be solved applying regenerative strategies.

- Use existing computational tools and simulations to design, assess, and propose modifications to the Housing and Beyond project with regenerative parameters, ensuring context-specific adaptations.

- Prioritize ecological aspects such as vegetation, energy, carbon emissions and water management, proposing ways for the building to contribute positively to its surrounding ecosystem.

- Transform complex ecological data into actionable insights, supporting informed design decisions within the academic exercise.

- Well - grounded assumptions and approximations of real site´s characteristics will be made along the process to perform calculations and simulations.

The thesis **will not**

- Develop novel theoretical frameworks in regenerative design.

- Create new computational tools or technologies for assessing regenerative parameters.

- Propose a new construction project

- Prioritize interior design, human-scale habitability, or economical aspects. While regenerative design intersects with human well-being, this study centers on ecological performance (e.g., habitat reconnection, water cycles) rather than human-centric spatial or social outcomes.

- Frame humans as the primary beneficiaries or stakeholders. Instead, it focuses on the building's role as a node within ecosystems, emphasizing ecological balance over direct human social or cultural impacts.

- Analyze social dynamics, community engagement, or equity implications of regenerative design. Its scope is limited to ecological and environmental performance, excluding socio-cultural dimensions.

- Provide calculations or metrics that shows final numbers or exact fidelity to the conditions of a real site, as the project will develop an early stage of design within an academic exercise.

1.8. Methodology

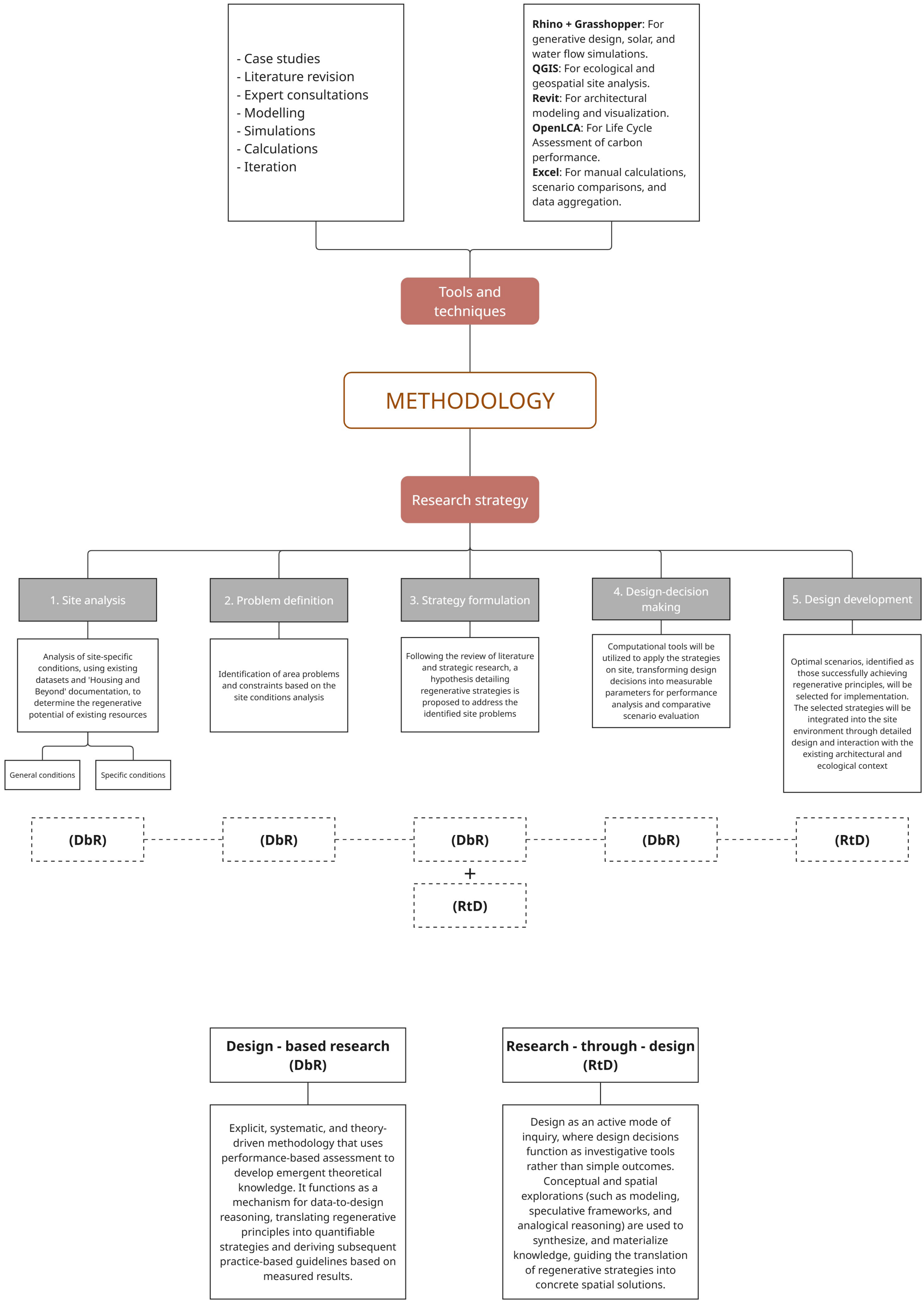


Figure 5. Project methodology

1.9. Research strategy

The research will be conducted as the design project is developed. Therefore it adopts Design-Based Research (DbR) and Research through Design (RtD) as complementary methods. DbR provides the systematic framework for iteratively testing and refining design hypotheses through measurable interventions, linking theory, simulation, and environmental data to assess outcomes such as energy efficiency, biodiversity gain, or water management performance. Meanwhile, RtD acts as the exploratory core of the process: the generative, conceptual, and speculative phase where prototypes, diagrams, and spatial experiments are created not merely to test, but to think through design.

Five sequential steps are proposed: site analysis, problem definition, strategy formulation, design-decision making, and design development. All these phases are supported by a cross-platform toolset including QGIS, Rhino/Grasshopper, Revit, and Excel.

1. Site analysis
Review of previous project data, included Housing and Beyond project performance is conducted to ensur all necessary information is present. Datasets are then separated into two categories: general site conditions, such as climatic data on precipitation and temperature, and local datasets, which are specifically obtained through on-site simulations for factors like wind, solar, and flood path conditions. This phase is implemented using Revit, QGIS, and Grasshopper, and the deliverables include high-resolution maps, quantified metrics, and a synthesized environmental baseline.

2. Problem definition
Problems and potentials of both the site and the project are analyzed, based on the information gathered in the previous stage. A simplify SWOT analyzing along with a brainstorming session is held on strategies aligned with regenerative design principles that could be applied, within the existing resources from the site and the project conditions. This early systems mapping guides the structure of the design research.

3. Strategy formulation
After understanding the site's characteristics, limitations, and potential of the project, this phase is supported on research, which includes a review of relevant literature and similar projects, as well as consultations with experts in the areas related to the defined problems to propose solutions that transform the Housing and Beyond project into a regenerative project. In this phase, a hypothesis is developed, where the proposed strategies are interrelated, understanding that the project will be developed as a system.

4. Design-decision making
To evaluate the feasibility of the hypothesis, each strategy must be measured and analyzed based on literature, reference projects, and consultations with experts in each area. Thus, each strategy will be tested in various scenarios through evaluable parameters in a trial and error process. In this stage, strategies will be studied through simulations and calculations. During this process, some data may be assumed, based on solid foundations in the project or similar sites, due to the early design stage.
Finally, strategies that prove not beneficial to the project's objectives will be discarded.

5. Design development
The final proposal is presented, where the strategies that work best for the site and objectives are applied, taking into account the unique conditions of the site and the existing project.
The final proposal is produced with deliverables visualizing the location and operation of the proposed project. Housing and Beyond has been transformed into a regenerative project.

1.10. Ethical aspects

Regarding the reliability and academic integrity of this research project, some critical aspects have been taken into account to maintain academic integrity throughout the thesis process.

1. This thesis uses initial data from Housing and Beyond project, which was developed in a previous academic design studio where the author collaborated with three other group members. All original information (plans, graphics, reports, etc) are presented without modification and is accurately attributed to the original group of authors. The current thesis, however, generates and present new information and documentation developed solely by the author.

2. Large Language models like ChatGPT and Gemini has been utilized in the following ways:

- To improve the readability of the text, checking grammar, spelling and clarity. This process has been made ensuring to maintain the exact meaning and intention of the author.
-The CONEFOR and OpenLCA tools were applied following a data entry guide generated by a ChatGPT, trained on the official manuals, with the process verified against the software authors' video tutorials.
- Image generation based on a detailed description provided by the author and based on a defined modeled basic render, with an iterative processes to guarantee the fidelity of the author´s ideas.

However, this tools has not been employed to generate ideas, content or write sections of the thesis, or conduct research and gather information, or influence in any way in the development of the current thesis. All research findings, analysis, and interpretations presented in this project are the result of the author´s work. Moreover, to support the reliability of the results, all calculations have been performed in accordance with relevant regulations, industry standards, literature review and consultation with experts in the field, clarifying all assumptions made through the entire thesis process.

2. THEORY

2.1. The Ecosystem

Ecosystems are the foundation of regenerative design, as they function as interconnected systems of living and non-living components. The term was first introduced by Tansley (1935), defining it as defining it as a biological assemblage interacting with its physical environment in a specific location. Therefore, ecosystems are not size-dependent, considering everything from the entire biosphere to smaller biological systems. According to Yeang (2006), they operate as open systems, pointing out the inherent interaction between elements and with a balance through continuous flows of energy and materials. Despite fluctuations, they achieve a dynamic equilibrium or steady state, which can be understood as a capacity to adapt and evolve depending on the site conditions to maintain that balance.
This research **adopts an ecosystem-centered approach** to regenerative design, emphasizing the architectural role in sustaining and enhancing ecological and biological systems.

2.1.1. Ecosystem components

In his book Ecodesign Manual (2006), Ken Yeang, pioneer architect in ecological responsive architecture, explains some of the fundamental components of ecosystems that are key aspects that architects and designers must understand when considering design at any scale, to interact with the complexity of this systems and propose proper solutions that can interact and became an active part of them. Consequently, it is necessary to start with the composition of earth itself.
In a ecological level this is divided by layers, which include:

• **The green belt or auto-trophic layer:** Where organisms and plants capture light energy and use simple inorganic substances to transform them into complex compounds.
• **The brown belt or heterotrophic layer:** Where organisms consume, reorganize, and decompose complex materials.
Moreover within this layers there are some components, these as the most important:

• **Inorganic substances** involved in material cycles (e.g., nitrogen (N), carbon (C), carbon dioxide (CO_2), water (H_2O), etc.).
• **Organic substances**, including proteins, carbohydrates, lipids, and those that connect biotic and abiotic elements.
• **Climate systems**, including temperature, rainfall, etc.
• **Minerals and nutrient cycles**, beyond food production.
• **Consumer organisms, phagotrophs:** Animals that consume organic matter or other organisms.
• **Decomposer organisms, saprotrophs:** bacteria, protozoa, fungi, and similar organisms that break down complex substances into simpler ones.
• **Producer organisms, autotrophs:** Primarily plants that synthesize food from simple substances and light energy. (Yeang, 2006, p. 32).

2.1.2. Ecosystem principles

For Capra (1996) it is important to understand how an ecosystem function because it is the only way to construct sustainable human communities, a new way to inhabiting the earth as a solution for the ecological crisis. This "ecoliteracy" is based on the knowledge of nature´s principles, that applied to human communities, they must be designed so that its ways of life, technologies, and social institutions honor, support, and co-operate with nature's ability to sustain life. (Capra F., 2007, p. 2).
One the most practical ways to understand ecology is trough the theory of living systems, that states:

1. Every living organism, from the smallest bacterium to all the varieties of plants and animals (including humans), is a living system.
2. The parts of living systems are themselves living systems.

3. Communities of organisms, including both ecosystems and human social systems such as families, or schools, are living systems. (Capra F., 2007, p. 4).
Therefore, an ecosystem can be also defined as a community, with complex relationships between parts, not just a collection of objects and species. To explain those connections there are some patterns and process that shape and defined it, and in consequence, there are the core ones from which nature supports and develop life.

1. Continual flow of energy: All living systems need energy and food to develop, an as a consequence all of them produce waste. However, the waste of one species is food for the next, which also is defined as a continued cycle of matter.

2. Network of chemical reactions: This is the way that the elements of ecosystems processes food and forms the biochemical basis of all biological structures, functions, and behavior.

Apart from the biological and non-biological components, there are some elements inherent to the relationships between components, which are defined by Capra (2007), that helps to study how ecosystem works, and give insights in its system function:

• **Networks:** It is the basic way of organization of any living system. Where is life, there is always a network.
• **Nested system:** The relationship between networks, or "a network within a network" (Capra F., 2007, p. 6). It is also connected proportionally to the complexity of a system.
• **Interdependence:** Life needs from the community to thrive, in consequence there is no development in isolation, and all the living systems depends from each other.
• **Diversity:** The success of a living system depends in its capacity to overcome any disruption or disturbance that can broke the network. For this, a system where species have a different function, sometimes overlapping between them, will be able to replace or sustain each other, while the whole system can reorganize. This is the resilience capacity of a system.
• **Cycles:** As stated, a healthy living system cannot produce any waste. That means that matter will continually cycle through the network. This is connected to the mutual dependence of elements withing a ecosystem, where the waste of one is the food of other.
• **Flows:** Even thought the living systems work within cycles, not all the elements are from the same cycle. This means that there will be always a conversion process, with gains and losses. For this, all the living systems are considered as open systems.
• **Development:** Connected to its resilient capacity, all the ecosystems experiment different stages, growing, changing, expanding, from the expanding first communities until the stable ecological cycles. However, this development is not gradual, as it exist ecosystems within ecosystem with its own development pace, which explain the complexity of living systems but also the non-linear adaptation, the co-evolution of a living system, and also the difficulty to predict or control it.
• **Dynamic Balance and Emergence:** With the capacity of adapt and overcome obstacles, living systems can maintain a constant balance, where communities regulate and organize itself. (Capra F., 2007, p. 5-9)

As indicated earlier, to create human communities that develop themselves in a collaborative way within the environment, it should take the nature as a model, therefore, this aspects must be transferred to the way that human are inhabiting spaces, and how human systems are working. Architecture, understood as the one that shapes the human habitat, have the capacity to influence how humans develop its life and their connection with their surrounding ecosystems.

2.1.3. Systemic thinking

For Reed (2007) the solution to avoid fragmented sustainable proposals it is necessary to start working with whole systems model, and the living system interrelationships in an integrated way needs to be studied.
The holistic manner to link the natural and built environment is not new, authors like Yeang

(1994) and Lyle (1994) already discussed the role of architects and designers understanding the earth system to sustain it. Whole systems thinking recognizes that the entirety is interconnected, and moves us beyond mechanics into a world activated by complex interrelationships such as natural systems, human social systems, and the conscious forces behind their actions. (Reed, 2007).
So, how to mimic natural principles in the built environment? For example, in nature, the carbon, nitrogen, and water cycles demonstrate the efficiency of closed-loop processes, which regenerative design seeks to replicate in human systems. With ecological principles waste will be another resource, eventually providing nourishment for something new. (Capra, 2007).

Despite the benefits, systemic thinking adoption is proved to be difficult, for Capra, there are two main reasons:
- The complexity of a system lies in its non-linear character. They don´t maximize variables but optimize them. Thus is quality and not quantity what matters.
- The current trend of the world is the materialism, where industrialization just produce to sell, a linear process that just extract, converts, sells and dispose.

Regenerative design is a process that consider human as an integral part of nature and that human and natural systems are one.

2.2. What is regenerative design?

Regeneration is defined as “recovering the parts that are damaged or not functioning properly” by the Cambridge Dictionary. In natural contexts, it refers to restoring ecosystems, surpassing sustainability’s goal of minimizing harm. Brown et al. (2023) define regenerative design as creating relationships that enhance human and ecosystem health, emphasizing the connection between humans, nature, and their elements.
Regenerative design, therefore, focuses on human collaboration with ecosystems, healing and fixing negative impacts to promote well-being, co-evolving as a “Whole Living System” (Reed, 2007). This concept highlights the interconnection of all living systems and the need for humans to contribute positively to it.

Ken Yeang defines bio-integration as the goal of eco-design, where human purposes are “harmoniously combined with the long-term patterns, flows, processes, and physical arrangements of the natural world” (Yeang, 2006, p. 25). However, regenerative design takes this further by focusing on remediation and the creation of new services, goods, and relationships that benefit both humans and ecosystems.
The term “regenerative design” has its roots in the 70s, with landscape architect John T. Lyle discussing it in his book Regenerative Design for Sustainable Development (1974). By the 1990s, the concept gained importance through the work of Bill Reed and Raymond J. Cole, who explored its meaning and applications. In the publication Sustainability: Restorative to Regenerative (Brown et al, 2018) the key definitions based of previous authors are stated as follows:

- **Sustainability:** Limiting impact by balancing what we take and give back.
- **Restorative:** Returning social and ecological systems to a healthy state.
- **Regenerative:** Enabling systems to maintain health and evolve over time.

Summarizing, the figure 1 shows how regenerative design goes a step further than sustainability, not just repairing the damage caused by the building process, but aiming to create a positive impact by giving more to the environment than it takes. It is the evolution of the concept where designs start with limiting "Degeneration" to "Doing No Harm" and finally to "Regeneration". This approach takes natural systems as models, adopting their resilience. Hecht et al. (2024) propose transitioning buildings from passive resource consumers to active participants in ecosystems. This involves maximizing the use of available energy, minimizing losses, and influencing positively in the health of surroundings ecosystems. Built environments that supports life.

2.2.1 Principles of regenerative design

John Tillman Lyle in 1994 describe regenerative design in a technical way, where principles are rooted in ecology, thermodynamics and landscape systems. To create designs that renew their own sources of energy and materials. Fig. 6
Despite the ecological mechanics approach, Lyle barely speaks about social or cultural dimension, which is also part of an holistic approach to design, with the risk to reduce regeneration almost to a engineering problem. However, without this framework, later works could drift into abstraction. Lyle grounds regenerative design in material reality.

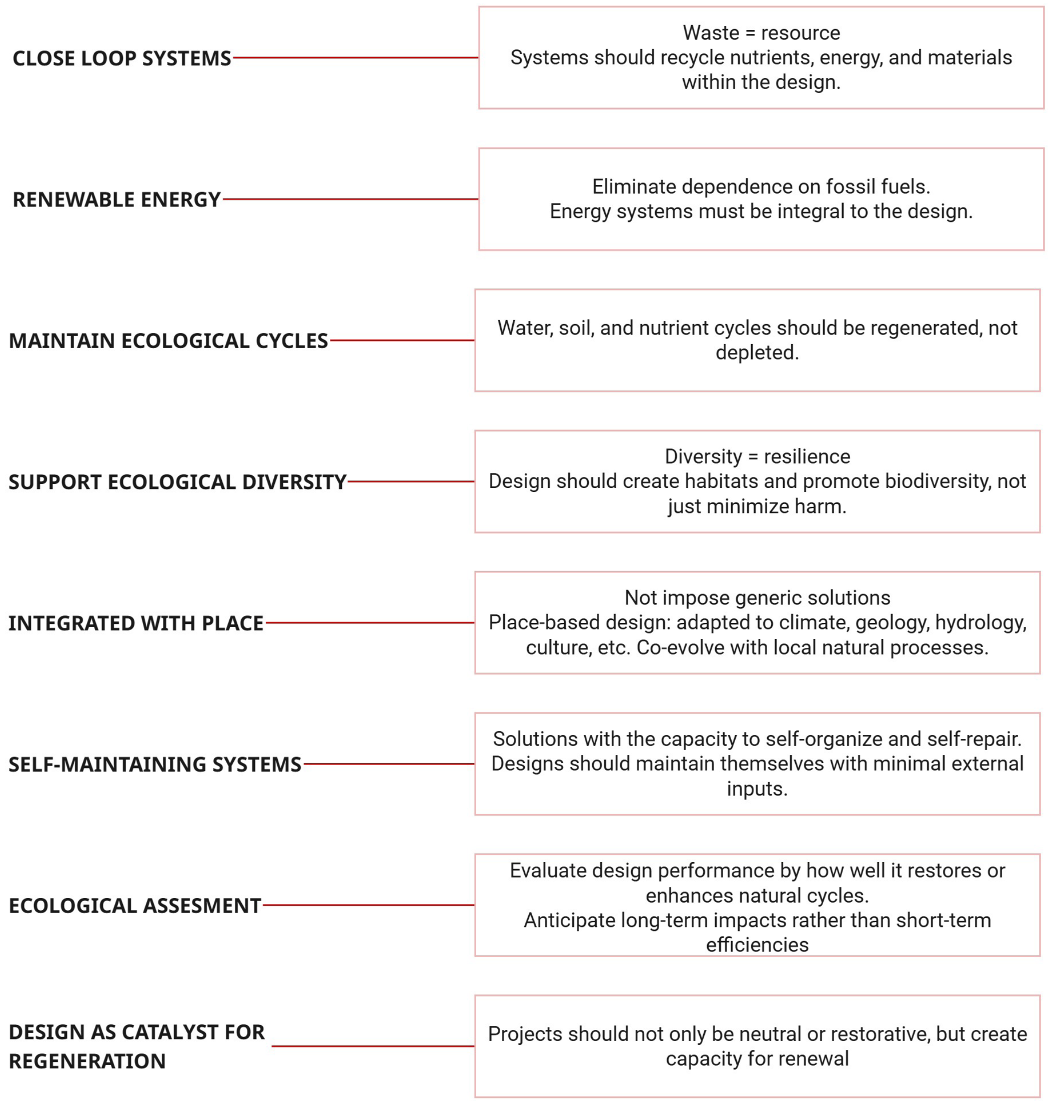


Figure 6. Description of regenerative principles extracted from Lyle (1994)

For Bill Reed in his 2007 article “Shifting from ‘sustainability’ to regeneration” the concept of regeneration is developed as a shift in worldview and practice, that can be paraphrased into guiding principles: Fig. 7
Reed focus on mindset and paradigm shift, however lacks actionable points. Moreover, to talk about stakeholders, participation needs engagement, and consider this as one of the

core principles can difficult the practice of regenerative design when face problems like social inequities,

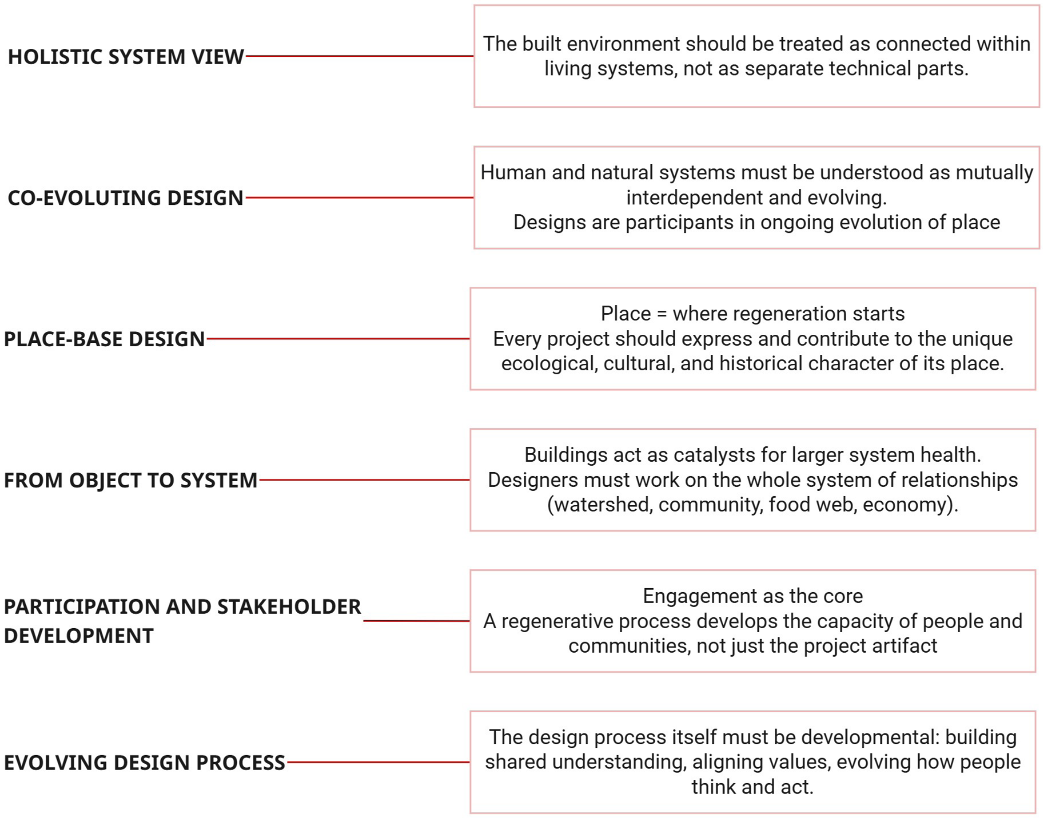


Figure 7. Description of regenerative principles extracted from Reed (2007)

In the book Regenerative Development and Design: A Framework for Evolving Sustainability (2016) by Pamela Mang and Ben Haggard, the authors describe principles of regenerative design (Fig. 8) more like a process, an operational guidance for practice and stakeholder engagement.

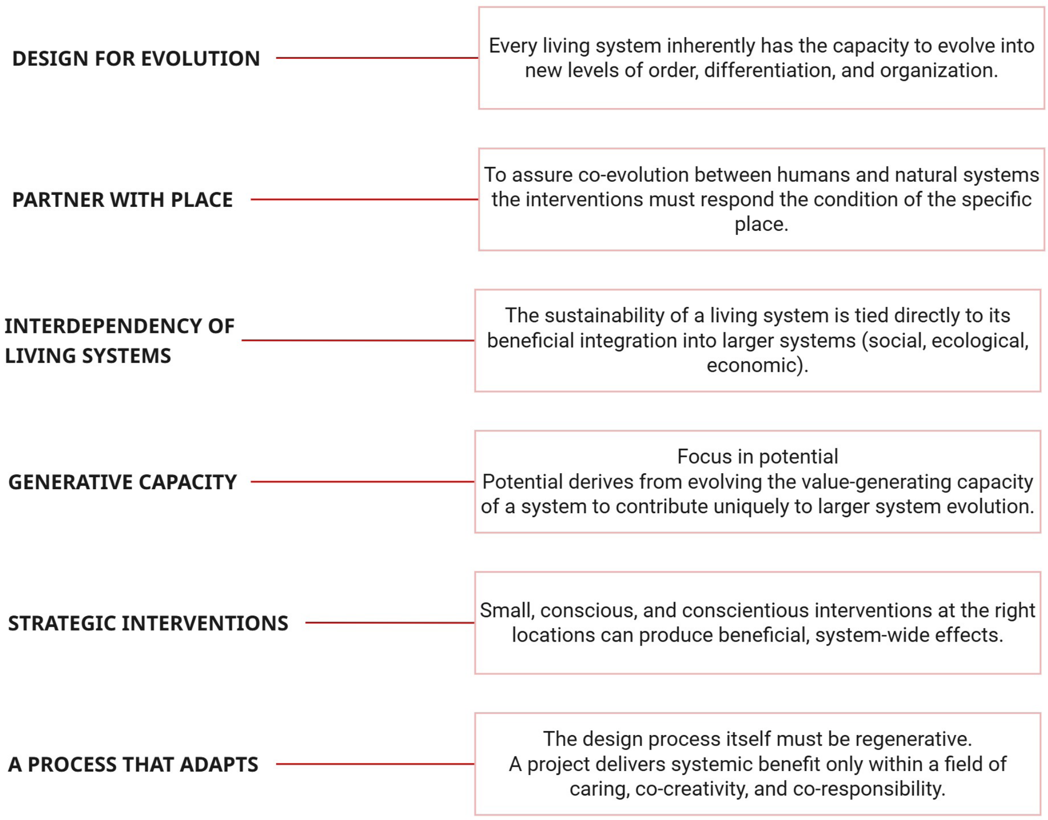


Figure 8. Description of regenerative principles extracted from Mang and Haggard (2016)

In summary, principles like “small interventions” can difficult the application when there is not a clear evaluation parameters about what is really beneficial to a place. Moreover, the idea of co-evolution is always possible and beneficial should be also analyses applied to the specif site conditions. Despite, Man and Haggard gives practitioners a framework to structure regenerative projects.

This thesis project aims to apply those principles of regenerative design to transform an existing sustainable project, going beyond sustainability. After this literature revision, a concept of regenerative design can be developed based on the common points from the different authors and practitioners.
Regenerative practices are tied to social participation and engagement, the inclusion of all kind of stakeholders is necessary for a successful regenerative design. And although the social sphere is out of focus for the present thesis, a sustainable project is taken as a starting point, where a social and participatory approach has been explored. Therefore, while the absolute importance of social participation is recognized, the priority will be the biophysical principles and approaches of regenerative design.

> Regenerative design is a integrative approach where the built environment contributes to restore and enhance ecological systems.
>
> It aims to align human development with natural processes, so it can encourages self-sustaining systems that renew resources, support biodiversity and increase ecosystem resilience.
>
> Moreover, it requires an understanding of natural systems, interdisciplinary collaboration among stakeholders, and innovative thinking to create solutions designed for mutual benefit for society and the environment.

2.3. Digital tools for regenerative design

An architect’s job is to shape space for human needs, which means to intervene in the environment. This demands a strong environmental consciousness and an ability to handle high complexity which is the core of regenerative design and a response to the climate crisis. Tackling this requires multidisciplinary knowledge, from energy and materials to biodiversity and thermal performance. Digital tools are now essential for this; they let architects manage, simulate, and integrate complex data into our designs. This allows for site-specific solutions and a clear view of a design’s consequences. The main challenge is translating data from various fields into a design. This is where specific frameworks become crucial, helping architects bridge the gap between raw information and a built solution.

2.3.1. Data - driven design

Data-driven design is defined as a design approach in which different kind of data such as environmental, material, ecological, and human well-being are part of the generative process rather than post-design constraints.
For Jabi (2013) data-driven design means parametric modeling and algorithm thinking were mathematical, geometrical, environmental and human parameters become part of computational models that allows designers to interact with them. Thus, data enables

iterative exploration of form and performance through logic and simulations. Naboni and Havinga (2019) recognized its value applied to regenerative processes. For this, data become a flexible tool to integrate environmental, ecological, material and human well-being data directly to regenerative process. It that way, it can helps to create a systemic and evaluative framework for assess benefits in terms of energy, carbon, ecology, and occupant health
Kun et all. (2020) expands this definition treating data as a exploratory tool, a form of design inquiry, where through exploratory data analysis (supported by methods like sensor data, open data, social data) it can help to test hypothesis, with real-time feedback, and give insights in design problems.

Across these perspectives, real-time performance feedback plays an important role: for Jabi (2013) the simulation helps to validate and refine parametric variations; for Naboni and Havinga (2019) it acts as a design partner, continuously informing regenerative decisions; and for Kun et al. (2020) it becomes part of the iterative exploration loop, where insights from data reshape the design problem itself. However, the difficulty to adopt data in the design process is highly debated, with some insights about the process of application:

1. From data to interpretation
In a systemic design approach, data is not taken at face value but interpreted in relation to design intent and context. Kun et al. (2020) argue that data must be explored and interpreted before to be translated into design. That means not all data is useful and it needs to be contextualized through problem framing. For example, energy consumption data in a housing project is not just a number; it becomes meaningful when interpreted as a pattern of occupant behavior that affects comfort and efficiency. Architects has the role to interpretert and filter the relevance, data is just useful if it is aligned with systemics goals.

2. From interpretation into parameters
Parameters are the bridge between environmental data and computational models. Once interpreted, the analysis should be transformed into measurable, manipulable entities. For Jabi (2013) parameters means the controllable aspects of the system, following a design logic. For instance, interpreted ecological data (species movement patterns) can become parameters like minimum corridor width for habitat continuity. These parameters convert complex, multidimensional conditions into manageable design rules, ensuring that when the input shifts, the whole system adjusts. The power of parameters lies in the relationships between them not just values, for example linking daylight lux targets to façade porosity and interior reflectance factors. (Jabi, 2013)

3. Parameters into design variables
This step turns performance goals into tangible design choices. For instance, a daylight requirement, like achieving 300 lux in most of a room, directly shapes the windows, glass area, and shades. According to Naboni and Havinga (2019), this method grounds regenerative design in reality, linking decisions to measurable ecological and social results with live performance feedback. It also fosters systemic thinking. Variables aren't optimized for a single goal, like daylight; it can also be balanced with thermal comfort, energy use, and well-being. So, for a regenerative housing project, hydrological data on soil infiltration can be set as a target rate, which then dictates specific design elements like the depth of a bioswale or the soil thickness on a green roof.

The character of this process is not linear but repetitive. Data interpretation is developed taking into account how technically feasible are the parameters, where limitations may be exposed or new opportunities that require revisiting the original data. Hence, the systemic value lies in how feedback loops are established. (Kun et al. 2020). For example, a simulation showing overheating in summer might force re-interpretation of wind data to refine ventilation parameters. Without this iterative loop, parametric models risk becoming rigid

codifications of poorly interpreted data.
Therefore, the quality of the initial data, the sources where it is extracted and the methods to read it can be a limitation for the understanding, which become a challenge for architects to interpret it properly. Moreover, there is necessary a basic literacy in the fields where the data belongs to perform a comprehensive analysis that can be successfully translated into design decisions, understanding the interaction and its consequences.

2.3.2. Toolkit and interoperability

As stated the complexity of manage multidisciplinary data can be solve through the application of a good toolkit. For both Lyle and Reed, interoperability is essential for systemic and regenerative practice. An example workflow can starts extracting and managing complex territorial and ecological data using e.g. QGIS; translating it into parameters for generative models produced by e.g. Rhino/Grasshopper; and then, making them viable for constructible, performance-tested variables, using e.g. Revit/BIM.
The tools available in the market are constantly changing and new ones are developed every day. At the time of this research there are some of the tools (Fig. 9) that can facilitate the process of regenerative design and some of them are going to be used during the development of the project:

STEP	TOOLS	HOW IT WORKS	EXAMPLE IN PRACTICE
Data Exploration & Interpretation	QGIS, ArcGIS, Google Earth Engine, Grasshopper plugins (Elk, TT Toolbox), Mapbox	Collect, clean, visualize, and layer datasets (climate, ecology, mobility, social data).	Using QGIS to overlay rainfall intensity with soil infiltration data to locate potential bioswales in a residential block.
Parameterization & Translation	Rhino + Grasshopper, Dynamo (Revit), Processing, Houdini, MATLAB, Python scripting	Encode interpreted data into measurable, manipulable inputs.	Translating solar radiation into a shading depth parameter in Grasshopper, which drives façade geometry adaptively.
Generative Design & Co-Creation	Grasshopper plugins (Kangaroo, Galapagos, Wallacei), Autodesk Generative Design.	Explore variations of design forms through parametric or algorithmic methods.	Running Galapagos in Grasshopper to optimize housing orientation for daylight and passive heating.
Real-Time Performance Feedback	Ladybug/Honeybee, ClimateStudio, ENVI-met, IES-VE, EnergyPlus, DesignBuilder, OpenLCA	Simulate and evaluate performance during design (energy, daylight, CFD, LCA, microclimate).	Adjusting green roof thickness in Honeybee to balance stormwater retention and thermal performance.
Cross-Domain Interoperability	QGIS ↔ Rhino/ Grasshopper ↔ Revit, Speckle	Ensure workflows across scales (territorial → building → component).	Linking QGIS hydrology data → Rhino terrain modeling → Revit BIM drainage design, ensuring consistency between urban and building water systems.

Figure 9. Some tools that can help to adopt regenerative design approaches

3. DESIGN DEVELOPMENT

3.1. Environmental analysis of site

3.1.1. GENERAL CONDITIONS

DATA SOURCE: Göteborgs Stad, ClimateStudio, Weatherspark (Appx. 1)

Housing and Beyond is located in Tynnered, Västra Götaland County, west part of Gothenburg, Sweden. With a population of 27,787 (2010) on around 29.85 km². Initially a countryside area, during 1960s, it began to be built up through the governmental Million Program (Miljonprogrammet). Thus, approximately 500-600 new apartments were built alight with new roads and infrastructure, increasing the urban density in the area. (Göteborgs Stad, 2022)

Figure 10. Geographical location of the site study

TEMPERATURE

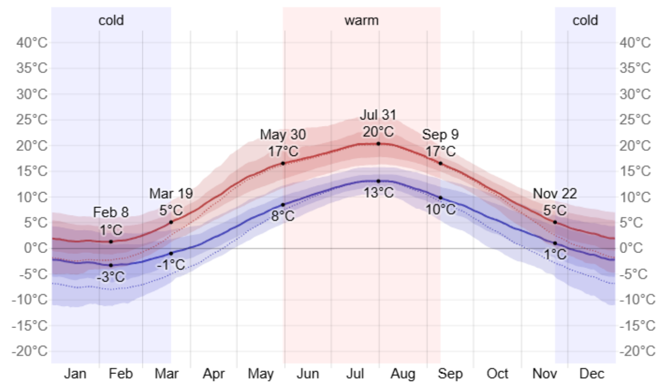


Figure 10. Average High and Low Temperature in Mölndal

WIND SPEED

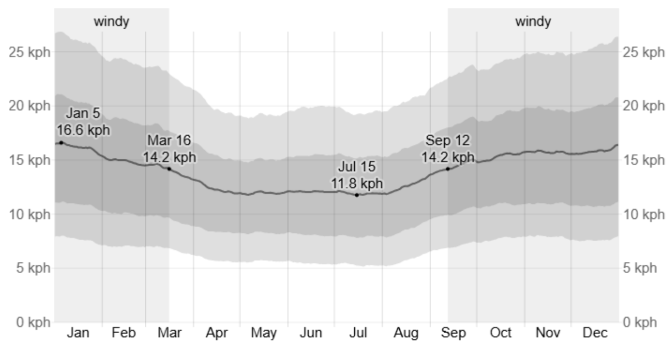


Figure 11. Average Wind Speed in Mölndal. Apx 1.1

warm season:
above 17°C
cold season:
under 5°C

driest months:
feb - may
average rainfall:
1100 mm/year

windier months:
above 3.9m/s
calmer months:
3.3 m/s

HUMIDITY

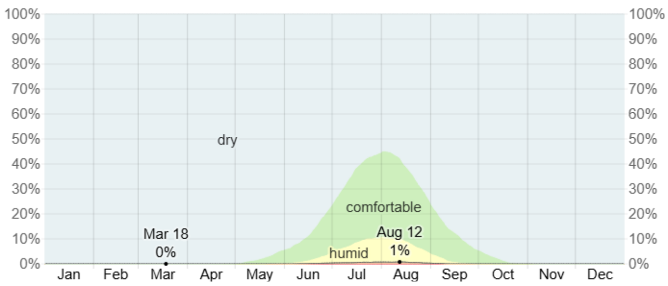


Figure 12. Humidity Comfort Levels in Mölndal

AVERAGE RAINFALL

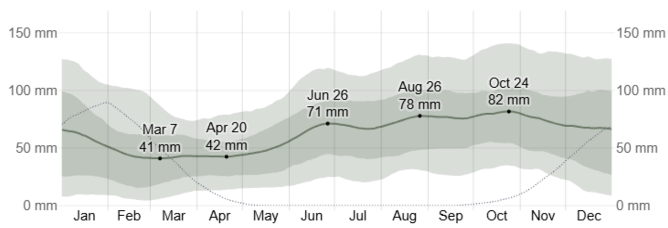


Figure 13. Average Monthly Rainfall in Mölndal

Image 1. Tynnered school south facade

3.1.2 . SPECIFIC SITE CONDITIONS

These conditions were simulated with data from the station located in Gothenburg, 57.76° North, 11.87° East (WMO 025120). The toolkit used was Revit, Ladybug through Grasshopper and Autodesk Forma. Maps and geographical data was extracted from Lantmäteriet dataset and produced using QGIS.

3.1.2.1 HISTORICAL CHANGE - LAND USE

DATA SOURCE: Lantmäteriet, OpenStreetmap

Through the years the site has been modified to respond housing and urban needs. Figure 14 and 15 show the comparison of the green areas that has been depleted. These green spaces are fragmented, with no direct connection between them, creating separated pieces, causing habitat damaged and lost of natural species. Moreover buildings and infrastructure become an obstacle for the remain fauna in the area. Ängås skola was part of this change since its construction 1969.

1960

Figure 14. Tynnered Map 1960 modified with location of Ängås skola. Source: Lantmäteriet

2021

Figure 15. Tynnered Map 2021. Source: Openstreetmap

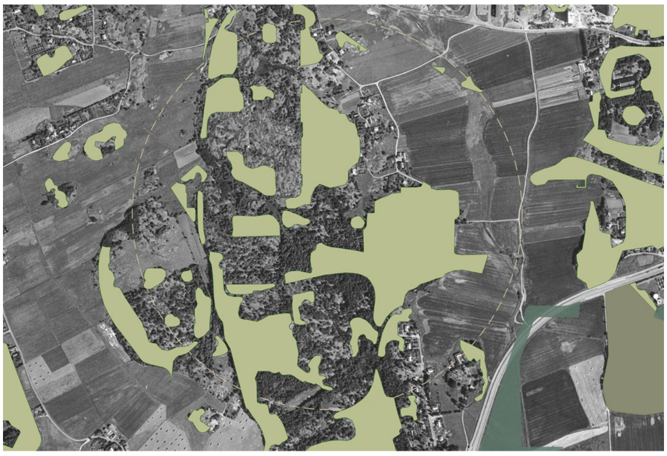


Figure 16. Layered map. Lantmäteriet 1960 historical map + Forest patches 2020 Openstreet map. Sc. 1:5000

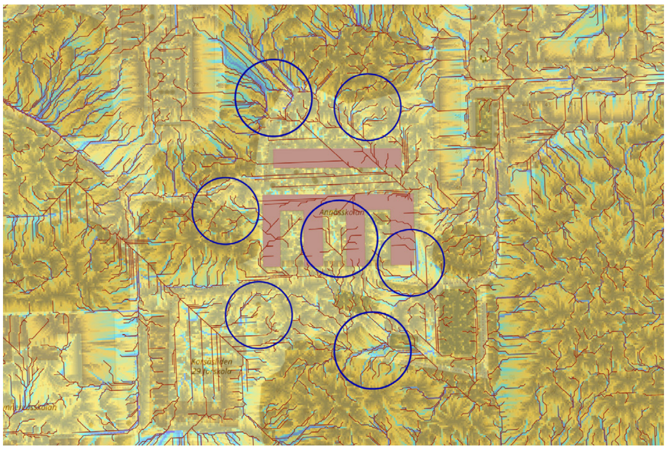


Figure 17. Water shed identification in the area. Sc 1:300

To understand the impact the Fig. 16 it shows these changes on the area, where the current forest remnants are superimposed on the 1960 historical footage to denote the lost forest areas.

3.1.2.2. WATER FLOWS

DATA SOURCE: Lantmäteriet, OpenStreetmap
The area's topography has been modified for construction, altering the soil composition and potentially affecting its absorption capacity.
As a result, new water accumulation zones have formed. To assess this impact, the direction of runoff is analyzed in relation to the current topography. As shown in the Fig. 17, combining these elements helps identify areas prone to water accumulation. Elk in Grasshopper is used to determine the direction of runoff. (Appx. 2).

Finally figure 18, show the remains pieces of forest numbered to evaluate the quality and potential connection, as well possible radios of intervention.

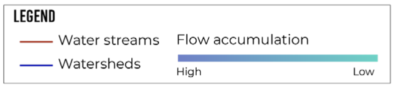


Figure 18. Radius of analysis - Forest nodes in 1Km radio

Forest area

3.1.2.3. GEOPHYSICAL CHARACTERISTICS

DATA SOURCE: Sveriges geologiska undersökning SGU

bedrock type (Appx. 3):
granitoid and metamorphic rocks

Characteristics:
- Low carbon storage potential
- Low fertility for agricultural uses of land
- High bearing capacity and stability
- Good permeability
- Low organic matter and low water retention

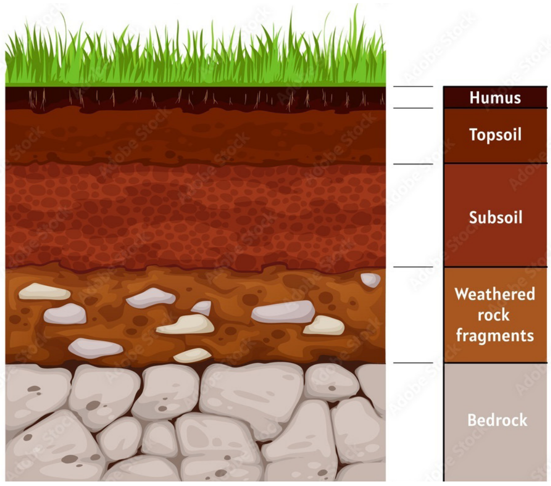


Figure 19. Soil layers Source: Adobe stock

Water management in the area is influenced by the permeability of the soil. In the figure 20 the map show the area with medium and high permeability. However, in the area the soil permeability is affected by a layer of asphalt in a radio of 100m around the buildings of intervention.

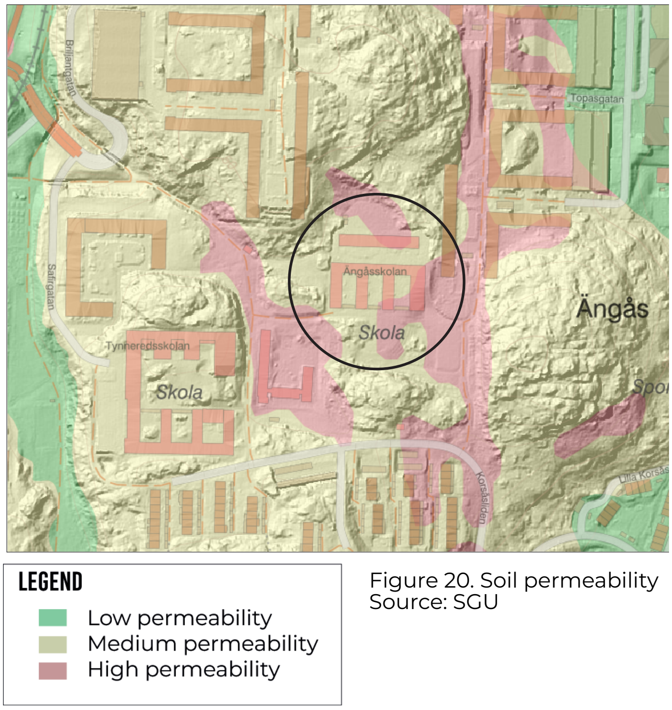


Figure 20. Soil permeability Source: SGU

Characteristics:

High-permeability soil
- Reduce runoff
- Support ground water recharge
- Not good for wetlands
- Suitable for rainwater gardens or bioswales
- Low fertility

Medium-permeability soil
- Better fertility
- Retain enough water to create wetlands
- Good retention of nutrients
- Easy to manage for soil movements

3.1.2.4. BIODIVERSITY

DATA SOURCE: Global Biodiversity Information Facility (GBIF), Artportalen, Naturvardsverket Portalen.

The analysis of natural species in the area cover records from 1935 onwards. However, data are scarce for the time, with an increase in 1961, this attributed to public participation. That means that data is primarily obtained for observation and report, and then from monitoring. Artportalen was used to identify the most common animal species over the last 50 years in the study area. The data was used to compile lists of common species, categorized into:

• Plants (shrubs, herbs, flowers) and Fungi. (Appx. 4)

Juniper
Junniperus comunis
Photo: Jose Angel Campos Sandoval

Clover
Trifolium
Photo: klostra.se

Dandelion
Taraxacum
Photo: J. Carmichael

Heather
Calluna vulgaris
Photo: Willow

Svalört
Ficaria verna
Photo: Oleg Kovtun

Lingonberry
Vaccinium vitis-idaea
Photo: vegtech.no

- Animals: Birds, insects (butterflies, bees, pollinators, beetles), and mammals. (Appx. 4)

Koltrast
Turdus merula
Photo: Jonn Leffmann

Citronfjäril
Gonepteryx rhamni
Photo: Didier

Honunsgbi
Apis mellifera
Photo: Andreas Trepte

Fälthare
Lepus europaeus
Photo: Paul Cools

Igelkott
Erinaceus europeus
Photo: Michael Gäbler

Rådjur
Capreolus capreolus
Photo: vegtech.no

- Trees (Appx. 4)

In a 1000-meter radius of analysis around the project site, the area is primarily open land with vegetation (≥10% coverage) and forested zones (trees >5m tall with >10% crown cover). The northern section features Trivial broadleaf forest, while the south and east contain Trivial deciduous forests (Fig. 21). Some of the species are:

Alder
Alnus glutinosa
Photo: AnRo0002

Birch
Betula pendula
Photo: Willow

Rowan
Sorbus Aucuparia
Photo: van den berk

Scots pine
Pinus sylvestris
Photo: Mattias

Willox
Salix
Photo: Hladac

Pedunculate oak
Quercus robus
Photo: van den berk

This data is referential, historical data limitations must be considered when interpreting long-term species trends.

3.1.3. PROJECT CONDITIONS

Housing and Beyond is a mixed-used complex, with communal activities for both, building users and residents of Tynnered area, reinforcing the community engagement.

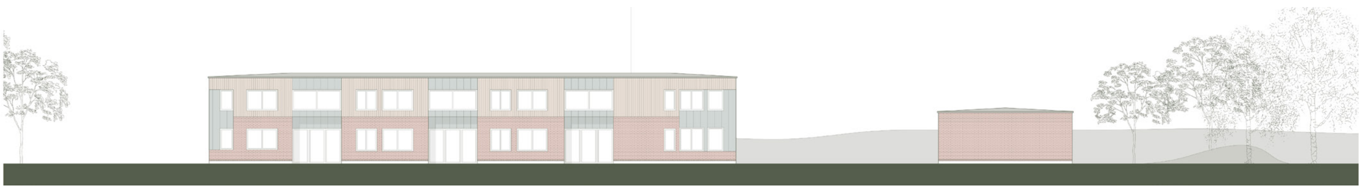


Figure 22. Housing and Beyond east facade

3.1.3.1. PEOPLE OCCUPANCY

DATA SOURCE: Boverkets föreskrifter och allmänna råd (2011:6)
The maximum occupancy (Fig. 23) is calculated according to the factors in the table 5:333 provide for the Swedish regulation authority.

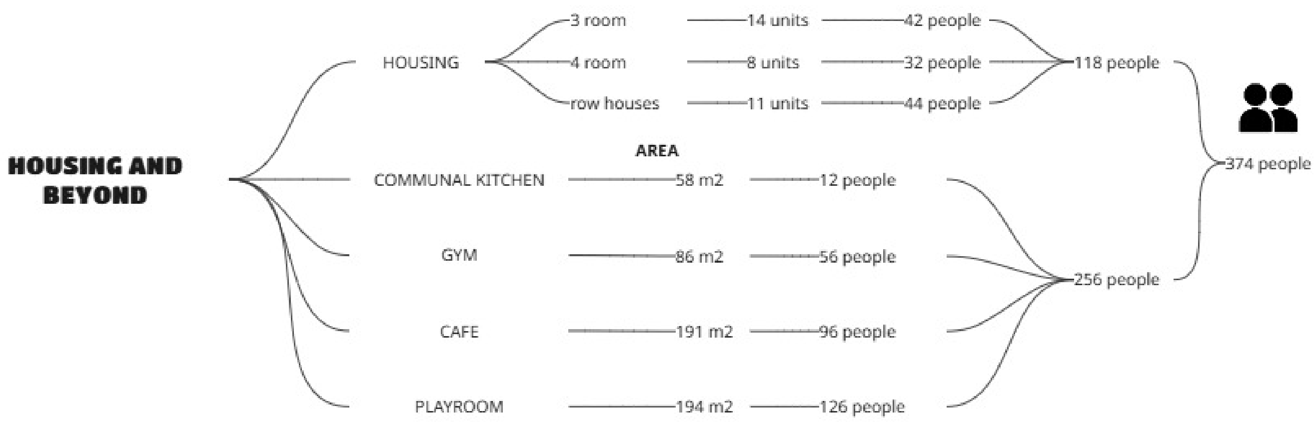


Figure 23. Architectural program Housing and Beyond with people occupancy

Image 2. Housing and beyond interior courtyards

3.1.3.2. ANNUAL OPERATIONAL ENERGY DEMAND

DATA SOURCE: Existing performance analysis in CAALA.

Energy reference area (AN): 6310 m²

Primary energy demand:
51 kWh/m²(AN)*year

End energy demand:
66 kWh/m²(AN)*year

• Electrical heat pump, water - water: 22 kWh/m²(AN)*year
• Hot water: 5 kWh/m²(AN)*year
• Auxiliar electricity: 2 kWh/m²(AN)*year
- User electricity: 37 kWh/m²(AN)*year

Useful energy demand:
79 kWh/m²(AN)*year

• Hot water: 9 kWh/m²(AN)*year
• Space heating: 70 kWh/m²(AN)*year

3.1.3.3. SOLAR AND RADIATION CONDITIONS

DATA SOURCE: Revit Insight

The temperature at the site varies within a range of approximately 5 to -15°C, with the coldest temperatures recorded from December to March. The warmest months are June, July, and August, with temperatures around 25°C.

Likely, the highest energy consumption for buildings in this area will be related to heating. Therefore, strategies to maintain comfort and reduce energy use may be key to the design.

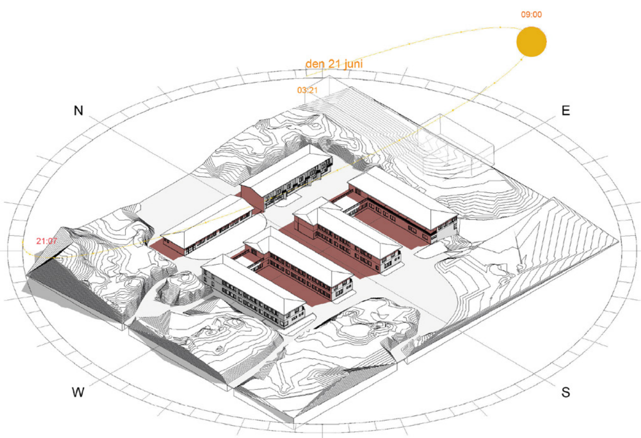


Figure 24. Solar shadow analysis in Revit

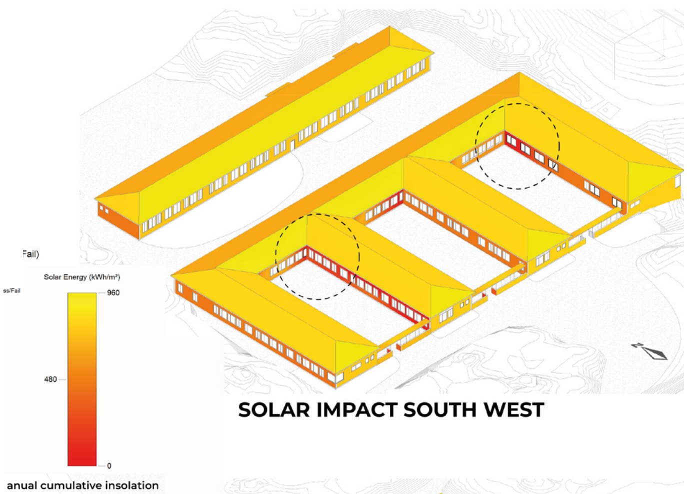
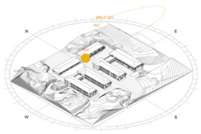
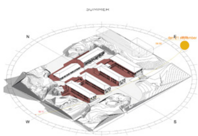


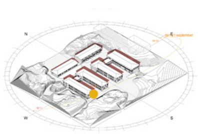
Figure 25. Radiance analysis in Revit Insight



21 Jun - 3pm



21 sept - 9am



21 sept - 3pm

	21 JUNE	21 DECEMBER	21 MARCH	21 SEPTEMBER
Altitud	50.26°	6.73°	30.34°	32.62°
Sun hours x day	18	6	12	12

Figure 26. Solar altitude and hours of sun available for the site

3.1.3.4. WATER CONSUMPTION

DATA SOURCE: Dimensioneringstal för vatten (VAV P83, Svenskt Vatten)

This calculus (Appx. 5) is a framework of common methods using tumble rules based on Swedish recommendations, to have an idea of demand in this early stage of design:

Total water usage (L/year)
17 m³/day

6 249 475 L/y
520 790 L/month
17 122 L/day

BLACKWATER

Toilet
Kitchen
Dishwasher

10 m³/day

3 676 809 L/y
302 204 L/month
10 073 l/day

GREYWATER

Faucets
Laundry
Showers

7 m³/day

2 572 666 L/y
211 452 L/month
7 048 L/day

This is an estimate. Exact consumption depends heavily on real usage patterns, the efficiency of fixtures (e.g., low-flush toilets, water-saving taps), and patterns of occupancy or behavior, which should be calculated in later stages of the design.

3.2. Problem definition

After a detailed examination of the area, an analysis of potentialities and problems is done. The objective is to identify the aspects in which the project can be improved in relation to regenerative design principles. Therefore, the opportunities are the result of the site´s current conditions and resources of the project, which can be integrated into the proposal of a regenerative project.

SITE ANALYSIS

PROBLEMS

- Energy demand supply from local grid
- Water consumption supply from local grid
- Waste generation and disposal
- Noise pollution from human activities
- Forest fragmentation and natural habitat disruption
- Buildings as obstacles for animal´s natural routes
- Alteration of soil quality
- Exterior areas without meaningful connection
- Alteration of natural drainage patterns and hydrology.
- Limited solar availability during winter
- Long pedestrian paths communicating from north to south, without access to the buildings
- Water accumulation in some areas
- Quality of bedrock makes difficult perforation and big modifications in the area
- A big percentage of the outside area is covered by asphalt
- The main uses of electricity is space heating, and user consumption
- Temperatures under 5 degrees during winter
- Facades in the north and the interior of the building are not receiving direct solar impact
- To have an electrical heat pump water to water means dependency to electricity for heating

POTENTIALS

Low energy demand compared to standards
Extensive open areas
Existing pedestrian routes
Closeness to public transport infrastructure
Unused roof area
Production of gray and black water
First floor as new construction
Terraces in the first floor
Asphalt as main material in the exteriors
Defined areas for kids and adults
Sports area
Spaces open for the public (Cafe and playroom)
Rain conditions suitable for rainwater harvesting
Comfortable wind speed
More than 10 hours of sunlight from March to September
Summer with temperatures under 25°C
Waste production
Design solved considering natural ventilation
Direct solar impact in south facades
Height of buildings don´t project long shadows
Hot water in gray water processes
Electric heat pump water to water has a good efficiency with a COP of 5 to 8, depending on system source
Electric heat pump water to water with very low emissions if there is a clean source of energy

OPPORTUNITIES

- Roof harvesting water for non-potable uses
- Gray water reuse loop (to non-potable uses and where it is allowed)
- On-site infiltration / sponge-city elements, that can also collect rainwater
- Pedestrian pathways with existing asphalt floor material
- Green spaces without vehicular disruption
- Big open spaces to propose green areas that connect the pieces of forest
- Rooftop availability for PV systems + small storage using the benefits of summer and autumn sun
- Waste heat recovery connected to the heating system, using heat from gray water
- Green refuges for wildlife in open space to avoid built obstacles
- Connects the building grounds to larger green areas
- Intensive planting at terraces and public spaces, interacting with the existing uses
- Habitat - friendly ground treatment: reduce the asphalt and increase natural areas
- On site organic waste processing from black water and food waste for extract bio gas or compost
- Open areas to treat water on site.
- Runoff accumulation are suitable to propose blue bodies that also can connect to the natural landscape
- Existing water in the building can be cleaned and reuse to create energy, through an small hydro system.
- Wildlife in the area can become part of the project, designing coexisting areas, withing the existing open spaces.

Figure 27. Simplify SWOT analysis. Diagram of problems, potentials and opportunities

3.3. Strategy formulation

As next step a systemic proposal can be defined with the detailed analysis of the opportunities in the existing project. However, to manage the information in next design stages three categories of action are identified, with a defined purpose which help in the research for solutions around that specific topic. This does not mean that each category operates independently; on the contrary, as will become evident throughout the study, the proposal solutions may be interdependent, or influence in more than one category. Fig. 28

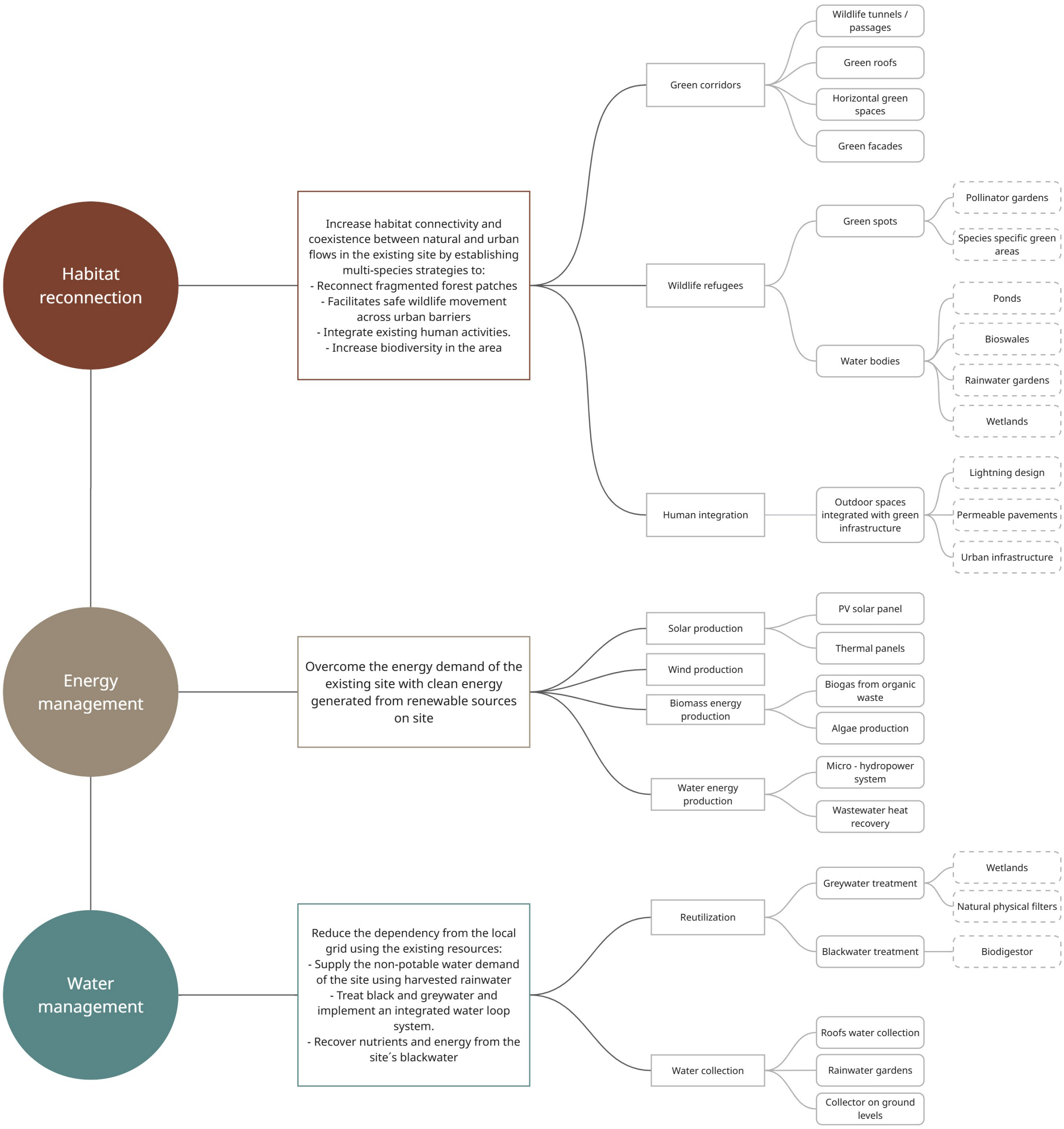


Figure 28. Diagram definition of objectives and brainstorming of solutions

In this project the elements that usually are consider as waste like graywater and blackwater from the buildings operation and other processes will be treated as resources, emphasizing the regenerative principle where “waste for one is an asset for other”.

Next, a revision of literature and case references will be done to understand what are the current methods that can fulfill the objectives, its basic operation, adjusted for the specific conditions of the site and aligned with the regenerative theories.

3.3.1. Habitat Reconnection

This field will prioritize the natural environment. To reconnect the habitat means to improves the condition of nearby forest fragments while creating new ecological connections, giving alternatives for the constructed obstacles (human infrastructure) that boost the biodiversity, conserving what already exists, but above all, habitat is refereed to human activities as part of the natural landscape, therefore the co-existence and relationship between aspect will be a decisive aspect of design. As Yeang (2006) notes, no living organism can survive without multiple links to others; therefore, by strengthening current links and establishing new ones, local biodiversity has the opportunity to thrive and expand. The key to avoiding fragmentation and to design towards integration of all living systems.

CASE REFERENCE
Sankt Kjelds Square

Designer: Bjørn Ginman
Location: Copenhagen, Denmark
Source: https://www.sla.dk/cases/sankt-kjelds-square-and-bryggervangen/

A urban regeneration project transforms a roundabout into Sankt Kjelds Square, an urban forest that prioritize water management and natural landscapes.

Analysis:

- Water management: Rainwater gardens, basins and permeable surfaces captures and retains rainwater
- Biodiversity Enhancement: 586 green species are added, increasing biodiversity in a dense urban area.
- Maintenance Intensity: Green areas and water systems require specialized maintenance to ensure plants thrive, basins don't clog, and the system functions as intended long-term.
- Conflicts of Use: While designed for multi-functionality, there can be tensions between different user needs. For example, children playing near sensitive natural areas or dog walkers in areas meant for water purification.


Image 3. Raingarden view. Photo: Mikkel-Eye_10

3.3.1.1. GREEN CORRIDORS

This is a continuous linear space that interconnects open areas through green infrastructure that preserves ecosystem values and functions, supplies clean water, purifies the air, and delivers additional ecological benefits. (Yeang, 2006, Russell, 2024). The corridor's defining feature is continuity, and it must prioritizes the movement of animal and plant species. This continuity can run horizontally through hedgerows, lines of closely spaced shrubs or trees forming a barrier (Pollard et al, 1974) or vertically via green walls that support climbing species. It can also rise above ground level by means of vegetated platforms or "land-bridges," interconnected green roofs, or the canopy layer of trees.

Green corridors can include terrestrial and aquatic habitats, depending on the characteristics of the site, with spaces that can serve as wildlife refuges, that are defined as spaces of terrain or water proposed to preserve natural species and their habitats, as part of a broader network. (McCauley J., 2014). . Another important factor is the native and introduced species. Endemic animals and plants play a crucial role in designing and operating green corridors.

The availability of shelter and food can decisively influence how they inhabit the space.
Given the complexity of an ecosystem where hundreds of species coexist and interrelate in various ways, to propose a green corridor that can cover the need of species it is recommended to select indicator species: organisms whose habitat, movement, and survival needs represent a broader ecological profile. As Yeang (2006) highlight the challenge is not to replicate biodiversity fully, but to create conditions in which multiple ecological processes and organism types can function concurrently.

Thus, it is useful to use the surrogate species approach defined as a technique to choose a small number of species to act as representative of others (Tälle et al, 2023).
Surrogate species means a species (or group of species) whose protection serves as a proxy for the protection of a broader set of co-occurring species or ecological processes, as a shortcut to simplify the immense complexity of biodiversity. Some examples of surrogate species:

- **Indicator species:** Species whose presence/absence reflects habitat quality
- **Umbrella species:** Protecting them also protects many others
- **Keystone species:** Species that have an important impact on others in such a way that the loss of them can mean the loss of the other.

However, some researchers claim that this grouping is rarely useful in conservation there are rarely strong correlations between the species richness of indicator species and other species, and conservation actions aimed at surrogate species will not uniformly benefit other species, and there are advantages and disadvantages in each group. (Tälle et al, 2023).
Since the sustainable project to be intervened has a residential use, the coexistence of animal, plant, and human species is a decisive design feature. Therefore the selection of species should based on the capacity to adapt, survive, and propagate in a human-altered environment. No single solution can meet every requirement of every species, so corridors in the project will focus on the target species and their specific needs.
Although surrogate species may not respond completely the needs for biodiversity restoration this will be target group for the present project, and to avoid bias, species with varied conditions are chosen.

3.3.1.2. HUMAN INTEGRATION

Housing and Beyond is a project whose main objective is to foster community connectivity, a housing project designed to host around 120 people in different residential and communal spaces. Those are defined as the users and are part of the system, exemplifying the co-existence within human and animal life in the Tynnered area.
When studying the co-existence of humans with wildlife, the disruption of the living of modes in both groups are the main challenge. Regenerative design has similar principles than biophilic theory, that argues for co-habitation and mutualism. Therefore, biophilic design is about creating good habitat for people as a biological organism in the built environment (Kellert et. all, 2008).
Design should go beyond human well-being but consider them as part of all species and for this, instead of segregate human and nature, it can be solved through strategic concentration of impact: work with tolerances of disturbance, considering habitats stressors. The practical implications extend to lighting, circulation, infrastructure, and sensory or temporal factors.

Some studies has proved that human presence is natural environments are taken as a form of predator risk for animal species. (Larson et al, 2016). Strategies to diminish the impact includes: reducing overall path density, routing high-use paths along habitat edges rather than through cores, and using boardwalks or bridges where crossings is essential (Forman, 2014).
The materiality over surface is another aspect to consider, not just to support hydrological functions through permeable surfaces but to reduce noise with materials like bound gravel or

resin-bonded aggregate. Temporal zoning, such as seasonal closures during breeding or time-of-day restrictions at dawn/dusk, allows wildlife activity to proceed with minimal disturbance. Companion policies for pets, such as designated off-leash areas outside ecological corridors and strict leashing in sensitive zones, are also important (Miller et al, 2001).

3.3.1.3. LANDSCAPE CONNECTIVITY

However, when thinking about ecological connectivity is wrong to assume that more green spaces are always better, instead, landscape structure like forest patches and its distribution influence in the capacity of species to move, the permeability and overall connectivity, which are crucial to sustain biodiversity. There are several method to asses the quality of green spaces, that can help architects and designers to propose conscious solutions that can reach ecological objectives. Some of the most common are:

- Graph-Based / Structural Connectivity: This approach models the landscape as a graph (or network) where habitat patches are nodes, and potential pathways between them are links (edges). It's powerful for prioritizing patches and links across large landscapes. The tools can be CONEFOR sensinode and Graphab. (Saura & Pascual-Hortal, 2007).

- Circuit Theory-Based: This approach models the landscape as an electrical circuit. Movement is analogous to current flow: it look for multiple paths simultaneously, with more "current" flowing through paths of lower resistance. It identify pinch points, barriers, and diffuse movement corridors. Most used tools are Circuitscape and Linkage Mapper Toolkit. (McRae, et al, 2008).

- Least-Cost Path (LCP) and Corridor Analysis: This is a simpler, pairwise approach. It finds the single path between two points that accumulates the least total cost. It's good for point-to-point analysis but can miss broader patterns. This is built into all GIS softwares. (Adriaensen, et al, 2003).

When designing for spatial connectivity, the graph method analyzes green areas as networks where patches = nodes and corridors = edges, showing which areas are central or isolated and how strong the network remains if some are lost (Pierik et al., 2016). It is scalable and useful in early design stages, though it depends on designer assumptions, expert guidance, and detailed GIS data that may be unavailable (Pierik et al., 2016).

Its main value in small projects lies in prioritizing which patches or hedges to preserve and where connections bring the "most gain." Expert input can be managed through local panels of ecologists, planners, or communities.

To address uncertainty, Pierik et al. (2016) propose a fuzzy logic approach combining structural (fragmentation) and functional (permeability) data, recognizing landscapes as "partially good" or "partially bad." This makes results more realistic and helps architects test whether proposed layouts support ecological flows even with limited data.

3.3.2. Energy management

The main focus in this field will be on-site renewable energy generation. It refers to the power used to provide services and maintain comfort. Energy in buildings consume around 30% of global final energy and over a half of electricity demand. The principal uses of energy include heating, cooling, ventilation, which accounts roughly 40 % of a typical building's energy budget, while lightning, and appliances in the rest of the energy budget in buildings. The demand can have variations depending uses of the building, occupancy, and seasons. (Delmastro & Chen, 2023)

Regenerative principles states that obtaining resources should be part of the same system, therefore, the building project should be responsible to create its own resources, not only aiming for reduction in energy consumption but exploring the possibilities to generate it with the existing conditions on site. Moreover, the objective is to close material and thermal loops, maximizing local resource productivity and increasing resilience, while avoiding waste embodied energy.
Empirical, site-specific measurement (irradiance, wind at mounting height, wastewater flow/temperature, waste composition) and system-level Life Cycle Analysis are prerequisites for responsible decisions in the field.
Within the different sources of energy generation, the Gothenburg's climate and urban context, and project conditions will define the characteristics of the system, however some parameters for prioritize the research on technologies are:
1. Good performance at northern latitudes
2. Integrate with existing systems or building clusters, and/or
3. Demonstrably close local loops: waste → energy → nutrients/heat

CASE REFERENCE
Västra Hamnen Bo01

Designer: City of Malmö
Location: Malmö, Sweden
Source: Austin, G. (2013). Case study and sustainability assessment of Bo01, Malmö, Sweden. Journal of Green Building

It is urban redevelopment project, transforming a former industrial shipyard and harbour into a sustainable residential and commercial district.

Analysis:

- Energy dependency: It was designed to be powered entirely by renewable energy produced within the Malmö city region.
- Energy sources: Geothermal Heating/Cooling, solar power, wind power, and heat pumps.
- Rainwater management: It is treated as a resource. It is directed through a network of open swales, ponds, and canals, without overloading the city's conventional sewer system.
- Grid reliance: Solar and wind are intermittent, meaning the district both draws from and feeds into the grid.
- Winter Performance: In the cold Swedish winters, the open water features freeze, which affect their function and also pose a safety risk if not properly managed.

Image 4. Solar PV in first BO01 east part Photo: Mälmo stad

3.3.2.1. SOLAR ENERGY

Solar Photovoltaics (PV)

PV are devices that convert solar energy into electricity through photovoltaics cells. The system of PV includes the of modules, inverters, batteries and all installation and control components for modules, inverters and batteries. (IEA PVPS, 2020).
In Sweden, this is the most common and adopted technology to generate clean energy, even thought the solar conditions of the area PV will yield lower than in southern Europe but still significant when sized and oriented realistically. It is adopted widely as on-building electricity source. Although the winter conditions diminish the productivity of PV during winter, there are some benefits in efficiency from the cold temperature. (IEA PVPS, 2020).
Latitude and local shading will reduce annual specif yield, thus specific measurements must be performed before design the system, however, some reports demonstrate that rooftop

PV can cover a significant portion of household electricity demand while reducing carbon emissions. (IRENA, 2020). In a rule of thumb, southern Sweden receives around 900–1000 kWh/ m^2 of solar irradiation manually, meaning a well-placed 1 kW PV array can generate roughly 800–1000 kWh/year.

Solar thermal panels
Thermal panels capture solar energy and convert them into heat, using sunlight to heat a fluid, which is then used to provide hot water for domestic uses or heating systems. Solar thermal can deliver high specific heat per m^2 during sunny months and can be integrated into district heating networks to reduce fossil peak. (Nguyen et al, 2024). In southern Sweden's climate, photovoltaic (PV) panels outperform solar thermal systems due to their ability to generate electricity year-round, even in diffuse sunlight, while thermal systems suffer from heat loss in cold weather and during winter irradiance there is need for large storage or District Heating integration, and limited current market in Sweden compared to central Europe.

After analysing local resources and market availability, rooftop photovoltaic panels emerge as the most viable option for Gothenburg's climate: solar irradiation is sufficient, PV technology is mature and cost-competitive in Sweden, and the system's effectiveness compares favorably with renewable alternatives.

3.3.2.2. WIND ENERGY
It is a renewable source that uses wind turbines to convert the kinetic energy of moving air into mechanical energy and then to electricity through a generator. The advantages are relate to the environmental impact, where wind is a natural and inexhaustible force. It is also a "carbon-free" energy source, as it does not burn fuel and produces no harmful emissions during operation. However, wind energy generation a freestanding micro turbine generally needs at least 4 000 m^2 for safe setbacks and still achieves capacity factors below 10 % in most urban or suburban contexts, making it a poor fit for dense housing projects. (U.S. Department of Energy's Wind Energy Technologies Office, 2022). Moreover, eecent systematic reviews of urban wind and rooftop turbine performance highlight turbulence, noise, vibration, and low mean wind speed as persistent problems. (Tsionas et al, 2025)

3.3.2.3. BIOMASS ENERGY PRODUCTION

Biogas from organic waste
This is a system that facilitates the anaerobic digestion of organic materials, converting them into biogas and digestate. This process not only generates renewable energy but also reduces waste and provides a nutrient-rich fertilizer. Various types of biodigesters are suitable for residential projects, each with unique designs and operational characteristics. (Rajendran et al, 2012).
In Sweden, the average household water consumption is 140–170 liters per person per day (L/p/d), with blackwater (toilet and kitchen wastewater) accounting for 25–30% (35–50 L/p/d) of total usage, according to the Swedish Environmental Protection Agency (2020) and Vatten & Avfall (2021).
This has been demonstrated as a potential energy source through biogas production while addressing waste management. According to Yeang (2006), anaerobic digestion of organic waste, including blackwater, can yield 0.3–0.5 m^3 of biogas per kg of organic solids, with 50–70% methane (CH_4) content, suitable for cooking, heating, or electricity generation. (Duan et al, 2025).

Algae production
Algae energy production is a electric generation method still on research. The electricity come as a result of electrons produces by algae during the photosynthesis process. Projects such as The Bio Intelligent Quotient Building in Hamburg incorporate in their facade "photho

bioreactors" that are transparent panels attached to the facade filled with water and liquid nutrients and carbon dioxide for the algae to grow. Those bioreactor produce energy for the building.
Thus, algae systems can treat CO_2 and nutrients (e.g., from wastewater) and produce biomass that can de transformed into energy. Recent studies shoe potential in Nordic climates but emphasize seasonal and energy-balance limits in northern latitudes. (Cheregi et. all, 2019).
Moreover, the cost of maintenance is higher compare to traditional methods, and low winter irradiance and cold temperatures reduce year-round productivity; harvesting/processing energy can negate net gains for fuel. (Cheregi et al, 2019).

3.3.2.4. WATER ENERGY PRODUCTION

Micro-hydropower system
The system produce energy from the flowing water by converting the gravitacional potential energy into electricity. The process need a vertical drop (head) to create pressure and a consisten volume of water (flow) to spin a turbine that is connected to a generator. (Boroomandnia et al, 2022). Microhydro can provide continuous generation if a reliable head and flow exist (natural channel or engineered fall).
The water source can not just been natural flows like rivers, but resources from the same project such as water treated. However, Micro-hydropower in a wastewater system is most viable for large communities (e.g., eco-villages, large resorts, industrial parks) with significant elevation change, where the scale makes the investment in infrastructure and continuous flow management more practical. (Boroomandnia et al, 2022).

Heat recovery from wastewater
Heat waste recovery is the process where the thermal energy that is produced from building operational processes is captured and reused. For this, heat exchangers and heat pumps can extract low-grade heat from sewage or wastewater streams. (Łokietek et al, 2023)
This thermally stable system has been applied at city scale in Gothenburg (Rya heat-pump installation), and in other parts of Sweden to feed district heating and building heat pumps. This is especially valuable in cold seasons because heat pumps achieve higher annual COPs against wastewater than against cold ambient air. (City of Gothenburg, 2024).
In residential project the technology can be applied trough Drain Water heat recovery (DWHR) that captures heat from the warm water from showers, baths, dishwashers, and washing machines. The application is extremely effective in building with high hot water demand. (Łokietek et al, 2023).

3.3.3. Water management

Water is both the basis of any ecosystem and an essential resource for any architectural project. Globally, the raise of population, the industrial processes and the develop of human life are expected to make freshwater increasingly scarce (Amin et al, 2023). Although household use accounts for only about 11 % of global withdrawals, residential demand grew by more than 600 % between 1960 and 2014 outpacing every other sector. Landscape irrigation and routine domestic activities now represent a major share of total freshwater consumption (Amin et al, 2023).
In Sweden, the average person uses about 140- 160 litres per day (RISE, 2020). The internal uses vary, for example, a study of eight Gothenburg homes showed a typical split: washbasins 23 %, showers and bathtubs 38 %, kitchen sinks 39 %. Of that total, 57–60 % is hot water (Johansson et al, 2007).
To apply regeneration in architectural design water becomes a resource, not just for consumption but for generation. Thus, the strategies proposed should be aligned to:
1. Minimize the water demand of the project

2. Collect natural water (from rain or natural sources)
3. Reuse the wastewater aiming for a close loop where waste become resource
4. Prioritize low impact solutions for treatment and collection, that works as part of the regenerative system

3.3.3.1. Greywater treatment

Greywater is defined as all the domestic effluents (shower, laundry, faucets, etc) excluding toilet flushes and kitchen discharges (Amin et al, 2023). To treat it means to purify the water with the quality to be reused. Depending of the treatment system and the legislation, it can be reused for potable and non-potable uses.
Sweden's building regulations (BBR) allow use of "övrigt vatten" (non-potable technical water) for toilet flushing, washing machines, and heating/cooling, however, it needs to be separated and protected from the potable water installation to avoid contamination, minimizing also microbial growth in storage/distribution. (Naturvårdsverket, 2024).
Aligned to the regenerative principles the methods to treat the greywater can go beyond obtaining clean water to reuse. For example: to use these nutrients as fertilizer for plants (in constructed wetlands/reed beds), to provide biodiversity habitats like wetland, or to moisture the soil adding organic matter through irrigation of treated greywater.
However, regarding the condition of the site, solutions must prevent freezing temperatures, low biological activity in cold weather, and high hydraulic loads during spring snowmelt. Systems often require insulation, protected/enclosed designs, or a focus on sub-surface treatment to prevent freezing. (Amin et al, 2023).

Biological and chemical treatment systems treat wastewater safely and some has advantages of cost, low energy operation or low mainteinancy. Specifically, biological treatments rely on the combined efforts of plants, microorganisms, and substrates, which work together to purify the water. (Fuentes et al., 2018). Some of the examples that are suitable for Nordic climates are the following:
Horizontal constructed wetlands are particularly suitable for the site conditions: they have good performance even in cold climate performing in a 70% of treatment efficiency in winter (Sijimol & Joseph, 2021), reduce reliance on the municipal grid, and enhance local biodiversity by providing habitat and water sources (Naturvårdsverket, 2024).
When the climate condition in winter are extreme, some strategies to address these challenges may include increasing treatment area, insulating from heat loss, deepening installation for freeze protection, and/or recirculating the water to keep it from freezing. (Wallace, 2009).

3.3.3.2. Blackwater treatment

Another opportunity to close the loop for the resources involved in a project operation is to treat toilet effluent as a resource. Proper blackwater management reduces pollution, safeguards public health, and recovers nitrogen and phosphorus for fertilizer (Jokerst et al., 2009). Anaerobic digestion also converts organic matter into methane rich biogas, supplying renewable household energy. Anaerobic bacteria break down organic matter in the absence of oxygen, producing biogas. This biogas is typically 50-70% methane, which can be captured and used as a renewable energy source for cooking, heating, or even generating electricity on-site. (Kuramae et al, 2021). (Fig. 30) Its biogas

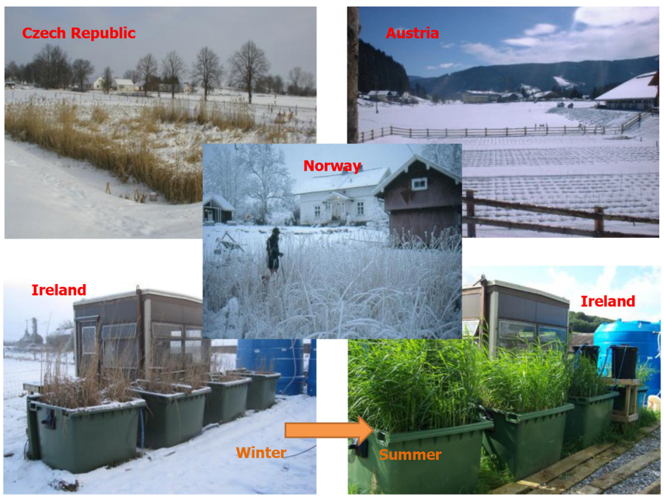


Image 4. Camera capturing of CWs in winter. From "Can Subsurface Flow Constructed Wetlands Be Applied in Cold Climate Regions? A Review of the Current Knowledge," by Bin et al, 2020, Ecological Engineering, *148*, p. 9 (https://doi.org/10.1016/j.ecoleng.2020.105992). Copyright 2020 by Elsevier B.V.

potential is calculated from Chemical Oxygen Demand (COD) data (Fuentes et al, 2018).

Treatment type	Technology	Key performance characteristics
Biological	Subsurface-flow wetlands	High pollutant removal (especially Biochemical oxygen demand and Total suspended solids) and odorless operation (Liang et al., 2020)
Biological	Membrane bioreactor (MBR)	Well-suited to urban sites; combines biology and membrane filtration (Al Chalabi, 2024)
Physical / chemical	Granular activated-carbon (GAC) filter	Cuts turbidity 94 %, COD 93 %, oil 91 % (Ali et al., 2020)
Physical / chemical	Sand filter	Lower removal than GAC but good coliform reduction (Mortula et al., 2023)
Hybrid	Aeration + sedimentation + GAC	Boosts overall efficiency for household reuse (Ali et al., 2020)

Figure 29. Some types of natural water treatment gathered from literature review. Own source

Compared to aerobic processes (which use oxygen), anaerobic digestion produces far less excess sludge (the leftover bacterial mass). This means less frequent and less costly sludge removal, handling, and disposal. However, the process is highly sensitive to temperature. Optimal methane production occurs in the mesophilic range (35-40°C). In colder climates, reactors may require heating to remain efficient

Therefore, the treatment of blackwater will generate: clean water to reuse as non-potable usage, fertilizer product and/or biogas to convert into energy.
However, it recovery efficiency and stability depend on consistent feedstock, temperature control and skilled operation where small scale digestion often struggles (unstable performance, low gas yields) unless there is a careful engineering design. (Wen et al, 2024).
Moreover, the proposal can get easily a scale mismatch on energy yield. The system should account for losses and non-regular loads, and some academic pilots show that to be feasible to produce a significant fraction of the project energy demand it should be neighborhood-scale digestion, or combine blackwater with food/kitchen waste to reach viable gas yields. As example there is the full-scale UASB pilots in Swedish districts were done at city-district scale to produce meaningful gas/benefit. (Abuzir et al, 2025)
Finally, regarding to environmental impacts, some LCAs and consequential analyses show decentralized systems can reduce them, but it's conditional: technology choice, electricity mix, treatment efficacy and what it replaces (e.g. district heating and centralized CHP vs. local gas engine). (Aliahmad et al, 2025).

Context	System	Typical removals / notes
Rural	Two-stage anaerobic package (modified septic + anaerobic filter)	CODtot 72.6 %, CODss 90.2 %, BOD 78.4 % (Sharma et al., 2016)
High-density	Sequential mechanical filter with wood shavings	Suspended solids 78–85 %, COD 60–80 % (Todt, 2017)
Low-infrastructure	Self-purification via composite microbial units + aeration	Enhances contaminant breakdown without extensive works

Figure 30. Different systems to treat blackwater

3.3.4. Hypothesis

After the detailed revision and comparison with site conditions, a proposal is developed as hypothesis of how the system can work when applying regenerative principles in the existing sustainable project. However, to get a final proposal every strategy should be evaluated in the design decision process. As mention above, every solution depend on factors such as occupancy, flows, demands, and other parameters from the site and the existing project. This conditions are specific for the study case, and the performance analysis will be based on methods for early stage design.
Therefore, the proposal is designed within three fields of action that summarize the opportunities of the existing site: habitat reconnection, energy management and water management, the strategies in every field are interconnected and have influence over each other as follow:

1. Solar PV + Wastewater heat recovery DHW + heat pump for space heating
PV on roofs as primary source of energy, with a battery system aims to cover the demand of the project. The energy used for the original heat pump of the project will be lowered extracting heat from the wastewater of the project.
2. Rainwater harvesting + Water reuse
Collection of rainwater in roofs and ground level areas, filtered and storaged. The principal uses of the water can be outdoor irrigation, toilet flushing and laundry.
3. Greywater natural treatment + Blackwater natural treatment
Grey and black water will be separated in the building operation and treated:
Greywater: Through subsurface wetlands / Blackwater: Through Anaerobic digestion
The water treated aims to be storage and reuse for: outdoor irrigation, feed blue bodies proposed in landscape design , feed non-potable uses (toilets and laundry). The excess will be disposed to the local grid.
4. Blackwater treatment + biogas production
Separate blackwater from grey water, treated black water on site through anaerobic processes, extracting clean water, for non-potable uses (irrigation and toilelt usage) while organics components will be used to extract biogas to generate electricity.

How to analyze the performance of the system proposed?

A data-driven strategy will be used, following parametric design logic, as proposed by Jabi (2013). This approach transforms complex analysis into measurable, manipulable entities known as parameters, the controllable aspects of the system that form the foundation for informed decision-making.
The analysis will be conducted through the following methods:

Data Translation into Design Parameters: Involves interpreting complex, multidimensional data (e.g., ecological species movement patterns, energy models, carbon footprints) and converting them into actionable design parameters (e.g., minimum corridor width for habitat continuity, or location).
Systemic and Relational Analysis: Define the relationships between parameters, not just their individual values. For instance, create explicit link between water consumption, and greywater treatment capacity, or energy demand with pv solar energy harvesting capacity. In that way, the system will be integrative and responsive, where it can adapt to constraints or goals.
Iterative Scenario Testing: The previous step will form the basis for testing strategies under a range of conditions through simulations and calculations. In an “trial and error” process the performance can be evaluated based on key metrics.

Carbon Lifecycle Analysis (LCA): A critical pillar of this parametric evaluation will be a comprehensive carbon lifecycle analysis. The results of the LCA will be integrated directly as a key input parameter, ensuring that carbon footprint is a primary, manipulable variable in the decision-making process. Therefore, it will evaluate the carbon emissions impact from the strategies proposed This allows to prioritize solutions that deliver both operational performance and a response aligned to regenerative principles. Fig 32

Given the early stage of design, certain data points may need to be based on well-documented assumptions. These assumptions will always be grounded in the specific context of this project or data from similar sites to ensure reliability.
The strategies evaluated will be the ones that can be simulated in early stages of design, it can be planned and designed using parameters that predict their effectiveness; however, for later stages of the project it will require the participation of different professionals that can validate and develop the proposal in detail.

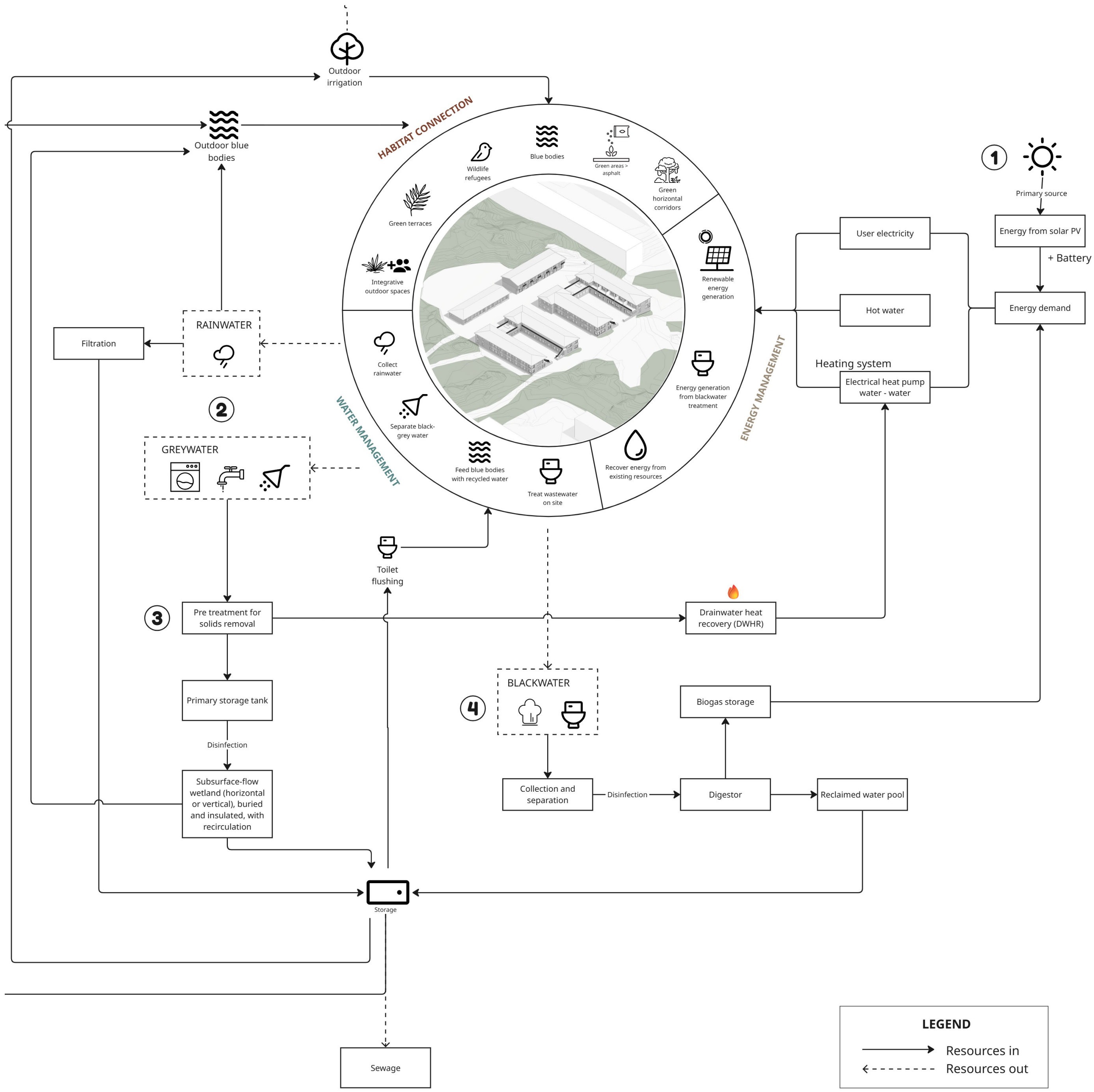


Figure 31. Diagram of proposed system implemented in the Housing and Beyond project

3.4. Design-decision making

The evaluation methods will be performed using computational tools, seeking to avoid the biases of conventional single-objective analyses, where the analysis typically privileges one metric while disadvantaging another, overlooking synergies, their effects, and possible conflicts (Reddy & Kumar, 2014).

Therefore, some strategies will be analyzed within each field, and the results will be integrated into the final design proposal, taking into account the influence that each strategy may have on another. For example, increasing the density of solar panels might produce an energy surplus but also add embodied carbon, while expanding wetland areas could improve on-site greywater treatment but reduce usable space for project users.

The calculations and simulations will be based on existing data and assumptions that represent conditions closer to the specif site. The results will be reviewed by professionals with knowledge in the specific area to verify their relevance. For that, the following professionals were consulted through the process:

- Gabriel Rodriguez: Environmental engineer with mention in biology. He works for Fundación Condor, An NGO that promotes the conservation of endangered species in Ecuador. His work focuses on encouraging coexistence between humans and wildlife in Ecuador, with animal control projects in green corridors in urban and rural areas.
Contact: grodriguez@fundacioncondor.org

- Mauricio Rico Gonzalez: Mechanical engineer with over 30 years of experience in project management and development. His work focuses on design, build and control alternative energy and water systems in areas with limited access to local grids. He has participated in projects in Colombia, Honduras, and Canada.
Contact: mauricio.rico58@gmail.com

3.4.1. Habitat Reconnection

STRATEGIES

Green corridors
- Horizontal green spaces

Wildlife refuges
- Green spots
- Water bodies

The core of this field is the reconnection, among forest patches, human and non-human species, to co-inhabit with nature. Such connections can be planned and designed using parameters that predict their effectiveness; however, as Mang et al. (2016) point out, designing regenerative strategies is only the beginning, once set in motion, they evolve on their own. The success of urban corridors will depend on the factors selected and their interaction with the surrounding environment. It is also worth noting that plant and animal species already migrate through urban areas and between disconnected patches despite built barriers, although these links typically take 30 to 60 years to establish (Yeang, 2006). As green spaces will be designed for fauna co-habiting, the behavior of species is part of the analysis. However, at it was state before, to work with the complexity of natural landscapes and their elements, then it is necessary to work through three steps:

Species definition – Which species will be addressed, and why?
Species needs – What are their movement, their requirements and constraints?
Landscape planting design – Which plant species best promote these interconnections?

Species definition

- Definition of a **target species** group (fauna)

Species needs

- Description of the target species group **needs**
- Selection of **suitable plants** matching the target species needs

Landscape connectivity

- Analysis of **forest patches** importance
- Evalution of **new green connectivity patches**

Figure 33. Workflow to analysis and propose strategies to reconnect habitat

3.4.1.1. SPECIES DEFINITION:

The target group is the umbrella one, as the focus of the strategies will be reconnection in a physical level, the landscape quality comes as a priority, thus designing to fulfill the habitat needs of a group of specie can be part of the solution.
To avoid the limitations of a single umbrella-species approach, several species within this definition with diverse ecological needs were chosen. In consequence, from the list of existing species collected (Appx. 4) the following species are selected:

Common Hedgehog
(Erinaceus europaeus)
Photo: Michael Gäbler

Koltrast
(Turdus merula)
Photo: Jonn Leffmann

Brimstone Butterfly
(Gonepteryx rhamni)
Photo: Didier

Common Frog
(vanlig groda)
Photo: Jörg Hempe

3.4.1.2. SPECIES NEEDS:

After the definition is important to understand the behavior of species the following parameters should be analyzed, in order to design space suitable for them:

- Mode of movement: Do the species travel along the ground, through the tree canopy, or in flight? How much area do they need to forage, migrate, and reproduce?
- Migration pattern: Do they migrate in a single, rapid journey or move slowly over time? Do they oscillate back and forth seasonally? How much space do they need to forage, migrate, and reproduce? Home-range size varies with body mass, food availability, and foraging behavior.
- Seasonal change: How do shifts in the landscape throughout the year affect them? Is interconnectivity adequate over time? Corridors must let individuals and populations reach suitable resources despite seasonal variation,
- Diet: What do they eat, and how do they obtain it?

The following table summarize this characteristics of the species selected:

Specie	Movement	Migrational patterns	Seasonal changes	Food
Common Hedgehog (Erinaceus europaeus) **Photo:** Michael Gäbler	·Terrestial, just ground · Mostly nocturnal · Daynests: thickets, hedgerows, compost piles, tall grass clumps.	· Not migration	· Hibernation · Spring is mating season	· Insectivorous ·Suplementary diet: fruits and fungi
Koltrast (Turdus merula) **Photo:** Jonn Leffmann	· Spend some time in ground · High movement during breeding, around 1.3 hectares	· Partial migrant	· Spring is mating season · Migrate in winter (around september)	· Omnivorous
Brimstone Butterfly (Gonepteryx rhamni) **Photo:** Didier	· Flying close to ground vegetation, short distance · Habitat with sheltered microclimates, and open sunny areas	· Not migrantion, short-distance dispersal flights	· Adults hibernate · Spring and summer need for nectar-rich flowering plants and host plants for larvae	· Adults feed primarily on nectar from flowers. · Larvae feed exclusively on buckthorn leaves
Common Frog (vanlig groda) **Photo:** Jörg Hempe	· Terrestial, short distances · Stays close to aquatic breeding sites	· Seasonal migrant · Short distances (500m - 1km)	· Spring movement to ponds · Hibernate in winter · Summer disperse	· Insectivorous

Figure 34. Characteristics of umbrella species, Appx. 1.6.1

Then, from the vegetable species of the area which ones are suitable to cover the needs of the species selected, regarding the parameters of movement, migration, seasonal changes and food availability. The information about the vegetable species was compiled from literature, Artportalen and Naturvardsverket Portalen. This information will help to include specific vegetation in the strategies design in later steps. Fig. 34

However, how to know that the proposal of green species is going to successfully improve the connection between forest patches and the co-existence between species?

3.4.1.3. LANDSCAPE CONNECTIVITY

TOOLKIT: Qgis+ CONEFOR Sensinode

To evaluate alternatives of habitat connectivity in the area of the project, it follows the graph-based approach, after the consultation with a biologist that have worked with urban projects. The scale of the present project and the conditions make it suitable to use the framework proposed by Pierik et al, (2016). Consequently, the mapping from the analysis is used as a base to identify the nodes, and the physical conditions from the place.

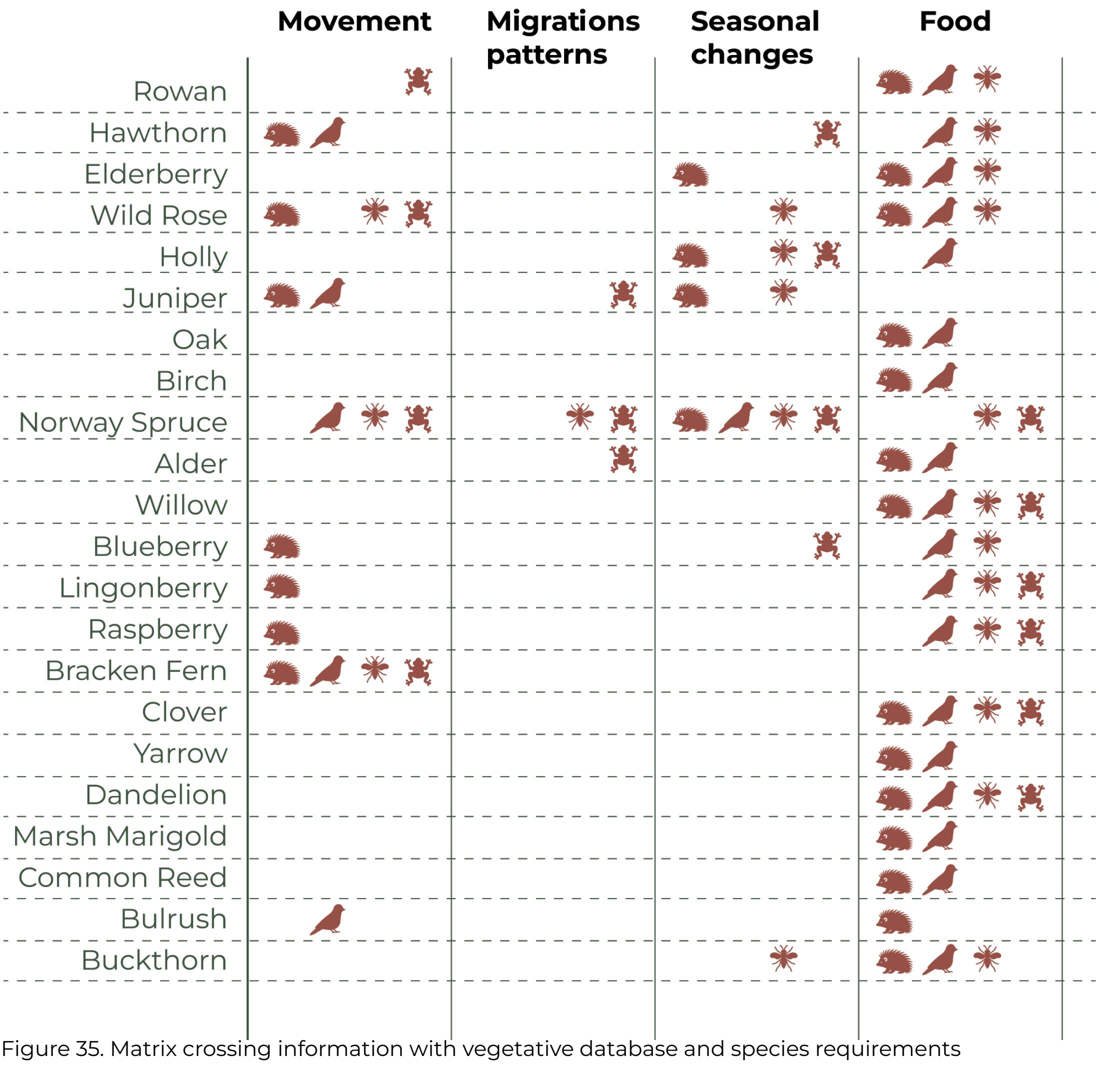


Figure 35. Matrix crossing information with vegetative database and species requirements

Moreover, it is identify some **parameters** that will help in the assessment of the landscape connectivity (Appx 7) :

Target specie
Range of movement
Maximum distance of dispersal
Probability of movement

The parameters of the selected species is extracted from literature, where the urban environments are considered as part of the analysis (Angstrom, 2025; Berger et al, 2020; Cooper et al, 2024; Halkjaer, 2025; Isaac et al, 2011; Korslund et al, 2024; Settele et al, 2008; Shakhparonov et al, 2022) and those data were validated with an environmental engineer to consider the early stage of the present project and the implication of its scale in the range of movements and the permeability through the space.

3.4.1.4. SPECIES RANGES

Range of movement
Maximum distance of dispersal
Probability of movement

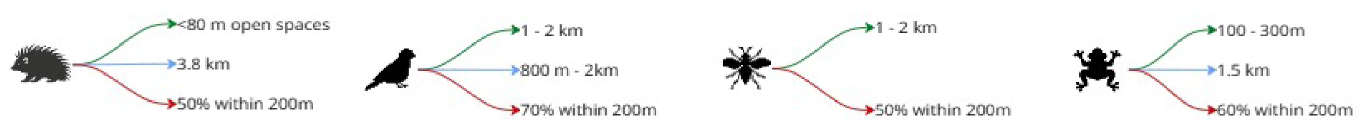


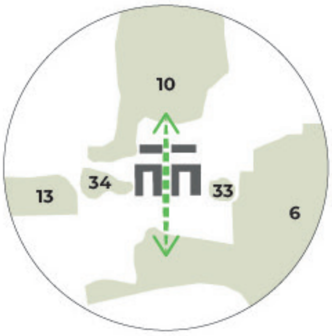
Figure 36. Umbrella species movement characteristics

With that information, CONEFOR will calculate the quality of nodes through the following metrics:

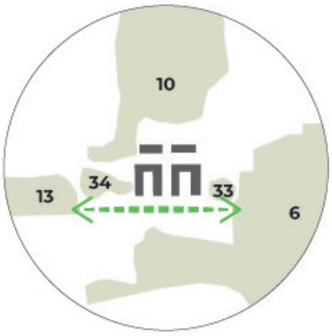
NL	NC	PC	Ec (PC)	AWF
Number of links between patches	Number of components, pieces	Probability that two points or individuals are connected efficiently in the landscape	The amount of "fully connected habitat area"	Area weighted flux: average of how many species are moving through the landscape. Average of all pairwise connections weighted by patch area and probability of connection

Therefore, three scenarios of connectivity are proposed and analyzed against each other, using principally tools like QGIS and Conefor Sensinode. (Appx 7)

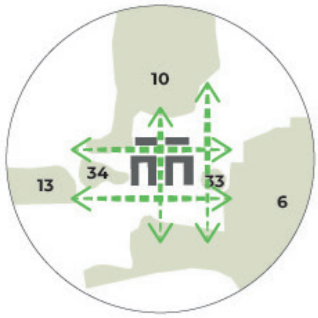
PROPOSED SCENARIOS



Scenario 1. North to south



Scenario 2. East to west



Scenario 3. Both directions

The third scenario showed the better performance in comparison, however:

3.4.1.5. FINAL OUTCOMES

- The landscape is highly fragmented. There is only a 6% chance a hedgehog can move between habitat patches in its lifetime.
- The habitat is broken into 5 separate clusters (effective connected habitats), with four of them too small and at risk of inbreeding and local extinction.
- Only one-third of the vegetated area actually functions as usable habitat for the selected species like the hedgehog.

However, with scenario 3:

Improve survival and foraging with a **150m** vegetated strip. It would fix the longest break (280m)

15%+

Overall connectivity by 15%, however, it is **not enough** to reduce the number of fragmented components

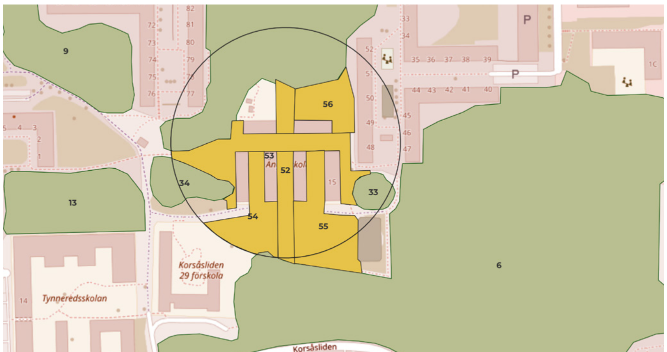


Figure 37. Scenario 3. New nodes proposal

The analyses showed that the most important forest patches are **far from the study area** and to connect the fragmented network the key is replicating this intervention on multiple properties around to collectively "re-stitch" the habitat.

Also, this metrics are **highly dependent on the information collected**, and the species selected. Although It gives an idea about the site connectivity to propose a design solution in early stages, further analysis and expertise knowledge is mandatory for later stages.

3.4.2. Energy management

STRATEGIES

Energy generation from renewable sources
- Solar PV
- Biogas from blackwater treatment

In this category the priority will be the generation of energy with the existing resources. This energy generation should be low environmental impact, and can close resources loops. Following the regenerative principle to generate more that it consume the main goal will be **to exceed the project's annual energy requirement**, that can be storage or feed back into the power grid. Therefore, the system will be:

- **As primary source of energy:** Rooftop photovoltaic panels to harvest solar power during the year, supported by a battery system.

- **As secondary energy source:** A biogas unit that converts site-generated organic waste from blackwater into energy.

Other methods considered is the energy recover from existing heat sources, in this case the proposal for a Drainwater Heat Recovery (DWHR) to collect heat from places like showers and laundry.

As first step the conditions of energy demand of Housing and Beyond are extracted from the previous analysis. It is important to highlight that the present thesis start with an existing project, working as a transformation proposal, thus, the existing resources and conditions will determine the performance of the strategies proposed.

3.4.2.1. SOLAR ENERGY GENERATION

TOOLKIT: Grasshopper + Ladybug

The placement of the PV solar system (Fig 38) is the existing building roofs, with around **2628 m².** However, to dimension the solar pv system of roofs, the energy demand should be quantified. The information is extracted from the Housing and Beyond project where a proposal of energy demand of the building was made as follows:

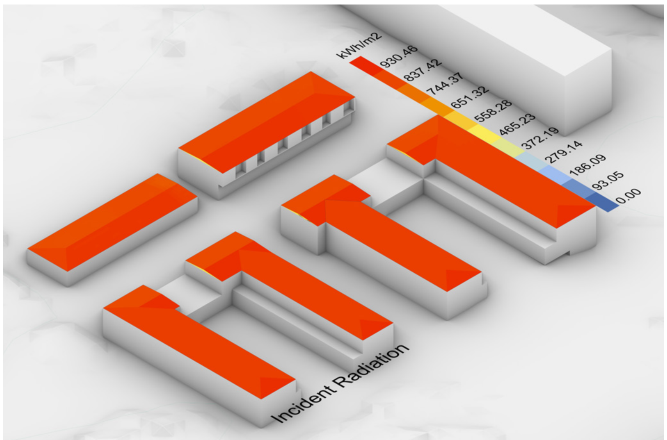


Figure 38. Incident radiation in Housing and Beyond

Energy reference area (AN): 6310m²

Primary energy demand:
51 kWh/m²(AN)*year

End energy demand:
66 kWh/m²(AN)*year

For the calculations, the end energy demand will be overcome for at least 15%.

With a simulation of the conditions it will be possible to analyze how effective can be the system and if the total area available will be

enough to generate energy for the demand.
The PV modules date is kept simple and conservative: a single, commercially typical crystalline-silicon module measuring 1.00 × 1.70 m with a constant efficiency of 15%.
Regarding to the solar angle and the distribution, the climatic conditions vary during the different month, thus, to evaluate efficiency, two scenarios are analyzed: Fig. 39, 40

Solar angle: To be simulated
Energy demand (+15%): 478 977 kWh/year
PV efficiency: 15%
PV dimension: 1.00x1.70m
Distribution: To be simulated

- Proposal 1: The existent tilt of the roof (12°), considering uniform distribution and location in **every side.**
- Proposal 2: An angle perpendicular to the average solar altitude during the higher solar incidence with a distribution that consider the shadow between panels and proper location to maximize solar collection in peak seasons.
The process is developed in Rhino+grasshopper (Appx. 1.8).

RESULTS:

- Adjusting the tilt to an optimal solar angle (proposal 2) **raises efficiency by almost 5%** compared to Proposal 1, and achieves almost the same annual output with less of the collector area, demonstrating that correct is the most effective from the analyzed cases.
- To have a surplus of energy during the whole year for the specific conditions it will be necessary an **area of PV modules that exceed** the available roof area
- The system must **consider a storage system**, to reach the energy demand during low or inexistent solar incidence (ex. Nights and winter season)
- A regenerative goal of producing 115 % of the building's annual demand would mean **exporting 30–40 % of the output to the grid**. However, t**he production of energy will not be constant**. This depend on solar conditions and, during low radiance periods, the demand is

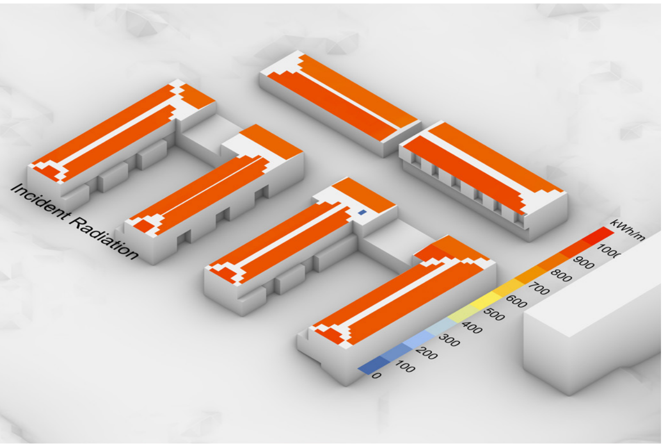


Figure 39. Proposal 1 with PV over the existing roof

Proposal 1 - Roof tilt

ENERGY PER m²: 129 kWh/m²
PV YIELD: 219 kWh/unit
TOTAL PV AREA: 3711 m²

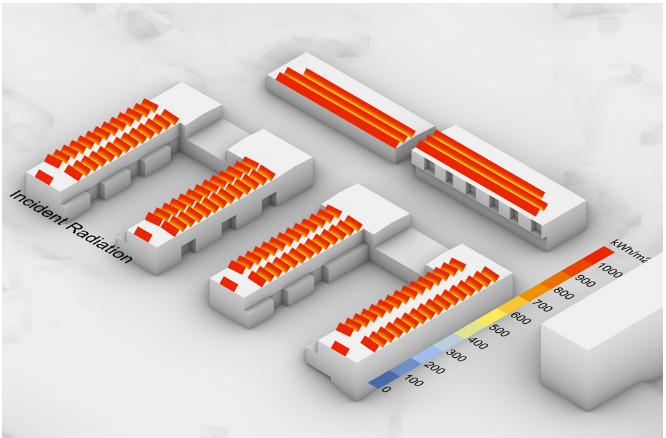


Figure 40. Proposal 2 with PV tilt 40° facing south

Proposal 2 - Efficient PV angle

ENERGY PER m²: 136 kWh/m²
PV YIELD: 230 kWh/unit
TOTAL PV AREA: 3535 m²

not going to reach 115% even when the system is dimensioned for it.
This results are discussed with a mechanical engineer specialized in water and energy systems for industrial and residential projects, and he pointed out some facts:

a) Southern Sweden has low winter solar radiation; most PV production is in late spring–summer while demand or heating loads can be higher in winter. Annual analyses is not proof the system can "cover nights" or winter evenings.
b) Battery size is very sensitive to what fraction of daily consumption occurs at night (and when demand peaks). Therefore the battery should be sized with case sensitivity (30%, 50%, 70%, etc, night consumption). However, it is not cost effective to size storage for more that some hours. Thus, it is **not recommended the seasonal storage.**
c) **The batteries increases a lot embodied carbon emissions**. In Sweden the grid is already relatively low-carbon, replacing grid electricity with battery-buffered PV at night may not reduce CO_2 much and could increase total lifecycle emissions.
d) Consider smaller batteries used for peak-shaving and shifting a few hours (4–8 h), combined with demand management or mixed systems (load shifting, thermal storage, smart control)

These considerations raise the question about the feasibility of the system compared with the existing energy source of the project: the local Swedish grid.
Sweden already operates one of the world's cleanest electricity grids (the IEA Emissions Factors 2023 database puts its average mix at roughly 25 g CO_2-eq kWh) and compared to on-site generation the goal surplus could be counter-productive: a standard European mono-silicon module carries about 43 g CO_2-eq kWh over a 30-year life (IEA-PVPS, 2022), so unless ultra-low-carbon panels are used, the embodied emissions of each exported kilowatt-hour would exceed those of grid electricity.

However, it can still help during winter peaks, when the country imports power. If there is a combination system that can generate enough electricity to cover those peak hours, it can reduce reliance on dirtier external sources.
Therefore, from the carbon perspective, what is the real impact of solar panels compared with the Swedish grid?

3.4.2.2. CARBON ANALYSIS (LCA)

TOOLKIT: OpenLCA

Category	Description
Primary Research Question	Is the integration of a rooftop PV system environmentally justified in Housing and Beyond in Tynnered, Sweden, when compared to using grid electricity for the same energy demand?
Functional Unit	12 019 000 kWh of electricity delivered over 25 years, corresponding to the total modeled energy demand of the building.
System Boundaries	- **PV system**: Cradle-to-grave (manufacturing, transport, operation, end-of-life) of PV modules only. - **Grid (ELCD)**: Cradle-to-gate, full upstream fuel supply chain, grid losses, and average EU imports. - **Corrected Grid**: Gate-to-gate, only modeled CO_2 emissions using SMHI's emission factor (19 g CO_2e/kWh).
Impact Assessment Method	ReCiPe 2016 Midpoint (H), selected for coverage of GWP, fossil resource use, and eutrophication.

Figure 41. Definition of the LCA for carbon emission analysis

Two scenarios are analyzed: Appx. 9

CASE 1

SOLAR PV

CASE2

SOLAR PV + battery

Case 1:
It compares:

1. A grid scenario reflecting Sweden's national emission factor of 19 g CO_2e/kWh (SMHI 2023).
2. The solar panel: Midsummer BOLD PV panel, information extracted form the corresponding EPD and scaled to match the total generation

The results reveal a clear environmental advantage for rooftop PV integration. Over a 25-year period, even when compared to a low-carbon national grid, the PV system reduces life cycle GWP by approximately 70%, demonstrating significant climate benefits despite its embodied impacts.

However, **independence from the grid means to storage energy**, initially the system is proposed to be completely independent from the grid, following regnerative principles, however, after consultation with an expert, the site climate conditions forces to have bigger battery systems that will be against environmental and economical cost.
Batteries accounts almost the 30% of the carbon emission in the whole PV system. (Victoria et al, 2019). Therefore the system is resized to calculate the environmental impact of PV with batteries to feed it during poor or inexistent solar radiation, specially at night where the demand will be about 40% of the total.

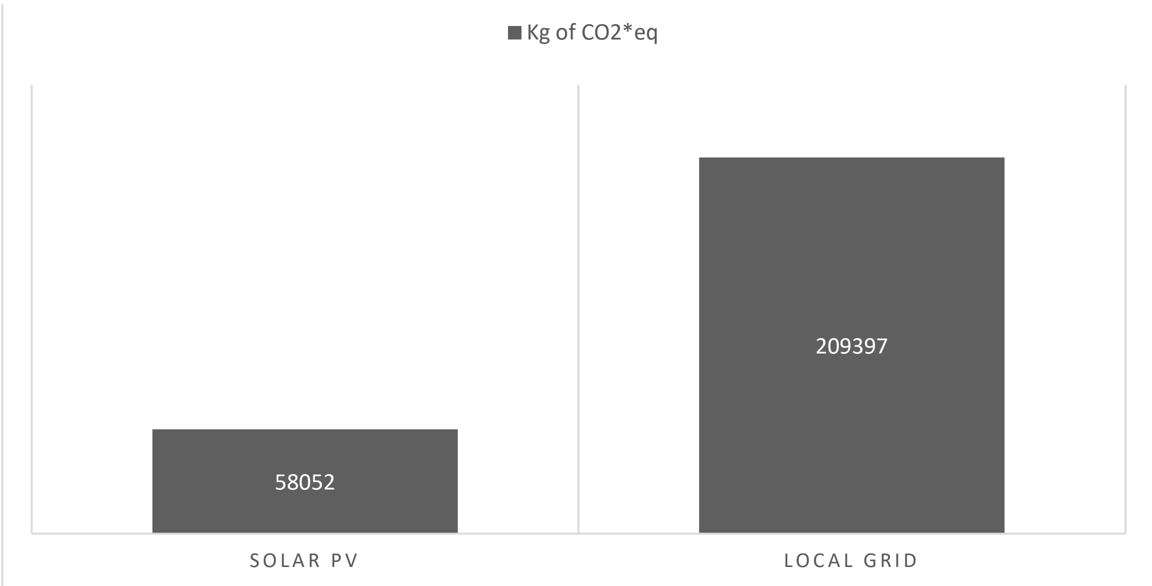


Figure 42. Comparison between LCA analysis case 1

This translates to a storage capacity of about 500 kWh for the whole system. Life-cycle data put the global-warming potential of lithium-ion batteries at roughly 150–200 kg CO_2-eq per kWh of capacity (GREET, 2022), so the battery alone embodies around 75000 kg CO_2-eq.

Case 2:
It compares:

1. A grid scenario reflecting Sweden's national emission factor of 19 g CO_2e/kWh (SMHI 2023).
2. The solar panel: Midsummer BOLD PV panel, information extracted form the corresponding EPD and scaled to match the total generation including + inverters, cabling, and standard mounting hardware.
3. The solar panel: Midsummer BOLD PV panel, information extracted form the corresponding EPD and scaled to match the total generation + battery storage system (500kWh) + inverters, cabling, and standard mounting hardware.

The battery system increase the carbon emissions of the system being almost similar to connect directly to the grid, however it is still a benefit to take advantage of the existing solar resources.

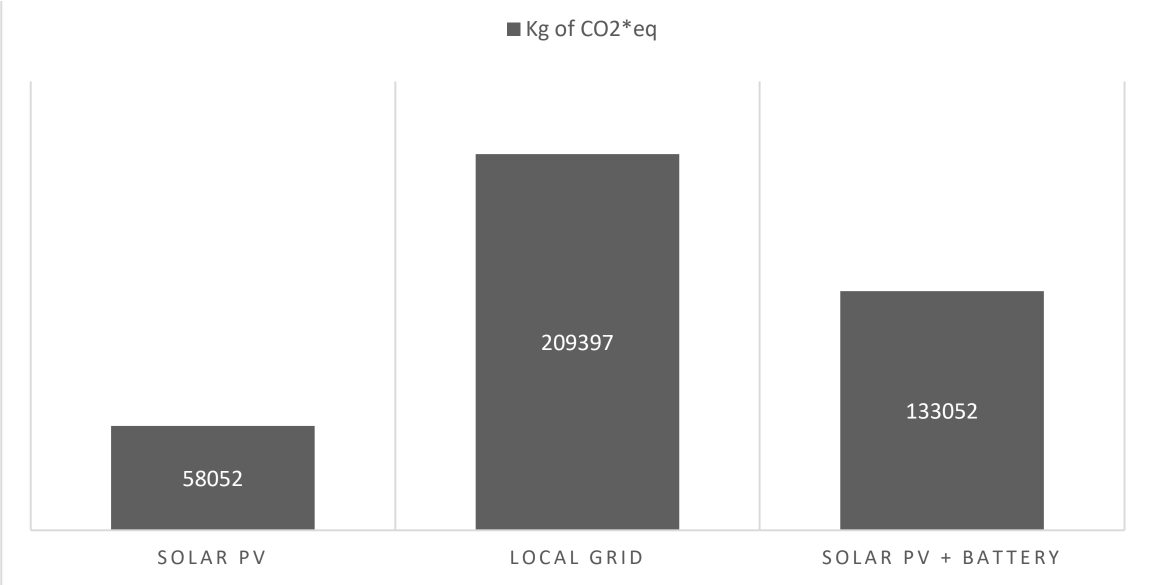


Figure 43. Comparison between LCA analysis case 2

Nevertheless **being independent from the grid is unfeasible** for the site specific location. The original goal of 115% annual surplus does not mean self-sufficiency in winter or low solar exposure seasons. Solar production in Sweden is extremely seasonal. The long summer days with up to 18 hours of sunlight generate a massive surplus, while the short, dark winter days produce very little. Therefore, the annual calculation of surplus is almost entirely generated between April and September.

- **Summer (May-July):** It will produce far more than 100% of the demand on a sunny day, where the surplus gets fed back to the grid and builds up annual credit.
- **Winter (Nov-Jan):** The production will be a small fraction of the demand. On a good December day, a system sized for a 115% annual surplus might produce only 5-10% of the daily electricity needs with many consecutive days with near-zero production due to snow cover and heavy clouds.

To cover the demand in winter, a massive battery bank will be need just during those months, and it would then be largely underutilized for the other 9 months of the year, which is very inefficient.
In consequence, complete energy self-sufficiency may look regenerative, but in this context it is not a favorable strategy. For Nordic contexts it is recommend to covering only about one-third of annual demand with PV and completing the mix with other renewable and storage. Victoria et al. (2019).

FINAL OUTCOMES:

The surplus of energy is inneficient for the site conditions because of performance system fluctuations

A optimized angle in solar PV array can reduce pv area, and increase solar collection efficiency

The battery component of the system is the major CO2 contributor. A battery system that covers more than hours demand has a big environmental and economical cost

A good solution: A mixed system with seasonal solar collection and grid comsuption with low energy consumption through resource integration

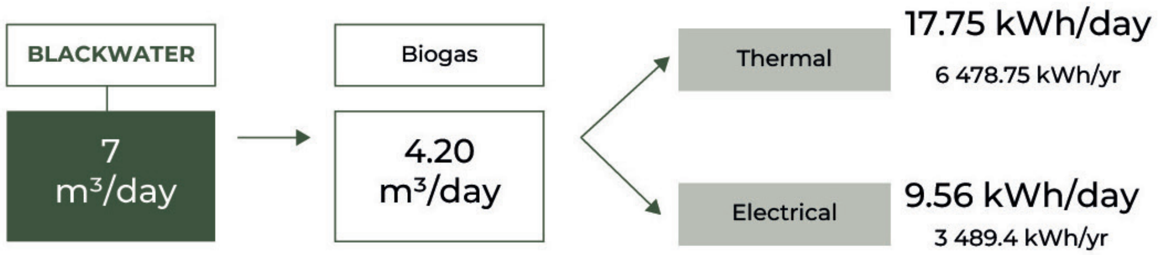
3.4.2.3. BIOGAS FROM BLACKWATER TREATMENT

TOOLKIT: Excel, ChatGPT

Blackwater treatment despite being part of the water management strategies, it is not just a resources to produce clean water to reuse but it can be source of energy, in this way, when talking about systemic design it means that elements are interconnected.
A plausible method for the site conditions is the treatment in **an anaerobic digester**, and its biogas potential is calculated from Chemical Oxygen Demand (COD) data. The process start with simple calculations based on literature, allowing to asses the feasibility of this strategy before to move to forwards stages of design.

Assuming a COD of 12 kg m^3 (Fuentes et al., 2018) for mixed toilet and kitchen waste and a daily blackwater flow of 7.0 m^3(with loss of around 30% from the original daily blackwater flow) the load result in **84 kg COD day.**

Field studies suggest 0.05–0.10 m^3 of biogas generated per kilogram of COD removed; using the conservative lower number it can yield 4.2 m^3 day of biogas. With an average of 65 % of methane in the biogas (FAO 1996; GTZ 2009), it gives 2.73 m3/day of methane, with an energy potential of **27.3 kWh/day** that can be transformed through a Combined Heat and Power (CHP) of 35% efficiency with results of:



However, the thermal energy to maintain a constant temperature (around 35°) for the anaerobic process in the digester needs to heat the original effluent from 5°-10° into at least 35°. **That process is the major consumer of energy**. Therefore, an energy balance is needed with deeper research about the performance of the system. The consultation with an engineer suggest:

- Don't design an on-site anaerobic digester as the primary energy source for a 7 m^3/day blackwater stream. With realistic assumptions it will remain a net energy consumer unless the system can yield a bigger amount of blackwater.

- The difference of temperature in the flow between summer and winter, and the insulation of the system will be decisive in the amount of energy the system uses to function, which need grounded data to be calculated.

Consequently, this strategy is not consider as part of the final proposal. According to ENERWATER Project. (2015). 5.5 kWh aprox. per m^3 of wastewater treated is needed in smaller plants for water treatment. Which means that the proposal will consume more energy than it can collect-
Thus, a better alternative is to **export blackwater to the local grid**. The proposal can be reconsider in the future when the blackwater flow is continuous and bigger, to generate enough energy to self-sustained and even export it to the be used by the project.

3.4.3. Water management

STRATEGIES

Reutilization
- Greywater treatment

Water collection
- Roof water collection

The focus of the system is to generate a closed loop where water becomes an existing resource of the project. That means to create a near-zero-waste water system that gets as little as possible from the grid and reuses every drop on site.

3.4.3.1. GREYWATER TREATMENT

TOOLKIT: Excel, QGIS

Used water is separated into greywater (from showers, basins, and laundry) and blackwater (from toilets and kitchens).
The aim is to treat greywater with natural solutions, that works not just to get clean water but also to boost biodiversity implementing green species an blue bodies in the area.
Therefore, constructed wetlands, as stated before, have high efficiency when appropriate plant species are selected, which will clean the effluent so that it can be reused for non-potable applications.

Considering local climate and soil conditions, **Subsurface Horizontal Flow Constructed Wetlands are selected**. Through natural processes, removes very efficiently organic pollutants and total nitrogen, with lower operating costs (Komunikasi et al, 2024). Sizing draws on practical methods suitable for early design: the UN-Habitat Constructed Wetlands manual offers a rule of thumb of roughly 1–2 m^2 per person for horizontal wetlands.

Depth guidelines call for about 0.4 m of gravel in horizontal beds (for oxygen transfer) and about 0.7 m in vertical beds (to achieve nitrification without clogging). This system perform different in every season, and is dependent to retention levels of the soil.
Hence, proper areas on the site should be selected to locate wetlands and insulation layers should be considered in the design. Constructed wetlands has seasonal sensitivity, therefore, insulation is going to be decisive to reasure the good performance of the strategy.
Aiming for the reuse of the greywater the system is sized with the annual greywater production and the recommendations of UN-Habitat, with a result of around of **42 m^3 of constructed horizontal wetlands.** (App. 12)

3.4.3.2. RAINWATER HARVESTING

TOOLKIT: Excel, grasshopper

All roof surfaces act as catchment areas. Run-off is conducted to a storage tank, filtered, and supplied back to the building for non-potable uses such as toilet flushing, irrigation, and cleaning. This system is connected to the solar PV strategy, where roofs carry photovoltaic panels, the shading they cast will reduce catchment efficiency; the net collection potential must therefore be recalculated to reflect the panel coverage.

Therefore, the following parameters are analyzed:

Average year rainfall
Factor of material run off
Area covered by PV

In consequence, and as decided before, the solar PV system will covered just the 60% of the energy demand, which will reduce the covered area in roofs. The process analyze the monthly average rainfall in the site location and then uses the run-off coefficients for roof materials and photovoltaic panels.

Average year rainfall
1100 mm

Total roof area
2628 m²

Water harvesting potential
1 998 315 L/y

The roof area covered by PV and the area left uncovered are multiplied by their respective run-off factors to obtain the total volume of rainwater that can be harvested (-10% losses) each year with a result of around 1 940 000 ll/y (Appx 11).

However, using annual rainfall ignores seasonality and dry months. For later stages of design like storage sizing, or water balance, It must break it into monthly rainfall values. The annual sum gives potential, not availability when needed. According Svenskt Vatten guidance, for the reuse, Sweden allows for non-potable indoor uses (toilet flushing, laundry) but must follow strict plumbing separation, and backflow prevention.
Despite, **rainwater cannot met all non-potable requirements** as the calculation shows, other strategies can be proposed to collect water to avoid dependence in roof collection

3.4.3.3. FINAL OUTCOMES:

As an aproximation for the minimun area of wetland needed to treat the calculated graywater production

Performance in winter:
- Insulation like mulch, gravel, or peat layers
- Deeper beds and Increase hydraulic retention time (HRT) to compensate for slower microbial activity in winter

The rainwater collected represent about a 36% of the total non-potable demand usage calculated for the project

Rainwater collected can be reuse in toilet flushing (large non-potable demand, relatively low water quality requirement, easy plumbing differentiation) and outdoor irrigation

3.4.4. System proposal

After the analysis of the strategies a system is proposed to be applied within the existing conditions of Housing and Beyond. The proposal works to reconnect the project with the environment, repairing its ecological footprint and integrating human activities with natural ecosystems. The focus of the project are three fields:
Following an analysis of both the general and local conditions of the area, three key fields of action have been identified:

- **Habitat reconnection:** Addressing forest fragmentation and biodiversity loss caused by the development of Tynnered in the 1960s.

- **Energy management:** Proposing alternatives to generate energy on-site through the use of existing resources.

- **Water management:** Implementing strategies to handle water on-site, treating it as a vital and regenerate resource.

This strategies are interconnected, working in synergy aligned to regenerative principles, and are adapted to specific conditions of the site and the existing project.
A decisive factor for the design are the climatic conditions, considering, as part of the proposal, the seasonal performance, with two extreme scenarios, as follows:

SUMMER

1. Solar PV + Wastewater heat recovery DHW + heat pump for space heating
PV on roofs as primary source of energy covering a 60% of the total demand, with a battery system for night energy consumption. In periods of low energy production, the local grid will be the secondary suminister.
Heat from wastewater will be recovered to feed the heat pump of the project, lowering the energy usage.
2. Rainwater harvesting + Water reuse
Collection and filtration of rainwater in roofs and ground level areas, with an storage system. The principal uses of the water will be outdoor irrigation, toilet flushing and laundry.
3. Greywater natural treatment
Grey and black water will be separated in the building operation, with greywater treatment on site with a system that includes natural solutions (subsurface constructed wetlands):
After the cleaning process. the treated water will be storage and reused for: outdoor irrigation, feed blue bodies proposed in landscape design , feed non-potable uses (toilets and laundry). The excess will be disposed to the local grid.

WINTER

1. Local grid + Wastewater heat recovery DHW + heat pump for space heating
The local grid will be the primary source of energy, with the system of solar PV panels as secondary source. The heat recovery will remain recovering energy to feed the heat pump of the project, lowering the energy usage.
2. Rainwater harvesting + Water reuse
Collection in winter will decrease efficiency, however, with insulation strategies of the collector and storage it can be possible to harvest water even during snow events. The principal uses of the water collected and filtrated will be toilet flushing and laundry.
3. Greywater natural treatment
Grey and black water will be separated in the building operation, with greywater treatment on site with a system that includes natural solutions (subsurface constructed wetlands): This elements will decrease its effectiveness during this season, however, the subsurface solution combined with proper layers of insulation allow the cleaning functioning even during winter .After the cleaning process, treated water will be storage and reused to feed non-potable uses (toilets and laundry). The excess will be disposed to the local grid.

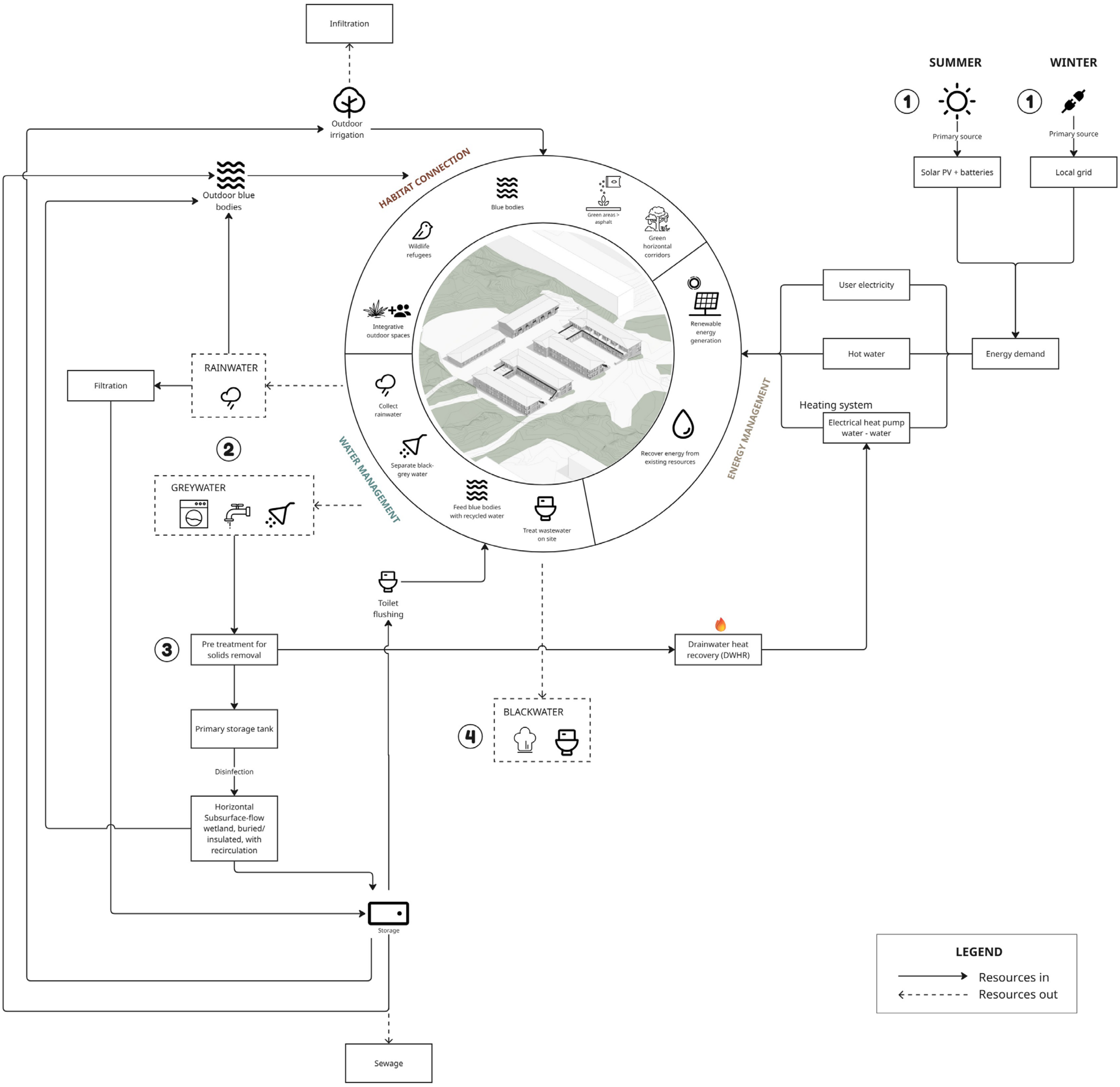


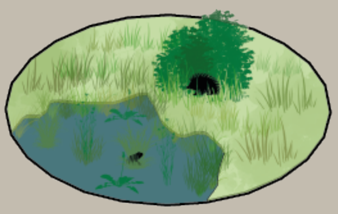
Figure 44. Diagram of proposed system to be implemented in the Housing and Beyond project

The system proposed is then a compilation of the outcomes in the previous analyzes stages, with a systematic thinking that contemplates the synergy of the different action working in the same site. In other words, the collaborative work and interdependence of the proposed actions, as well as the impact of the site's specific conditions, were all taken into account.

Therefore, as can be seen, the chosen strategies **are not those that performed best** according to the calculations, but rather **a balance between what is optimal and what works at the intervention site.**

The next step is to apply those strategies in the site, defining the spatial design that will transform the existing project Housing and Beyond.

3.5. Design development

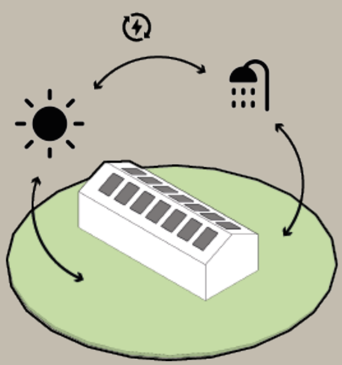


- Pollinator spots
- Communal gardens
- Species-focused vegetation

Enhancing biodiversity and microhabitats

3.5.1. Conceptual design

The system proposed in now translated into design intentions applied to the site. All strategies will connect to the existing functions in Housing and Beyond within the three fields (Habitat reconnection, energy and Water management)



- PV solar panels
- Heat recovery

Utilize renewable and recovered energy

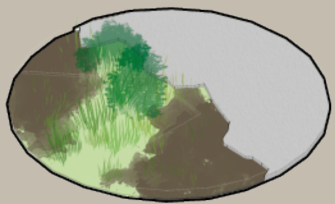
KEY ACTIONS

Topography-based design

Pedestrian flows within green spaces

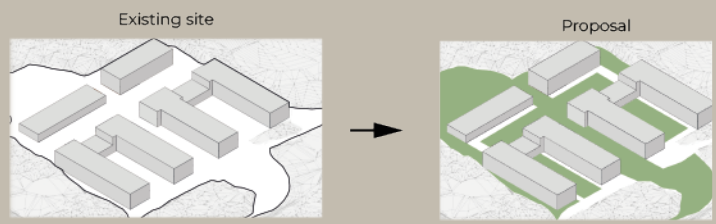
Water patterns based design

Designing for human - nature co-existence



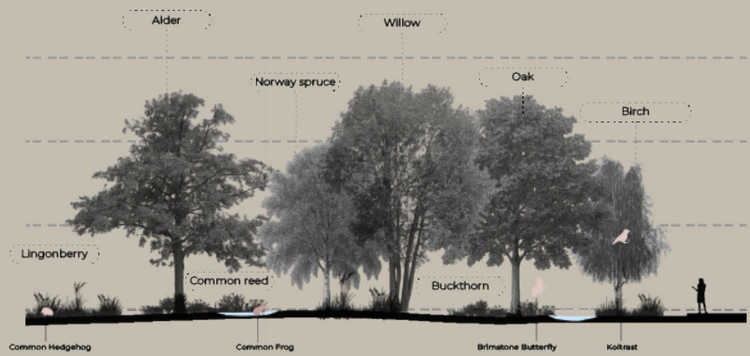
- Remove asphalt
- Permeable pavements
- Elevated paths

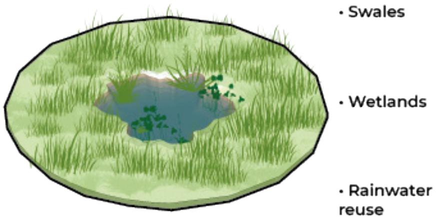
Restoring the ground to nature



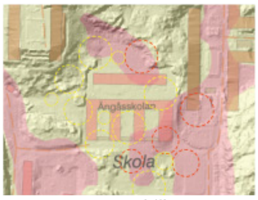
- Local species
- Improve soil permeability

Reviving soil and vegetation system





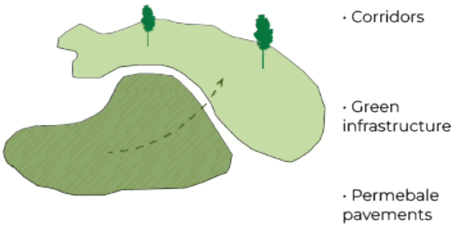
Rebuild natural water cycles



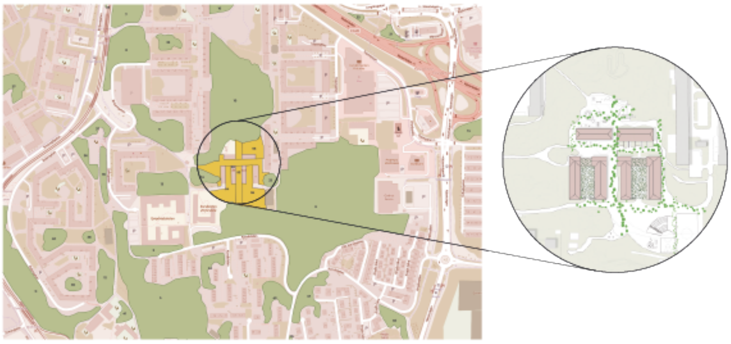
Permeability

Water flows

Current site - location of waterflows



Connecting fragmented habitats



3.5.2. Documentation

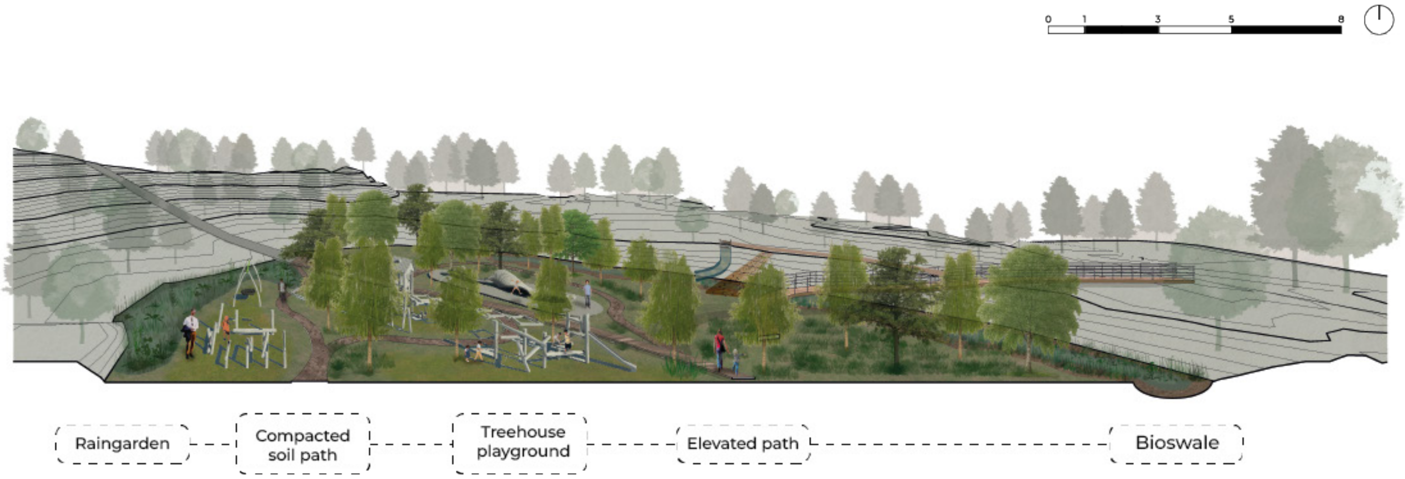
Plans, sections and visualizations are developed in this stage, generating a spatial proposal of the system in the existing site.

Symbology:

AREAS		GREEN INFRAESTRUCTURE	PEDESTRIAN PATHS
① Climbing playground	⑦ BBQ area	Bioswales	Existing asphalt
② Tree house playground	⑧ Pollinator garden	Raingardens	Compacted natural surface
③ Obstacles playground	⑨ Outdoor gym	Constructed wetland	Wood chips
④ Swings playground	⑩ Existing sports area		Exposed natural soil
⑤ Outside Cafe area		Existing trees	Elevated wood path
⑥ Communal gardens		Proposed trees	Bridge

DESIGN MASTER PLAN - GROUND FLOOR

PERSPECTIVE SECTION A



PLAYGROUNDS EXPERIENCE

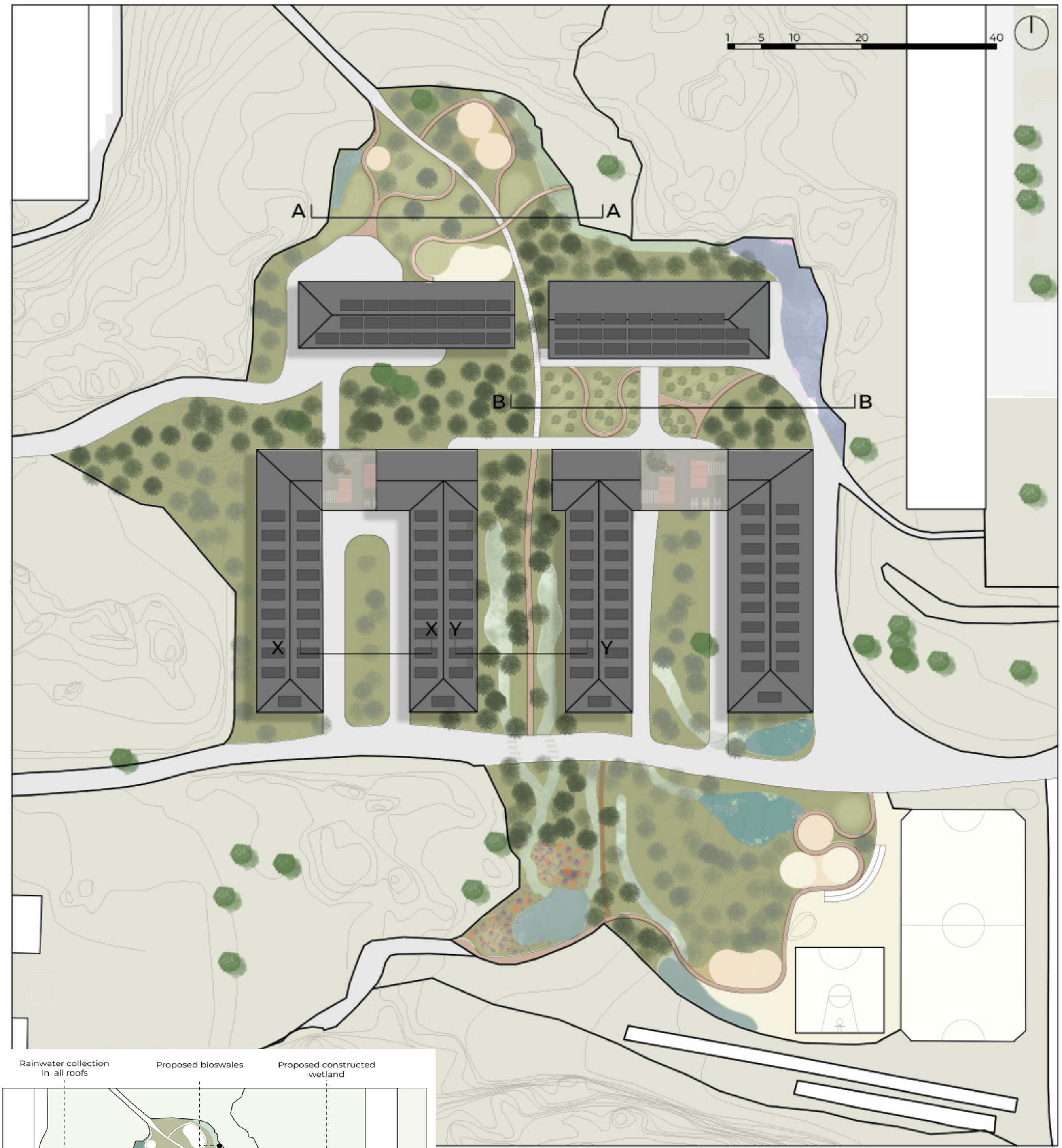
Obstacles playground
AI generated Google Gemini

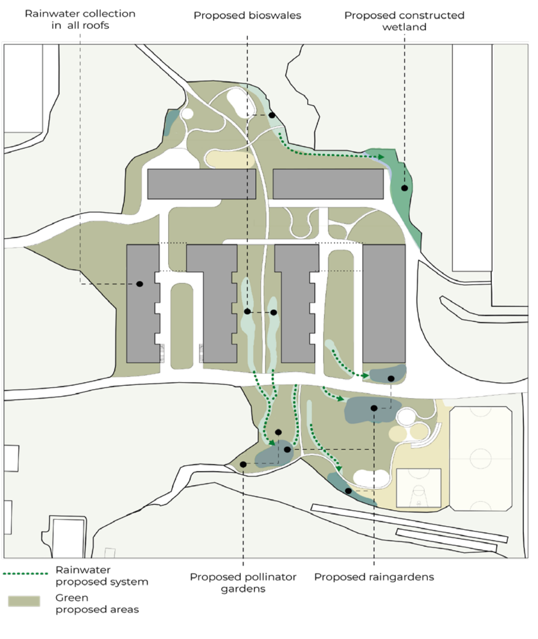
Treehouse playground
AI generated Google Gemini

Climbing playground
AI generated Google Gemini

PERSPECTIVE SECTION B

DESIGN MASTER PLAN - ROOF

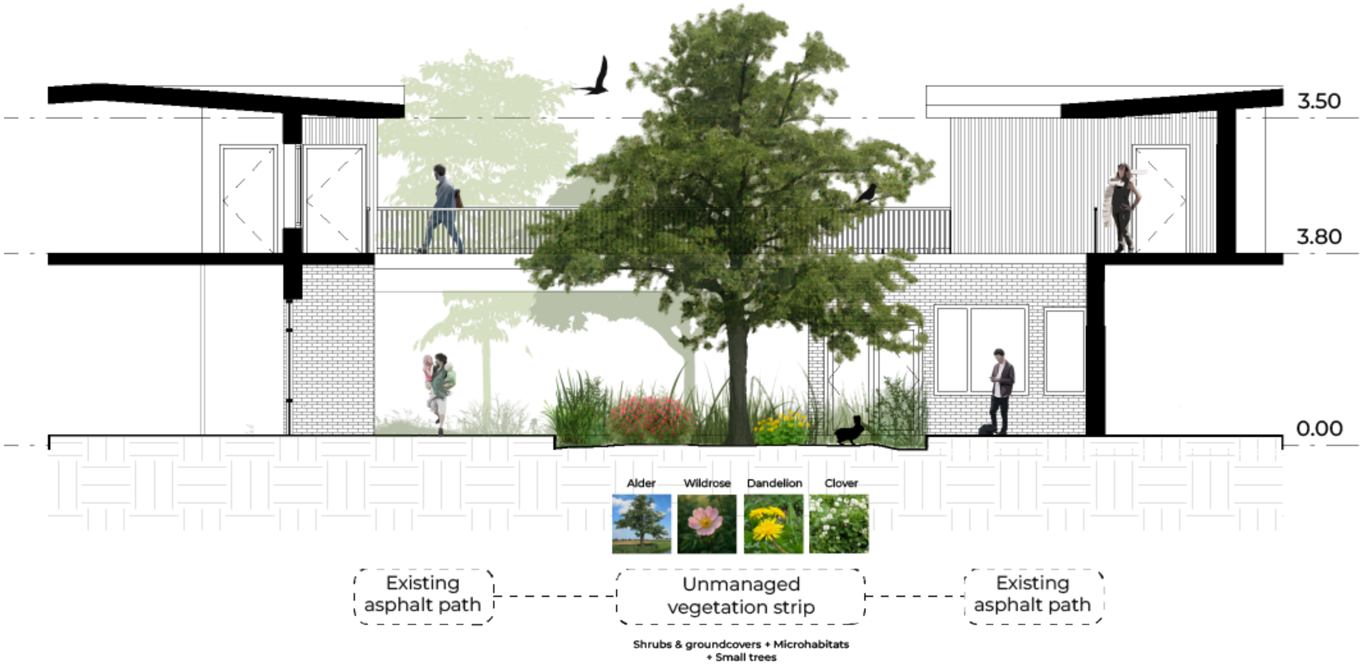


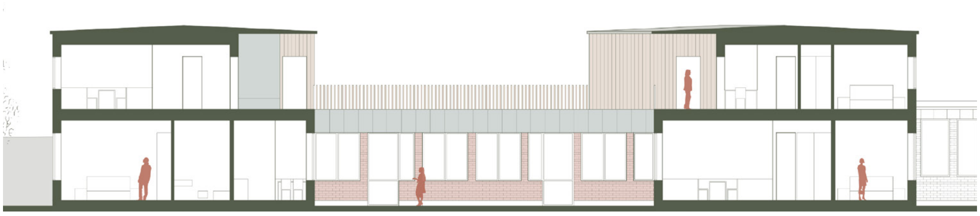


3.5.2.1. Green infrastructure

The connectivity of the site is not just determined by the horizontal green corridors, but elements that are part of the overall connectivity, offering spaces for animal movement and refuge but also supporting residents activities. Therefore, communal gardens, playgrounds that allows nature exploring, pedestrian pathways, swales and raingardens are part of the green infrastructure.

SECTION X - ESC. 1:150

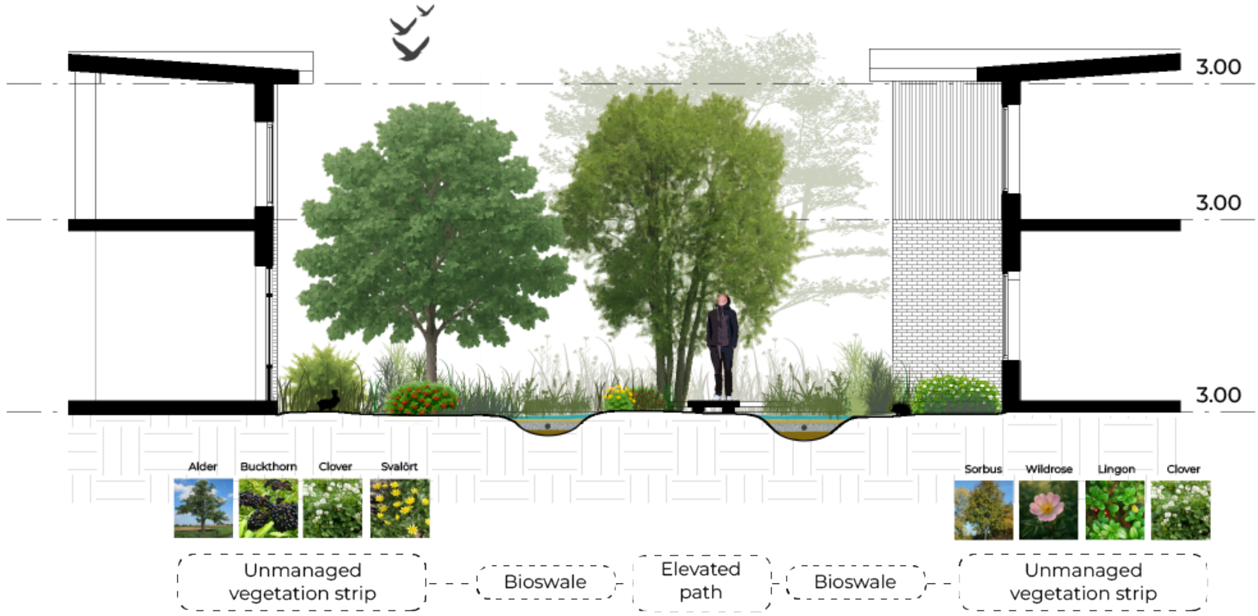




BEFORE - Figure 60. Housing and Beyond section BB

Image created with Sketchup, Twinmotion, Enhance with DALL-E 3 and AI Nanobanana

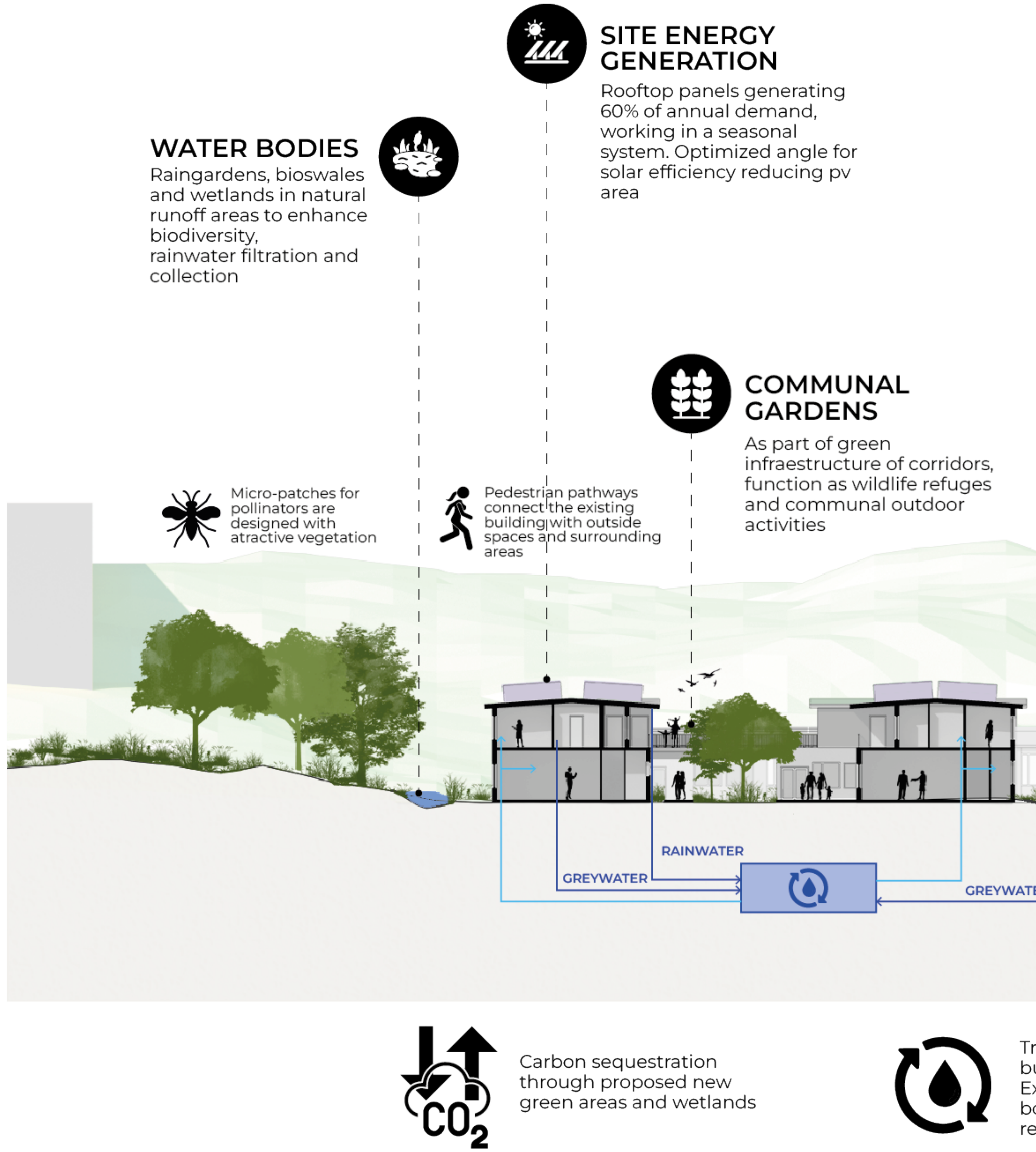
SECTION Y - ESC. 1:150



BEFORE - Figure 61. Housing and Beyond section BB

View to south facade of the complex. Image created with Revit, Photoshop, Enhance AI Nano Banana

SUMMARY ILLUSTRATIVE SECTION - EAST TO WEST



WILDLIFE CORRIDORS

Prioritizes nature with diverse local plants and water infrestructure to support biodiversity and animal movement

CO-EXISTENCE WITH NATURE

Combines pedestrian pathways with green spaces, promoting human-wildlife coexistence.

WILDLIFE REFUGES

Green areas served as “stepping stones” along the green corridors serving as refuges for animals

RAINWATER HARVESTING

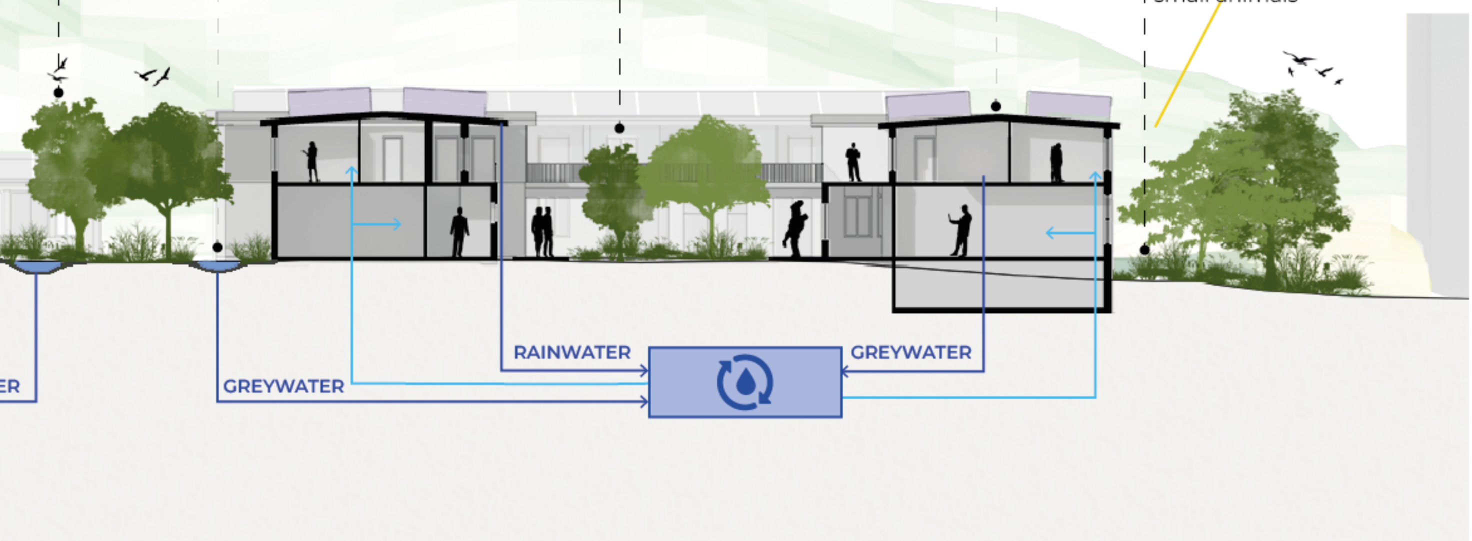
36% of annual water demand can be potentially collected in roof and floor surfaces. Used for non-potable needs

GREYWATER TREATMENT

Horizontal Flow Constructed Wetland treat greywater from the existing buildings to be reuse

Soil repair by removing pavement and allowing water to filter through naturally

Proposed around 5 000m² of new green areas with local, non-invasive plants to support pollinators and small animals



eated water reused in uildings or for irrigation. xcess water feed water odies, filters into soil, eplenishing groundwater.

Vegetation responding to the site specific conditions and needs align with needs of the existing building

Aerial view. Revit + Lumion + Photoshop

4. CONCLUSIONS AND DISCUSSION

The current context of architectural practice is still inadequate to address environmental crises. Design interventions are often fragmented and generic, applied without context resulting is a set of detached strategies, frequently technocentric add-ons that do not respond to the reality of a site and therefore fail to contribute to environmental health. Today, however, the availability of tools and data gives architects and designers the possibility to work within multidisciplinary fields, moving beyond conventional workflows and integrating contextual information into design decisions.

This research proposed an exploratory transformation exercise using an existing building complex to move beyond sustainability toward regeneration in an early design stage project. Following a Design-based Research methodology, the process began with an environmental site analysis to understand site conditions and the needs of what already exists. From this, the problem definition emerged, in which the potentialities of the site were explored. Next, literature and case references were revised to collect solutions suitable for the site conditions aligned with the previously identified potentialities but considerer the relevance with the regenerative principles previously analyzed.

Moving into the next stage, the core of the research, an hypothesis is proposed and tested through a performance-driven assessment. This assessment was conducted using computational tools that not only extracted data but converted them into trial scenarios simulating the site and project conditions. As this unfolded, the management of data, the interpretation of results, and the iteration of different proposed scenarios constituted a research process in themselves. Parallel to these iterations, conversations with experts in energy, water, and ecology contributed to the definition of the final proposal, which was organized into three interrelated fields of action aligned with regenerative objectives.

As a result, the proposal became a compilation of the experimentation outcomes, where performance-based decisions prompted the question: Is the most effective option always the most optimal? At this moment, one of the principles of regenerative design reinforced the direction of the project. Since regeneration operates as a system, a synergy between what exists and what is new, the strategies tested were not isolated solutions but complementary, and sometimes even dependent, actions with reciprocal consequences. Consequently, the best-calculated scenarios were not always selected for the final proposal.

The final outcome is the proposal of an early stage system that contemplates the reconnection of forest pieces through green infrastructure (green areas, raingardens and bioswales) recover water cycles, within the natural physical water flows, improve soil filtration, collect rainwater that can cover a part of the non-potable demand of the building and treat wastewater on site to be reuse. Also, energy is targeted through the recover of heat energy from existing resources within the building complex and the collection of solar energy in roof to cover a part of the annual energy demand.

Finally, through a Research-through-Design methodology, the system was translated into design intentions, where everything already existing was considered part of the site intervention. Thus, the transformation of the site consisted of gathering the needs of the existing project and spatially exploring how they could converge with the new system proposed in this research. This speculative design exercise envisioned a green corridor supporting animal movement while functioning as a habitat connector not only within the natural environment but also for the residents of the existing building complex. Also, natural water flows were integrated into playgrounds and outdoor spaces, supporting biodiversity and natural cycles while interacting with the existing activities in the area. However, understanding that in-depth knowledge and participation is needed for future stages of development in the current project.

4.1. Objectives

Regenerative principles were identified through theories from Lyle (1194), Reed (2007) and Mang y Haggard (2016), and then translated into spatial strategies in the design development stage, responding to the logic of the context and the site.

Computational tools such as QGIS, Rhino + Grasshopper, etc., were applied, and became a central part of the design workflow allowing the extraction of data, and the test and iteration of spatial solutions to develop the design proposal.

The performance and evaluation of potential in the proposed regenerative solution system was carried out in the Design-decision making stage, analyzing their capacity to work together as a system and defining the final design proposal.

4.2. Research questions

How can the ecological components of regenerative design principles be translated into site-responsive, interconnected spatial design strategies to transform an existing sustainable architectural project into a regenerative one?

This project demonstrates the translation of defined regenerative principles into actionable strategies when the strategies proposed are conceived through a holistic design approach. However, it also shows the limits of performance-driven design, where not everything measurable is meaningful for the overall objectives of the design. Regeneration aims to create more of what it takes, but this statement, when applied to isolated solutions, can result in counterproductive proposals.
In that way, the systemic thinking approach highlighted by several authors who have defined regenerative principles for architectural and spatial design becomes essential. Therefore, this thesis presents the transformation of an existing building complex, an academic exercise with sustainable characteristics, seeking to go beyond sustainability by analyzing how this project can contribute to ecosystem health. For that, the site analysis was a core stage, providing an environmentally grounded understanding of the site and its existing conditions.

In addition, the exploration of multidisciplinary knowledge was an important part of this thesis, demonstrating that collaboration across fields is mandatory when regeneration is part of the design intentions. Then, once a hypothesis sustained by regenerative objectives was defined, several strategies were tested, establishing parameters to assess and compare their performance potential. For this, an holistic analysis supported by expert consultation and literature review helped determine the optimal design system proposal to be applied on site.

Which computational tools and workflows can support the application of regenerative design strategies to transform an existing sustainable architectural project?

With Geographic Information System tools, ecological and environmental data was extracted to be analyzed, becoming an essential tool to manage information from different fields like water cycles or topography characteristics. Since this research was focused on the ecological component of regenerative design, ecological data such as fauna and flora definition or soil quality was crucial for the development of the proposal. As the project advanced into later stages, tools like Grasshopper through Rhino allowed the parametric iteration of the strategies proposed, applied to the specific site; in other words, using simulations of the site conditions. Consequently, this made possible the interaction with different factors at the same time and in defined scenarios, e.g. solar incidence in winter and summer over the PV panels.

However, **full systemic integration at a computational level was not achieved** through this thesis project. Limitations in software knowledge and tools availability undermined the definition of a workflow capable of interacting with all the strategies suggested simultaneously, receiving immediate feedback to be translated into design intentions. Even so, the systemic integration was carried out in a more analog way, where computational tools were used separately but their results contributed to other processes, functioning in collaboration with each other.

In addition, specific tools were incorporated when required by particular site conditions. For example, CONEFOR was used as a response to the need to analyze animal movement, allowing a spatial ecology and conservation planning tool to support this analytical step. Finally, Building Information Modelling through Revit supported the design development process, where strategies were applied as spatial interventions on site, as well as the documentation creation. For visualization, tools like Photoshop and Illustrator were core components of the workflow, while the generative potential of AI was briefly tested, allowing the visual exploration of scenarios on site through detailed descriptions of the design proposal.

Overall, the computational tools were decisive for the entire development of the thesis, proving to support the role of architects in connecting different disciplines to generate a design proposal that transform an existing site into a regenerative project.

About the metrics and calculations

This projects developed an early stage design which means that the project viability will be stated, identifying constraints and limitations, and present basic documentation to explore potential solutions and get a preliminary look of the functional and aesthetics aspects of a project. Therefore, the calculations performed during this research represent an approximation of the potentialities for the project. Thus, those does not represent in any way, a final calculation with exact fidelity to real conditions. A lot of simulations has been based on well - grounded data and assumptions where its relevance has been verified in consultations with experts on the subject, and compared with literature but can no be stated as final numbers or representation of reality. To get final results on metrics and calculations, closer to real contexts, it should be conducted deeper analysis in later stages of the project with participation of experts in the specific areas, which may modify which has been here presented.

Architecture as a response of the context

This project shows that architecture can not longer be separated from the ecological, social, or cultural contexts that host it, not just with a physical connection, but nowadays building are increasingly expected to be aligned with natural dynamics, to start being part of its surrounding, understanding its impact and generating benefits, not just reducing harm. However, this shifts demands a change in how architecture is conceived, where the designers should now work across fields such as ecology, sociology and engineering, raising the uncomfortable question of whether architects are prepared to handle this level of complexity and data.

The Role of Computational Design: A Bridge, Not a Shortcut

This project is an experimental platform where computational tools connect ecological data

with design decisions. The premise is not that architects must master every technical domain, but that they must interpret interdisciplinary inputs into spatial, ecological, and perceptual understanding. A building begins with habitat and community, not with construction. However this process rely heavily on parameters and its performance assesmen, which, can led to wrong assumption or interpretations specially in early stages of design. The results obtained through this thesis proposal are theoretical, tested in computational simulation that While these initial approaches can certainly bring the architect closer to the correct functioning of the proposal, where the project objectives are met, they are far from the real-world solution. The complexity of a system makes it impossible to accurately predict the success of the proposal, where not all strategies can be tested or not all conditions can be simulated. Furthermore, uncertainty increases when working with unpredictable natural elements. Therefore, in addition to the initial design stage covered in this thesis, the iterative analysis process demonstrated by this project should be applied to subsequent design stages.
In other words, a design process based on parameters defined in computational flows can reduce uncertainty at the time of design, can inform about the conditions for generating a contextual design and also give an idea about its impact, but it is far from being a completely faithful representation of the reality of the site and the response of the project.

The Architect´s evolving responsibility

Throughout the project, the question emerged: What is the architect's role in regenerative design? Working across ecology, engineering, data science, and design, this thesis revealed both the potential and limits of the architect as a systemic thinker and integrator.
Conversations with the architects Ken Yeang, Mauro Cepeda, and Santiago Morales exposed differing but complementary views:

Yeang: Design must begin with a holistic ecological process. Isolated or generic strategies are fundamentally flawed. Architecture requires cross-disciplinary integration from day zero, and long-term monitoring is non-negotiable.

Cepeda & Morales: Architects should not mistake themselves for engineers. Metrics and certifications risk distorting design intent. Numbers matter, but so does reading climate through perception, understanding communities, and judging qualitative impacts. Tools enhance design, only when grounded in theory and real application.

It seems that the architecture practice is changing, where architects must integrate environmental, cultural, and social knowledge as deeply as they understand structural principles, and regeneration seems to provide tools this holistic mindset.

Regeneration is not a fixed goal; it is a process of continuous adaptation. Site, context, ecological functions, spatial responses, and the users needs guide the design, not just abstract metrics. Digital tools help clarify these complex interactions, but they cannot replace critical judgment. Therefore, Regeneration tries to be a shift in how architects approach design: a combination of performance data, coexistence, ecological responsibility, and long-term resilience.

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6. APPENDIX

ENVIRONMENTAL SITE ANALYSIS

1. GENERAL CONDITIONS - HOW THE DATA WAS EXTRACTED?

Mölndal is chosen as the weather analysis location for availability of data and location close to the study area (Tynnered). The data is extracted from the website Weather Spark, which explain the data source as follow:

- The report illustrates the typical weather in Mölndal, based on a statistical analysis of historical hourly weather reports and model reconstructions from January 1, 1980 to December 31, 2016
- The temperature is an estimation of the 3 weather station available in the area: Gothenburg City Airport (ESGP, 59%, 16 km, northwest, 10 m elevation change), Gothenburg-Landvetter Airport (ESGG, 37%, 16 km, east, 146 m elevation change), Anholt Island Automated Reporting Station (EKAT, 3.2%, 110 km, south, 0 m elevation change). For each station, the records are corrected for the elevation difference between that station and Mölndal according to the International Standard Atmosphere , and by the relative change present in the MERRA-2 satellite-era reanalysis between the two locations.
- All other weather data, including cloud cover, precipitation, wind speed and direction, and solar flux, come from NASA's MERRA-2 Modern-Era Retrospective Analysis . This reanalysis combines a variety of wide-area measurements in a state-of-the-art global meteorological model to reconstruct the hourly history of weather throughout the world on a 50-kilometer grid.

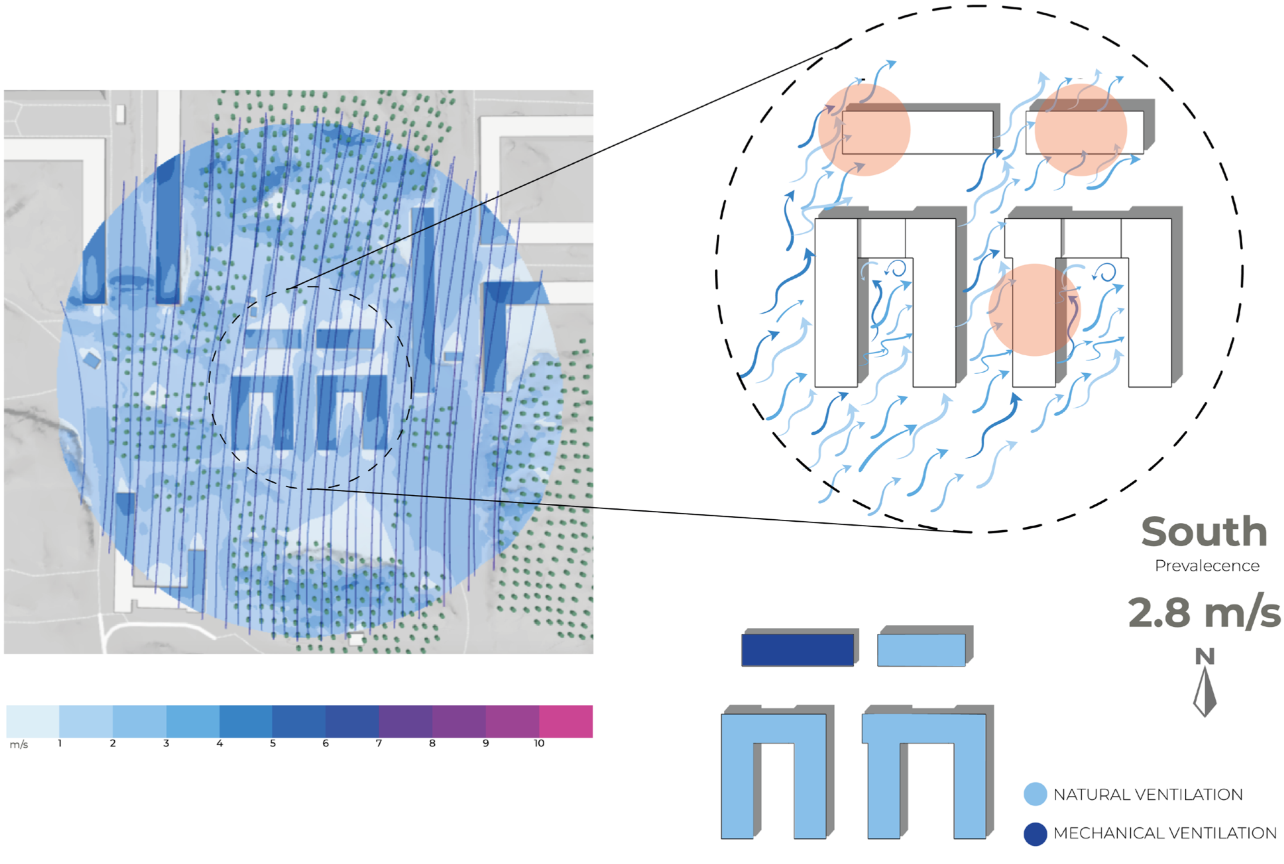


Image 1. Wind conditions on site

2 SPECIFIC CONDITIONS

Analysis of land topography to determine the direction of the runoff, and where there can be water accumulation. Grasshopper + Helk.

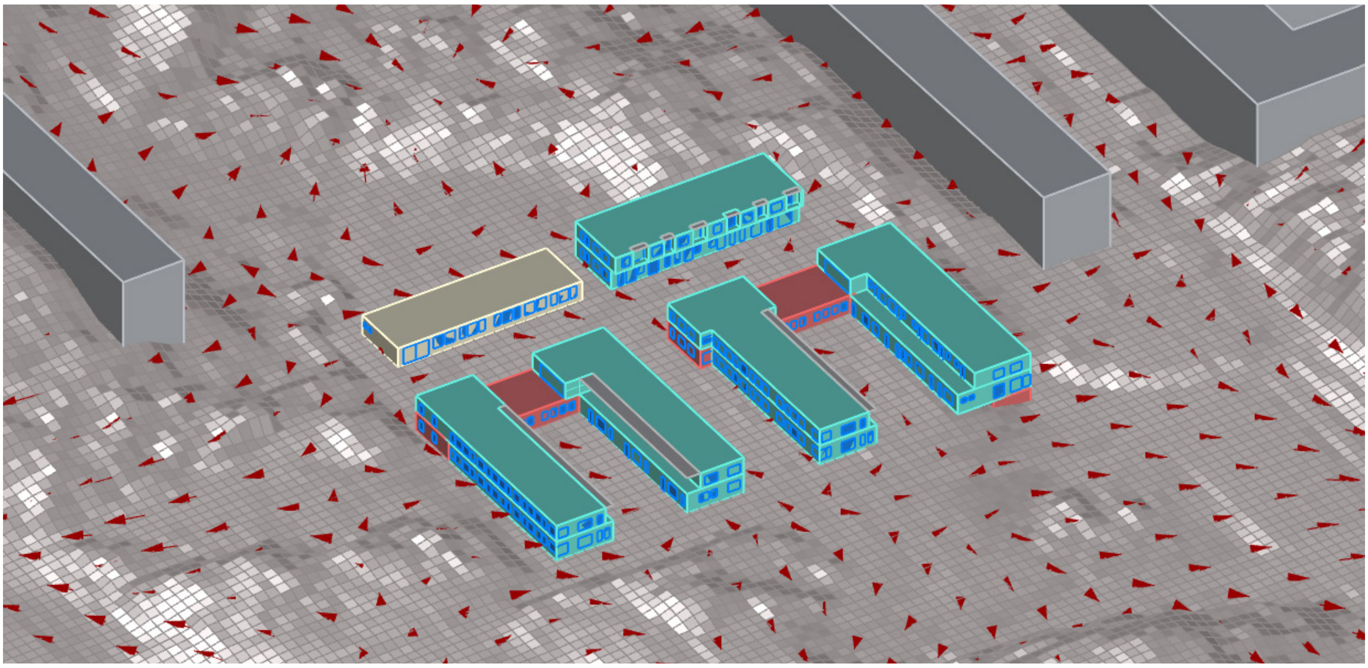
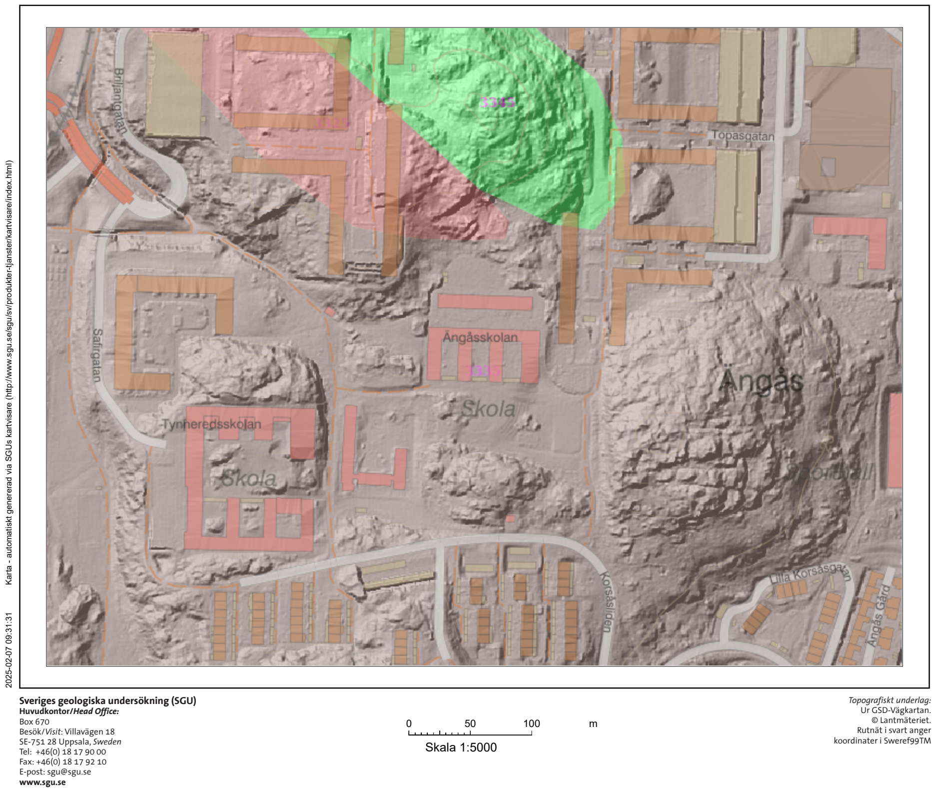


Image 2. Identification of streams direction based on topography

3 SPECIFIC CONDITIONS - SOIL QUALITY

The soil composition is extracted from the Digital Soil Map of Sweden and refers to topsoil permeability (upper 2 dm). Regarding to the permeability, the FAO (2021) states that even in bedrock granite type soils the medium/high permeability characteristics of the overlying can reduce runoff and flooding risk by allowing rapid infiltration. Moreover, the quality of the bedrock can be a factor of influence in the permeability of soils, for example fractures and granular decomposition in granite can allow high permeability while less weathered or exposed bedrock with limited fractures is more feasible to have medium permeability.



LEGEND

- Granitoid metamorphic
- Granite syenitoid
- Gabbro, pyroxenite, anorthosite, diabase, granophyric, granite and metamorphic equivalents

Image 3. Soil bedrock materials. Source: SGU

4 SPECIFIC CONDITIONS - BIODIVERSITY

These tables are compiled after a search for the most common species in the Västra Götaland area. The search engine used to extract the data is the GBIF (Global Biodiversity Information Facility), a global database that presents the occurrences of various species. This database is fed by other databases; in this case, the information available on Artportalen, which is an open system to report the species observation in Sweden. Occurrences refer to an individual record of species that have been observed, each occurrence being a data point that provides evidence of the presence of a particular species in a particular location. This data is feed with other portals: Bird Ringing Centre in Sweden (NRM) Lund University Biological Museum - Botanical collection, and the SLU Artdatabanken. It is understood that the information on the most common species may not be accurate since this designation depends on many variables and in-depth studies; however, as an academic exercise, this data offers a sample of the species in the area.

Category	Common Name	Scientific Name	Habitat Notes
Trees	Scots pine	*Pinus sylvestris*	Dominant on drier slopes; significant regionally.
	Birch	*Betula pendula/pubescens*	Common on drier slopes; regenerating consistently.
	Pedunculate oak	*Quercus robur*	Mixed woods; large trees host rich epiphytic flora.
	Rowan	*Sorbus aucuparia*	Mixed woods.
	Norway spruce	*Picea abies*	Less common; present mainly through plantings.
	Alder	*Alnus glutinosa*	Wetter hollows, around ponds and streams.
	Willow	*Salix spp.*	Wetter areas near water sources.
Shrubs and Understory	Juniper	*Juniperus communis*	Rocky ground.
	Heather ("ljung")	*Calluna vulgaris*	Abundant on granite outcrops; blooms in late summer.
	Blueberry ("blåbär")	*Vaccinium myrtillus*	Common understory in pine woods, berries annually.
	Lingonberry ("lingon")	*Vaccinium vitis-idaea*	Common understory in pine woods, berries annually.
	Bracken fern	*Pteridium aquilinum*	Common on forest floor.
	Raspberry	*Rubus idaeus*	Thickets along trails.
	Honeysuckle	*Lonicera periclymenum*	Thickets along trails.
Herbs and Flowers	Wood anemone ("vitsippa")	*Anemone nemorosa*	Deciduous groves; blooms prominently in spring.
	Lesser celandine ("svalört")	*Ficaria verna*	Shady spots in deciduous areas.
	Greater celandine ("skelört")	*Chelidonium majus*	Shady, sheltered areas.
	Dandelion	*Taraxacum spp.*	Open lawns, meadows; widespread.
	Clover	*Trifolium spp.*	Common in grassy open areas.
	Yarrow	*Achillea millefolium*	Meadows and grasslands.
	Buttercup	*Ranunculus spp.*	Commonly found in open grassy areas.
	Common reed	*Phragmites australis*	Wet corners with standing water.
	Bulrush	*Typha spp.*	Standing water, marshy conditions.
	Marsh marigold	*Caltha palustris*	Ditches and wet depressions.
Fungi and Mosses	Hypnum mosses	*Hypnum spp.*	Boulders, forest floor.
	Cladonia lichens	*Cladonia spp.*	Thin soils on rocky outcrops.

Table 1. Vegetation species in the area

Common Name	Swedish Name	Scientific Name	Habitat/Notes
Roe deer	Rådjur	*Capreolus capreolus*	Urban fringes, gardens, common locally
Moose	Älg	*Alces alces*	Surrounding forests, occasional visits
Wild boar	Vildsvin	*Sus scrofa*	Increasing around city outskirts
Red fox	Rödräv	*Vulpes vulpes*	Urban-adapted, gardens, occasional mange
European badger	Grävling	*Meles meles*	Gardens, suburban areas
European hedgehog	Igelkott	*Erinaceus europaeus*	Gardens, nocturnal
Red squirrel	Ekorre	*Sciurus vulgaris*	Forests, gardens, common on mature trees
Brown hare	Fälthare	*Lepus europaeus*	Fields, lawns, open grasslands
Bats (common pipistrelle, northern bat)	Fladdermöss	Various	Roost in old trees, forage over clearings

Table 3. Mammals species in the area

Category	Common Name	Swedish Name	Scientific Name	Habitat/Notes
Butterflies	Small tortoiseshell	Nässelfjäril	*Aglais urticae*	Gardens, meadows
	Brimstone	Citronfjäril	*Gonepteryx rhamni*	Gardens, woodlands, early spring
	Painted lady	Tistelfjäril	*Vanessa cardui*	Meadows, gardens
	Peacock	Påfågelöga	*Aglais io*	Gardens, meadows
	Green-veined white	Rapsfjäril	*Pieris napi*	Gardens, fields, hedgerows
	Common blue	Puktörneblåvinge	*Polyommatus icarus*	Grasslands, meadows
Bees and Wasps	European honeybee	Honungsbi	*Apis mellifera*	Gardens, urban parks
	Bumblebees	Humlor	*Bombus spp.*	Common pollinators, widespread
	Common wasps	Getingar	*Vespula spp.*	Gardens, urban spaces
Beetles and Others	Seven-spot ladybug	Sjuprickig nyckelpiga	*Coccinella septempunctata*	Gardens, urban greenery
	Ground beetles	Jordlöpare	Various	Forest floor, gardens
	Leaf beetles	Bladbaggar	Various	Forest edges, shrubs

Table 5. Pollinator species in the area

Category	Common Name	Swedish Name	Scientific Name	Habitat/Notes
Urban/Suburban Birds	Great tit	Talgoxe	*Parus major*	Common in gardens and parks
	Blue tit	Blåmes	*Cyanistes caeruleus*	Gardens, feeders, woodlands
	Eurasian blackbird	Koltrast	*Turdus merula*	Gardens, lawns, hedges
	Eurasian magpie	Skata	*Pica pica*	Very common urban scavenger
	House sparrow	Gråsparv	*Passer domesticus*	Common in urban areas, near houses
	Great spotted woodpecker	Större hackspett	*Dendrocopos major*	Trees, parks, gardens
Forest/Parkland Birds	Eurasian jay	Nötskrika	*Garrulus glandarius*	Woodland areas, oaks
	Chaffinch	Bofink	*Fringilla coelebs*	Woodlands, parks, gardens
	Common chiffchaff	Gransångare	*Phylloscopus collybita*	Wooded areas, shrubs
	Robin	Rödhake	*Erithacus rubecula*	Woodlands, gardens
Birds of Prey	Eurasian sparrowhawk	Sparvhök	*Accipiter nisus*	Woodland edges, hunts small birds
	Common kestrel	Tornfalk	*Falco tinnunculus*	Open areas, fields, urban outskirts
Regionally significant	White-backed woodpecker	Vitryggig hackspett	*Dendrocopos leucotos*	Mature forests, conservation importance
	Tawny owl	Kattuggla	*Strix aluco*	Mature forests, old trees

Table 4. Bird species in the area

5. SPECIFIC CONDITIONS - WATER CONSUMPTION

The calculation of water demand for the was solved using **a fixture-based approach**, that is the reliable existing data from the Housing and Beyond project. It was based on the reference document Dimensioneringstal för vatten- och avloppsinstallationer (VAV P83, Svenskt Vatten) and cross-checked against Swedish average consumption statistics. This allows that the results are both technically aligned with national guidance and consistent with per-capita use.

5.1 Fixture flows: evidence-based values

The first step was to extract the flow rates and volumes per event for each installed fixture. These were obtained directly from the selected manufacturer product sheets, from fixtures in the Swedish market:

FIXTURE	BASELINE		BRAND
TOILET	2.5	lpf	Toalettstol Gustavsberg
LAVATORY	4	lpm	FM Mattsson
KITCHEN FAUCET	5.5	lpm	FM Mattsson
SHOWER	9.5	lpm	FM Mattsson
DISHWASHER	9	l/cycle	Bosch Series 4
LAUNDRY	50	l/cycle	Electrolux Series 600
URINAL	1	lpf	Gustavsberg

Table 5. Baseline flow rates by fixture

lpf = liters per fludh
lpm = liters per minute
lpc = liters per cycle

5.2 Usage assumptions: scenario-based, anchored to evidence:

In the second step typical daily usage frequencies or durations per fixture were assigned. VAV P83 does not specify fixed daily use per fixture, but provides standard flow capacities and guidance on simultaneity for system dimensioning. To translate this into daily consumption values, usage had to be assumed.

To avoid arbitrary choices, usage was based onto two forms of evidence:

- Swedish household water statistics: Average domestic consumption in Sweden is 140L/person/day (Johansson et. all., 2007). This is generally distributed as 30L for toilet flushing, 60L for personal hygiene (showers and handwashing), 15L for dishwashing, 15L for laundry, and the remainder for cooking/cleaning. (Johansson et. all., 2007) These figures were used as a benchmark to ensure the modeled totals remained realistic.

- A medium baseline scenario: Consultation with an expert allows to generate assumed values that were compared with other water calculation methods (U.S. Green council Guidelines for water calculation). Therefore, the values are based on typical practice/archetypes, dependent on spaces usage. The VAV P83 report explicitly warns about this kind of uncertainty and recommends sensitivity testing and documentation. Thus, the numbers represent a medium sensitivity scenario that can be proved with average Swedish water consumption.
For this exercise, the values used are:

VOLUME PER-FIXTURE PER DAY *assumed

		Housing	Café	Gym	Communal kitchen
Toilet	f/toilet/day	18	60	45	30
Shower*	l/shower fixture/day	106	-	-	-
Kitchen faucet	min/faucet/day	25	90	-	45
Lavatory	min/basin/day	8	30	15	15
Urinal	f/urinal/day	-	92	-	-
Dishwasher	cycles/day/unit	1.25	6.15	-	1.5
Laundry	cycles/day/unit	0.4	-	-	-

* Assumed a shower of 8 minutes and 1.40 showers/fixture/day

Table 6. Assumed volume per-fixture per-day

5.3 Calculation procedure

Daily consumption per fixture was calculated as follows:

- Toilets and urinals: number of flushes × flush volume.
- Taps and showers: minutes of use × flow rate (L/min). For showers, minutes per event were multiplied by the number of shower events per day.
- Dishwashers and laundry machines: number of cycles × volume per cycle.

The resulting per-fixture daily consumption was multiplied by the number of fixtures in each program (housing, café, gym, communal kitchen). The totals were summed to obtain building-wide daily demand (litres/day), converted to cubic metres per day (m^3/day), and extrapolated to annual values (m^3/year).

TOTAL DAILY CONSUMPTION l/day

	Housing	Café	Gym	Communal kitchen
Toilet	1980	600	225	150
Shower	4682	-	-	-
Kitchen faucet	4538	990	-	990
Lavatory	1408	600	120	120
Urinal	-	92	-	-
Dishwasher	371	111	-	27
Laundry	119	-	-	-
TOTAL	**13097**	**2393**	**345**	**1287**

TOTAL WATER CONSUMPTION	17.12 m3/day	6249 m3/year
GREYWATER	7.05 m3/day	2573 m3/year
BLACKWATER	10.07 m3/day	3677 m3/year

Table 7. Total daily consumption

Blackwater and greywater separation

For the purpose of system design, demand was split into blackwater and greywater categories.

- Blackwater sources: Assumed as toilets, urinals, and kitchen taps
- Greywater sources: Showers, lavatories, dishwashers, and laundry

It should be noted that regulatory frameworks sometimes classified dishwashers and laundry as blackwater due to contamination, however, the considerations can be redesigned in later stages of the project.

Conclusions

}The most influential variables in the exercise are the assumed number of shower events per day and kitchen tap usage time. For example, if every resident showered once daily (instead of 1.40 showers per fixture), shower demand alone would nearly double. Therefore, reducing kitchen faucet minutes has a significant impact on greywater volumes. Thus, while the fixture flows are evidence-based, the daily usage frequencies must be treated as scenarios rather than precise predictions.

As a calculation check, the result is divided by the number of residents in the project: 118 people, this equals **145 L/person/day**, slightly higher than the Swedish national household average. The increase is justified because the project includes café, communal kitchen, and gym facilities, which add to the load.

DESIGN-DECISION MAKING

European hedgehog (Erinaceus europaeus)
Added to Sweden's Red List in 2020 as Near Threatened, the hedgehog has declined by roughly 40 % since 1998 (Thurfjell 2020; Halkjaer 2025). Habitat loss, pesticide use and road mortality are the main causes. Many hedgehogs now persist mainly in towns and gardens, and sightings in Gothenburg suggest the city provides a refuge as rural populations wane.

Ecological role
Nocturnal insectivores, hedgehogs curb urban pests by eating slugs, snails, earthworms, beetles and caterpillars, plus small vertebrates and fallen fruit. Their droppings redistribute nutrients and seeds, and they themselves feed larger carnivores, though in cities cars and lawn-mowers are the chief threats. Hedgehogs need mosaic habitats with brush piles, leaf litter and log stacks for cover and hibernation. A hedgehog-friendly green space, with "messy" corners, compost and minimal chemicals, also sustains rich communities of soil fauna, amphibians and other small wildlife.

Eurasian blackbird (Turdus merula)
Once a forest species, the blackbird colonised cities in the nineteenth–twentieth centuries and is now classed as kulturgynnad, benefited by human landscapes (Sjöberg 2003). Not red-listed, its urban populations are stable or rising; milder winters and plentiful food keep more individuals in southern Swedish cities year-round (Johansson 2015). Because blackbirds coexist easily with people, ornithologists use them as indicators of urban ecosystem health (Karlsson 2014).

Ecological role
Omnivorous blackbirds eat worms, snails and insects as well as fruits and berries. By consuming grubs and slugs they help control garden pests, and their worm-pulling aerates lawns. Seed dispersal via berry consumption aids plant propagation and nutrient cycling. Blackbirds are prey for urban predators such as sparrowhawks and domestic cats, supporting those species' diets.
This specie of bird nest in dense shrubs, hedges or low trees and may raise two to three broods each season. Territories with varied vegetation benefit blackbirds and, in turn, many other songbirds and pollinators; bird diversity generally follows habitat heterogeneity (Hjorth 2025). Highly tolerant of humans, the blackbird is cherished for its melodious song, voted Sweden's national bird in 2015 (Johansson 2015). It adapts to city life by singing louder and at higher pitch to outcompete traffic noise, exploiting artificial light to extend singing hours, and visiting feeders or scavenging scraps. These behaviours show that blackbirds fulfill their ecological functions even under urban conditions.

Brimstone Butterfly (Gonepteryx rhamni)
The Brimstone is a widespread Palaearctic member of the white-and-yellow butterfly family Pieridae, common across Europe, Asia, and North Africa. Adults are medium-sized, with a wingspan of about 6 cm; males are bright sulphur yellow, while females are a pale greenish white. Remarkably long-lived for a butterfly, individuals can survive almost a full year by overwintering as adults (Settele et al., 2008).

Ecological role
Brimstones are key early-season pollinators. Because they hibernate through winter and can take to the wing on warm days as early as late February, they are often among the year's first butterflies (Schmidt 2025). In woodland habitats they are principal pollinators of primroses (Primula vulgaris), transferring pollen between the pin and thrum flower morphs and ensuring cross-pollination. Their larvae feed exclusively on buckthorn (Rhamnus spp.) leaves, influencing buckthorn populations through herbivory.

Throughout its life cycle the species uses a variety of habitats. Females lay eggs on alder or purging buckthorn growing in wetlands, scrub, and hedgerows (Settele et al., 2008). After breeding, adults disperse to woodland edges, hedges, and meadows for nectar, then seek sheltered evergreen thickets or ivy to hibernate (Schmidt 2025). Thanks to this adaptability, Brimstones also thrive in human-modified landscapes, parks and large gardens—provided that host plants and nectar sources are available.

Common Frog (Rana temporaria)

Specie	Umbrella species role	Tolerance to urban environments
 Common Hedgehog (Erinaceus europaeus) Photo: Michael Gäbler	STRONG	HIGH
 Koltrast (Turdus merula) Photo: Jonn Leffmann	MODERATE	VERY HIGH
 Brimstone Butterfly (Gonepteryx rhamni) Photo: Didier	STRONG	MODERATE
 Common Frog (vanlig groda) Photo: Jörg Hempe	STRONG	MODERATE

Table 6. Umbrella species role

The Common Frog, or European common frog, is a widely distributed amphibian native to Europe and parts of Asia (Ogrodowczyk et al., 2024). Adults measure roughly 7–10 cm, have smooth skin, and display variable colours, often brown or olive with dark spots and a mask-like patch behind the eyes. They breed in spring and can live five to ten years in the wild.

Ecological role

R. temporaria occupies two trophic positions. As adults they are generalist predators, consuming insects, spiders, worms, slugs, and snails; in gardens they provide natural pest control by devouring slugs and snails. Tadpoles graze on algae and detritus, cycling nutrients and limiting algal growth in ponds. Frogs themselves are prey for birds, fish, and small mammals, transferring energy from lower to higher trophic levels. In some ecosystems their abundance can even influence predator populations.Highly adaptable, the common frog inhabits forests, grasslands, peat bogs, marshes, and sub-arctic tundra edges, and it thrives in human-modified environments.Farmland, rural gardens, and city parks can all support populations if moist refuges and breeding ponds are available. Each spring adults gather in shallow ponds or slow-moving water to lay clumps of eggs. Outside the breeding season they disperse, sheltering in damp undergrowth, hedgerows, or leaf litter while hunting invertebrates. In winter they hibernate in pond mud or in humid terrestrial hide-outs such as log piles or cellars to avoid freezing. Even urban areas can host common frogs when ponds connect to surrounding green spaces.

1.6.1 UMBRELLA SPECIES CHARACTERISTICS

The movement ranges and dispersal probabilities of the four target species were compiled from published studies and analogous projects; site-specific probabilities were then adjusted to reflect Tynnered's climate and topography. Because data sets vary in scope and methodology, the values below represent logical ranges consistent with this analysis and the study area.

European hedgehog (Erinaceus europaeus)
In fragmented landscapes hedgehogs enlarge their home ranges and travel faster than in continuous habitat (Berger et al., 2020). Urban studies show that movement probability depends far more on habitat quality (80 %) than on connectivity (19 %) (Braaker et al., 2014). While Baker & Harris (2007) noted the hedgehog home ranges and urban barriers movement restricted if patches are >200 m apart in cities. Rondinini & Doncaster (2002) points that hedgehogs avoid roads and are reluctant to cross more than 80 m of open terrain.

Common frog (Rana temporaria)
Survival hinges on connectivity between breeding ponds and terrestrial refuges. Graph-based models demonstrate that anthropogenic barriers greatly impede dispersal, while specific habitat corridors are critical for movement. Elevation, land use, and distance to forest patches are the main determinants of connectivity (Decout et al., 2010; 2012).

Eurasian blackbird (Turdus merula)
Average juvenile dispersal in urban green corridors is about 500 m, whereas adults typically move around 100 m; documented home ranges can extend to roughly 1.27 km (Grim 2012; Mattson 2018). Movement probabilities vary with individual traits or vegetation.

SPECIE	RANGE OF MOVEMENT	MAXIMUN DISTANCE OF DISPERSAL	PROBABILITY OF MOVEMENT	SOURCE OF INDEX
Common Hedgehog	- 1 to 2 km nocturnal - 300 to 400 m - < 80 m open spaces	3.8 km	Assumed* 50% within 200 m because the open spaces	- Baker & Harris (2007) - (Korslund et al., 2024)
Koltrast	- 1.27 km home ranges - 30 m for nesting	800 to 2,000 km	Assumed* 50% within 200 m	(Mattson Monika, 2018)
Brimstone Butterfly	1 to 2 km	-	Assumed* 50% within 200 m because the open spaces	(Isaac et al., 2011)
Common Frog	100 to 300 m	1.5 km	Assumed* 50% within 200 m because the open spaces	(Shakhparonov et al., 2022)

Table 7. Summary of movement´s ranges of the umbrella species selected

7 LANDSCAPE CONNECTIVITY - WORKFLOW

The workflow developed for this project integrates spatial data preparation in QGIS 3.x with graph-theoretic analyses in CONEFOR Sensinode 2.6, a software package that allows quantifying the importance of habitat areas and links for the maintenance or improvement of connectivity, as well as evaluating the impacts on connectivity of habitat and landscape changes. The parameters to analyze the quality of connection in the landscape are: Target specie, the range of movement, maximun distance of dispersal and the probability of movement in the current conditions of the site. With this information the metrics calculated in CONEFOR are: NL, NC, AWF, Ec (PC) and PC, the table 8 explains their meaning according to CONEFOR manual user.

PARAMETER	DESCRIPTION	METRIC	TOOLS
Target specie	individual specie selected as the focus of the study as representative of other with similar needs and / or characteristics	**Connectivity indices** **NL** Number of links between patches **NC** Number of components, pieces **AWF** Area weighted flux: average of how many species are moving through the landscape. Average of all pairwise connections weighted by patch area and probability of connection **Ec (PC)** This is the effective habitat area that is reachable. The amount of "fully connected habitat area" **PC** Probability that two points or individuals are connected efficiently in the landscape	Qgis Conefor
Range of movement	The typical distance a species travels during its daily or routine activities (e.g., foraging, resting, mating), often within a known habitat or territory. (Baguette & Van Dyck, 2007):		
Maximun distance of dispersal	The furthest distance a species can move — usually during rare events like seasonal migration, territory shifts, or colonizing new habitat. (Nathan et al., 2003)		
Probability of movement	The likelihood that an individual will successfully move between two patches — typically a function of distance, barriers, and species traits.		

Table 8. Parameters and metrics to analyze landscape connectivity

Thus, the process of analysis is developed in 6 steps:

7.1 Data acquisition and harmonization.

Four sources were collected: (i) forest-stand polygons from Artdatabanken (SHP), (ii) species-occurrence records from Sveriges Natur-portalen (CSV), (iii) a 2 m digital elevation model from Lantmäteriet (DEM) and (iv) OpenStreetMap vector layers (roads, rivers, settlements). All layers were re-projected to SWEREF99 TM (EPSG 3006) and clipped to a 1.5 km radius area of interest centered on the focal landscape.

A performance analysis is done through Conefor to see the current quality of connection. The pieces of forest are considered nodes, and are assigned a number to recognize them:

7.2 Scenario construction.

Within QGIS, three mutually exclusive corridor networks were hand-digitised: Scenario 1 (north–south alignment; 52 nodes), Scenario 2 (east–west alignment; 52 nodes) and Scenario 3 (orthogonal composite; 56 nodes). Each scenario comprises candidate stepping-stone patches and their intended linear connections. A single quality-control loop allowed minor geometry edits where topological gaps or overlaps were detected.

NC: 5 components
NL: 124 links
AWF: 3.198545E10
EC (PC): 360671.50 m²
PC: 0.0578151 → 5.7%

Image 4. Current state of the nodes. QGIS and identification on existing nodes (forest patches)

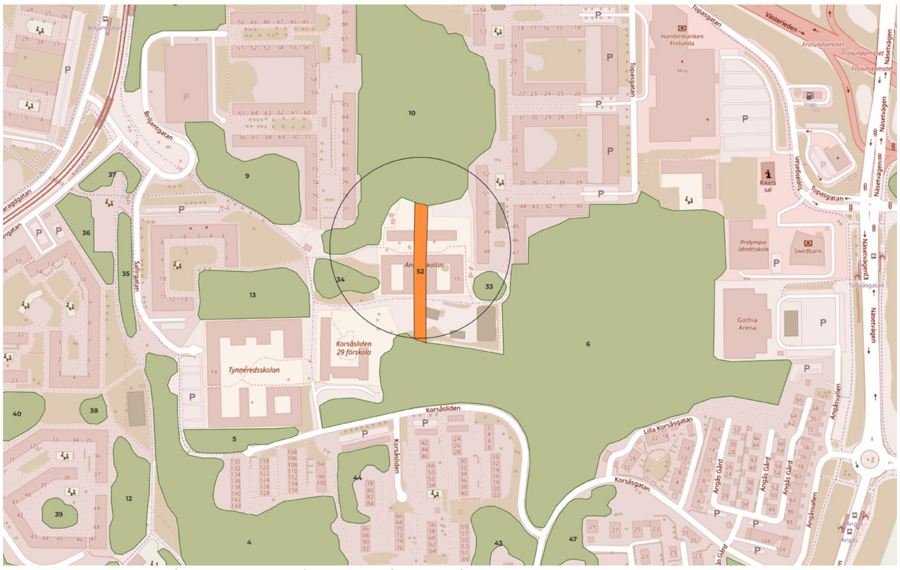


Image 5. Scenario 1 Connection North-south

NC: 5 components
NL: 133 links
AWF: 3.256541E10
EC (PC): 370953.32 m²
PC: 0.0596450→ 5.9%

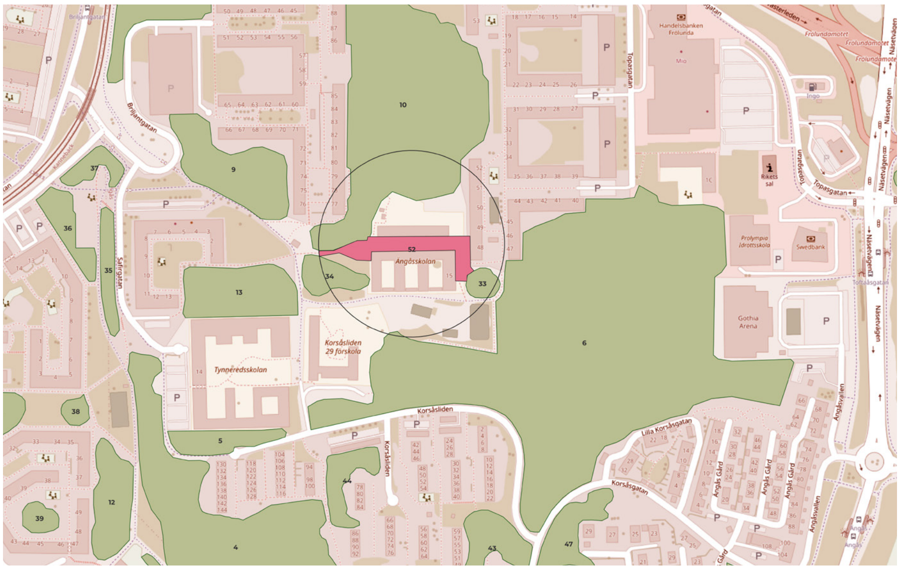


Image 6. Scenario 2 Connection east-west

NC: 5 components
NL: 134 links
AWF: 3.546582E10
EC (PC): 371025.25 m²
PC: 0.0598631 → 5.9%

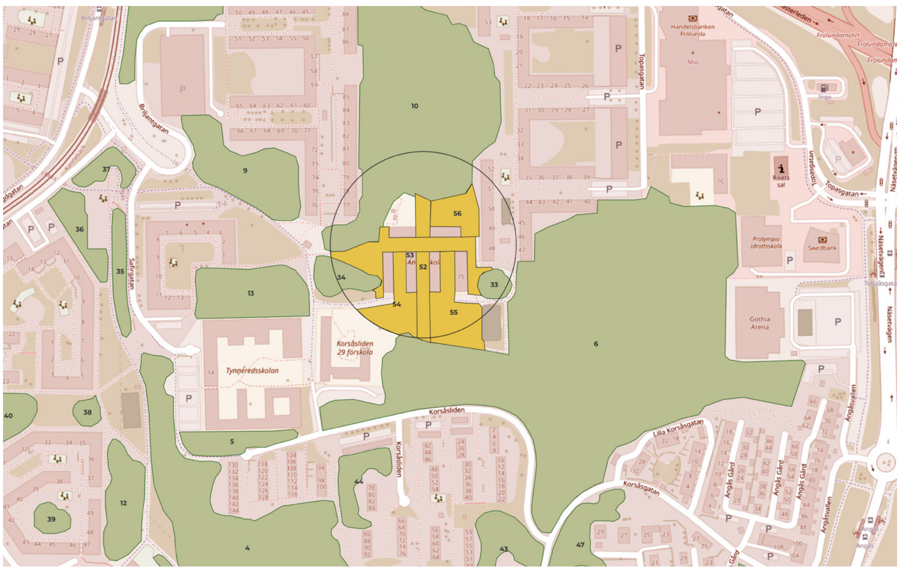


Image 7. Scenario 3. New nodes proposal

NC: 5 components
NL: 167 links
AWF: 3.528375E10
EC (PC): 387310.40 m²
PC: 0.0666708 → 6.7%

7.3 Export to CONEFOR.

For every scenario, node centroids and pairwise connections were exported to plain-text .nodes and .distance tables via the ‘Conefor Inputs and Outputs’ QGIS plugin. Edge weights were suppressed, and analyses were conducted with a topological distance to emphasize structural rather than cost-weighted connectivity.

7.4. Graph-theoretic analysis.

CONEFOR was selected over alternatives such as Circuitscape because:

- It directly implements the Probability of Connectivity (PC) and Integral Index of Connectivity (IIC) families that rank the marginal contribution of each patch to overall habitat availability;
- It operates efficiently on node–link graphs, obviating the need for resistance surfaces that needs expertise knowledge; and
- Its command-line interface enables batch evaluation of multiple scenarios.

The software computed six complementary metrics, NC, NL, AWF, Ec(PC), PC and IIC, under the habitat-availability (reachability) framework of Pascual-Hortal and Saura (2006). This framework “integrates habitat patch area (or quality) and inter-patch connections in a single measure,” acknowledging that connectivity is ecologically meaningful only when sufficient habitat is present; a landscape of well-linked but tiny patches, or of abundant habitat that is highly isolated, will both yield low availability. The parameters for the analysis are based in the maximum area available for design, the distance between patches and the data about species movement collected. (Appendix 1.6.)

7.5. Decision rule and error handling.

Metric reports were imported into a spreadsheet and ranked. The chosen scenario was the one scoring highest in ≥ 4 of the 6 indices; ties were resolved by Ec(PC), which simultaneously captures patch area and configuration. There was an iterative process where the workflow either adjusted parameters and re-ran the model or reverted to scenario editing for a single corrective pass

7.6. Cartographic synthesis and deliverables.

The winning network (Scenario 3 in the baseline run) was merged with extant forest patches and symbolised in QGIS; elevation shading and OSM transport layers provided spatial context. Outputs consist of a publication-ready map (PDF/PNG) and plain-text metric tables.

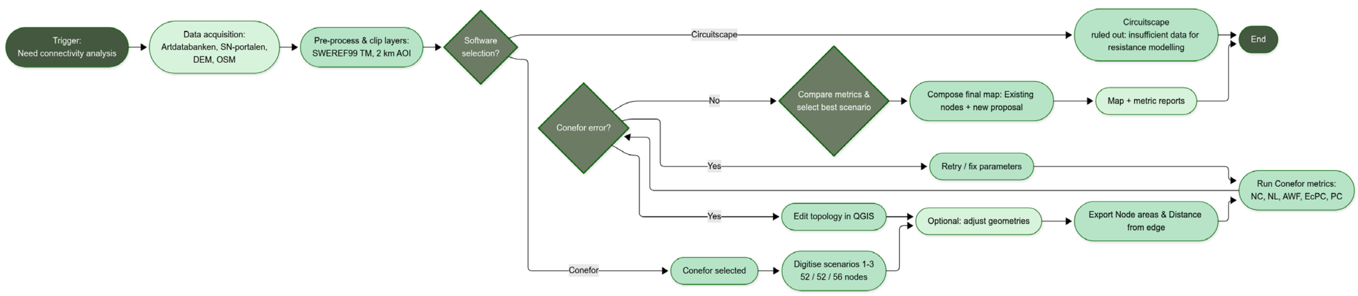


Image 8. Workflow illustrating softwares and processes used to analyze and develop proposed landscape connectivity

Summarizing, the workflow is explained as follows:

RESULTS:

In the current state, there is only a 6% chance that a species, especially the hedgehog, can reach any other patch in two steps during its active lifespan, resulting in a fragmented matrix. There are five highly functional forest components. Four of them (sizes 7, 5, 3, and 2 patches) are liable to inbreeding and local extinction without new links. Daily movement within the main 34-patch web is okay, but landscape-wide flow is difficult, and it is noted that large green spaces (1, 3, 6, 14, 15, and 48) still account for >70% of total flux. From a species perspective, the hedgehog in particular, only a third of the study area functions as habitat, even though 0.80

km² is technically vegetated.
Constructing a 150 m vegetated strip would eliminate the corridor's single longest break, sparing animals a risky 280 m detour around fences and built obstacles. The improvement boosts local survival and daily foraging, yet it still falls short of reconnecting the entire suburban mosaic. Network metrics underline the point: the number of components (NC) remains at 5, and the landscape-wide probability of connectivity (PC) rises by only about 15 %, leaving overall link quality low.
It is worth noting that, within the 1 km study radius, the most critical forest patches lie farther from the project site. Linking distant fragments, such as patches 13 and 14, separated by roughly 500 m, could be a true game-changer for habitat connectivity.

Even so, at a neighborhood scale the proposed strip would make nightly foraging easier and provide a modest boost to long-term gene flow. If similar interventions were replicated on other properties, their combined effect could substantially re-stitch the fragmented habitat.

Overall, CONEFOR answer the pragmatic question: "If a patch is removed or restored, how much does overall landscape connectivity change?" This demonstrate the data-driven decisions importance such as prioritizing existing 'keystone' patches for strict protection or focus strategies on gaps where installing micro-forests, vegetated overpasses or riparian buffers would maximize functional gain.

8 SOLAR GENERATION - WORKFLOW

8.1. Calculation of solar angle

1. The solar angle is calculated based in the average of the summer solstices and the autumm and spring equinox:

21 JUNE	21 DECEMBER	21 MARCH	21 SEPTEMBER
Altitud	**Altitud**	**Altitud**	**Altitud**
50.26°	**6.73°**	**30.34°**	**32.62°**
Sun hours x day	**Sun hours** x day	**Sun hours** x day	**Sun hours** x day
18	**6**	**12**	**12**

Table 9. Solar altitud and hours of sun available for the site specif location

8.2 Shadow length calculation

1. Calculate the vertical height (H) of the panel's upper edge above the base
2. Now calculate shadow length (S) at solar noon using and buffer is added (20%)
4. Comparison with online calculator Easy solar.
Finally, the distance of 1.86m is rounded into 1.90m and tested with Grasshopper+LadyBug script and the distance is adjusted into 2.20m which reflect an optimal distance between rows, with less affectation but diminishing the PV spread.

$$H = L \cdot sin(\theta) = 1.70m \cdot sin(40°)$$

$$H = 1.70m \cdot 0.6428$$

$$H = 1.093m$$

$$S = \frac{H}{tan(Sun\ Elevation)}$$

$$S = \frac{1.09m}{tan(40°)}$$

$$S = 1.548\ m$$

$$S = 1.548\ (20\%)$$

$$S = 1.858m$$

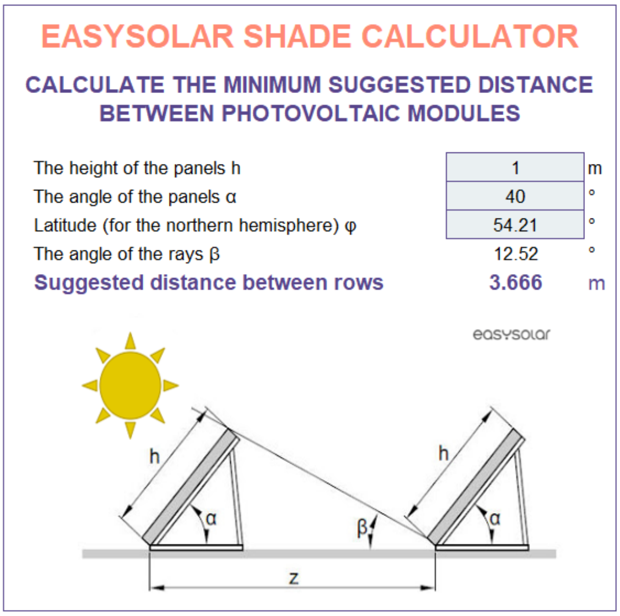


Image 10. EasySolar calculator. https://easysolar.app/en/shading-calculator/

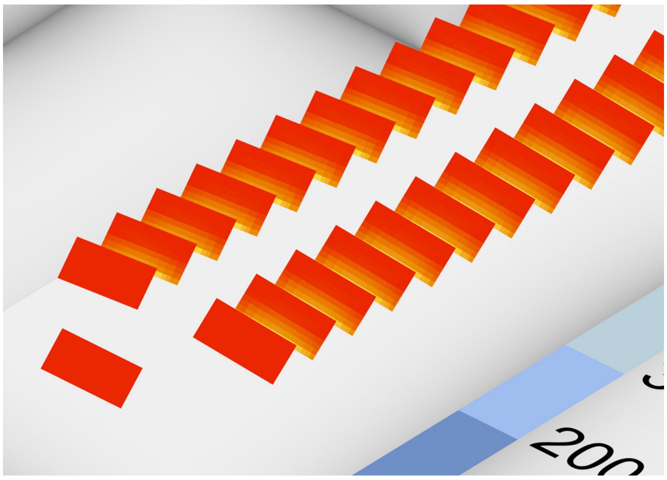


Image 11. Solar incidence in PV in proposal 2

The workflow was created to estimate in early stages, how much electricity a residential roof could generate with photovoltaic (PV) panels aiming to have more production that surplus the demand at least in 15%, that means to generate about 478 977 kWh/y, for the specific site conditions. Working entirely in Rhino 3D and its Grasshopper visual-scripting environment. The procedure starts with a massing model of the building and its surroundings and ends with annual energy-yield figures.

All simulations run locally. Ladybug Tools handles climate data, solar-radiation calculations and basic post-processing. The only external file is an EPW weather record for Gothenburg, chosen for its closeness to the site's latitude and solar climate. Roofs from the context buildings are modeled so that Ladybug can account for mutual shading, a factor that often dominates performance in dense urban settings. To isolate geometric influences, the PV hardware is also modeled, with specific location an distribution for each scenario.
Therefore, the simulation runs the following proposals:

- **Proposal 1:** Panels adopts the existing roof pitch, requiring minimal structural change.
- **Proposal 2:** The second proposal questions whether photovoltaic panels must be "perfectly" perpendicular to the sun's rays to be truly efficient. An annual study first identified the months with the most daylight and, for each, calculated the average monthly solar altitude. (Table 9). Then, an average of the tilt angle is calculated to represents periods of highest solar incidence.

This availability-based approach is essential in Sweden, with low solar availability in winter; designing for the worst cases would require extremely steep panels and excessive row spacing. Instead, an average from March to October, marked by the equinoxes and summer solstice, excluding the winter solstice, was used. The analysis produced an optimal tilt of 40°. Since varying solar heights create shadows that markedly reduce performance, a minimum row spacing was then calculated. After a quick shadow simulation panels will therefore be installed with at least 2.20 m between rows.

LIMITANTS:

- The study uses monthly averages, missing daily shading variations.
- Ignores the effects of panel temperature and long-term degradation.
- Manual layout of pv is subjective; an algorithmic approach would be better.

Even so, the workflow delivers a credible set of annual-energy metrics that integrate smoothly with the project's life-cycle-carbon assessment, allowing a genuinely performance-informed selection of the final roof strategy.

9. LCA PV VS ENERGY FROM THE GRID

The calculation begins by establishing the LCA's goal and scope, compiling the life-cycle inventory (LCI), and selecting the impact categories. The central question is whether the proposed PV system achieves lower carbon emissions than the Swedish grid, given its favourable energy output. The modeling is carried out in openLCA.

To minimize import-related emissions, a Swedish-made solar module is chosen: the BOLD panel from Midsummer. BOLD is a CIGS (copper–indium–gallium–selenium) thin-film photovoltaic that converts light directly into electricity.

The following is extracted from the calculation in previous calculations:

Data	Value
Energy output per m² (year 1)	135.50 kWh/m²/year
PV module area (115%)	3535 m²
Energy per unit panel	230.35 kWh/year
Panel type	Midsummer BOLD (from EPD)

The total PV electricity generation over 25 years accounting for degradation is calculated

$$E_{25y} = E_1 \times \frac{1 - (1-d)^{25}}{d}$$

Where:

- E_1 = Year 1 energy output
- d = degradation rate (0.007)

$$E_1 = 135.50 \times 3535\ m^2$$

$$E_1 = 479\ 842.50\ kWh/year$$

Total: 11 020 892 kWh over 25 years

Calculations of the Embodied Impacts of the PV System are performed

Estimated potence: 113 Wp

$$Conversion\ factor = 113\ Wp\ per\ m^2$$

$$3535\ m^2 \times \frac{113\ Wp}{m2} = 39\ 455\ Wp = 394.55\ kWp$$

Then, it is applied to the EPD values for the PV unit

Impact	Per Wp	× Total Wp	Total Impact
GWP	0.113 kg CO_2e	× 39 455	**4 458.42 kg CO_2e**
ADP (fossil)	2.37 MJ	× 39 455	**93 508.35MJ**
CED (PENRT)	2.93 MJ	× 39 455	**115 603.15MJ**
EP (freshwater)	1.33E-5 kg P eq	× 39 455	**0.525 kg P eq**

This scenario was run with the SMHI-reported average of 19 g CO_2e kWh, yielding credible results that reflect current Swedish conditions, with a result of:

Swedish grid:
209,397 kg CO_2e
PV-only (módulos + inversor + BOS):
58,052 kg CO_2e

72.3 % less GWP than the local grid

LCA PV INCLUDED BATTERY VS ENERGY FROM THE GRID

The calculation is carried out at a conceptual level to assess the life-cycle impact of a PV system with integrated storage. It assumes a battery storage for night periods, working seasonally.

The battery is calculated for an scenario of consumption of 40% of the total demand with around 3 days of backup storage for resilience assuming 1–2 full cycles/week of energy arbitrage. As an expert recommendation the battery calculated total capacity is 500kWh, equivalent to a small neighborhood battery. The embodied carbon of the battery, assuming that is a Lition battery with 150–200 kg CO_2e per kWh (GREET 2022) and single replacement over 25 years:

Parameter	Value
Battery capacity	500 kWh
Annual cycles assumed	100–150
Lifetime coverage	Entire 25-year building lifespan
Embodied GWP	75 000 kg CO_2e
Unit process impact	1 output = 500 kWh battery → 108088.66 kg CO_2e to air (carbon dioxide, fossil)

The BOS (Balance of System) components are also modeled with the EPD (SolarEdge SE66.6K Inverter) With this information and the same LCI and method from the first calculation, the analysis is run with the following results:

Swedish grid:
209 397 kg CO_2e
PV (modules + inversor + BOS) + battery:
133 052 kg CO_2e

The battery represents 56.4 % of the total system GWP. However, the system still improve in around a 36% the performance of the Swedish grid.

10. BLACKWATER ENERGY POTENTIAL - WORKFLOW

To estimating biogas production it is used a COD-based approach. Given a Chemical Oxygen Demand (COD) concentration of 12 kg/m³, which is representative of high-organic blackwater from combined kitchen and toilet sources (WHO, 2006; von Sperling, 2007) (table 10), the daily COD load was determined to be 37.68 kg/day.

Based on WHO-recommended biogas yields for field conditions, a conservative conversion factor of 0.05 m³ of biogas per kg of COD removed was applied, yielding a total daily biogas output of 1.88 m³/day. Assuming a typical methane content of 65% in biogas (SNV, 2009; IEA Bioenergy, 2020), the daily methane yield would be approximately 1.22 m³/day.

To translate this into usable energy, a lower heating value (LHV) of 6 kWh/m³ for biogas is employed, which accounts for its diluted composition relative to pure methane. This results in an estimated thermal energy output of 7.32 kWh/day. Finally, if the biogas is utilized for

BLACKWATER TYPE	COD range	Source
Toilet	1–6 kg COD/m³	(WHO, 2006; EPA guidelines)
Kitchen	15–30 kg COD/m³ (depending on food type, grease content, and dilution)	Metcalf & Eddy (*Wastewater Engineering*, 5th ed.). Study: *COD of household greywater with kitchen waste* (Ottoson & Stenström, 2003).

Table 10. Chemical Oxygen Demand COD Range extracted from literature

electricity generation via a Combined Heat and Power (CHP) system, an electrical conversion efficiency of 35% is assumed, producing approximately 2.44 kWh/day of electricity.
This approach integrates design standards and empirical yield values from established biogas studies, to present a conservative but realistic feasibility estimates suitable for early-stage design projects.

Mixed Blackwater (Toilet + Kitchen)

- **Toilet water:** 6 kg COD/m³ (higher end, assuming low-flush toilets).
- **Kitchen water:** 20 kg COD/m³ (mid-range for residential sinks).
- **Blended COD:** If toilet and kitchen flows are roughly equal (50/50):

$$COD_{mix} = \frac{(6kg/m^3+20kg/m^3)}{2} \qquad COD_{mix} = 13kg/m^3$$

12kg/m³ to account for variability

HOW MANY BIOGAS PER KG/COD

Toilet: 0.03 m³/kg COD (mid-range).

Kitchen: 0.07 m³/kg COD (mid-range).

AVERAGE: 0.05 m³/kg COD

Daily production blackwater

10.07 m³/day

accounted for losses

7 m³/day

$$COD_{load} = 7\ m^3/day \times 12\ kg/m^3$$
$$COD_{load} = 84\ kg\ COD/day$$

→

BIOGAS= 84 kg COD/day× *0.05 m³/kg COD*

BIOGAS= 4.20 m³/day

METHANE= 4.20 m³ × 0.65

METHANE= **2.73 m³/day**

Electrical energy:
9.56 kWh/day
Thermal energy:
17.75 kWh/day

10. RAINWATER HARVESTING CAPACITY

Rain-water harvesting is the system's first resource-conservation measure. Early in the design process a green-roof option was examined as a way to pre-filter run-off. Modelling showed, however, that conventional roofs collects 85–95 % of rainfall, a near-optimal capture rate, whereas green roofs retain 30–70 % in their substrate, plants, and evapotranspiration, causing delayed and irregular collection.

They also demand higher maintenance and, in Sweden's climate, risk winter freeze that degrades performance. Because the same roofscape must also host photovoltaic panels, a clean balance between energy generation and water capture is essential.
The project therefore prioritises maximising the collected volume with conventional roofing, while filtering the water through ground-level treatment units instead of vegetated roofs.

Annual rainfall data from SMHI and Climate Consultant show that Gothenburg receives roughly 1,100 mm of precipitation a year, with the wettest period running from August to October. Because rain is fairly evenly distributed, storage sizing can concentrate on bridging the drier late-winter and early-spring months.

Rain-water harvesting.

Run-off coefficients for roof materials and photovoltaic panels are taken from published calculations. The roof area covered by PV and the area left uncovered are multiplied by their respective run-off factors to obtain the total volume of rainwater that can be harvested (-10% losses) each year with a result of 1 998 315 L/y.

MATERIAL ROOF	AREA M2	FACTOR RUNOFF	WATER HARVESTING CAPACITY
asfaltsmatta	831	0.70	639 870
PV	1796	0.8	1 580 480
Average year rainfall	1100		
Total area roofs m2	2,627.58		
Water harvesting capacity roof total (yr)	(-10% losses) 1 998 315 L/y		2 220 350 L/y

Table 11. Rainharvesting potential calculation

The calculation starts caculating the rooftop collection area.
Run-off coefficients are assigned according to the roofing materials: 0.80 for the asphalt-mat surfaces and 0.70 for the sections covered by photovoltaic panels (Ozeren & Merve, 2022). Each coefficient is then multiplied by the annual rainfall reported by the Swedish Meteorological and Hydrological Institute to estimate the total harvestable volume. The harvesting system can cover 32% of the total demand in the building.

11. WETLAND DIMENSION

The design of HSSF wetlands is typically based on the first-order plug-flow kinetic model by Kadlec and Knight, but for early-stage architectural planning it is used simplified sizing from WHO and UN-Habitat guidelines:

Recommended surface area: $5m^2/m^3/day$
Required wetland area: $7.05m^3/day \times 5m^2/m^3/day = 35.25m^2$

+20% buffer for: Cold-season performance, potential underperformance, maintenance zone at inlet/outlet

TOTAL WETLAND AREA POTENTIALLY REQUIRED: $42.30\ m^3$