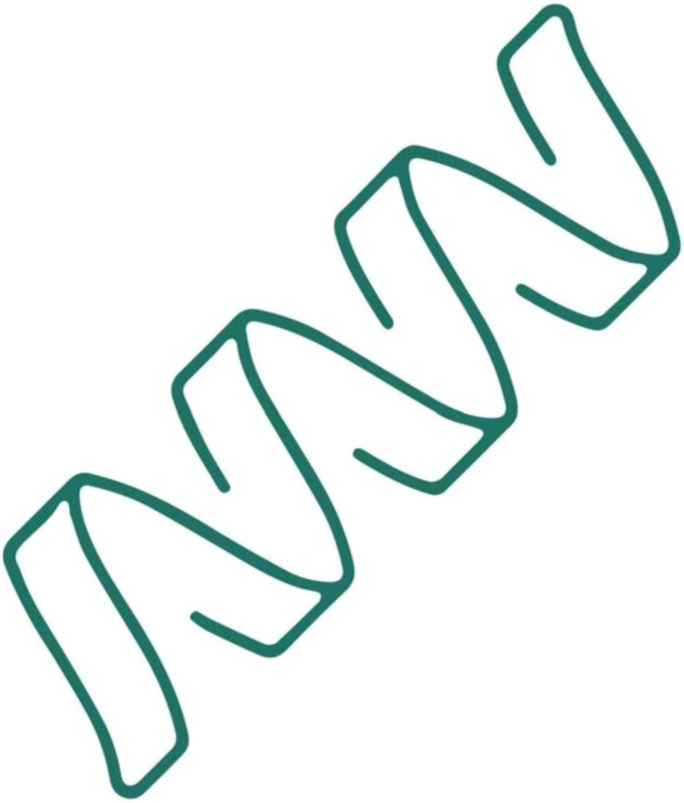
ARCHITECTURAL FOOD LAYER

Urbanised Protein Production



LION MAUL

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Master's thesis to obtain the degree "Master of Science in Architecture"

ARCHITECTURAL FOOD LAYER - Urbanised Protein Production

Sustainable design

Supervisors of the architectural project:
Prof. Dipl.-Arch. ETH/SIA Dietrich Schwarz
MSc Arch. David Kloeg

Supervisors of the theoretical report:
Dr. Katia Frey

Supervisors of the technical report:
MSc Arch. Andreas Lehner

Supervisors of the preliminary study:
Prof. Dipl.-Arch. ETH/SIA Dietrich Schwarz
MSc Arch. David Kloeg

Writing advisor:
Dr. Julia Stelter

Student:
Lion Maul, 190190

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Fig. 1 Protein symbol

Liechtenstein School of Architecture (LSA)
University of Liechtenstein
Fürst-Franz-Josef-Straße
9490 Vaduz, Liechtenstein

UNIVERSITÄT LIECHTENSTEIN

PREFACE

The present Master's thesis, titled "Architectural Food Layer - Urbanised Protein Production" is structured into four interrelated sections that build upon one another. The findings from the sections serve as the basis for the master thesis.

It begins with the main component, which documents the architectural project and its design, exploring how the production of protein-rich food can be spatially and systemically integrated within the urban context.

The design is grounded in insights derived from a theoretical report, which investigates new typologies for communal living aimed at strengthening food autonomy and social cohesion. Complementing this is a technical report, which explores the integration of building services systems with innovative methods of food production.

A preliminary study forms the conceptual foundation of protein-rich food production systems, which is listed in the appendix of this master thesis, examines the theoretical underpinnings of nutrition in general, and protein-based food systems in particular.

TABLE OF CONTENTS

01

°

ARCHITECTURAL PROJECT

ARCHITECTURAL FOOD LAYER

- Urbanised Protein Production

ABSTRACT

This project explores how architecture, as a mediating discipline, can integrate decentralized and community-based forms of food production into built environments to foster sustainable, resilient, and socially embedded food cultures in cities. Using the former industrial harbour of Leith in Edinburgh as a case study, it develops an architectural food layer concept that revitalize underused industrial areas by incorporating diverse forms of protein-rich food production systems, such as insect farming, algae cultivation, aquaponics, and vertical farming, into a vibrant, mixed-use neighbourhood.

The architectural concept integrates private and public areas, forming an active interface between production, community, and dwelling by open and adaptable structures. Sustainable wood building, productive galleries, and communal growing spaces foster ecological, social, and functional synergies, making food an inherent part of urban living. The integrative design demonstrates how urban planning and architectural strategies can help establish a future-oriented urban food culture, one that combines ecological responsibility with social interaction and considers humans as active participants in the food production cycle.

TABLE OF CONTENTS

INTRODUCTION

At a time when global food systems are increasingly under pressure, whether due to climate change, resource scarcity, or growing urban populations, the question of how we will produce our food in the future takes on central importance. Architecture, as a formative discipline, faces the challenge of not only designing spaces for living and dwelling but also actively shaping the conditions for a sustainable and forward-looking food system. Food production can no longer be conceptualized as centralized, external, and disconnected from cities, instead, it must be decentralized and integrated into the urban fabric. This gives rise to the following research question:

"*How can architecture act as a mediating discipline between production, community, and space to help establish a visionary, sustainably resilient, and socially embedded culture of food production in an urban and architectural context?*"

To answer this question, the thesis approaches the subject of food not merely in functional terms but views it as a complex cultural, social, and biological phenomenon. At its core lies the idea of an integrative urban system that links production, consumption, and architecture, with the aim of creating new spaces where food is not only produced but also experienced.

Using the former industrial harbour of Leith in Edinburgh as a case study, this research explores how dormant urban structures can be reactivated through a new "Urban Food Layer." The focus is on protein-rich, resource-efficient forms of production such as insect farming, algae cultivation, and vertical farming, not as futuristic techno-utopias, but as tangible spatial and architectural strategies.

This conceptual project weaves together nutritional science, ecological analysis, and architectural design to form an integrative model that understands the human being as part of a farm cycle, and in doing so, radically re imagines the urban landscape and its architectural buildings.

1.1 BASIS OF NUTRITION

Before architecture engages with designing spaces related to nutrition, production, or consumption, it is crucial to first develop a fundamental understanding of what food truly entails. Food is far more than a mere functional element of daily life, it represents a central aspect of human existence and biologically. Those aiming to conceptualize food architecturally must grasp its composition, purpose and its effects on the human body. Only with this foundation can concepts for food cultivation be devised that adequately reflect the complexities and scope of nutritional processes. For this reason, a preliminary study on the topic of nutrition and food was conducted, which can be found in chapter 5.2. The following section provides a summary of the key findings:

To comprehend human energy requirements, it is essential to examine the concept of food and its nutrient profile. Foods provide the body with energy, predominantly through three primary macronutrients: carbohydrates, proteins, and fats. These macronutrients constitute the majority of daily intake, whereas micronutrients such as vitamins and trace elements, while not energy-yielding, play indispensable roles in numerous physiological functions (IQWiG, 2022).

An average adult's daily energy intake is approximately 2200 kilocalories (kcal). Ideally, this energy is derived from roughly 50% carbohydrates, 30% fats, and 20% proteins. Both carbohydrates and proteins supply about 4 kcal per gram, while fats are more energy-dense, providing approximately 9 kcal per gram (IQWiG, 2022).

CARBOHYDRATES

Mainly serve as a rapid energy source for the body and brain. They consist of sugar molecules that can be simple (e.g., glucose, fructose) or complex (e.g., starch), (Morris, 2021). Within the body, all carbohydrates are broken down into sugars, absorbed into the bloodstream, and transported into cells with the aid of insulin. Although the body can synthesize glucose from proteins if necessary, carbohydrates are particularly vital during periods of intense physical exertion (Macdougall, 1999).

PROTEINS

Are composed of amino acids and are essential for the construction and maintenance of bodily tissues, especially muscles (Trumbo, 2002). Nine of the twenty amino acids are considered essential and must be obtained through diet (Wolfe, 2016). Animal-based proteins typically offer a complete amino acid profile and are therefore regarded as higher quality (Gorissen et at., 2018).

FATS

Perform a variety of crucial functions: they store energy, protect vital organs, form cellular membranes, and act as precursors to essential hormones (Morris, 2021). Notably important are the essential fatty acids omega-3 and omega-6, which must be consumed through food. While omega-6 intake is generally adequate, omega-3 deficiency is common. Key sources of omega-3 include fatty fish and certain plant oils such as flaxseed oil (Mariamenatu, 2021).

VITAMINS

Are organic compounds necessary for numerous metabolic processes. They support the immune system, blood clotting, energy metabolism, and the formation of skin, bone, and blood cells. Deficiencies in vitamins can result in serious health issues, such as scurvy from vitamin C deficiency or osteoporosis due to insufficient vitamin D (Krank, 2024).

NUTRIENT DISTRIBUTION

The optimal balance of macronutrients varies according to individual factors including age, sex, activity level, and health goals. On average, for an energy intake of 2200 kcal per day, the recommended distribution is as follows:

Carbs: 275 g (approx. 1100 kcal, 50%)
Proteins: 110 g (approx. 440 kcal, 20%)
Fats: 73 g (approx. 660 kcal, 30%)

This balanced ratio, for an average human being, ensures sustained energy supply, supports muscle development, and aids in preventing metabolic disorders such as diabetes and obesity. Increasingly, dietary guidelines emphasize a regimen rich in proteins and fats combined with complex carbohydrates to promote a healthier lifestyle (Goedecke, 2024).

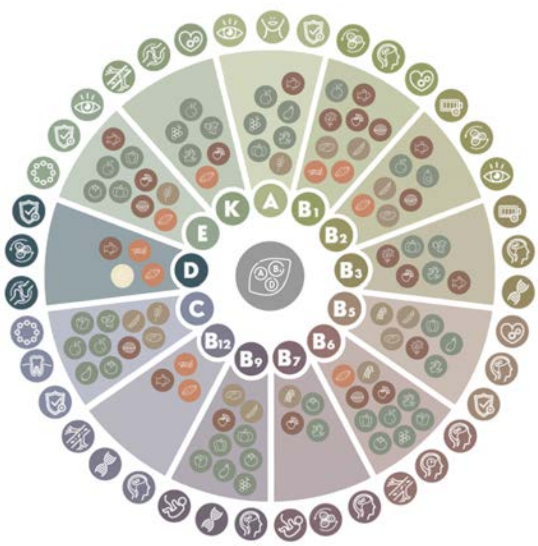


Fig. 2 Vitamin scheme

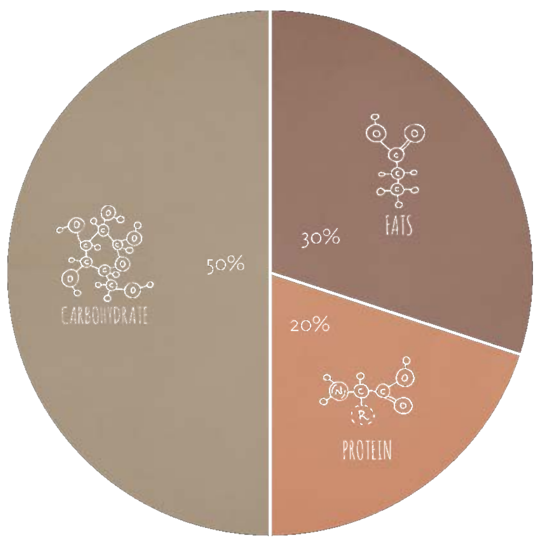


Fig. 3 Nutrient distribution scheme

FOOD LIFE CYCLE ASSESSMENT

To determine which food products have the greatest ecological footprint, a food life cycle assessment is conducted in the following section (see more in Chapter 5.2). The food life cycle assessment results of the study are quite clear and show that foods derived from animal products are largely responsible for a large percentage of environmental impacts. These food products emit up to 70 times more greenhouse gases per unit compared to their plant-based alternatives and require about 15 times as much water resources. Thus, it can be inferred that traditional methods of producing animal foods are significant sources of greenhouse gas emissions and water resource overconsumption (Sonesson et al., 2010).

On average, each person in Germany emits a total of 11 tons of greenhouse gases every year. Of this total, approximately 1.5 to 2 tons, or as much as 15–20%, can be attributed to food consumption. Even more than 40% of these food-induced emissions can be linked to the consumption of animal products, and plant foods account for as low as 8% (Koerber et al., 2009).

Production of animal feed that is protein-rich requires a high energy input, particularly regarding fertilizer, pest control, and fuel demands. A large amount of this energy is lost as heat through the animals' metabolic processes, for instance, 6 to 16 kilograms of grain are required to produce just 1 kilogram of meat. Meat, milk, and cheese are all major contributors to the overall "climate footprint," largely due to inefficient energy transformation, methane from ruminant animals, and fertilizer application. Plant foods are associated with considerably lower greenhouse gas emissions: beef generates more than 13,000 grams of CO2 equivalents per kilogram, with pork and poultry generating 3,200 grams and 3,500 grams, respectively. Vegetables, potatoes, and wheat play a smaller role, by 150 g, 200 g, and 415 g CO2 equivalents per kilogram (Koerber et al., 2009).

Yet, animal foods are still an essential part of a nutritionally adequate diet. Meat is one of the main sources of high-quality protein, which must constitute roughly 20–25% of an individual's daily caloric intake, that is, somewhere around 550 to 650 kilocalories a day for the average adult (Koerber et al., 2009).

Although carbohydrates comprise a large portion of the daily diet (almost 45–55%), the environmental contributions of carbohydrate cultivation, more specifically in terms of CO2 emissions, greenhouse gas production, and water consumption, are greatly reduced. Hence, it would not make much sense to place emphasis on carbohydrate cultivation practices in the subsequent discourse. In the following the focus lies in the production of alternative protein-rich food sources (see more in chapter 5.2).

Fig. 4 Life cycle assessment dataset

CO2-equiv. Comparison		CO2-equiv./kg				l Water/kg
Product	Source	CO2	CH4	N2O	Total	CO2
Beef	Ogino et al. (2007) Japan	7	23	2	32	15 000
	Casey & Holden. (2006a, b), Suckler, Ireland				32	15 000
	Williams et al. (2006), ”Average UK beef”				16	15 000
	Williams et al. (2006), ”100% suckler”, UK				25	15 000
	Verge, et al. (2008) , ”Average Canadian beef”	4	15	11	30	15 000
	Cederberg et al. (2009a), ”Average Brazilian beef”	0	31	9	40	15 000
	Cederberg et al. (2009b), ”Average Swedish beef 2005”	3,5	17,5	7	28	15 000
	Cederberg & Darelius. (2000), ”Swedish beef"	3	10	6	19	15 000
	AVERAGE				27,75	15 000
Pork	Williams. et al. (2006)				6,4	5 000
	Basset Mens & van der Werf. (2003)				8	5 000
	Cederberg & Flysjö. (2004)	1,2	1,1	2,1	3,6	5 000
	Strid Eriksson. et al. (2005)				3,5	5 000
	Cederberg. et at. (2009)	1,3	1,3	2,6	5,2	5 000
	AVERAGE				5,34	5 000
Poultry	Thynelius. et at. (2008)				1,5	3 900
	Pelletier. et at. (2008)				2,6	3 900
	Cederberg et al. (2009)	1,2	0,1	1,2	2,5	3 900
	Williams et al. (2006), conventional				6,1	3 900
	Williams et al. (2006), free-range				7,3	3 900
	AVERAGE				4	3 900
Fisheries	FHL. (2009)				15	0
	AVERAGE				15	0
Aquaculture	FHL. (2009), Hering frozen				1,2	1 500
	Findus. et at. (2008), Cod				4,8	3 500
	Pelletier & Tyedmers. (2007), Salmon				4,2	3 000
	AVERAGE				3,4	2 666,67
Grains	Cederberg. et al. 2008)				0,46	700
Garin Legumes	Blengini & Busto. (2009), Soy				0,8	1 500
	Blengini & Busto. (2009), Peas				0,3	500
	AVERAGE				0,55	1000
Vegetables	Sonneson. et at. (2010), Tomatoes				0,45	700
	Sonneson. et at. (2010), Carrots				0,2	500
	AVERAGE				0,33	600

PROTEIN-RICH FOOD PRODUCTION

Based on the findings of the food life cycle assessment, the following section focuses specifically on protein-rich food production systems. A comprehensive study on this topic was conducted in Chapter 5.3. The outcome is a set of analysed and researched methodologies for sustainable protein production in an urban context, which create a new diet, namely insect farming (40% of protein demand), algae cultivation (15% of protein demand), fish farming (25% of protein demand), and the production of wheatgrass and microgreens in vertical farms (15% and 5% of protein demand). Together their production produce 7,2 times less CO2 and consume 3,2 times less water than conventional protein based food products, especially meat. Integrated with the human component, these systems together constitute a fully self-sustaining farm cycle. Including, detailed production flows, quantified input and output data, spatial requirements, and architectural floor plan schematics.

The resulting farm cycle operates with minimal external inputs and reveals the synergies and interdependencies between the various production systems. This body of research forms the foundation for the following architectural project, which aims to synthesize and expand upon these findings to design a productive food infrastructure embedded within a built and urban environment, one in which human inhabitants are not passive users but integral components of the system itself. Rather than limiting itself to internal building operations, this concept envisions the residents as active and passive participants within the metabolic loop, benefiting from and contributing to it far beyond subsistence alone.

The vision is to be reflected in new typologies of collective housing, integrated with open cultivation spaces, both internal and external to the building complex, freely accessible to all.

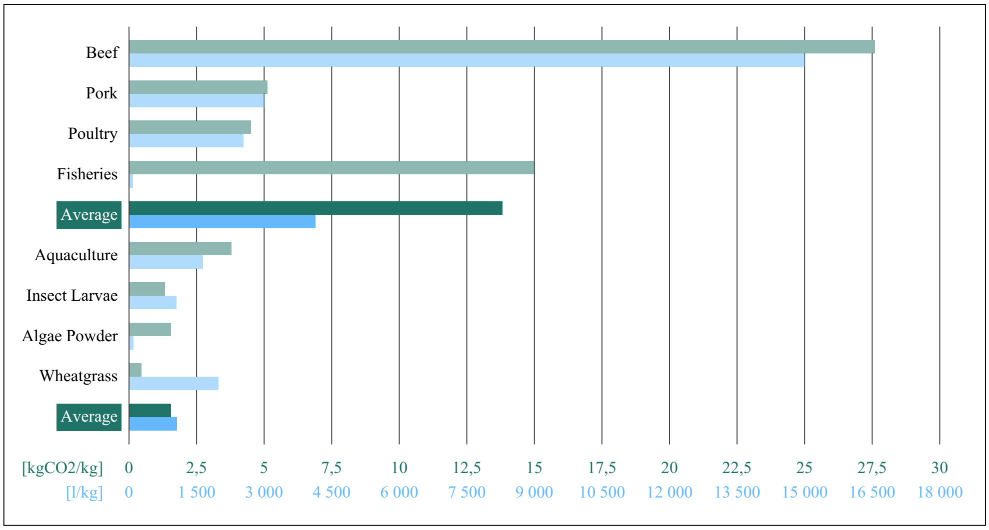


Fig. 5 CO2 emission and water consumption comparison

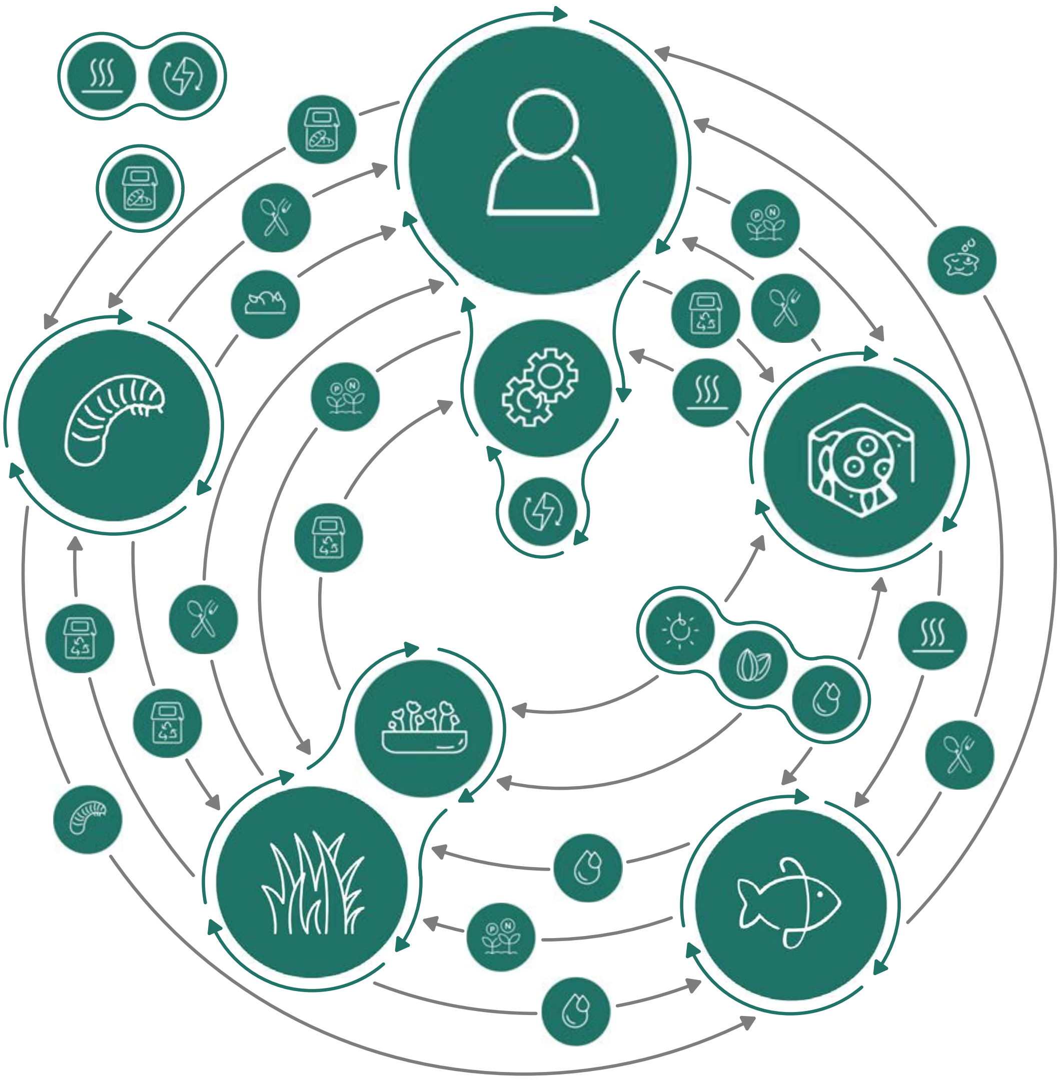


Fig. 6 Farm cycle scheme

1.2 URBAN ANALYSIS OF LEITH

The concept of a "living machine" as part of the food chain becomes more compelling when rooted in the specific urban context. The goal is to reactivate underutilized industrial land by integrating food production with human habitation, establishing a new, sustainable form of urban industry.

The former industrial harbour of Leith in Edinburgh serves as the case study. Analysis reveals significant untapped potential, particularly in the sealed surfaces of the western harbour area, which has seen minimal use for decades.

Leith's structure plan shows a gradual decrease in urban density toward the west, where derelict industrial zones indicate long-term economic shifts. The green space plan reveals that most open spaces are concentrated along waterways, with only scattered parks and little integration into the dense built environment.

The mobility plan highlights a new tram line linking Leith to Edinburgh's city centre via the "Leith Walk", alongside bus routes and a limited cycling network. However, the latter lacks adaptation to the urban context and offers minimal user comfort.

Leith's economic core remains along the "Leith Walk", a historic route to the city centre. Attempts to shift this centre Northwest, most notably through the construction of a large shopping mall, were unsuccessful. Roughly half of the complex was dismantled after just twenty years, underscoring the project's limited viability.

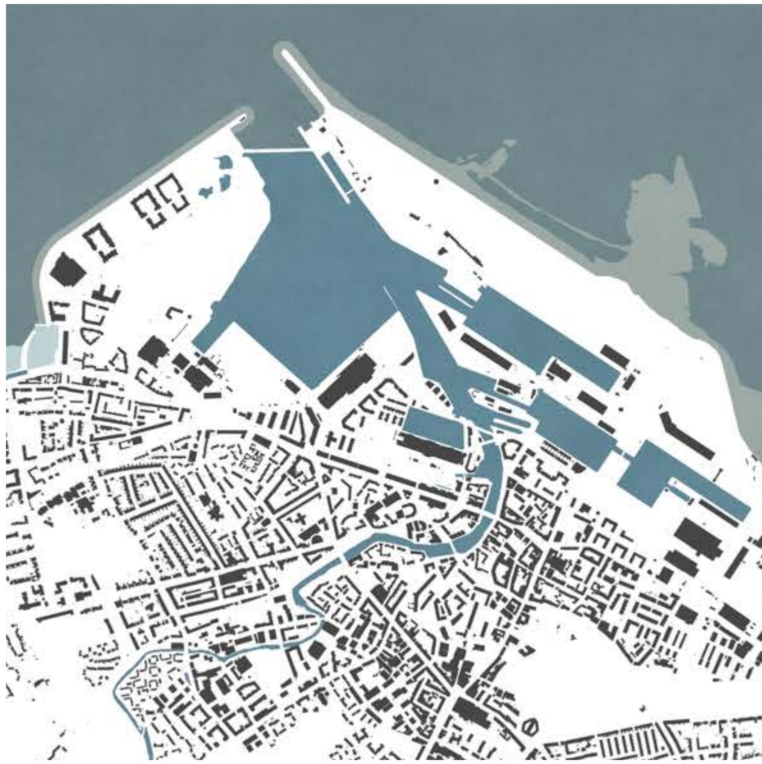


Fig. 7 Structure plan S 1:27 500

Fig. 8 Mobility plan S 1:27 500

Fig. 9 Green space plan S 1:27 500

Fig. 10 Building use plan S 1:27 500

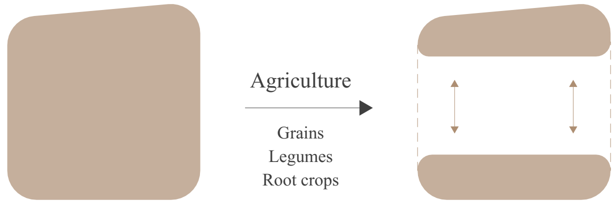
1.3 URBAN FOOD LAYER

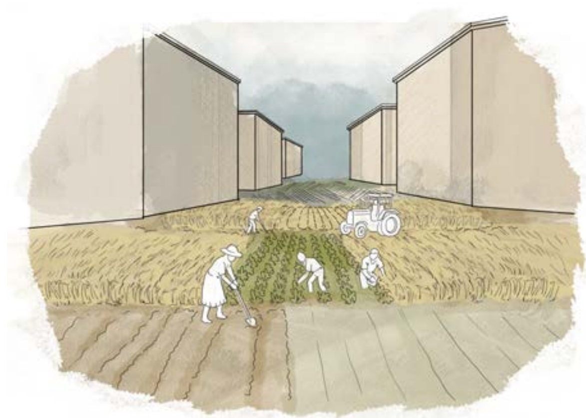
A fundamental rethinking of food production cannot be confined to the scale of the individual building. Just as a building's use is shaped by the demands of food systems, its urban placement should likewise be guided by an overarching food layer. The specific mode of food production plays a decisive role in determining how architectural formats respond , in terms of form, density, and spatial organization.

The aim of this approach was to integrate an urban food layer as an integral component of the urban fabric. To this end, a conceptual matrix was developed that links distinct nutritional typologies with architectural forms and urban configurations.

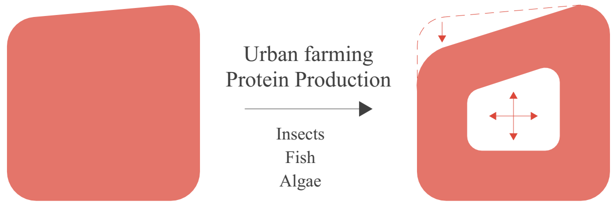
Based on a multi-scalar comparative study of case studies on Chapter 2.3 and 2.4, the investigation examined systems ranging from small-scale rural communities to large-scale, collectively organized structures. These insights were complemented by a nutritional analysis of different cultivation methods and their specific nutrient outputs (see Chapter 5.2).

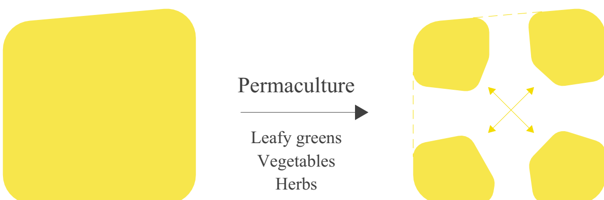
This led to a spatially differentiated design strategy in which food production is structurally interwoven with the building form and creates new urban atmospheres. For instance, forest-based fat production using nut trees results in lower spatial density and vertical typologies such as towers, whereas land-intensive agricultural for carbohydrates demand a rethinking of urban interstitial spaces to accommodate productive uses.

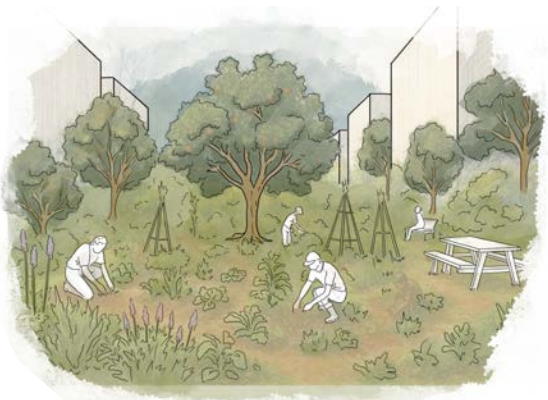





Food Forest
Nut trees
Berries
Root crops


Urban farming
Protein Production
Insects
Fish
Algae


Permaculture
Leafy greens
Vegetables
Herbs




Fruit Gardens
Fruits
Citrus fruits
Climbing fruits

The conceptual urban matrix, referred to as the Urban Food Layer, is now applied to the existing urban fabric of the Leith harbour area in Edinburgh. As previously analysed, this site offers ideal conditions for the reactivation of derelict industrial land through the implementation of a food-oriented urban strategy. In 2010, the City of Edinburgh proposed a development framework aiming to connect the historic district of Leith with a new, mixed-use neighbourhood and to transform the former harbour into a vibrant residential area. While parts of this proposal were partially realised in the western sector, the project was never fully implemented due to financial constraints and a lack of sustained interest.

The Urban Food Layer concept builds directly upon this context and investigates how urban form and structure are altered when the developed urban food layer is superimposed onto an existing planning framework. Designated building zones are systematically reconfigured according to food production typologies. The resulting in-between spaces and architectural volumes are functionally and spatially integrated with the respective forms of food production and embedded into the existing infrastructural system of Leith.

The outcome is a diverse and sustainable urban quarter defined by a range of new atmospheric qualities structured in three districts by the application of the urban food layer. Varying housing typologies emerge in response to specific agricultural formats, creating a coherent spatial holistic identity. Moreover, the central dock basins are re-naturalised in order to enhance local biodiversity and establish high-quality public waterfront spaces.

Fig. 11 Proposed development plan | from city council S 1:27 500

Fig. 12 Proposed development plan | Urban food layer with existing structure

Fig. 13 Proposed development plan | With urban food layer S 1:27 500

e S 1:27 500

Fig. 14 Proposed development plan | Urban food layer in focus S 1:27 500

Fig. 15 Urban food layer model

1.4 ARCHITECTONIC FRAMEWORK

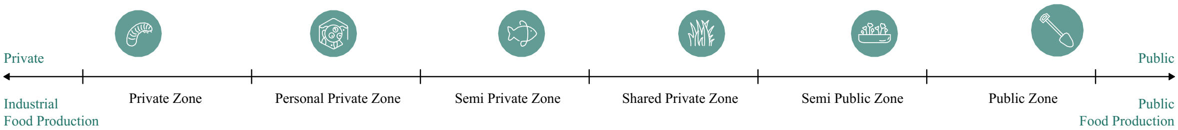


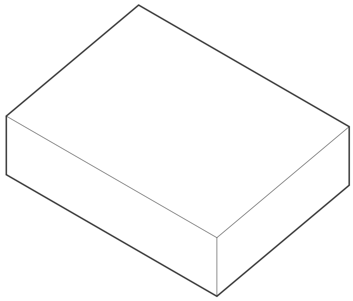
Fig. 16 Food production systems by privacy

The functionality of the urban and architectural Food Layer is exemplified through a “proof of concept” and illustrated in a dedicated architectural project. The concrete spatial implementation and integration within the urban context can be traced in the plans presented on page 24. Building on the insights from Chapter 1.1, namely, that the integration of protein-rich alternative food sources has a significant positive environmental impact, the conceptual focus lies in incorporating precisely these food categories. Spatial programming, production requirements, system flows, and uses are based on the concepts for protein-based food production developed in Chapter 5.3.

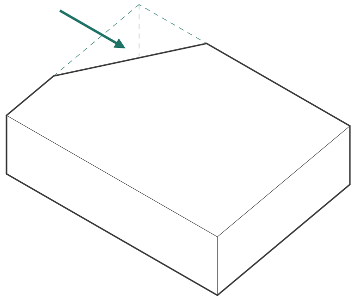
Central to the proposal are production methods such as insect farming, algae cultivation, aquaponics and fish farming, vertical agriculture with wheatgrass and microgreens, as well as classical urban farming. These systems are spatially differentiated within a new housing typology and strategically assigned along a spectrum of private to public zones. In private areas, the emphasis is on technologically supported, industrial-scale production aimed at efficiency and large-scale output. Public and semi-public spaces, by contrast, are dedicated to community-based food production, fostering social interaction, civic participation, and the cultivation of neighbourhood cohesion.

Through a step-by-step integration of various functional elements and the developed urban food layer, the original building mass gradually transforms into an open and dynamic structure. The introduction of a central courtyard not only generates high-quality outdoor spaces, but also encourages neighbourly interaction. A deliberate dissolution of the built volume allows for new pathways and visual connections, reinforcing the building’s integration into the urban fabric. The activation of rooftop areas as well as the eastern and western façades, oriented to the sun, for food production lends the building a productive envelope with both ecological and social impact. Courtyards and open spaces are re imagined as zones of active urban farming, turning the building into a site of both habitation and production.

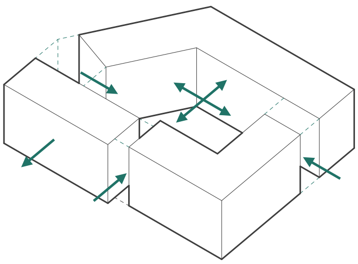
Fig. 17 Architectonic framework pictographs



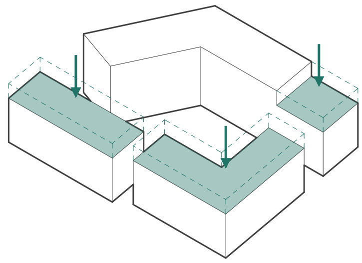
Starting point defined volume of the master plan



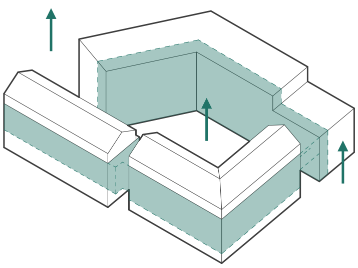
Creation of exterior spaces



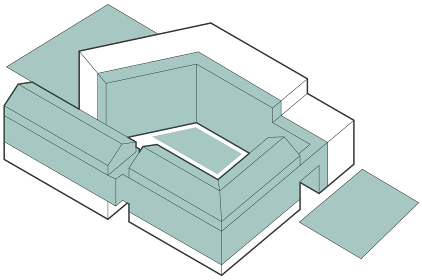
Courtyard for neighborhood interaction and dissolution of the volume for connectivity



Activation of the rooftop for food production

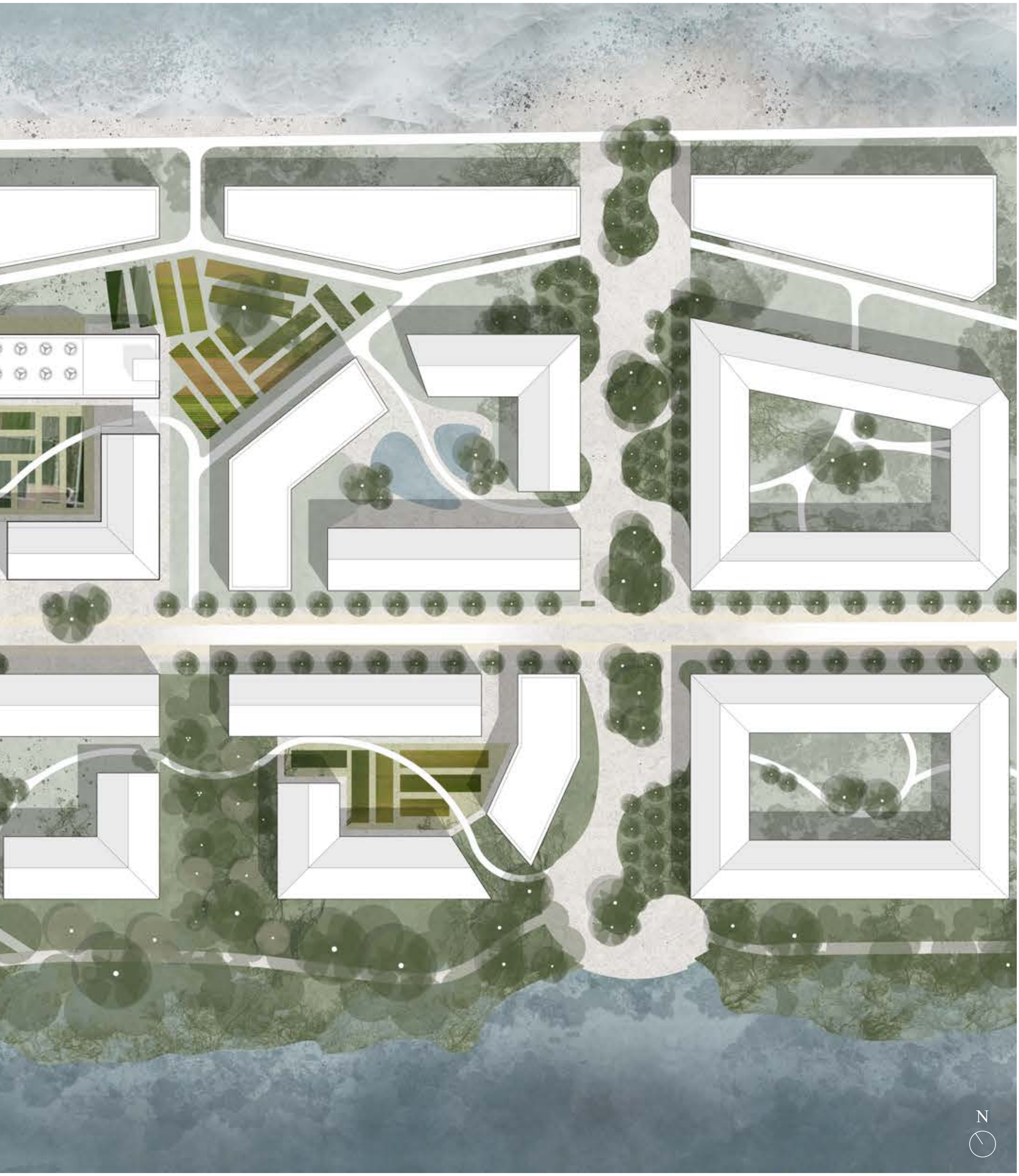


Activation of the east, west façades and outdoor spaces for food production



Activated building through food production and a farming community

Fig. 18 Urban site plan S 1:1500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GROUND FLOOR | 0.

The architectural concept translates the underlying technical infrastructure into a spatially legible differentiated structure. Located on the ground floor is the aquaculture facility, complete with the necessary technical systems. Portions of this infrastructure are deliberately staged as display elements within the entrance hall and made visible from the street, thus rendering the otherwise concealed food production process accessible and engaging for the public. In doing so, the project embeds productive functions directly into the everyday urban experience.

Additionally, four technical service rooms are integrated into the ground floor, equipped with the building systems developed in Chapter 3.0. Located adjacent to the western technical room, the energy hub for the algae cultivation system is spatially integrated into the building infrastructure. This hub supports the operation of the algae façades, which are positioned along the southwest elevations.

Within Complementing these production-oriented elements, the ground floor also accommodates a diverse range of publicly accessible uses: a market hall, café, bakery, cafeteria, food laboratories, a food workshop kitchen, and flexible commercial spaces. These spaces utilize the products generated on site as the basis for their offerings, thereby closing the loop between production and consumption. Collectively, these public programmes activate the interface between food systems and everyday life, making the integration of housing, community, and urban food production both tangible and socially resonant.

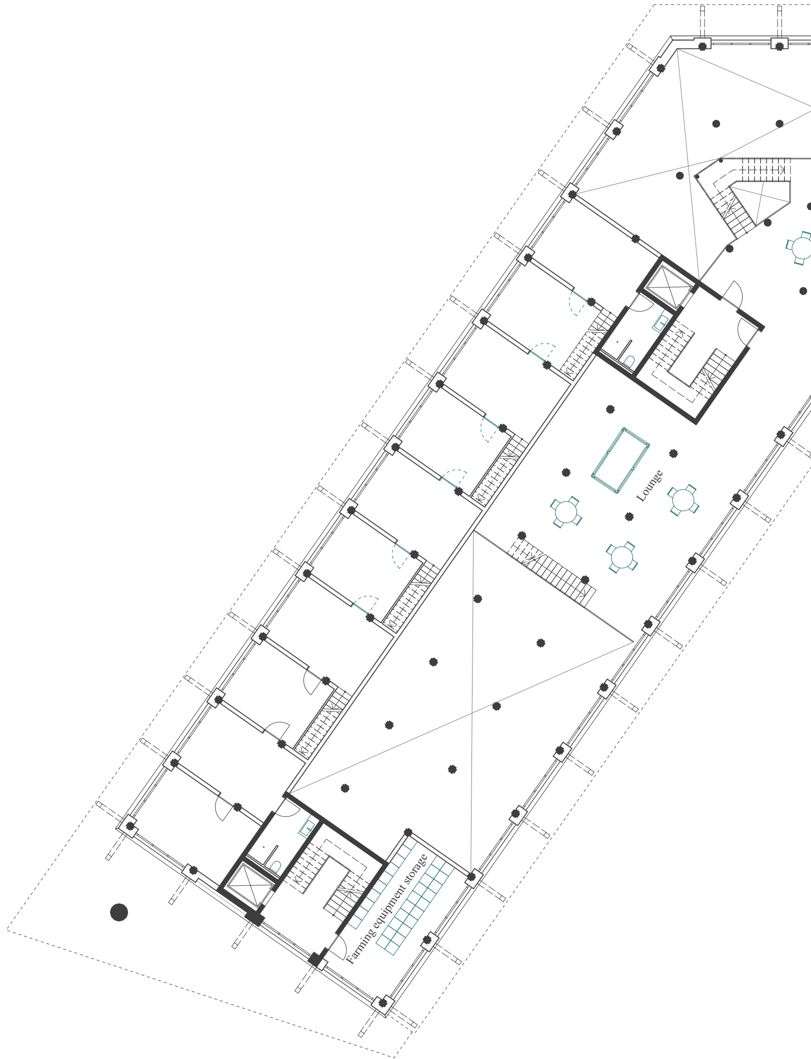
Fig. 19 0. Floor S 1:400


Output
Entrence hall/Reception
Lab
Office
Storage
Food Storage
Hygiene/Prep area
Food Storage
Fish farming
Technical room
Urban farming
Commercial area
Bicycle storage
Conference room "flex"
Commercial area
Cafeteria/ Restaurant
Coffee shop
Shop
Bakery
Market hall

FIRST FLOOR | 1.

The first floor plays a multifunctional role within the building concept. On one hand, it opens up to the ground floor through double-height spaces, creating a sense of spatial generosity and enabling visual connections between the production areas and communal zones. On the other hand, it accommodates shared spaces accessible to the approximately 300 cooperative residents, fostering social interaction and neighbourhood cohesion. In addition, several residential units are located on this level.

Another key element of this floor is the insect farming facility, which is integrated along with the necessary ancillary spaces such as storage and processing areas. To ensure spatial efficiency, supporting functions, including offices, sanitary facilities, and changing rooms, are spatially consolidated on the ground floor.



- Standart apartment
- Hochpaterre apartment
- Maisonette apartment
- Senior apartment
- Student/Pension apartment
- Open plan apartment
- Big room apartment

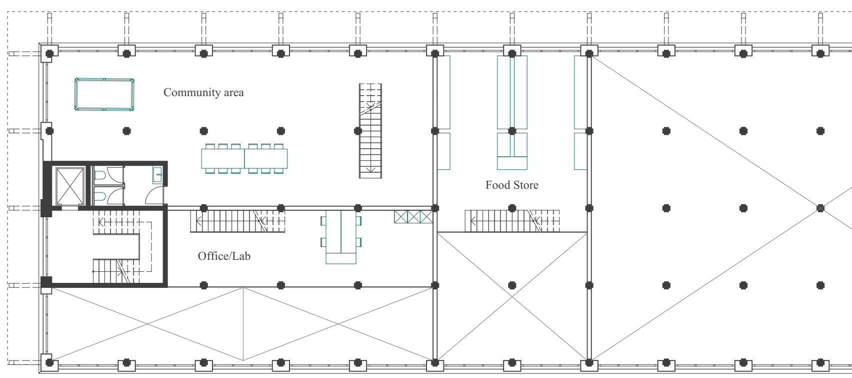
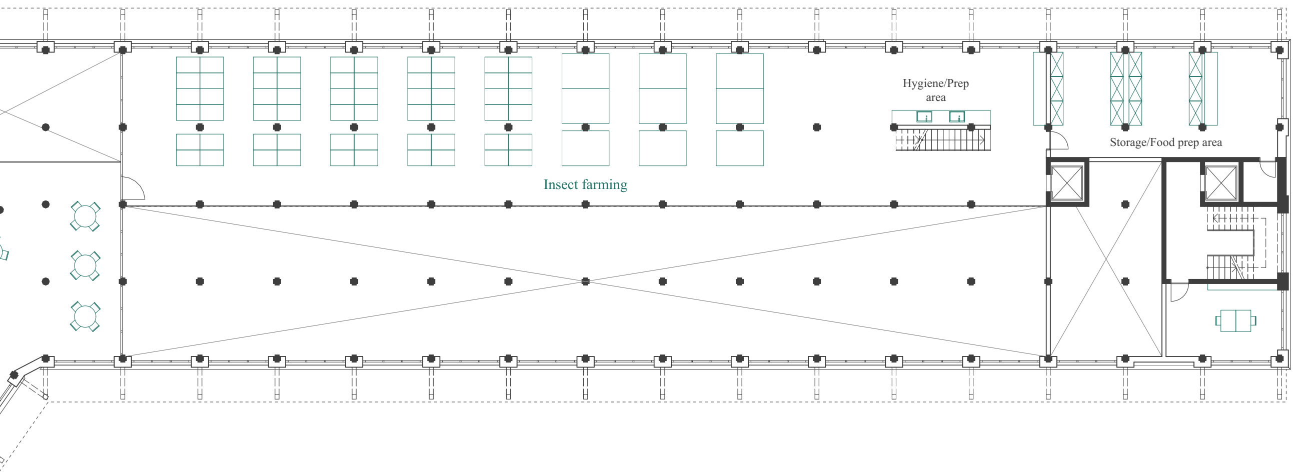


Fig. 20 1. Floor S 1:350


Hygiene/Prep
area
Storage/Food prep area
Insect farming


Office
Staff
Dressing W
Dressing M
Cafeteria/
Restaurant
Community area

SECOND FLOOR | 2.

From the second to the seventh floor, the building accommodates its residential units. Vertical circulation is organized through stairwells positioned both centrally and at the ends of the structure. Constructed in reinforced concrete, these circulation cores not only serve as access points but also function as stabilizing elements within the timber skeletal framework. From these cores, open-access galleries lead to the individual apartments. These galleries also serve as activated shared cultivation spaces for microgreens and various vegetable crops. By embedding food production directly into the building's circulation system, they become multifunctional zones that blend everyday routines with sustainable practices, which fosters informal social encounters and strengthens community ties.

- Standart apartment
- Hochpaterre apartment
- Maisonette apartment
- Senior apartment
- Student/Pension apartment
- Open plan apartment
- Big room apartment

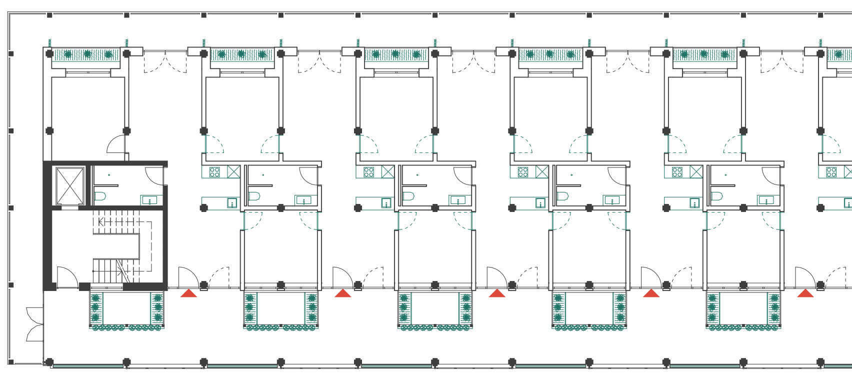
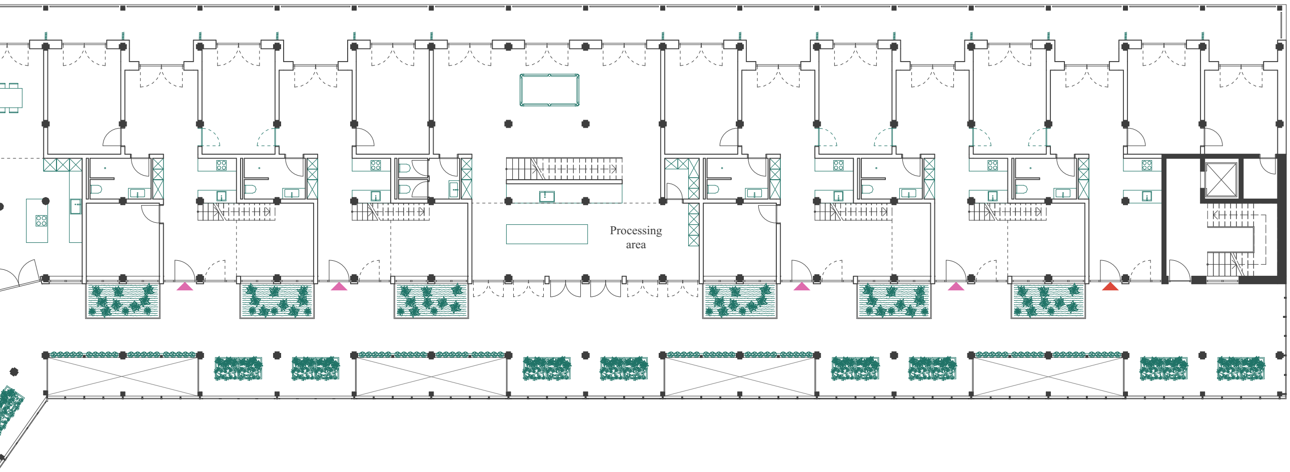
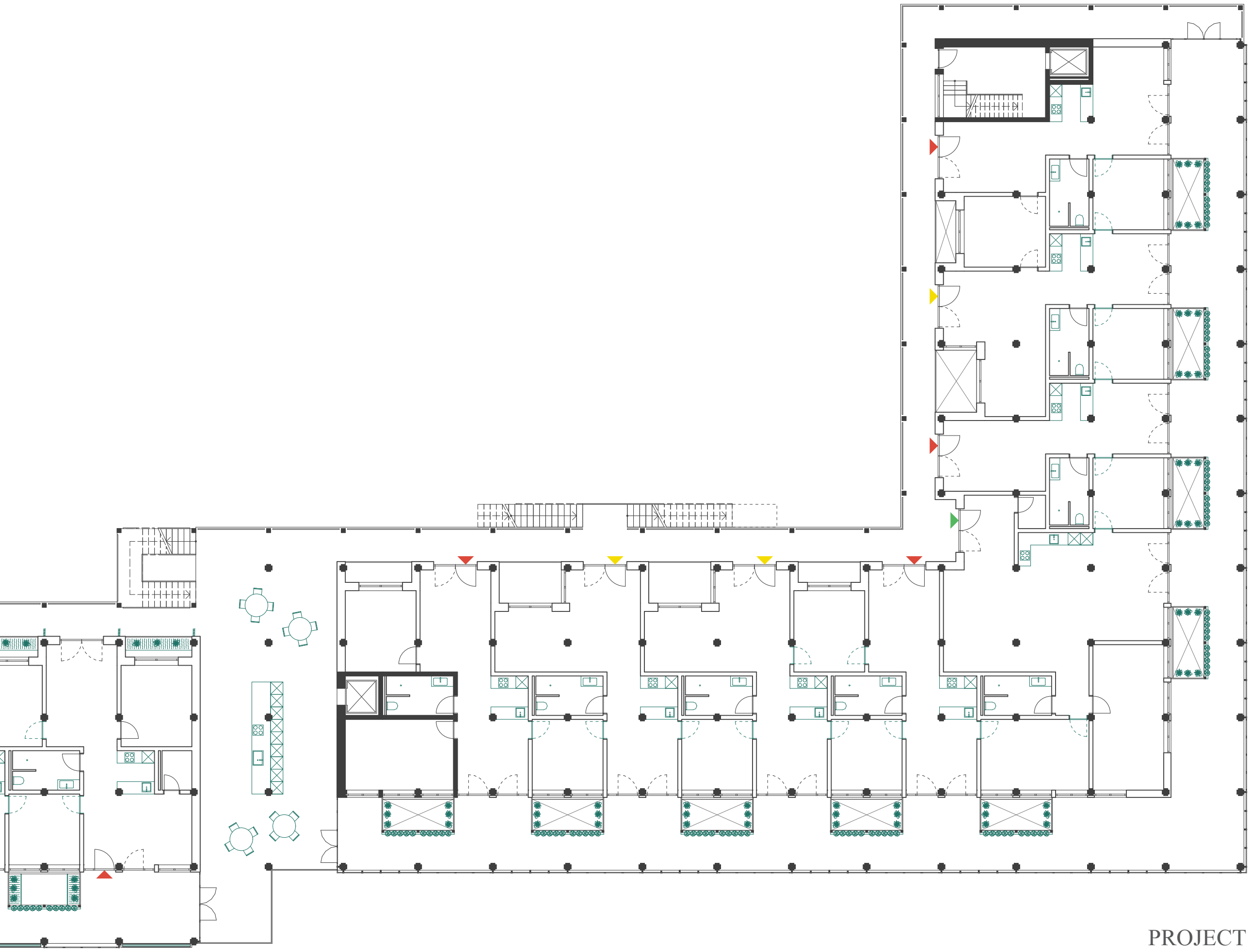


Fig. 21 2. Floor S 1:350


Processing
area



THIRD FLOOR | 3.

To support a diverse residential mix that addresses a wide range of demographic groups, the modular grid of the standard apartment unit, detailed further on page 48-51, is deliberately varied both horizontally and vertically. This differentiated interpretation of the grid generates a spectrum of unit sizes and spatial configurations, enabling a flexible and inclusive residential structure that accommodates a diverse range of households, from multi-person family apartments to student housing and senior living units, with layouts ranging from two- to seven-room apartments. The result is a holistic housing mix that promotes spatial diversity and social integration throughout the building.

Standart apartment
Hochpaterre apartment
Maisonette apartment
Senior apartment
Student/Pension apartment
Open plan apartment
Big room apartment

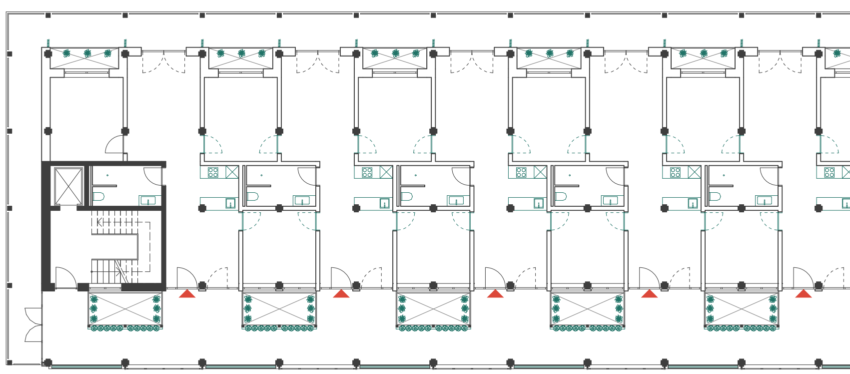
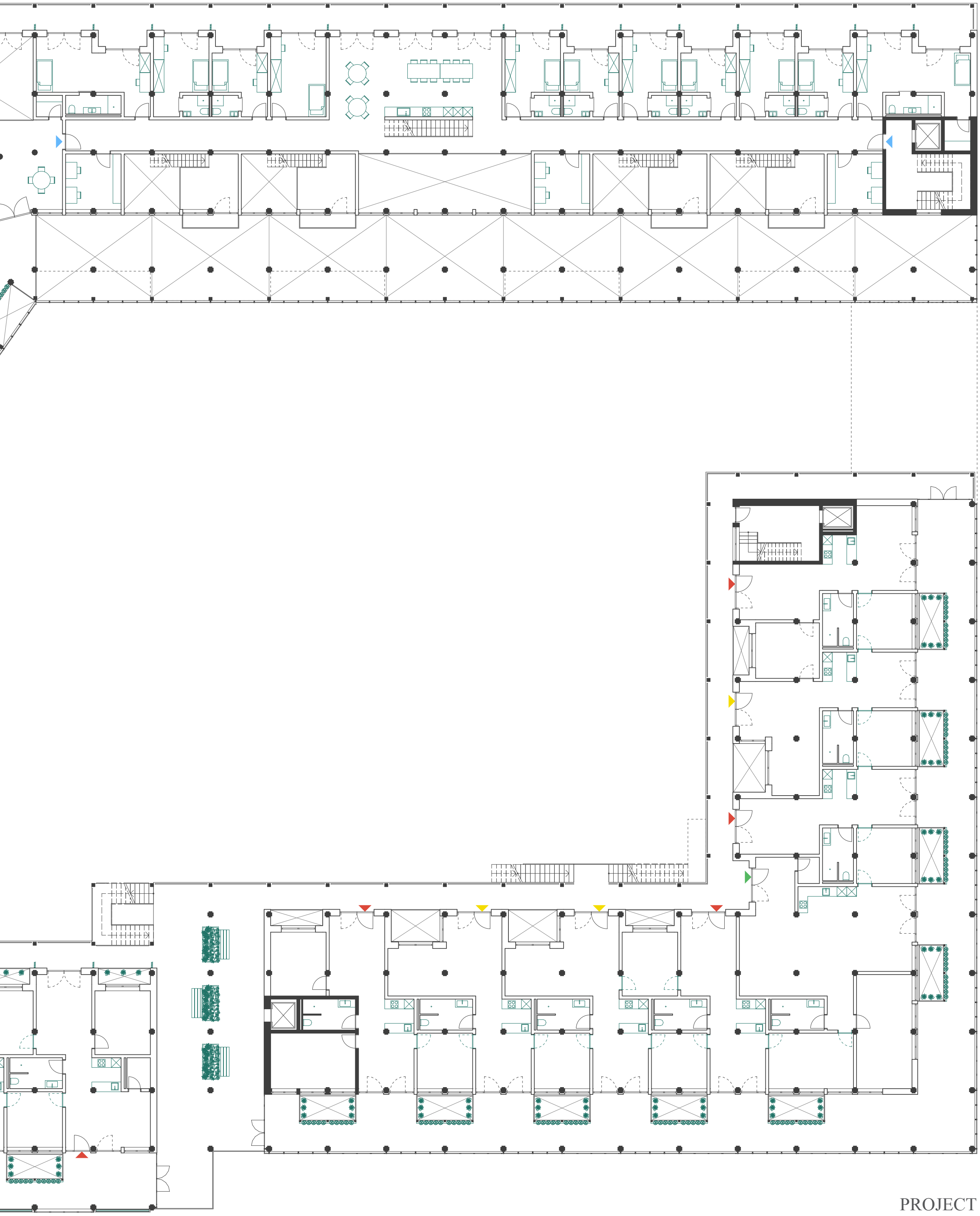


Fig. 22 3. Floor S 1:350



SIXTH FLOOR | 6.

The sixth floor is defined functionally by the presence of two greenhouses located on the roof of the building. The first of these greenhouses is exclusively for the cultivation of wheatgrass through vertical hydroponic systems, while the other serves as a freely accessible cultivation area for residents, complete with an adjoining production kitchen. Like in the other levels, there are indoor and outdoor communal kitchens and dining spaces to foster social interaction and collective preparation and consumption of the harvested products. The facilities are also complemented by a sun deck that has an outdoor kitchen and a sauna, which provide areas for leisure and social interaction.

This combination of production, social use, and recreation creates a multifunctional environment on every floor, emphasizing the integrative character of the building concept and further strengthening the connection between living, community, and sustainable food production.

- Standart apartment
- Hochpaterre apartment
- Maisonette apartment
- Senior apartment
- Student/Pension apartment
- Open plan apartment
- Big room apartment

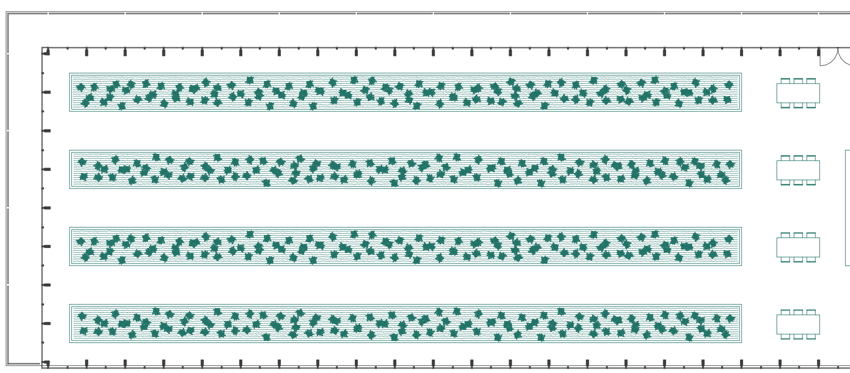


Fig. 23 6. Floor S 1:350

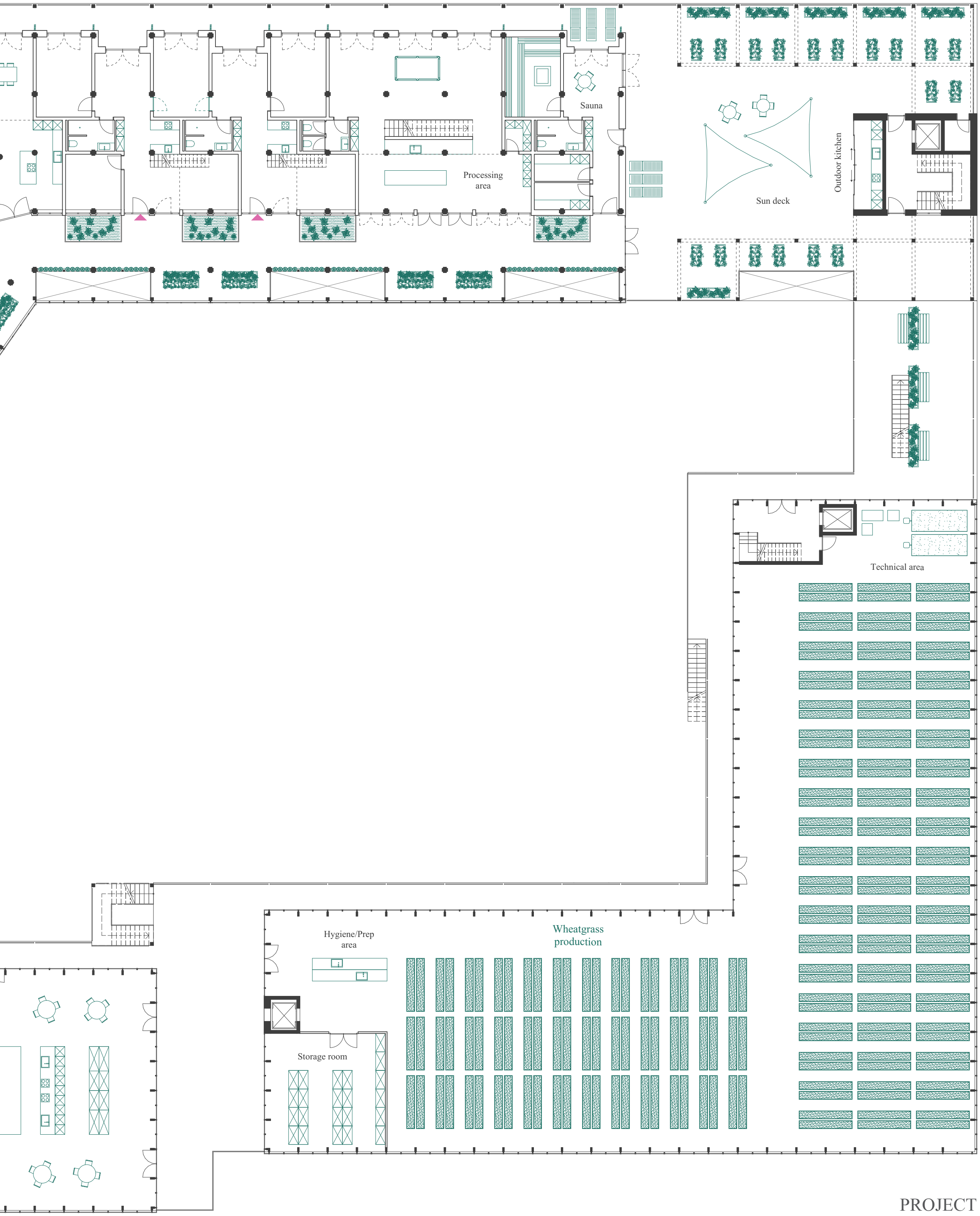
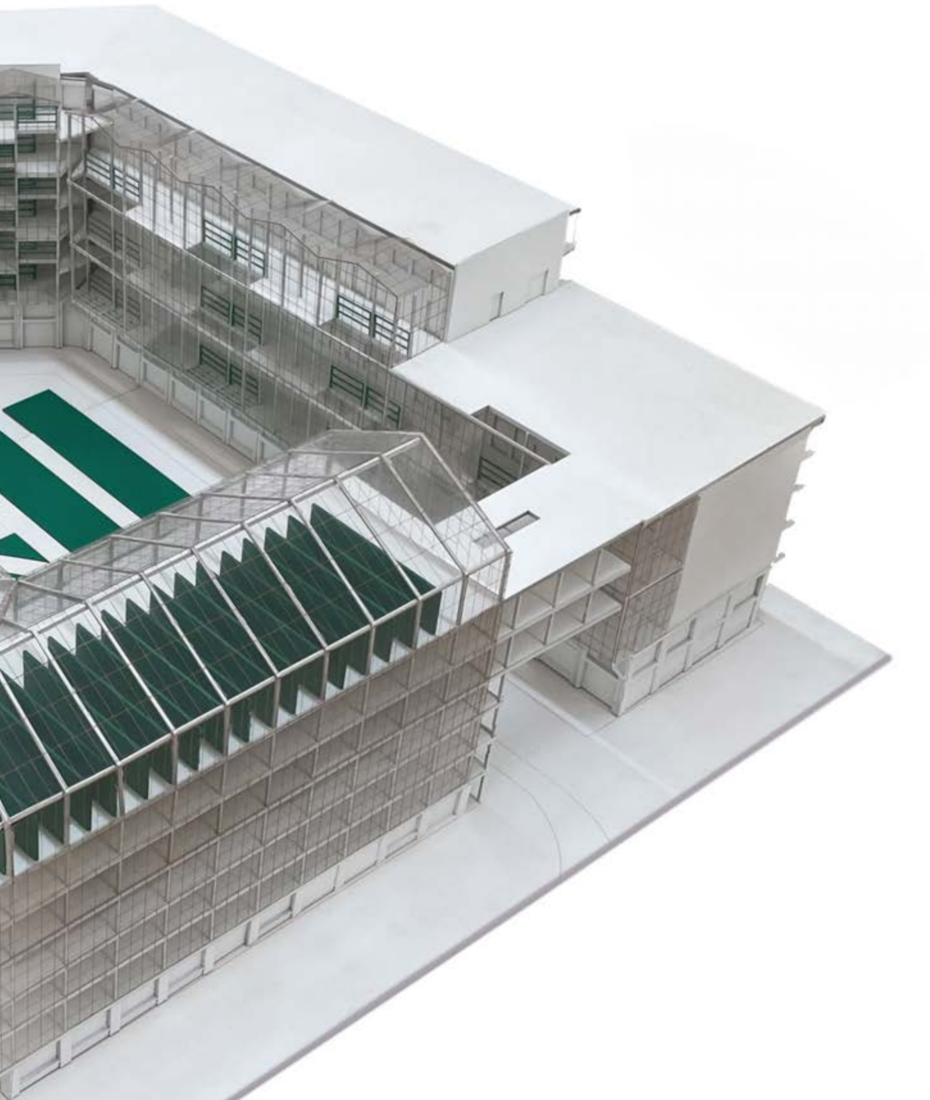

Sauna
Processing area
Sun deck
Outdoor kitchen
Technical area
Hygiene/Prep area
Wheatgrass production
Storage room

Fig. 24 Model of the building | Elevation

Fig. 25 Model of the building | Perspective



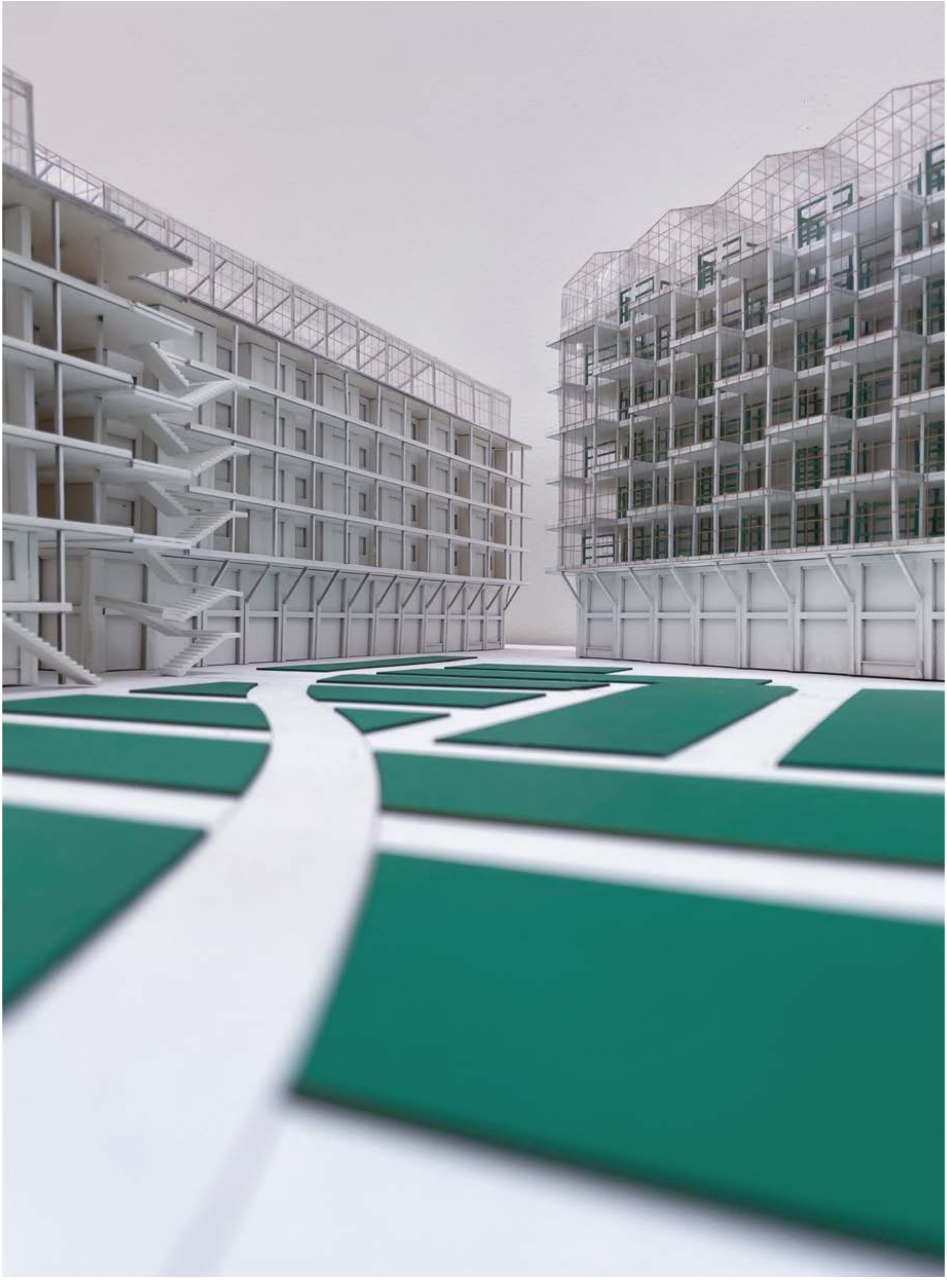


Fig. 26 Model of the building | View in the courtyard

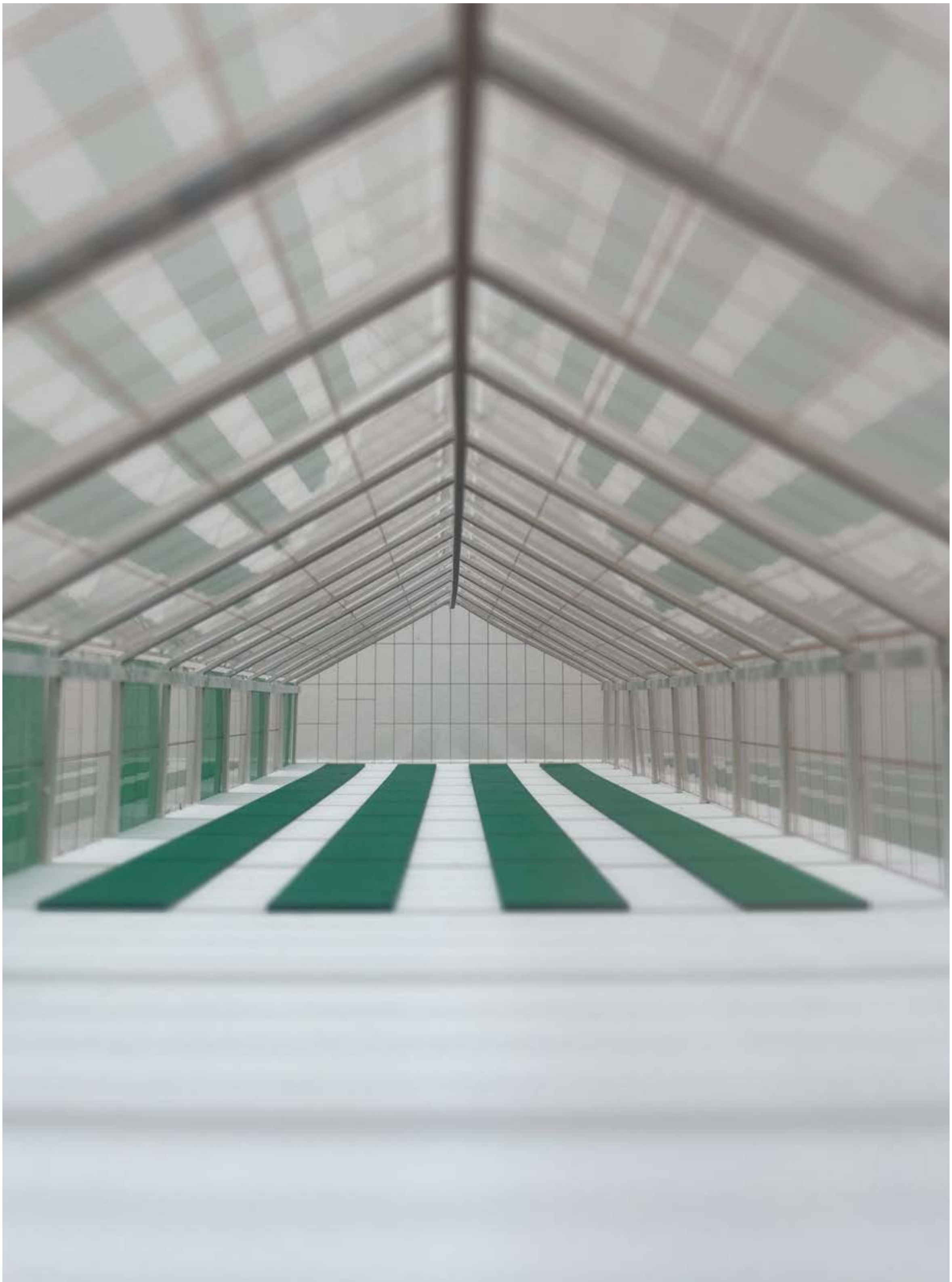


Fig. 27 Model of the building | View in the rooftop greenhouse

1.5 CONSTRUCTIONAL BASIS

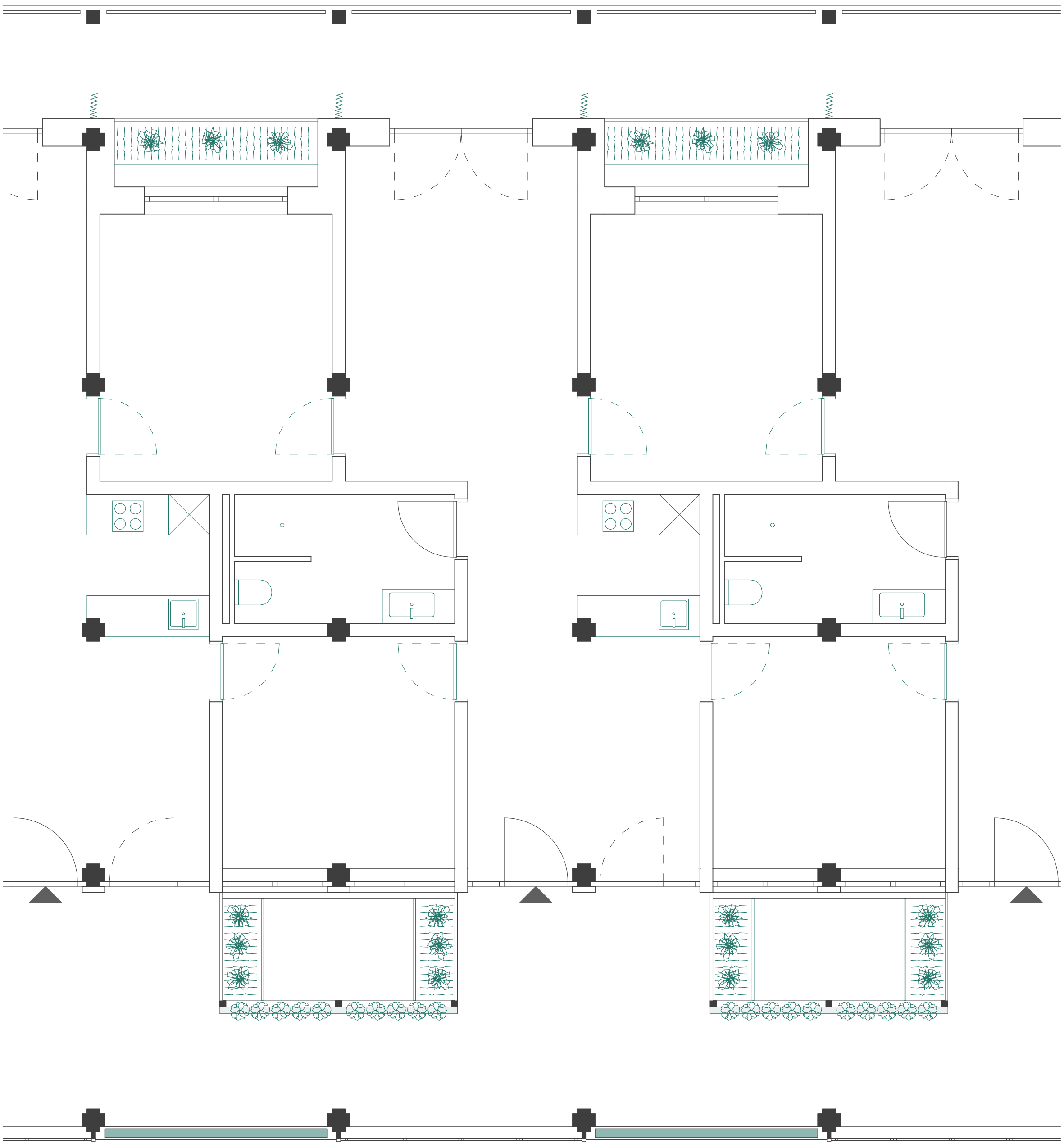
The building's construction is based on a sustainable architectural principle that combines a timber frame structure with a 3.6-meter grid and timber-concrete composite floors. Structural stability is ensured by reinforced concrete cores housing staircases and elevators, which simultaneously serve as the building's vertical circulation system. A projecting access gallery with a perforated steel grating floor functions as a horizontal distribution element, while also allowing maximum daylight penetration to the façade and adjacent planting zones.

Interior partition walls are constructed using timber stud framing with a clay plaster finish, offering both excellent acoustic performance and high indoor air quality. The apartments are designed as cross-ventilated units, ensuring optimal natural lighting and ventilation. Within the structural grid, they are offset by half a module to create spatial niches and high-quality transitional zones. Centrally located technical cores, composed of wet rooms such as kitchens and bathrooms, enable efficient distribution of supply and drainage systems. Laterally adjoining flexible spaces can be adapted as bedrooms, home offices, or extension areas. Through the modular connectivity of these spaces, a diverse range of apartment size, from 1.5 to 5.5 rooms, is made possible within the standard unit typology. The internal organization and allocation of units is managed cooperatively within the housing association, allowing for long-term adaptability to demographic and social change.

In the building's exterior zones, such as balconies and access galleries, movable partitions and curtains allow residents to individually adjust levels of privacy. Furthermore, the galleries are collectively cultivated as planting areas for microgreens and vegetables. Each resident thus has direct access to a personal gardening space directly adjacent to their apartment, reinforcing the connection between living and urban food production.

Viewed holistically, this housing model, combined with the architectural food layer, creates an ecologically, socially, and functionally cohesive living environment. It unites dwelling, community, and food production in a synergistic manner, fostering a sustainable everyday culture, strengthening neighbourhood relations, promoting regional food sovereignty, and empowering residents to actively shape their dwelling and urban environment.

Fig. 28 Apartment module S 1:100



FLOOR PLAN IN DETAIL

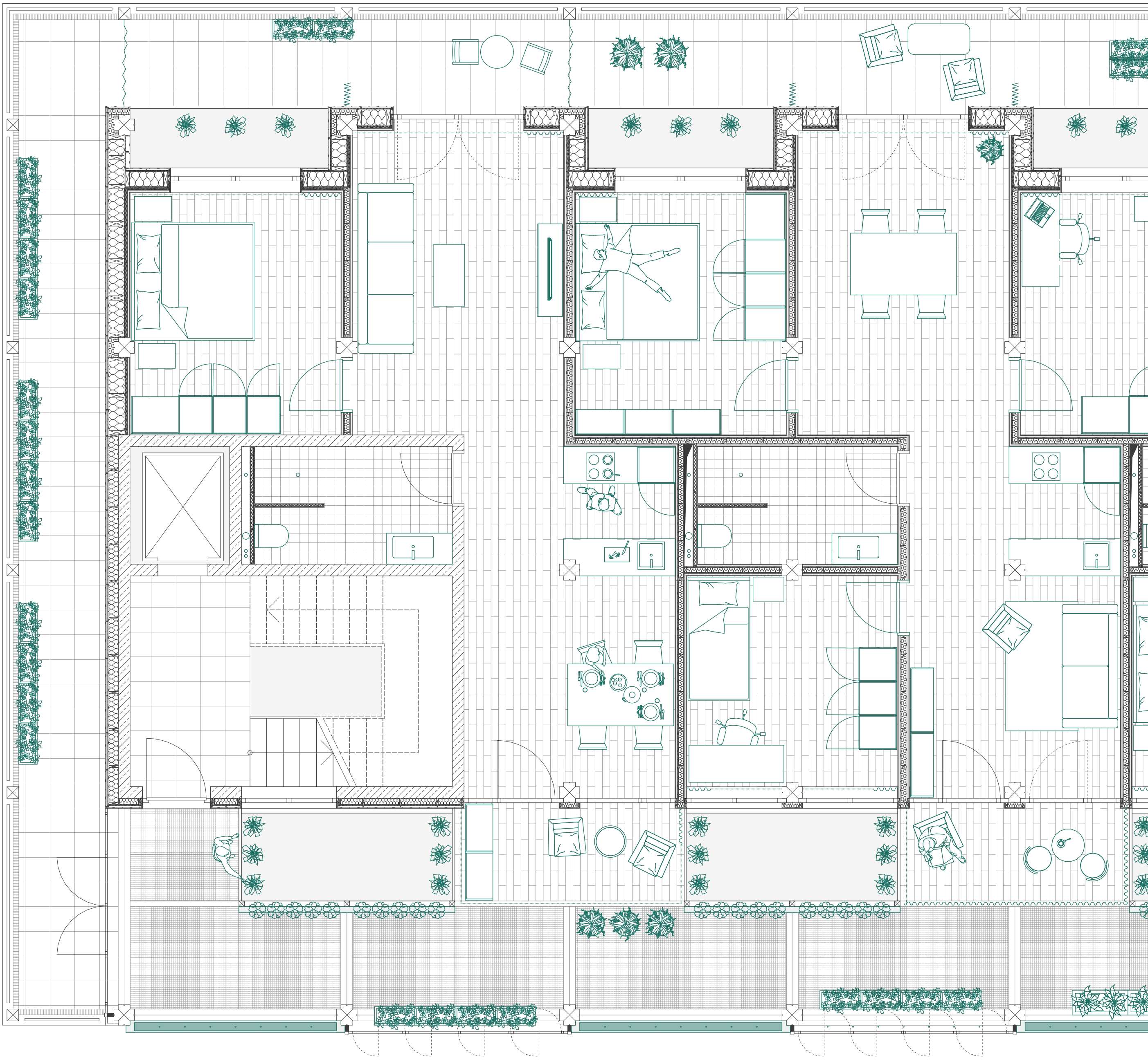
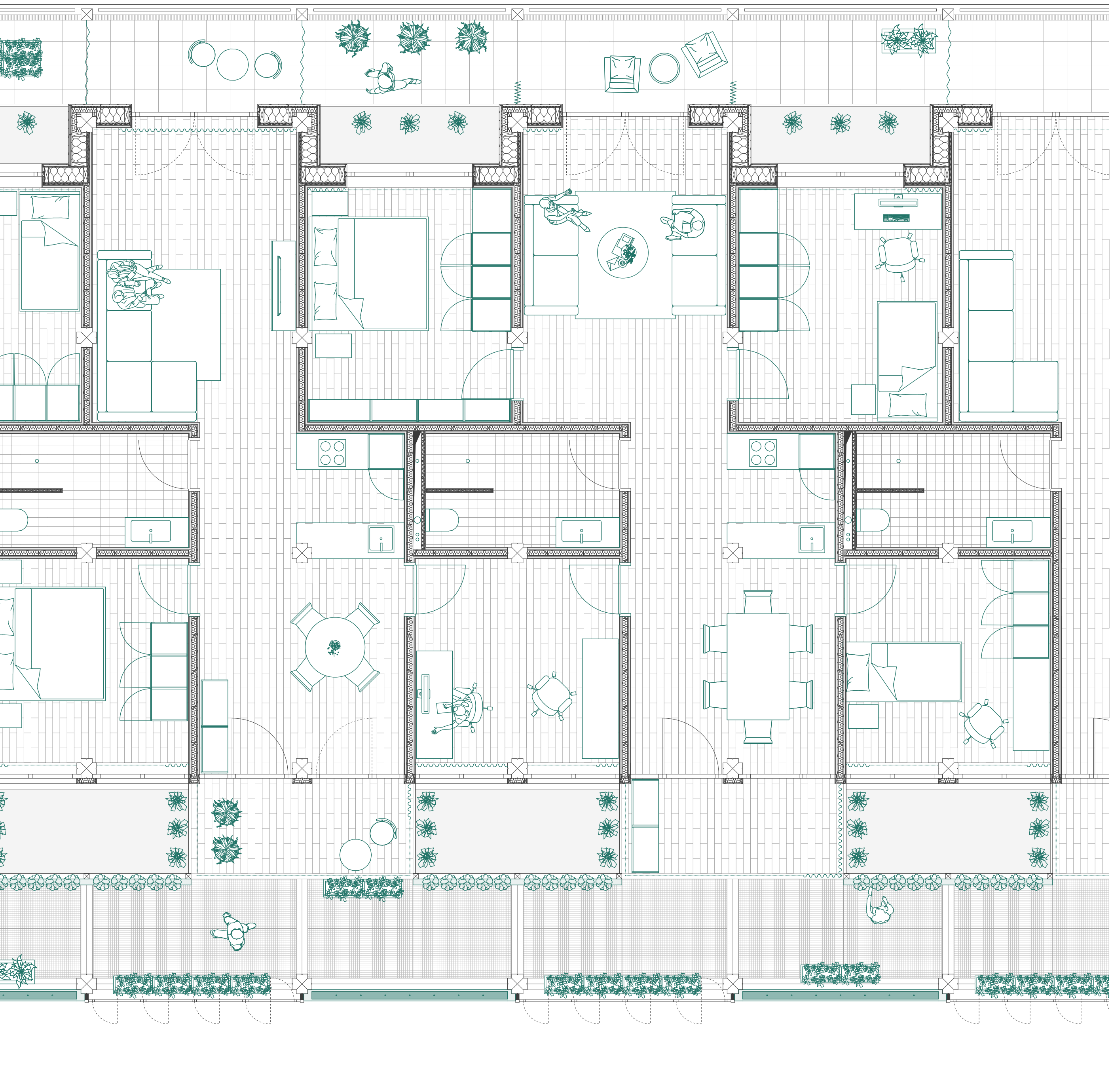


Fig. 29 Floor plan detail of standard apartment S 1:100



SECTION/DETAIL PLANS

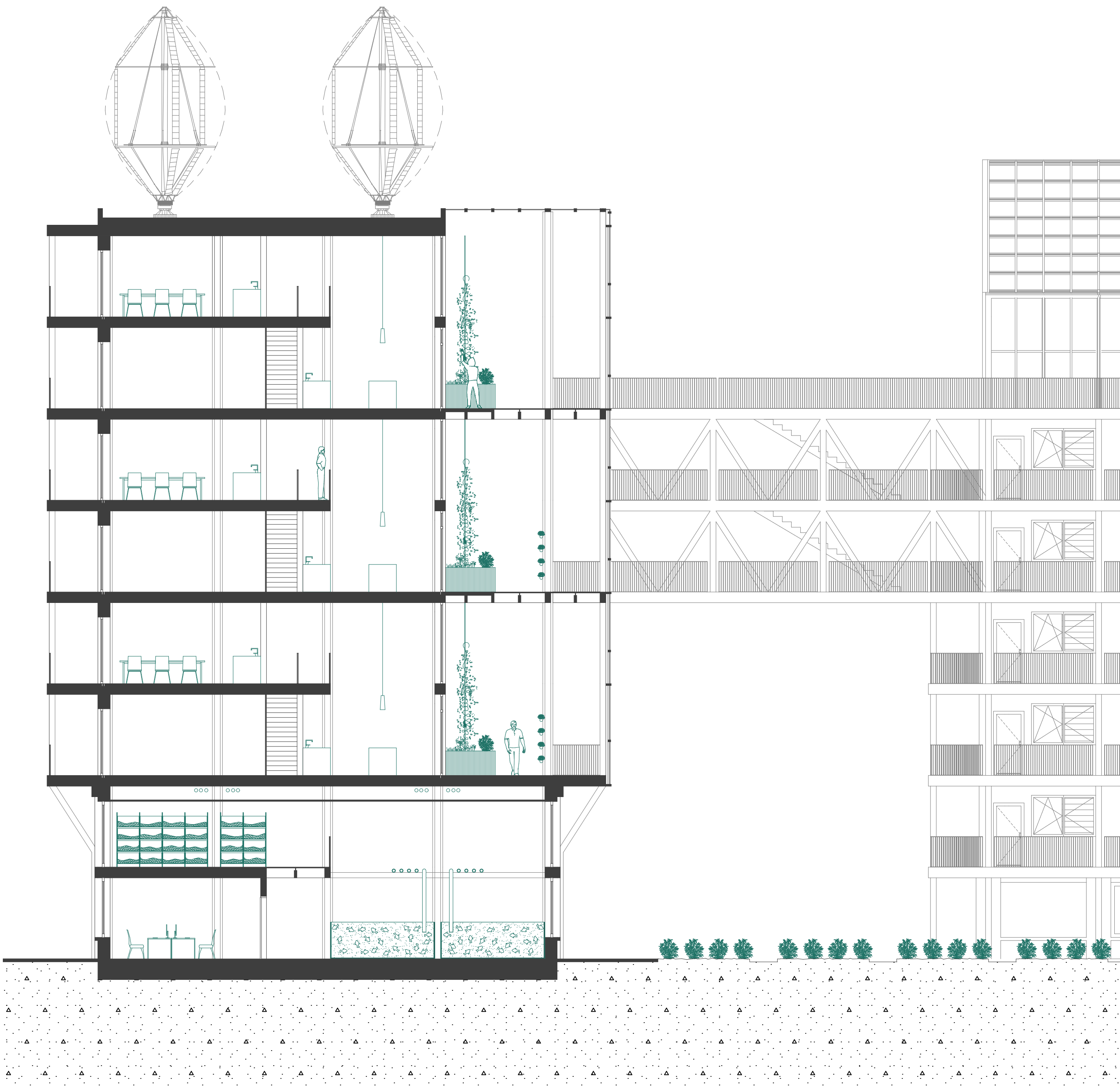
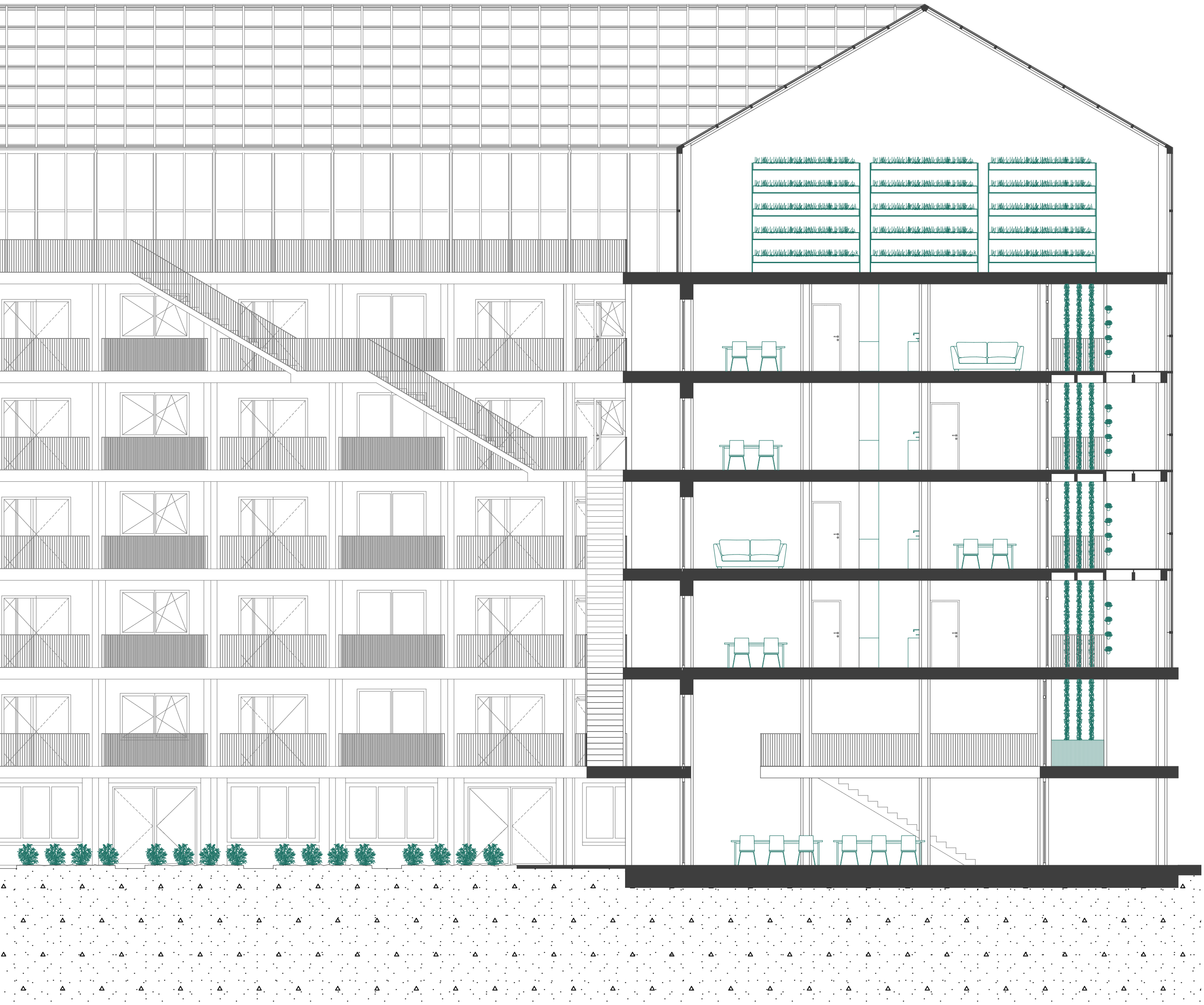
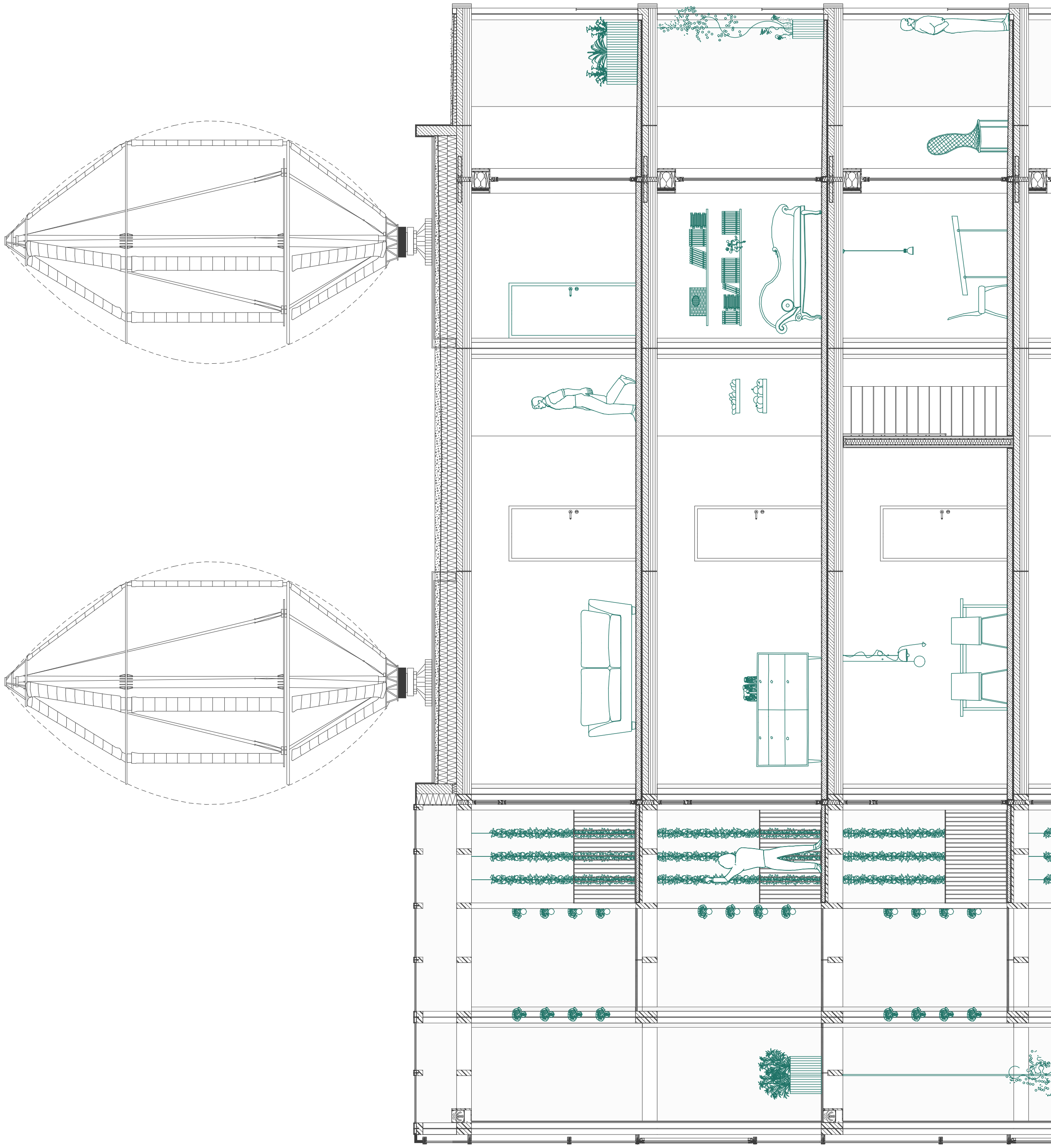


Fig. 30 Section S 1:200





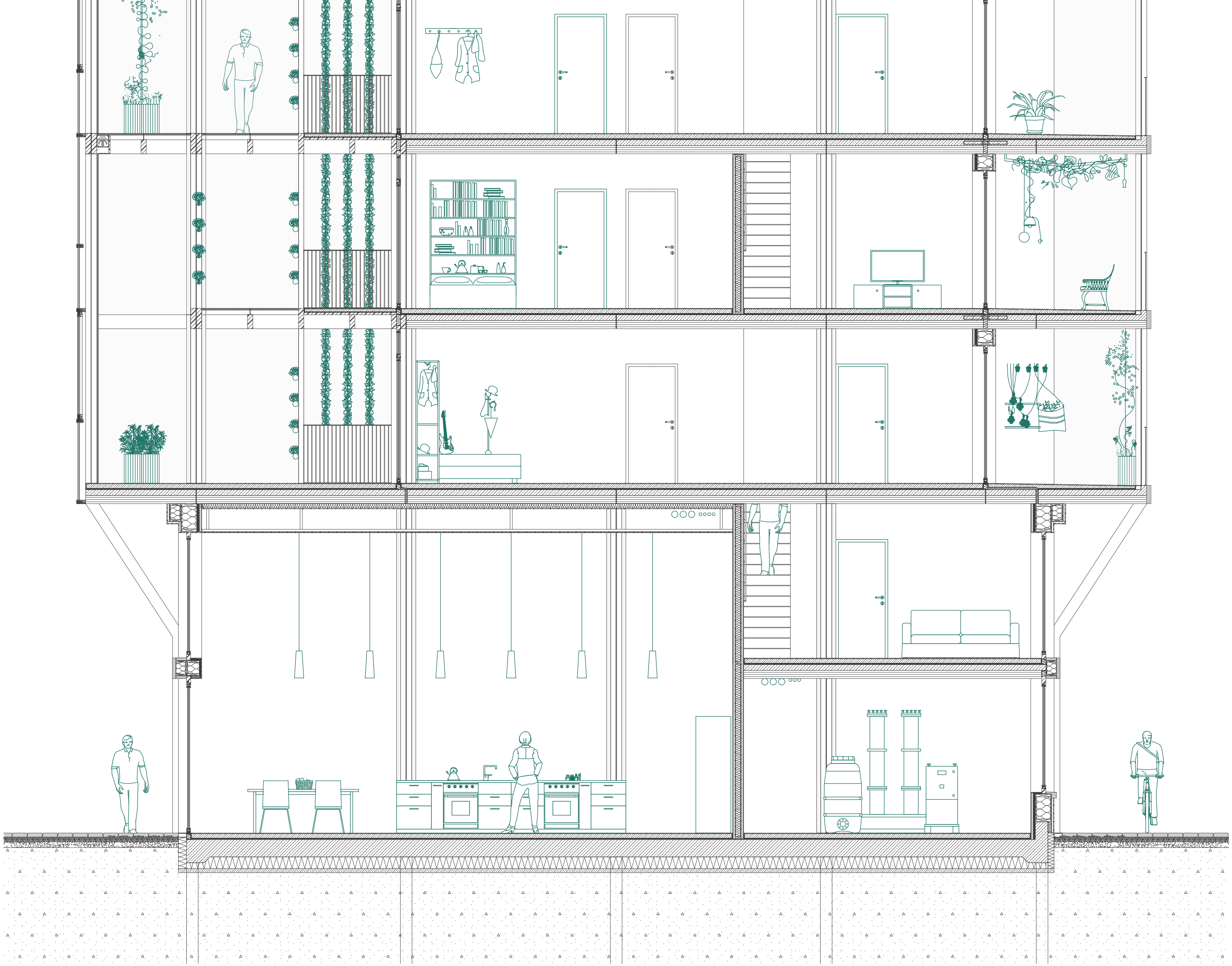


Fig. 31 Facade section S 1:100

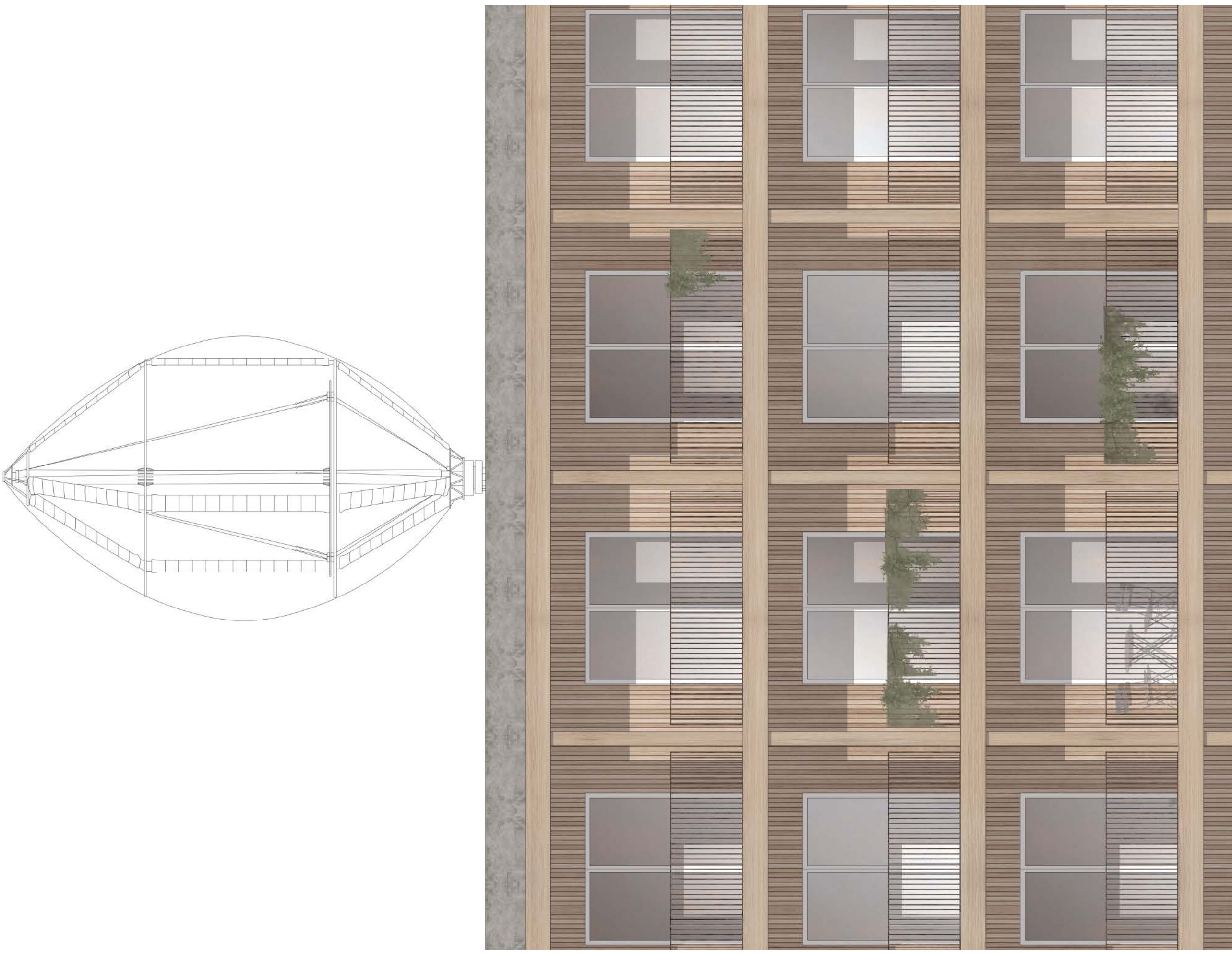


Fig. 32 Elevation detail S 1:100

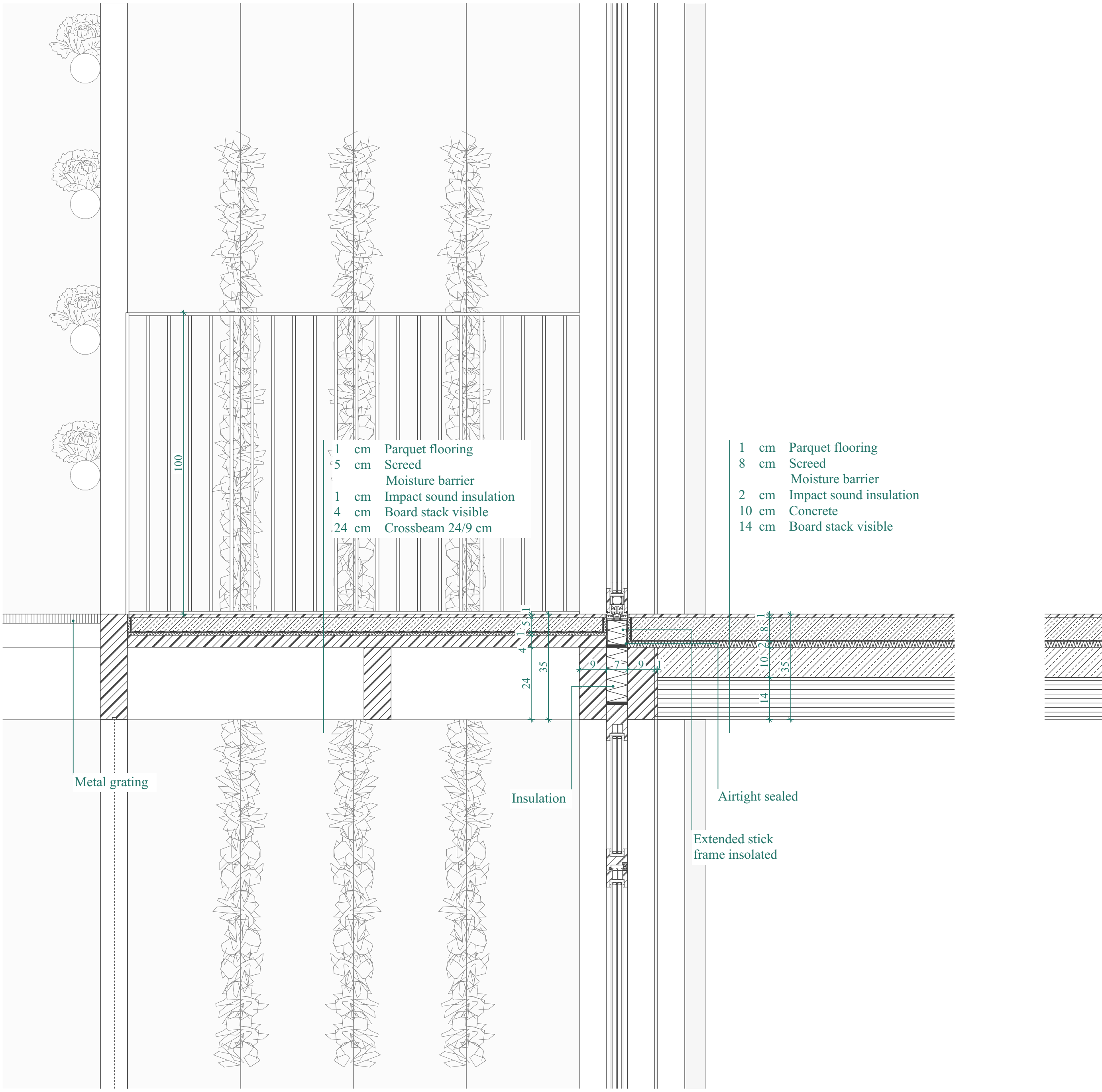


Fig. 33 Detail | Greenhouse connection S 1:20

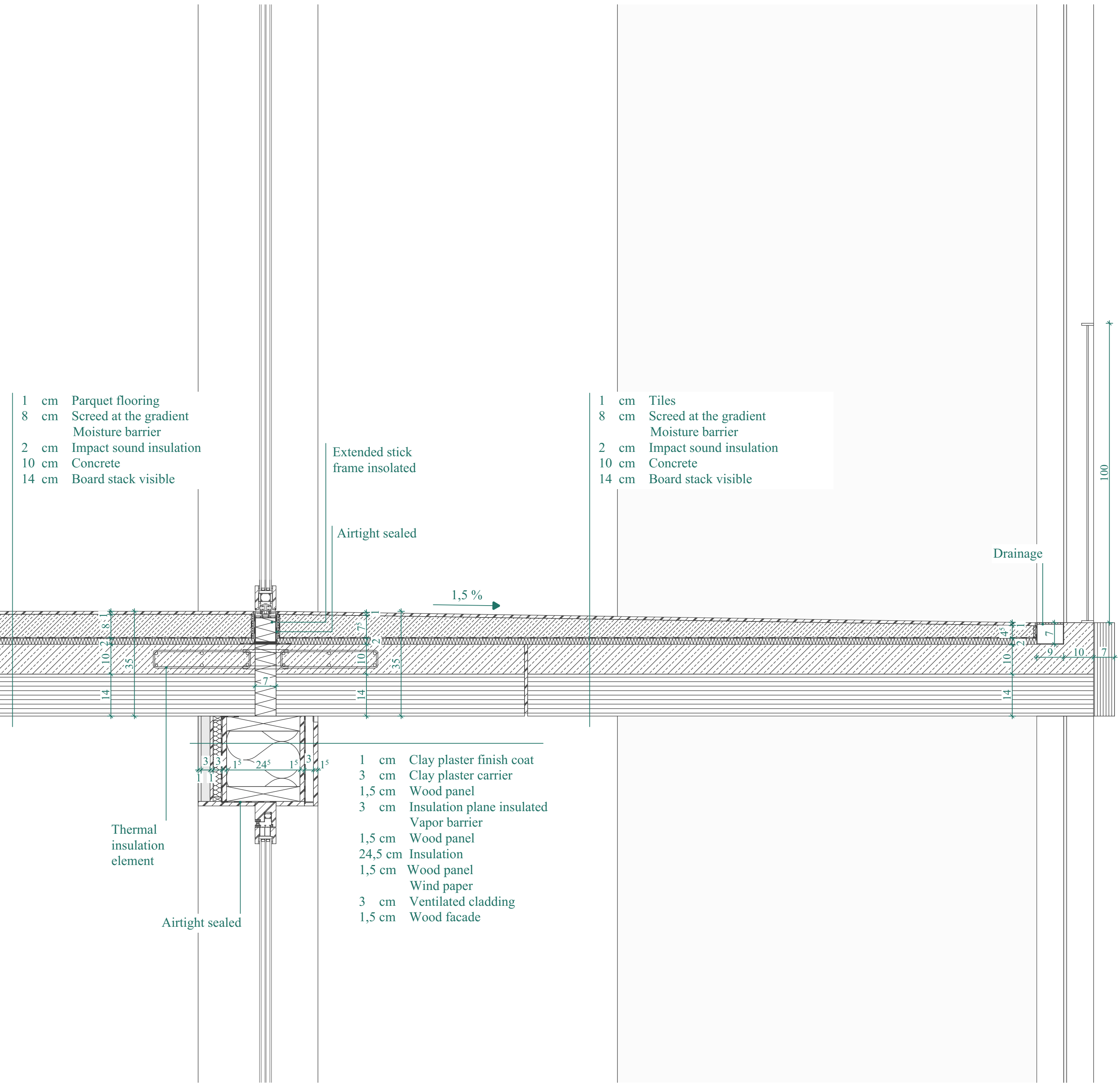
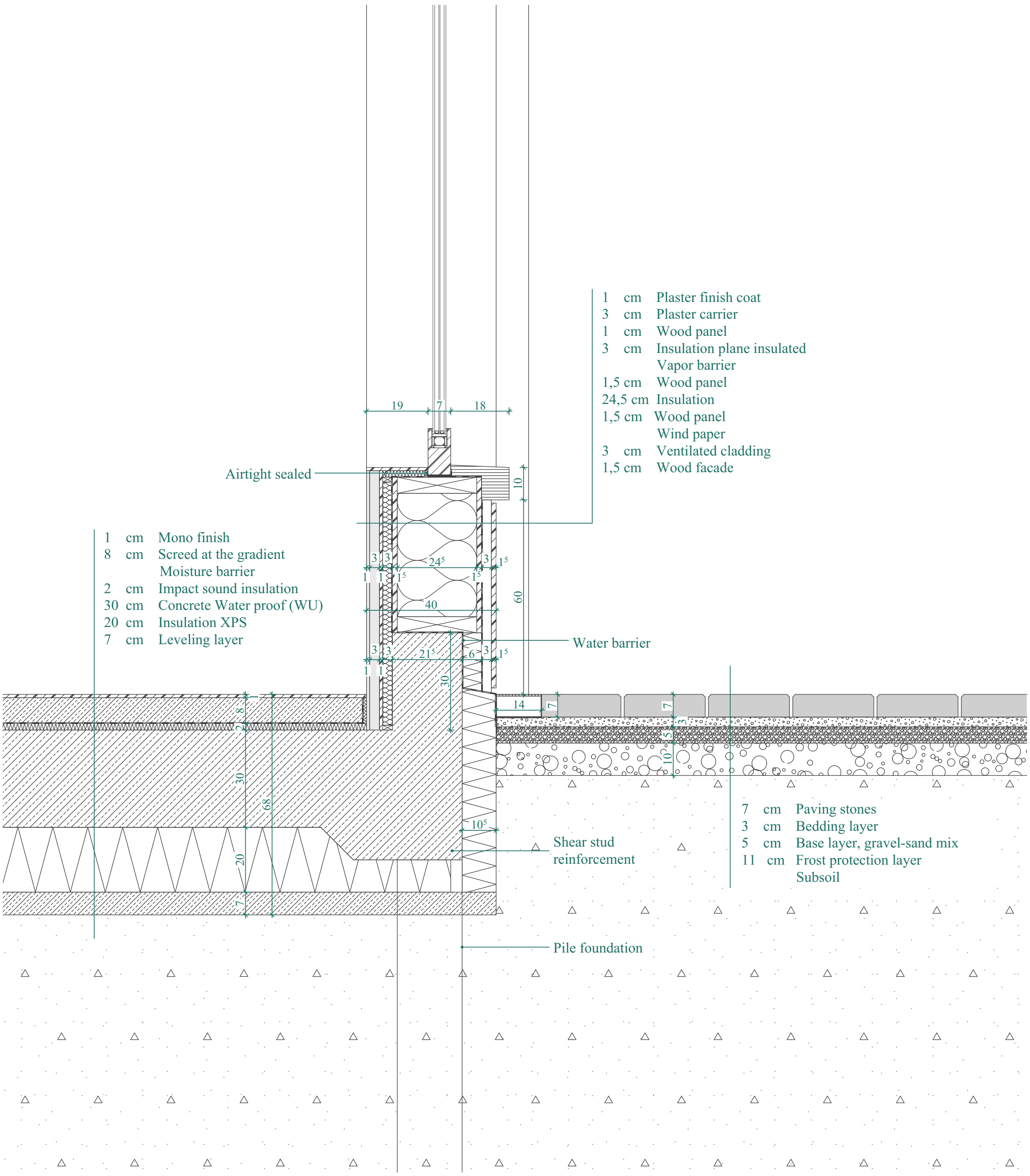


Fig. 34 Detail | Balcony connection S 1:20



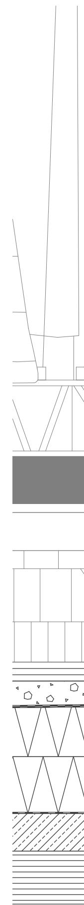


Fig. 35 Detail | Plinth S 1:20

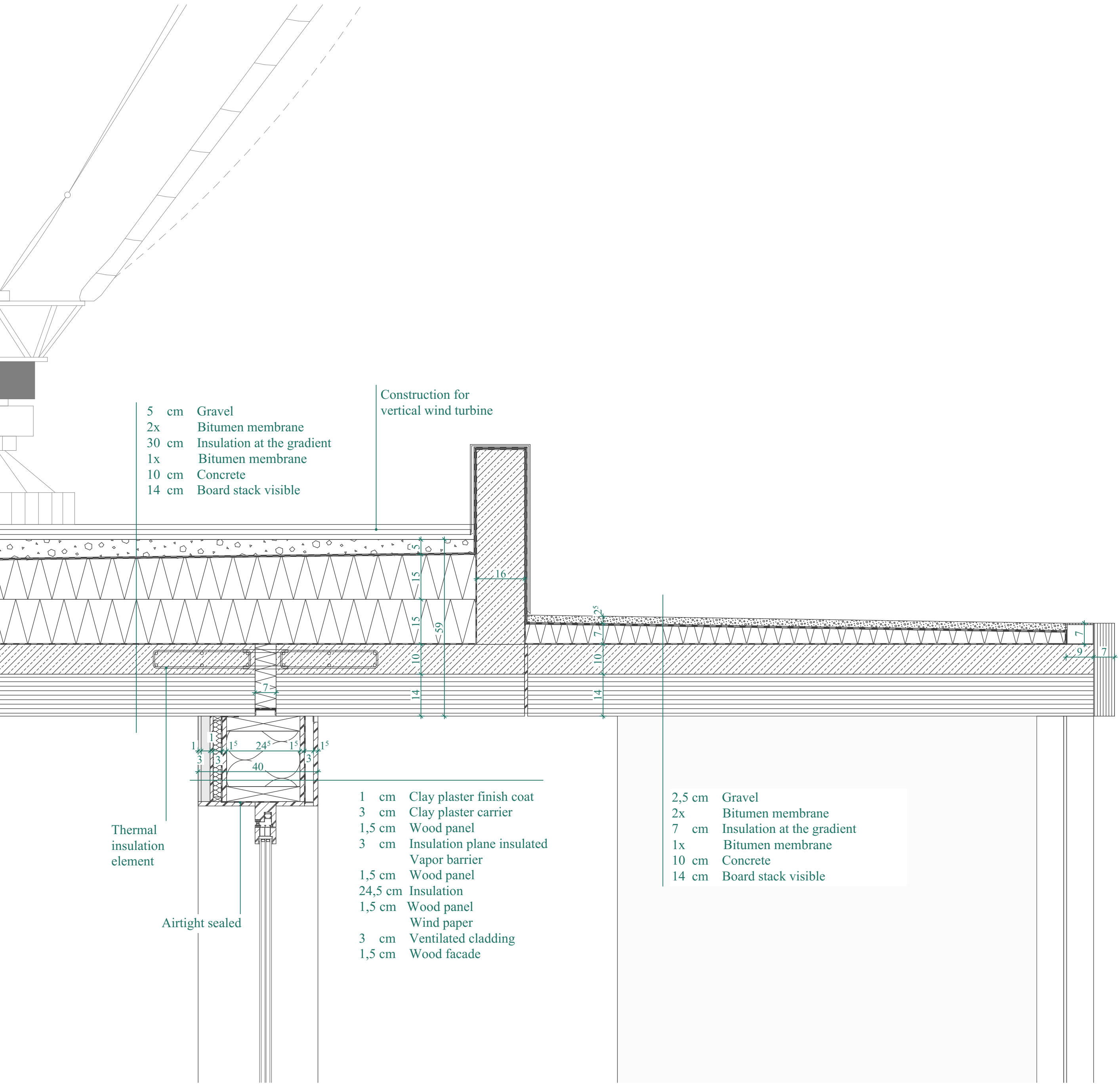


Fig. 36 Detail | Parapet S 1:20

1.6 CONCLUSION

At the beginning of the architectural project, the research question was posed:

"How can architecture act as a mediating discipline between production, community, and space to help establish a visionary, sustainably resilient, and socially embedded culture of food production in an urban and architectural context?"

The result is a new, architectural food layer which is mediating discipline that facilitates the incorporation of decentralized and communal modes of food production into city-built structures. The concept integrates resilience-driven, and socially consistent food culture in the urban environment and within its built structure. The "Food Layer" Matrix demonstrates how urban systems can be connected with various typologies of food production in order to turn former empty or low-used areas into productive, lively, and sustainable districts. Using the former industrial harbour of Leith in Edinburgh as a case study, it becomes evident how targeted urban and architectural interventions can reactivate industrial areas and convert them into hybrid living environments where production, housing, and community are closely intertwined.

The architectural concept focuses on various innovative protein-rich food production methods, such as insect farming, algae cultivation, aquaculture, vertical farming, combined with traditional urban farming, and makes these processes publicly accessible through transparent design elements. Thereby, humans are part of the system and represent the final link in a self-contained farm cycle, in which its components mutually support each other. Food production is no longer perceived merely as technical infrastructure but as a dynamic component of everyday urban life and social interaction. Architecture creates a blend of private, semi-public, and public spaces that facilitate communal gardening, neighbourhood activities, and individual use. This not only enhances local food sovereignty but also fosters social cohesion and active community engagement among residents.

In addition, the environmentally friendly wood building with a modular, variably utilisable floor plan provides great flexibility for addressing varied demographic and ecological needs. The building and its inhabitants are actively involved in food production through productive galleries and rooftop gardens, transforming the structure itself into a living part of the urban ecosystem.

Overall, the project demonstrates that architecture transcends mere functional use. It becomes a mediating platform that interweaves ecological and social dimensions, thereby enabling a holistic, future-proof, and resilient food culture.

Fig. 37 Visualisation | Inside of the greenhouse facade

Fig. 38 Visualisation | urban farming courtyard

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1.7 LIST OF FIGURES

1.7 LIST OF AIDS

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Deepl	Translation of text passages	All chapters

02

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THEORETICAL REPORT

FARMING COMMUNITY
Housing types for food self-sufficiency and community

ABSTRACT

Given the rapid growth of urban areas alongside the simultaneous exploitation and displacement of agricultural land, the question arises as to how food production can be sustainably integrated into the urban context. This theoretical report examines how the interaction between humans and nature, as well as between living and food, can be re imagined to overcome the fundamental separation of city and countryside. Building on a historical and theoretical analysis, as well as the evaluation of numerous case studies, it demonstrates that the reintegration of food production into urban spaces holds both ecological and social potential. Crucially, food must be understood as an integral part of urban planning, with productive spaces deliberately designed, actively involving residents in planning, implementation, and maintenance. The created design guidelines and planning instruments offer concrete courses of action to spatially and structurally anchor food within the urban fabric. The insights gained provide a robust foundation for architectural projects that conceive of housing and food as a unity and contribute to the development of resilient, solidaristic, and sustainable cities.

TABLE OF CONTENTS

INTRODUCTION

In urban areas, populations are growing rapidly, while agricultural land is increasingly shrinking and increasingly exploited. Due to this ongoing centralization of food production, alongside the rising demand for food, people are gradually losing their grip on themselves and their food. This negatively impacts the environment, as well as the quality of our food. In order to make food production future-proof, it must be changed, local, sustainable, and resource-efficient. In this process, the interaction between humans and nature plays a crucial role. From an architectural perspective, the theoretical question arises:

"How is it possible to redefine the relationship between humans and nature, food and dwelling, in such a way that the relation between humans and food can be re-established by actively involving dwelling in food production?"

This theoretical report will explore and answer that question, laying the conceptual foundation for an architecture project that will explore further the connection between housing and food production.

The report begins by defining the food production object and establishing why it is important to reintegrate it into an urban context. Case studies on varying scales are selected to compare diverse innovative housing forms that combine community, food self-sufficiency, and sustainability. Their varied contexts provide a solid basis for comparative insights into future-proof housing concepts. To contextualize and compare these projects, specific parameters are established that enable a qualitative analysis.

The research focuses on the impact of such projects on human beings and the environment, and how they are able to develop new forms of coexistence and community through the integration of the human into the process of food production. Such observations and analyses provide the foundation for developing design guidelines, which forms the basis for the architectural and urban structures featured in the master's thesis project.

2.1 URBANITY AND NUTRITION

The interconnection among the city, landscape, and food preparation is of fundamental importance in the exploration of societal development, past and contemporary. Food and land were initially viewed as commons, anyone had a right to hunt, gather and work the land. With sedentarism and expanding cultivation of the land, however, this relationship took a drastic turn (Mumford, 1976). The establishment of property rights, along with the development of division of labour and property institutions, brought about a city-rural dualism in which urban areas progressively dominated agricultural production (Lefèbvre, 1972).

Over time, the city became the driving force of technological and economic development, and the countryside was converted into a source of food, raw materials, and labour. Although cities remained dependent on agricultural production for centuries, their direct relationship with food eventually faded, symbolically and spatially. Lefèbvre (1972) refers to this process as the "political city," which rules, protects, and simultaneously exploits the countryside.

As trade increased in the late Middle Ages and the "commercial city" emerged, the function of urban centres started to change. Cities were no longer simply consumers but also producers, points that channelled markets and streams of trade. This slightly softened the strict divide between city and countryside. But centralizing and rationalizing tendencies, especially in food production and consumption, became even more pronounced with industrialization. This was followed by an increasing alienation of the population from the source of their food, as witnessed in the development of mass production and international supply chains (Giedion, 1969).

Cities today are faced with the task of overcoming this alienation and devising new methods of re-establishing food production in the city. The attempt at re-localizing production is not just a move towards the re-urbanization of agriculture but also a promising move towards the mitigation of greenhouse gas emissions. The trend demands a re-visioning of urbanity, one that now views the city no longer as a place of consumption but as an actor in the food system. At the centre of this discussion is how cities of the future will engage with their environment, energy, and food systems and what local production and landscapes will mean to the development of a sustainable urban future (Ziegler, 2010).

2.2 DEVELOPMENT OF URBAN AGRICULTURE

The importance of urban agriculture is best seen during a crisis. In World War I, for instance, the food shortage in Vienna saw the takeover of empty lots as vegetable gardens and gave rise to the so-called "bucket gardens" in Vienna. While Berlin had allotment colonies for the workers, in Vienna the movement was politicized. During World War II, "Victory Gardens" were an important component of United States and United Kingdom food production. In Vienna, parkland and garden spaces were encouraged to provide food supply (Ziegler, 2010).

Following the economic boom of the 1950s, agriculture was no longer relevant to the urban setting. However, with the ecological movements of the 1970s and again from the 1990s onwards, urban agriculture was re-evaluated. The Continuous Productive Urban Landscape (CPUL) theory, as introduced by André Viljoen, proposed that urban green spaces be permanently productive, also for the production of food (Ziegler, 2010).

There has been a renaissance of urban gardening since the 2000s. In Vienna, for instance, Gartenpolylog network facilitated the establishment of community gardens in socially disadvantaged neighbourhoods. Such projects aim at inter cultural exchange, education, and social interaction. "Naschgarten" on the Danube Canal and rooftop cultivation in the former Sophienspital are some of the new forms of urban agriculture (Ziegler, 2010).

It transpires that the subject of urban agriculture is centuries old, as is the issue of how it might be incorporated into cities and housing models. The reasons for the incorporation have also differed. During periods of crisis, it was a means of food production. During periods of affluence, it was a means of recreational space. Agricultural areas have repeatedly been incorporated into urban planning, but food production itself progressively moved into the background throughout the 20th century. In the 1960s, agricultural use lost its purpose while motorization and suburbanization pushed agricultural land out of the urban region. Today, the current environmental and climatic crisis, of which contemporary, centralized food production is one of the principal drivers, is giving us more incentive than ever to come up with new ideas for incorporating food production into cities and forms of housing in a more sustainable manner.

The following examination of a number of case studies concentrates not just on urban areas, but also on their inhabitants, their living conditions, and the societal context within which they are located. The objective is to look for ways in which the synthesis of housing and food production could lead to new housing concepts and a new kind of urban society and neighbourhood.

2.3 CASE STUDY PARAMETERS

In the comparative analysis of architectural innovative residential configurations projects, community formation, and self-management, it is necessary to analyse systematically a number of aspects. Such an analysis is founded on six criteria in an organized matrix, which allows comparison in depth of different projects, thereby facilitating an analytical review. This method enables an overall evaluation of new housing types from which design recommendations can be deduced. The chosen projects are various innovative housing types that incorporate community, autonomy, and sustainability. They originate from different contexts, which gives a wide basis for comparison and allows the extraction of valuable insights for future-proof housing concepts.

ARCHITECTURAL STRUCTURE

This course enables systematic analysis of spatial organization, from settlement level to the design of individual dwelling units. Integration within urban or rural context, circulation systems, building typologies, and residential densities are the most significant factors. Understanding these factors is essential in assessing the spatial logic and sustainability of each project.

SOCIAL COMMUNITY

Most of the new housing forms attempt to promote communal living, enabled by forms of architecture and participatory processes. Social dynamics analysis, such as community structures, affordable housing, and social cohesion, illuminates the manner in which communal relationships are formed and the role the participation plays in daily life and planning.

FOOD SELF-SUFFICIENCY

A unifying requirement across the projects that are under research is the integration with food production. This includes not only the type and diversity of cultivation but also organizational models, the degree of self-sufficiency, and collaborations with external actors. This aspect shows how food systems can be integrated in domestic environments.

SUSTAINABILITY STRATEGIES

Through examination of ecological rules such as resource-efficient construction, renewable energy systems, and water management, he ecological profile of each project can be captured. This allows for comparison of low- and high-tech techniques and environmental implications to be evaluated.

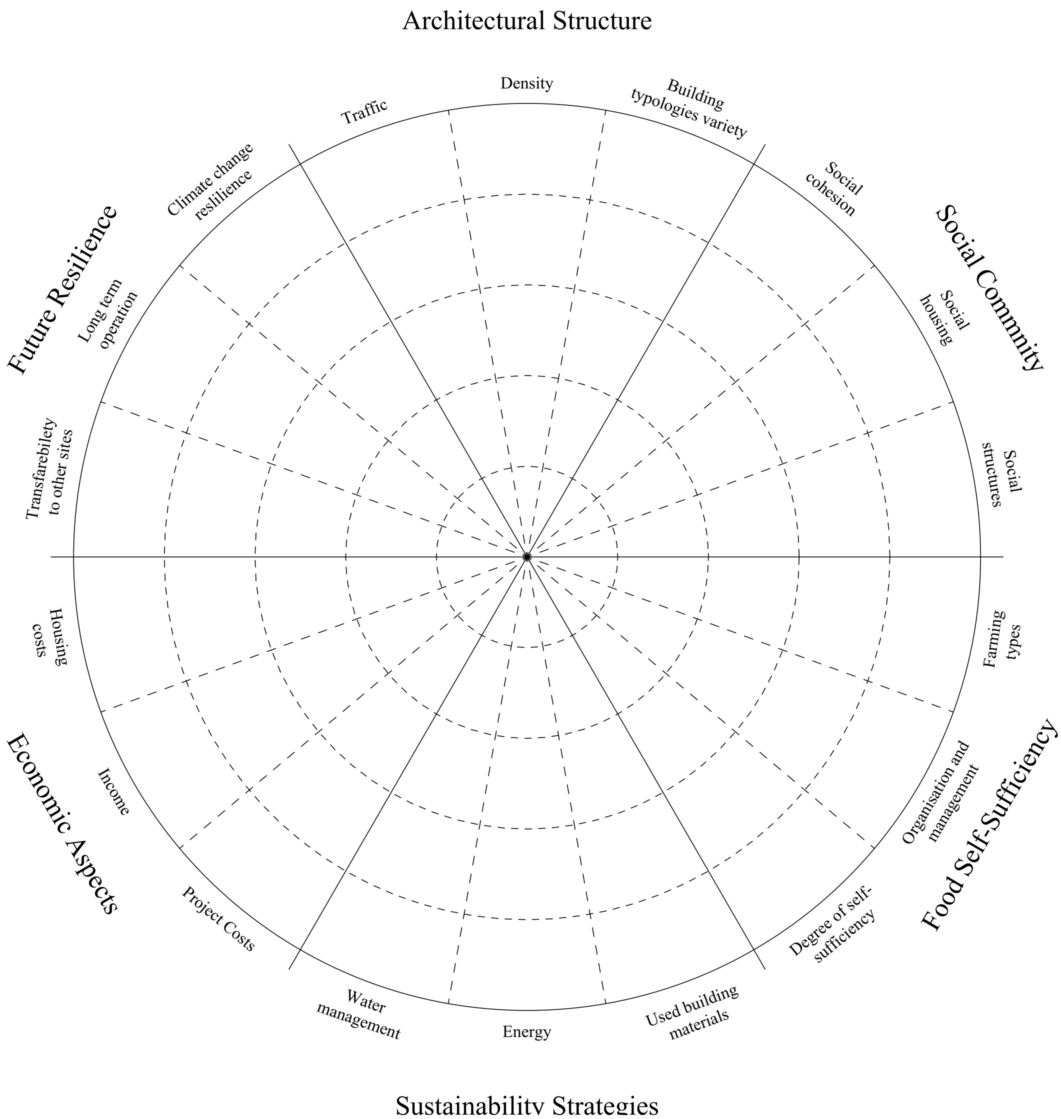
ECONOMIC ASPECTS

The economic dimension of a project pertains to both its viability and future potential. Criticism of funding models, operating and rental costs, cooperative or common-based models, and the financial impacts of self-reliance provides an added element to the architectural and social perspectives.

FUTURE RELIANCE

Their transferability to other context are questions of crisis resilience, sustainability over the long term, flexibility, and capacity for future evolution. This criterion allows for assessment of the potential for innovation and applicability in broader systemic settings of the projects.

Fig. 39 Spider diagram basis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Building typologies variety
Traffic
Social cohesion
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Future Resilience
Long term operation
Transfarebilety to other sites
Housing costs
Economic Aspects
Income
Project Costs
Farming types
Organisation and management
Food Self-Sufficiency
Degree of self-sufficiency
Water management
Energy
Used building materials
Sustainability Strategies

ECOVILLAGE, HANOVER

The Ecovillage Hanover serves as a compelling example of community-oriented living, where social connectivity, participation, and shared responsibility form the foundation of everyday life. Through a participatory planning phase in which the future inhabitants were actively involved in making decisions, a strongly anchored community developed, one founded upon self-organization and co-determination (Cityförster, 2020; ISSS research + Plan Común, 2020).

The shared areas like gardens, kitchens, co-working spaces, and workshops enable day-to-day interactions, exchange, and support among one another. Not only does it heighten social proximity but also social resilience, the ability of a community to react to adversity as a whole (Cityförster, 2020; ISSS research + Plan Común, 2020).

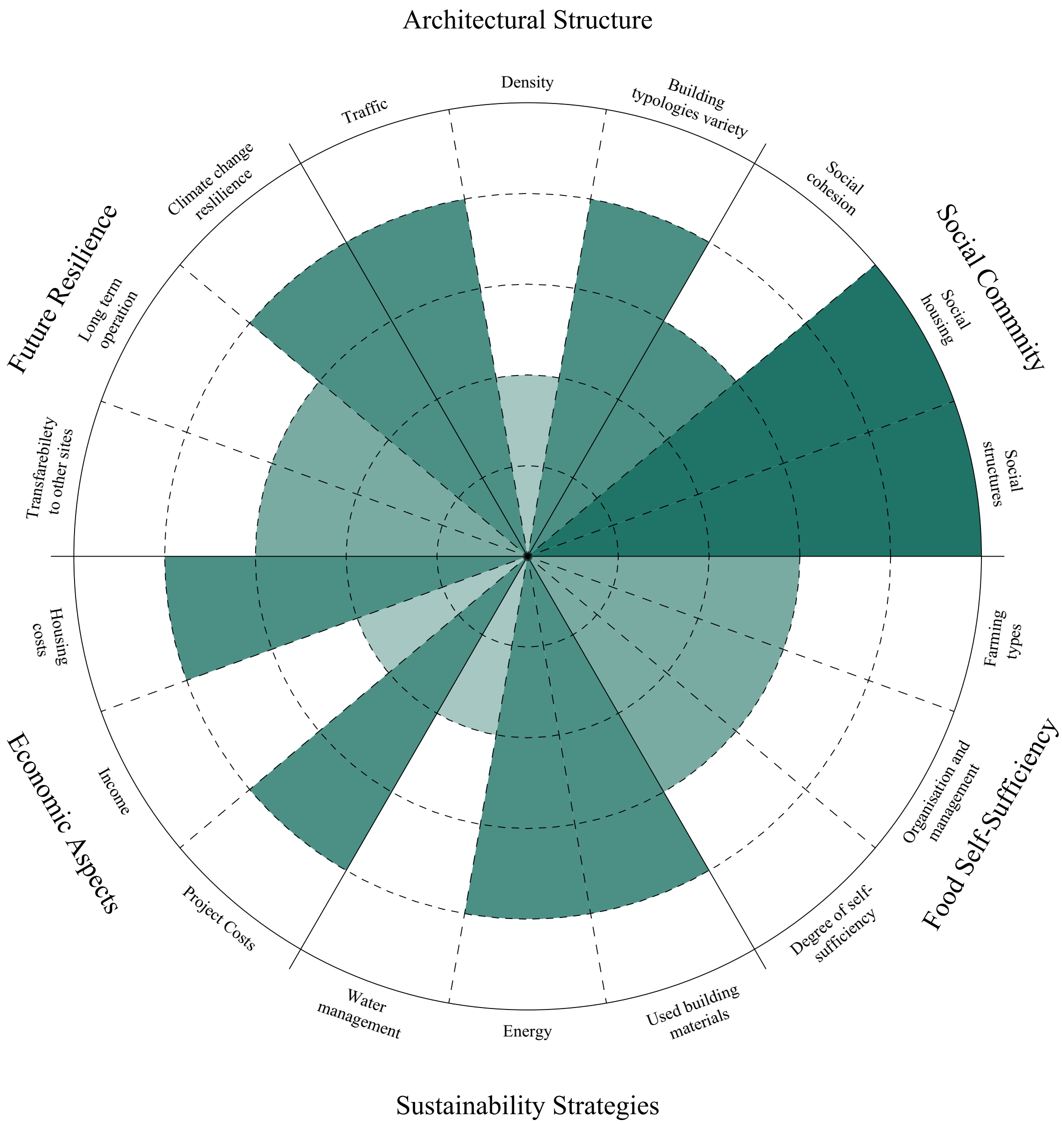
In parallel, the commons-based formats of the project, like food co-ops and community-supported agriculture, represent a break from individualized consumption patterns. By sharing resources and workloads, residents not only benefit ecologically but also economically, a critical component of making socially inclusive housing possible (Cityförster, 2020; ISSS research + Plan Común, 2020).

Therefore, the project revalidates social inclusion, reinforces neighbourhood bonds, and operates as an example of how city planning and architecture can positively impact social sustainability. It has been successful in interweaving the policies of social housing, solidarity economies, and participatory urban development (Cityförster, 2020; ISSS research + Plan Común, 2020).

Fig. 41 Cooperative village square

Fig. 42 Village centre

Fig. 40 Spider diagram of the ecovillage, Hanover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Density
Building typologies variety
Traffic
Social cohesion
Social Commnity
Social housing
Social structures
Climate change reslilience
Future Resilience
Long term operation
Transfarebilety to other sites
Housing costs
Farming types
Economic Aspects
Income
Organisation and management
Food Self-Sufficiency
Project Costs
Degree of self-sufficiency
Water management
Energy
Used building materials
Sustainability Strategies

CODHA APARTMENT BUILDING, GENEVA

The CODHA apartment building is an excellent example of how high-density housing and affordable housing can be combined with community and sustainability. Its dense, multi-story design enables land efficiency in urban areas with space for communal outdoor areas like rooftop gardens and shared rooms. In this way, it provides sustainable densification without a reduction in quality of life (Kurz, 2019; Archdaily, 2020).

Of specific interest is the cooperative ownership model, underpinned by a combination of crowd funding, public grants, and private investment. This reduces entry costs for residents and guarantees long-term renting security. Through collective organization of urban agriculture, economic synergies are established, reducing the cost of living via locally produced food, shared infrastructure, and minimized reliance on external supply chains (Kurz, 2019; Archdaily, 2020).

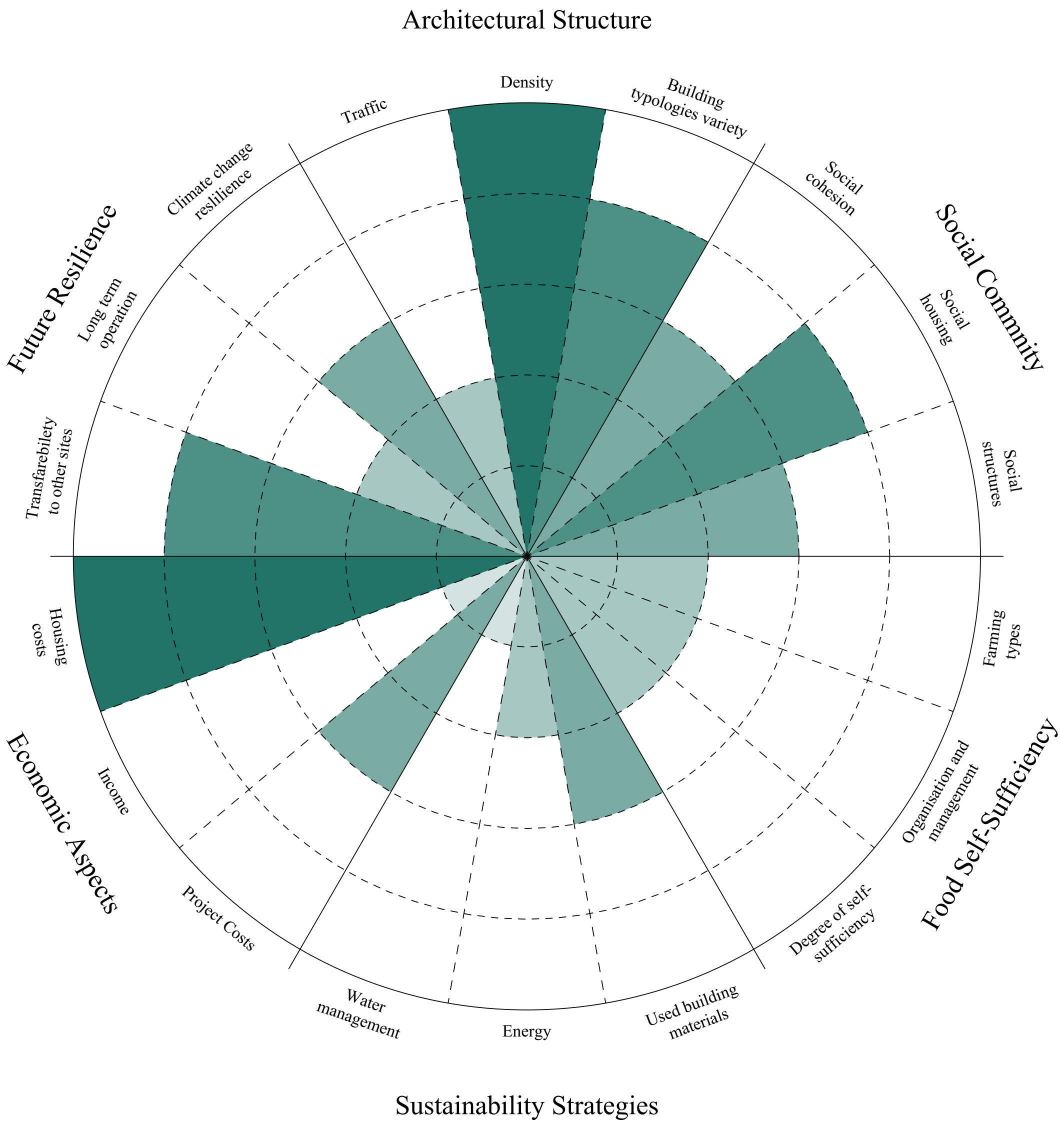
In all, the CODHA apartment building offers an economically feasible solution to traditional housing development, one that fosters social harmony and environmental stewardship.

It is a visionary response to inclusive and sustainable urban growth (Kurz, 2019; Archdaily, 2020).

Fig. 44 Greenhouse on roof

Fig. 45 Courtyard

Fig. 43 Spider diagram of the CODHA apartment building, Geneva


Architectural Structure
Density
Building typologies variety
Traffic
Social Commnity
Social cohesion
Social housing
Social structures
Future Resilience
Climate change reslilience
Long term operation
Transfarebilety to other sites
Housing costs
Economic Aspects
Income
Project Costs
Farming types
Organisation and management
Food Self-Sufficiency
Degree of self-sufficiency
Water management
Energy
Used building materials
Sustainability Strategies

URBAN VILLAGE PROJECT

The Urban Village Project presents a visionary modular system that can theoretically be applied across a spectrum of contexts, from rural villages to dense urban settings. It impresses with a diverse range of building typologies, from multi-family to tiny houses, while also accommodating small-scale self-sufficiency. By integrating living, working, and communal functions into a dense but green format, land use is minimized without compromising quality of life (Urban Next Lexicon, 2023; Space10, 2019).

The materials used, such as recycled steel, timber, and other sustainable building resources, significantly reduce the project's ecological footprint. It is also supplemented with the integration of green technologies like solar panels, rainwater harvesting systems, and communal energy storage, which lower long-term operational expenses and lift the burden from the environment (Urban Next Lexicon, 2023; Space10, 2019).

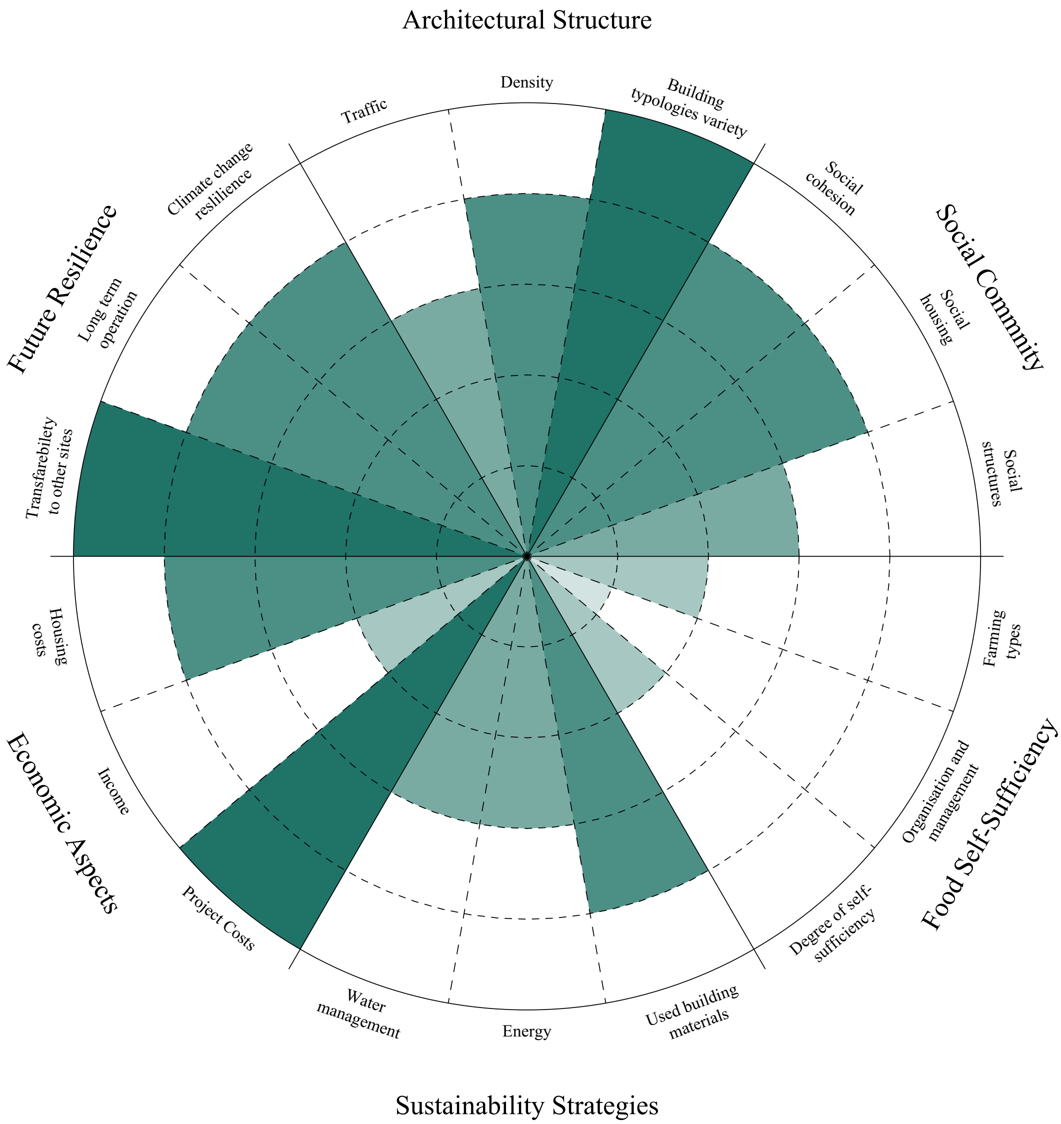
In terms of project financing, the Urban Village Project presents a new model. A combination of crowd funding, public subsidy, and private finance renders the project financially sustainable and socially inclusive. Its model of cooperative ownership provides long-term affordability of housing and creates local economic cycles by incorporating small businesses and promoting shared use of resources (Urban Next Lexicon, 2023; Space10, 2019).

In total, the project demonstrates how thoughtfully chosen building types, eco-friendly materials, and socially oriented financing models can make affordable, sustainable, and community-minded urban living a reality (Urban Next Lexicon, 2023; Space10, 2019).

Fig. 47 Urban village

Fig. 48 Modular system

Fig. 46 Spider diagram of the Urban village project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Density
Building typologies variety
Traffic
Social cohesion
Social Commnity
Social housing
Social structures
Climate change reslilience
Future Resilience
Long term operation
Transfarebilety to other sites
Housing costs
Farming types
Economic Aspects
Income
Organisation and management
Food Self-Sufficiency
Project Costs
Degree of self-sufficiency
Water management
Energy
Used building materials
Sustainability Strategies

ÖKODORF SIEBEN LINDEN

The Sieben Linden ecovillage is notable for its high social cohesion, which is actively fostered through shared decision-making, common areas like workshops, communal kitchens and farming, and frequent social events. Its co-housing design strengthens social relationships by grouping separate living units into social groups around shared communal spaces.
The resulting spatial closeness gives rise to a culture of trust and reciprocity, foundations for secure, long-term communities (Henseling et al., 2017).

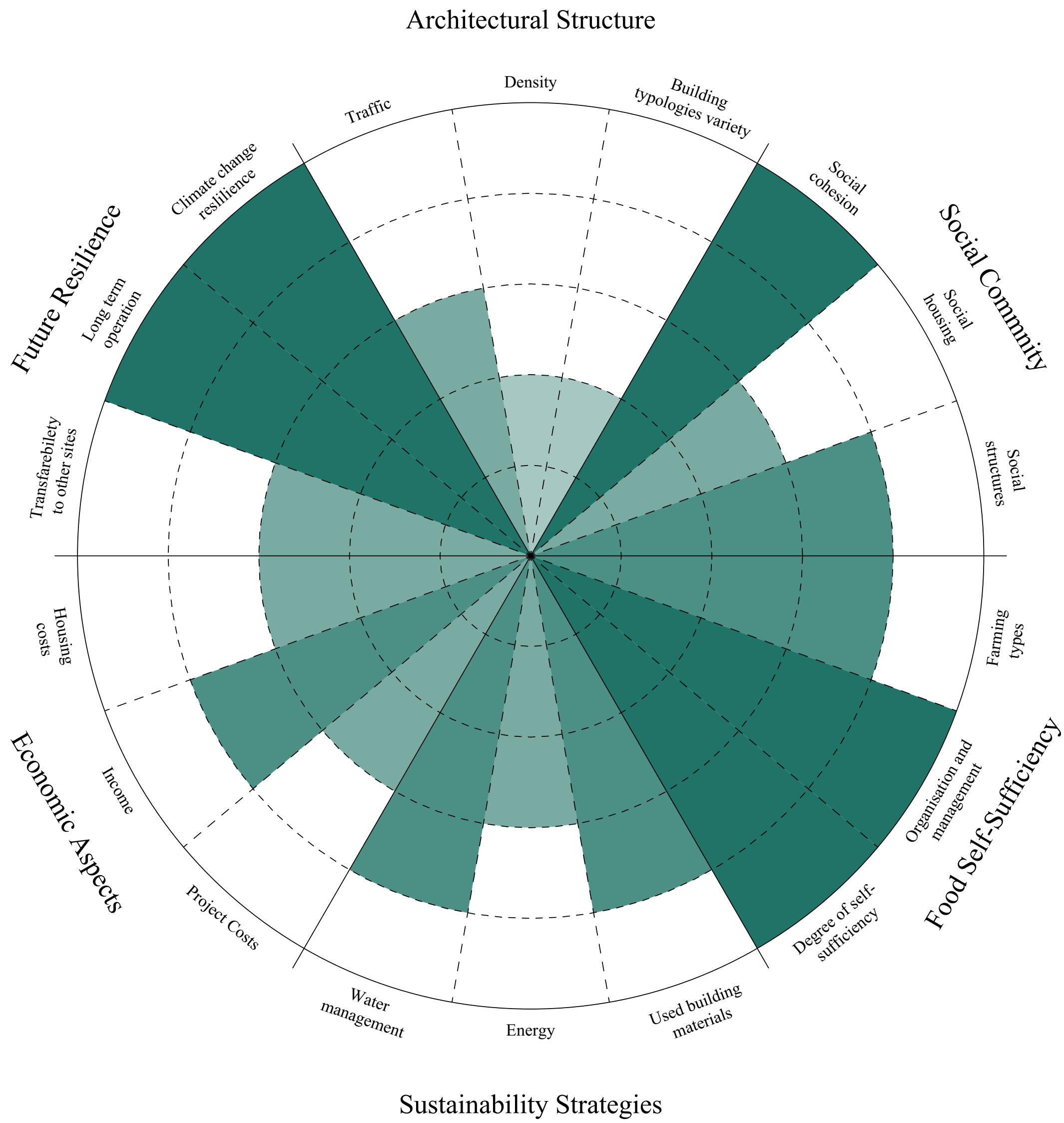
Agriculturally, the village maintains permaculture principles at all times, with community gardens and greenhouses. This diversity in forms of cultivation ensures ecological effectiveness at high levels while fostering autonomy from external supply chains. Agriculture is deeply embedded in the daily lives of residents, making food sovereignty a lived and shared practice (Henseling et al., 2017).
Self-sufficiency is organized in a cooperative form. Inhabitants share the labour of producing, distributing, and maintaining everything from vegetable beds to electricity networks. Such self-management not only saves money, but it also encourages intensive identification with, and responsibility towards, shared living space (Henseling et al., 2017).

Finally, Sieben Linden is a future model with collective knowledge, organic farming, and self-organized structures, it is a resilient system capable of handling crises flexibly. The ecovillage shows that social density and sustainable lifestyles are possible within a changing environment (Henseling et al., 2017).

Fig. 50 Top view of the Ökodorf

Fig. 51 Community farming

Fig. 49 Spider diagram of the Ökodorf sieben Linden



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Density
Building typologies variety
Traffic
Social cohesion
Social Commnity
Social housing
Social structures
Farming types
Organisation and management
Food Self-Sufficiency
Degree of self-sufficiency
Used building materials
Energy
Water management
Project Costs
Income
Economic Aspects
Housing costs
Transfarebilety to other sites
Long term operation
Future Resilience
Climate change reslilience
Sustainability Strategies

DIE AUENWEIDE, BADEN-WÜRTTEMBERG

The project stands out for a well-planned choice of sustainable building materials supporting both energy efficiency and harmony with nature. The utilization of natural materials like wood, straw, and stone minimizes the environmental footprint as well as optimizes thermal insulation, resulting in an enormous decrease in energy usage. Green roofs and straw insulation are essential design elements that not only assist in enhancing environmental performance but also indoor climate and air quality (Gerst, 2025; Die Auenweide, 2025).

The construction cost of the project is minimized through a cooperative ownership structure in which residents are owners and users of the infrastructure. Collective use of resources, like shared workshops, kitchens, and gardens, fosters low-cost living (Gerst, 2025; Die Auenweide, 2025).

In terms of water and energy management, the project utilizes several innovative, resource-conserving features. Solar panels on the buildings achieve a high proportion of energy needs, and biomass heating offers a low-impact option for heat generation. Rainwater collection and greywater recycling also minimize water usage and decrease reliance on water from external sources. These ecological steps have an amazing impact in terms of protecting the environment through minimizing the consumption of resources and optimizing building performance (Gerst, 2025; Die Auenweide, 2025).

In total, the project forms a livable, resource-conserving setting through the utilization of green materials and avant-garde energy mechanisms, showcasing ecological along with economic sustainability for years to come (Gerst, 2025; Die Auenweide, 2025).

Fig. 53 Farming and housing

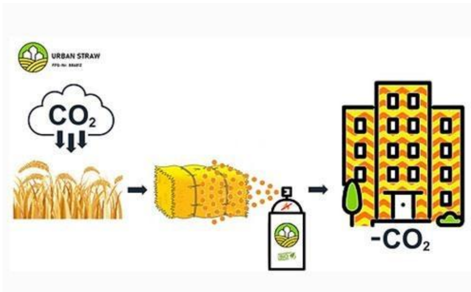
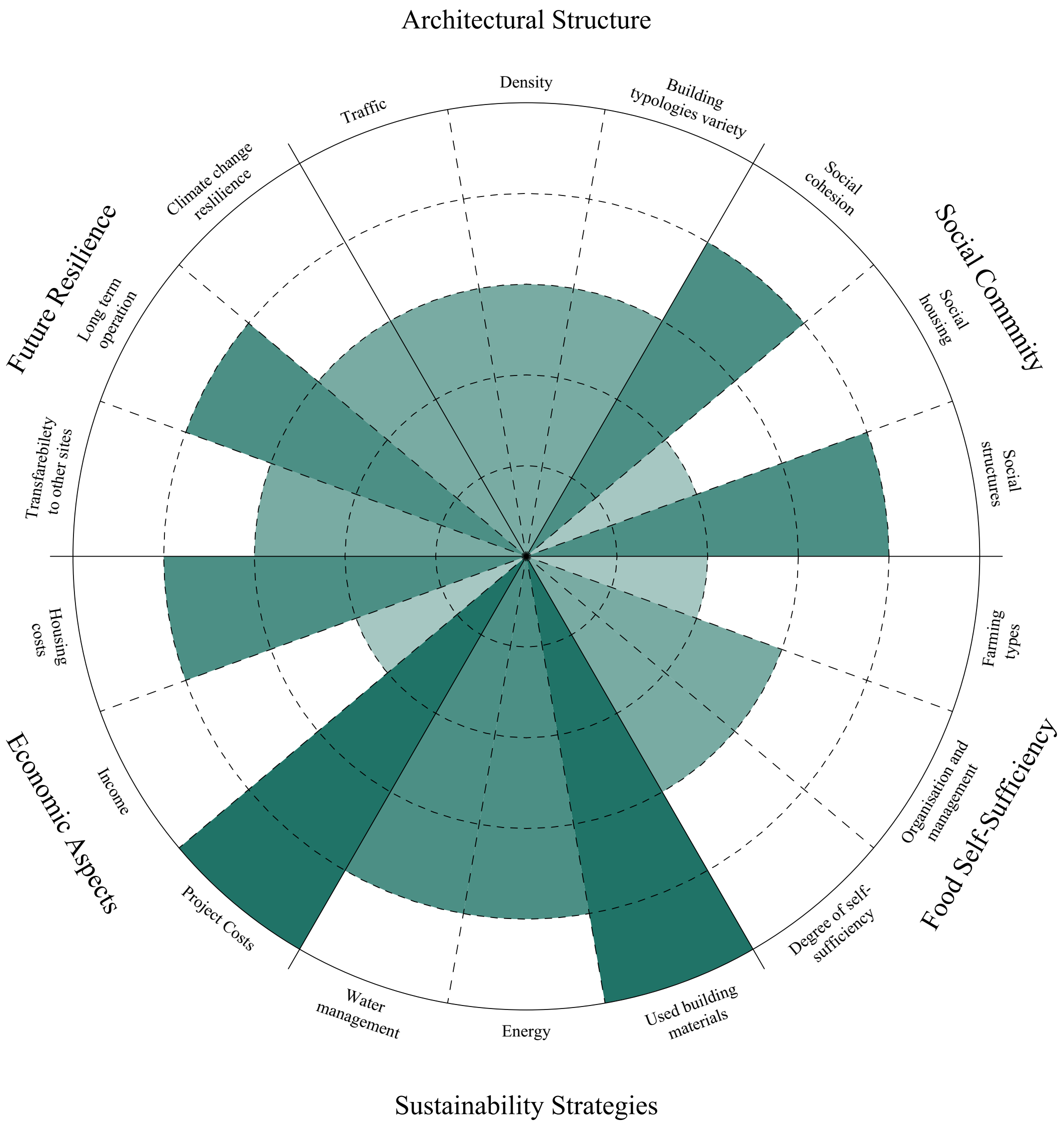


Fig. 54 Straw insulation system

Fig. 52 Spider diagram of the Auenweide, Baden-Württemberg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Density
Traffic
Building typologies variety
Social Commnity
Social cohesion
Social housing
Social structures
Food Self-Sufficiency
Farming types
Organisation and management
Degree of self-sufficiency
Sustainability Strategies
Used building materials
Energy
Water management
Economic Aspects
Project Costs
Income
Housing costs
Future Resilience
Transfarebilety to other sites
Long term operation
Climate change reslilience

BEDZED, UK

BedZED sets high standards in the transport, energy, and water industries. The project encourages green mobility by giving precedence to pedestrian and cycling areas and limiting automobile movement and enhancing public transport accessibility. In terms of energy efficiency, the houses are aligned with Passive House principles, and high thermal mass is used to manage indoor temperatures and reduce energy use. Dedicated ventilation concept supplies indoor air. Solar panels and a biomass plant originally installed help in harvesting renewable energy and achieving zero carbon emissions (Scoon, 2016).

Water is managed at optimum level by harvesting rainwater and recycling greywater, which minimizes water use to a great extent. Collectively, they present an interesting example of eco-friendly and resource-efficient living (Scoon, 2016).

While BedZED is not explicitly concerned with food production, it actively facilitates urban agriculture by means of allotments, community gardens, and green roofs. These support a degree of self-sufficiency, cut down on food transport emissions, and enhance community cohesion. Food-sharing initiatives and community partnerships also encourage sustainable consumption and reduce the environmental footprint (Scoon, 2016).

Fig. 56 Housing view

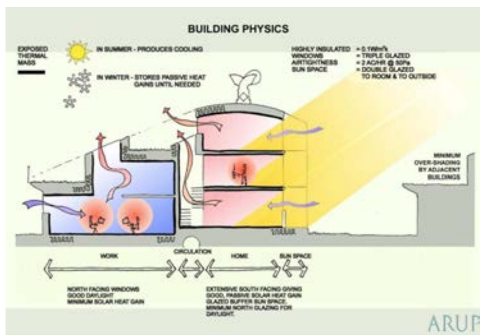
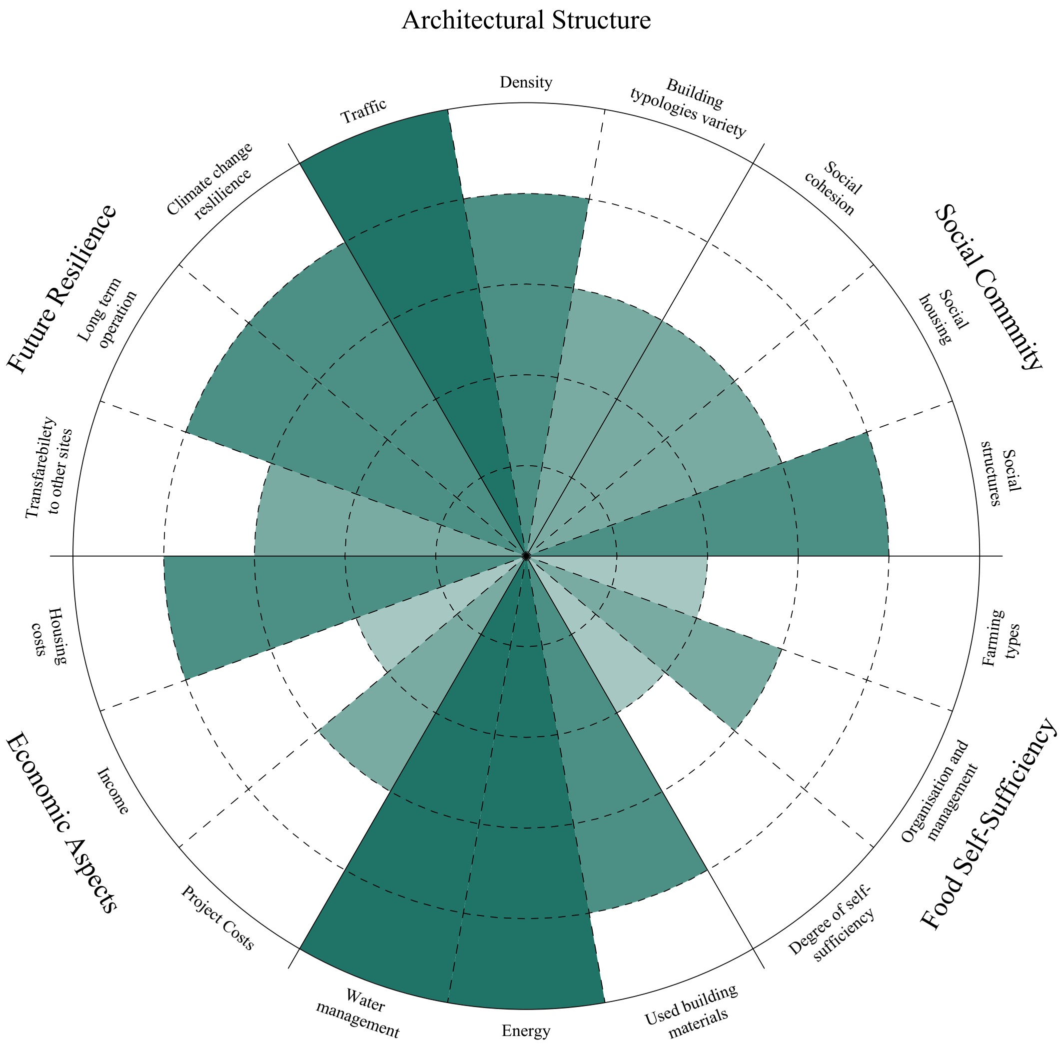


Fig. 57 Cooling system

Fig. 55 Spider diagram of the BEDZED, UK


Architectural Structure
Density
Building typologies variety
Traffic
Social Commnity
Social cohesion
Social housing
Social structures
Future Resilience
Climate change reslilience
Long term operation
Transfarebilety to other sites
Housing costs
Farming types
Economic Aspects
Income
Project Costs
Water management
Energy
Used building materials
Degree of self-sufficiency
Organisation and management
Food Self-Sufficiency

2.4 DESIGN GUIDELINES

The evaluation of foundational research and case studies clearly reveals that integrating food production into the built environment holds significant potential for sustainable urban development. This integration extends beyond ecological benefits such as improved micro climates or closed material cycles, it also encompasses vital social dimensions like participation, education, and collective responsibility. Food and its cultivation become a tangible, designable aspect of urban neighbourhoods, shaping both the dynamics of communal life and the spatial configuration of our cities and villages.

Implementing these insights requires the structural embedding of productive elements into planning practices. Food systems must not be treated as add-ons, but rather integrated early and holistically into planning processes. This necessitates appropriate planning and legal frameworks. Existing instruments, such as zoning plans, open space strategies, and design regulations, must be revised to enable and promote productive uses, such as urban agriculture, community-managed gardens, or edible landscapes.

Moreover, practical guidelines and check-lists for planners and architects have proven helpful in anchoring food systems spatially within the built environment. These tools offer orientation on how productive areas can be spatially and technically integrated, for instance, through the use of rooftops, the coupling of rainwater harvesting with cultivation areas, or the incorporation of production spaces into communal courtyards and neighbourhood plazas.

A key insight from the case studies is also the importance of participatory processes, particularly through cooperatives and their specific internal guidelines. The long-term establishment of productive spaces is most successful when residents are actively involved in planning, implementation, and maintenance. Participation becomes not just a method, but a structural component of productive neighbourhoods. At the same time, the complexity of such projects demands close cooperation among architecture, urban planning, agricultural sciences, local authorities, and civil society actors. New professional roles, such as food coordinators or neighbourhood-based managers, can help moderate interfaces and support these processes in the long term.

Ultimately, it becomes clear that productive neighbourhoods do not emerge by chance. They are the result of deliberate planning decisions, appropriate legal frameworks, and interdisciplinary collaboration. Only when clear guidelines, incentives, and standards are established can the interplay between housing and food production become a defining element of future urban spaces.

2.5 CONCLUSION

The research question posed in this report:

"How is it possible to redefine the relationship between humans and nature, food and dwelling, in such a way that the relation between humans and food can be re-established by actively involving dwelling in food production?"

Can be answered based on the theoretical discourse and the analysis of various case studies:

A new form of interaction between dwelling and food production is possible provided that food is understood as an integral part of urban planning and not as an additional or secondary function. Reintegrating food production into the urban context, as it once was during the history of urban planing, can help to bridge the divide between city and countryside, re-establish a sense of responsibility for food among urban dwellers, and generate both ecological and social value. However, this requires a fundamental shift in planning practices, legal frameworks, and the roles of involved stakeholders.

The case studies presented demonstrate that productive urban spaces are not only theoretically conceivable but practically implementable, especially when residents are actively involved in the planning, realization, and maintenance of such spaces. Participation emerges as a crucial driver for the sustainable establishment of productive neighbourhoods. It fosters identification, conveys knowledge, and creates social networks that enrich urban living with a new, communal dimension.

Moreover, it becomes evident that successfully integrating food production into urban structures depends on specific technical, spatial, and organizational conditions. Design guidelines and planning instruments, such as the use of rooftops, the combination of rainwater harvesting and cultivation areas, or the inclusion of growing spaces in communal courtyards and neighbourhood plazas, can act as bridges between theory and implementation. They offer concrete strategies for spatially embedding food systems within the built environment.

In conclusion, human beings can once again become active participants in the food system, especially in urban settings. Reconnecting humans with food, and housing with cultivation, opens up new perspectives for urban development and social coexistence alike. The insights gained here provide a robust foundation for a architectural project to follow and offer tangible approaches for shaping resilient, future-oriented, and socially cohesive urban spaces.

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2.7 LIST OF FIGURES

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03

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TECHNICAL REPORT

PROTEIN-RICH FOOD PRODUCTION SYSTEMS INTEGRATED INTO BUILDING TECHNOLOGY

ABSTRACT

The aim of this technical report is to re conceptualize building services engineering by integrating it into the food production chain. Various protein-based food production systems are examined with regard to their interaction with water and energy cycles. These include algae cultivation, fish aquaculture, vertical farming for the growth of wheatgrass and microgreens, as well as pyrolysis and wind energy systems for sustainable energy generation. These systems, and their respective participants, are arranged in a systematic order within a technical spatial arrangement to generate a closed-loop water and energy system that can produce food in an efficient, resource-conserving, and environmentally sustainable way.

TABLE OF CONTENTS

INTRODUCTION

As the global climate crisis escalates and natural resource systems approach their limits, it is clear that conventional methods of building services, primarily centred on consumption and efficiency, are no longer effective. Buildings today are significant energy users, freshwater extractors, and waste generators. However, they continue to be inert entities in the broader ecological system. In response to these issues, the architectural field must transcend sustainability as a goal external to the discipline and integrate circularity. The following research question arises:

“How can building technology be re imagined as a dynamic infrastructure that integrates new food production systems to establish a regenerative, circular urban metabolism between food, waste and energy that promote sustainable urban living and ecological consciousness?”

As the basis lays the so called “Farm Cycle”, from a previous preliminary study. A theoretical infrastructure in buildings that integrates food cultivation, water purification, waste recycling, and renewable energy into a unified metabolic system (see more in Chapter 5.3 and 5.4). Through interlinked decentralized systems like aquaponics, microalgae agriculture, pyrolysis processes, and wind power generation, in combination with human activity, the Farm Cycle turns buildings into self-sustaining, regenerative systems that enhance ecological balance.

This article examines the technical aspects of such an integration. It outlines each subsystem and how they contribute to a self-sustaining flow of matter and energy, where waste becomes input, and production and consumption are synchronized. Rather than a speculative idea, this strategy addresses the building technology behind it to create a technical framework of the system, thereby enabling buildings and their architects and service planners to make a technical contribution to local resilience and environmental renewal.

3.1 BUILDING SERVICES SYSTEMS

As part of a preliminary study (see Chapter 5.0), four distinct protein-based food production systems were analysed alongside human activity in terms of process flow, data sets, and spatial requirements, and subsequently integrated to form a unified "farm cycle."

The farm cycle is an integrated systems framework within which water, energy, and biological resources are in continuous flow in a managed and interdependent circuit. At its core lie the water and energy cycles, which function not only as the physical link between subsystems, but also as the foundational layer for building services engineering and local food production.

By linking thermal energy grids, wastewater treatment, algae cultivation, aquaponics, and pyrolytic conversion of organic waste, the model demonstrates how different technical processes can be integrated in a single infrastructural system. The individual systems, each running independently, are analysed and integrated herein throughout this report. The case studies based on the various methodologies are analysed and critiqued on their technical basis. The aim is to analyse these systems further and to create a prototype for an independent building services system, where one system's output is another system's input. The suggested closed-loop system hopes to uncover and promote new ways of combined food production. Furthermore, the report also identifies and includes the various actors needed in this operation and upkeep of these systems.

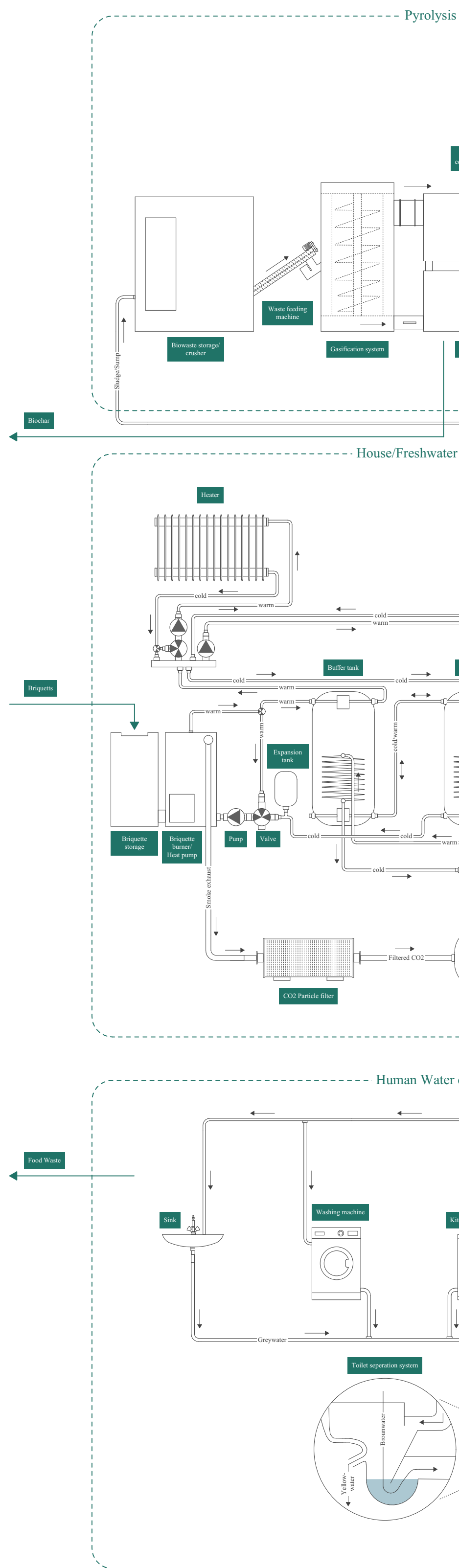
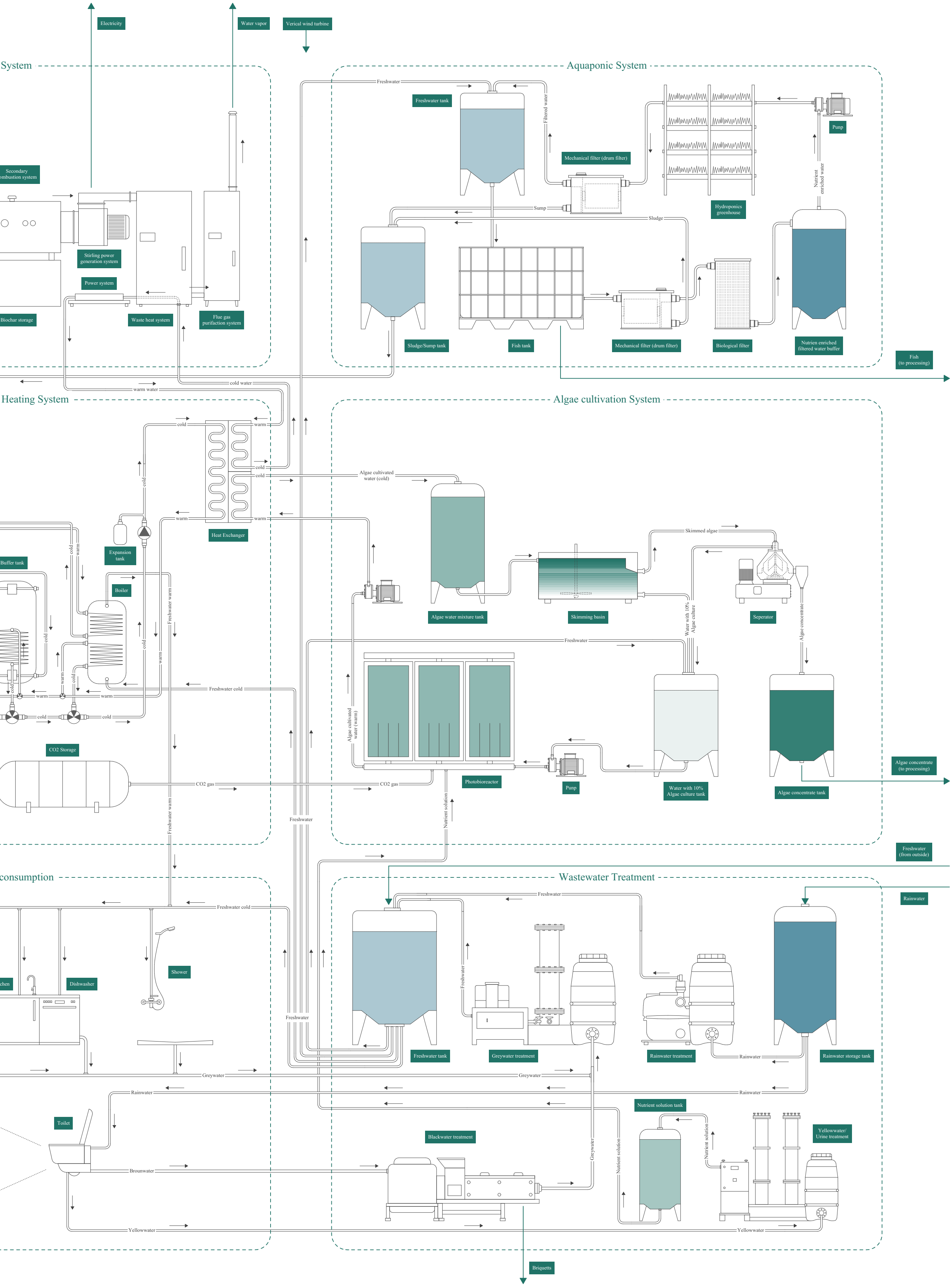


Fig. 58 Building services system scheme



Electricity
Water vapor
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Secondary combustion system
Stirling power generation system
Power system
Biochar storage
Waste heat system
Flue gas purification system
Aquaponic System
Freshwater
Freshwater tank
Filtered water
Mechanical filter (drum filter)
Hydroponics greenhouse
Pump
Nutrient enriched water
Sump
Sludge
Sludge/Sump tank
Fish tank
Mechanical filter (drum filter)
Biological filter
Nutrient enriched filtered water buffer
Fish (to processing)
cold water
warm water
Heating System
Algae cultivation System
cold
warm
Heat Exchanger
Algae cultivated water (cold)
Algae water mixture tank
Skimmed algae
Skimming basin
Seperator
Expansion tank
Buffer tank
Boiler
Freshwater warm
Freshwater cold
Water with 10% Algae culture
Algae concentrate
Algae cultivated water (warm)
Photobioreactor
Pump
Water with 10% Algae culture tank
Algae concentrate tank
Algae concentrate (to processing)
CO2 Storage
CO2 gas
Nutrient solution
Freshwater (from outside)
consumption
Wastewater Treatment
Rainwater
Kitchen
Dishwasher
Shower
Freshwater tank
Greywater treatment
Rainwater treatment
Rainwater storage tank
Greywater
Toilet
Nutrient solution tank
Blackwater treatment
Yellowwater/ Urine treatment
Brownwater
Yellowwater
Briquetts

HOUSE/FRESHWATER HEATING SYSTEM

The water heating subsystem within the proposed “farm cycle” infrastructure is a multi-source thermal network, founded on conventional as well as regenerative technologies. Not only does its design satisfy the sanitary requirements of human inhabitants, but it also serves as an essential infrastructural component ensuring ideal thermal conditions for several food production systems, such as algae bioreactors, insect breeding chambers, and aquaponics modules.

The primary thermal load is managed by an air-to-water heat pump, chosen due to its high coefficient of performance (COP) and suitability for low-exergy urban contexts. Running predominantly during off-peak times, the heat pump provides the base load requirement for domestic hot water. To cover stretches of elevated demand, e.g., morning peak times or seasonal peaks, a biomass-fueled auxiliary module is activated. This auxiliary system uses the combustion of compressed organic briquettes, which are internally derived from Faces briquettes, thereby effectively closing the loop of organic energy (Solarbayer, 2025). Notably, the system captures thermal energy from two intrinsic sources, the algae photobioreactors and the pyrolysis reactor. During their operation, both sources produce low-grade waste heat, which is recovered through the use of plate heat exchangers and directed to a centralized thermal storage tank. The tank system is stratified for optimal energy extraction against real-time demands, thus minimizing thermal losses (HaiQi, 2025; Wurm et al., 2013).

Drinking water is heated through the method of hygienically separated, closed-loop spiral heat exchangers. This method establishes the physical segregation between the drinking water system and the energy and cultivation subsystems, meeting health and safety regulations while reducing the possibility of cross-contamination (Solarbayer, 2025).

The multi-level heating system not only meets food systems’ micro climatic requirements but also provides a stable supply of domestic hot water. Its redundancy, energy conservation, and synergy with biological subsystems place it at the core of the building’s autarkic metabolic model.

PERFORMANCE VERIFICATION		Units	Person/day	Person/year	300P./year	Source
Input	Electricity	kWh	0,2	80	23 985	Gasag (2025)
	Freshwater	g	21	7 667	2 300 000	Eawag (2021)
	Feces Briquetts	g	14,2	5 200	1 560 000	HaiQi (2025)
	Heat (House Technic)	g	0,1	43	13 000	Kümpel (2023)
Output	Freshwater warm	l	10,7	3 887	1 166 175	Eawag (2021)
	House Heating	kWh	1,6	600	180 000	Kümpel (2023)
	CO2	g	240,6	87 833	26 350 000	HaiQi (2025)

Tab. 1 Performance verification House/Freshwater heating system

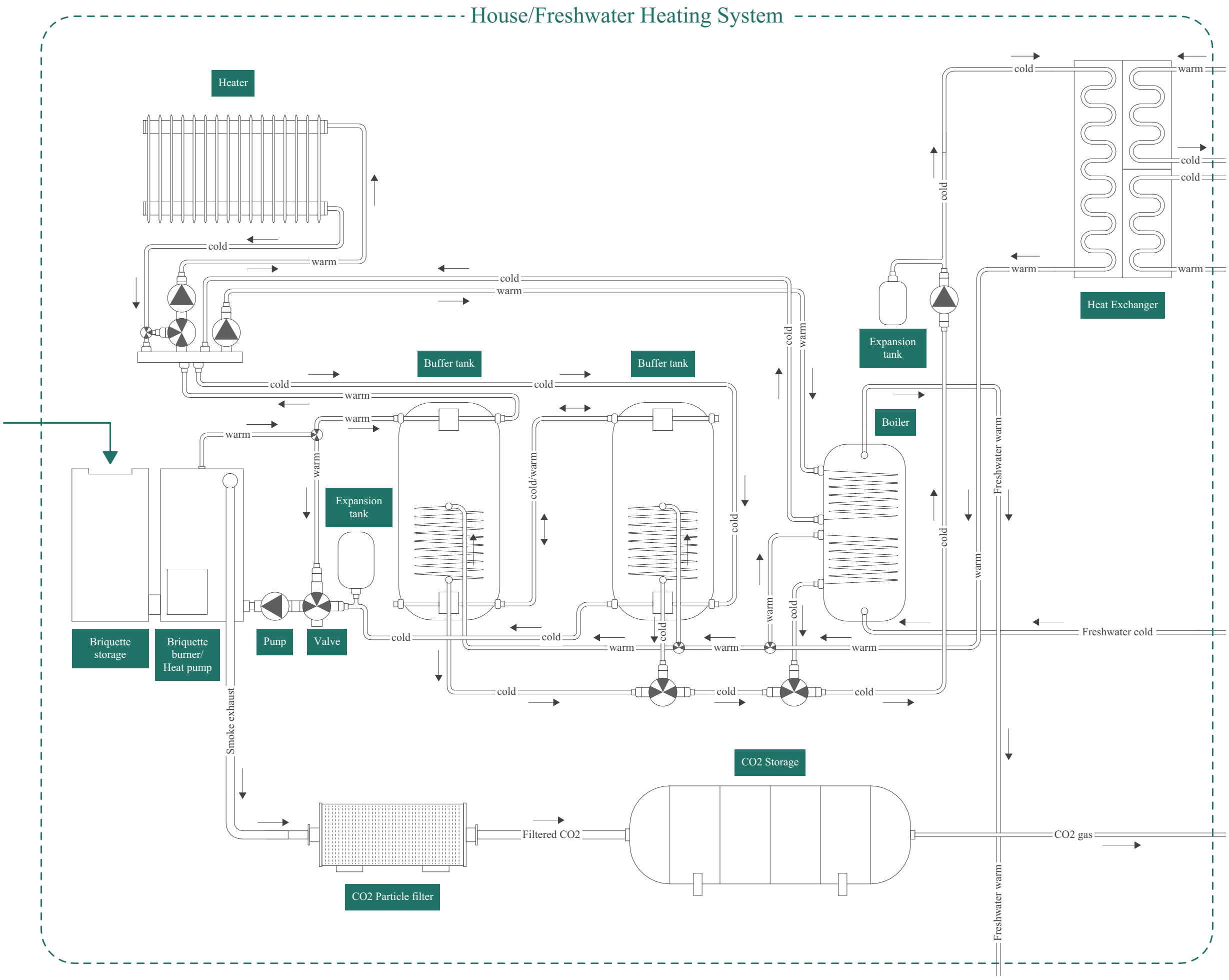


Fig. 59 House/Freshwater heating system in detail

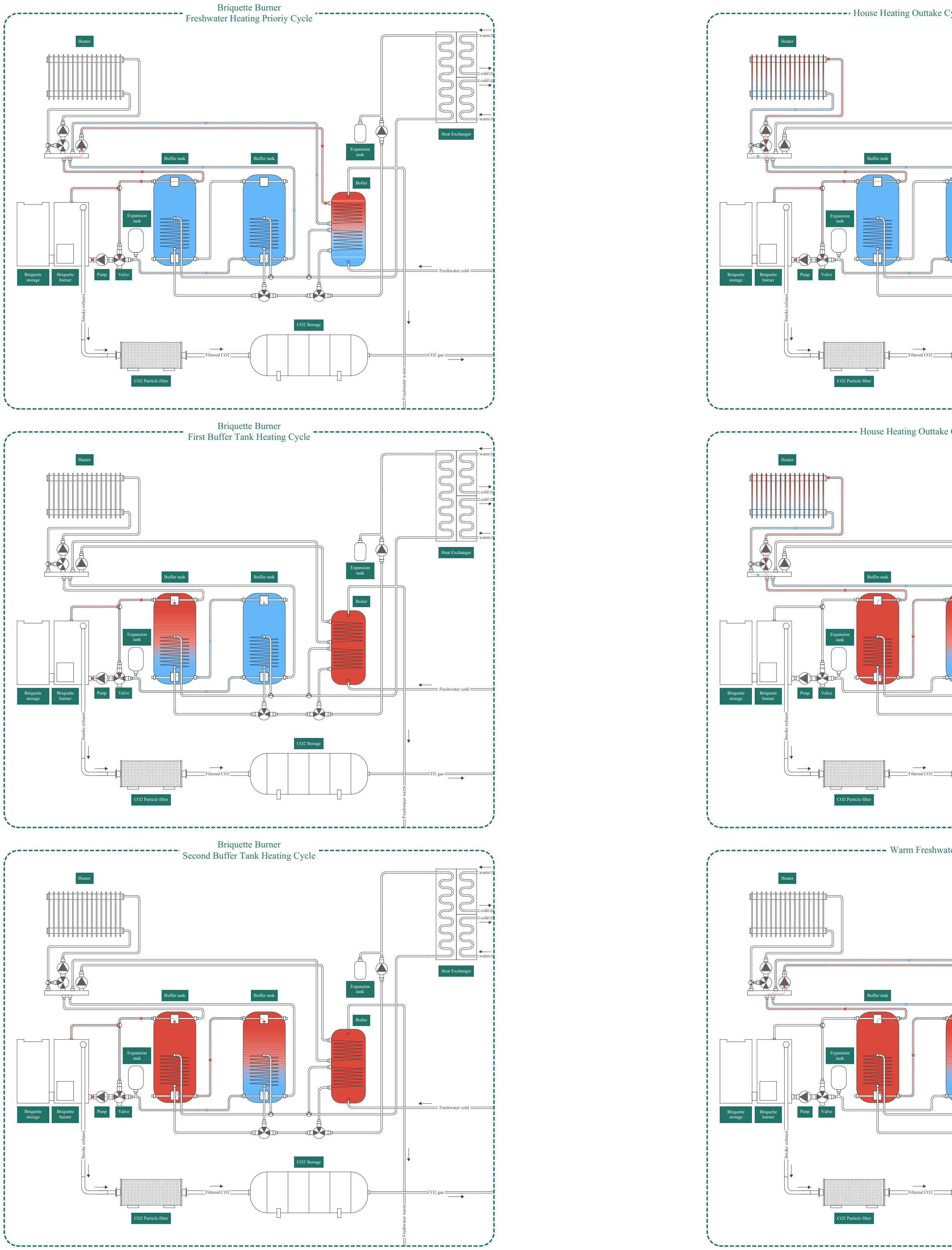
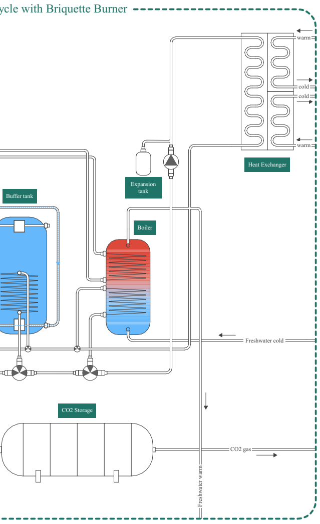
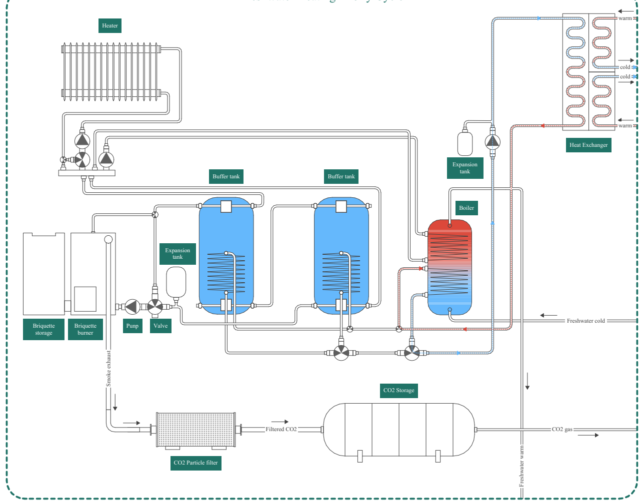


Fig. 60 Warm water heating cycle schemes

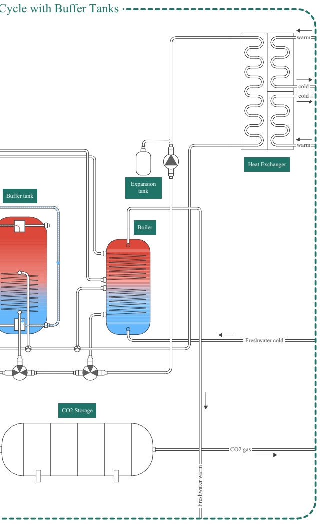
ycle with Briquette Burner



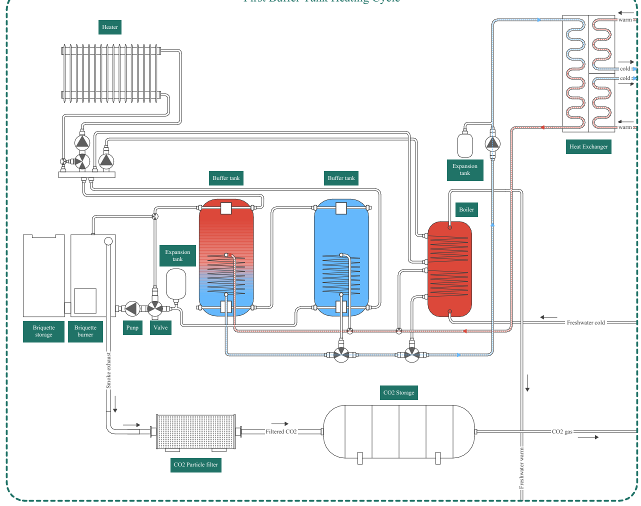
Heat Exchanger
Freshwater Heating Prioriy Cycle



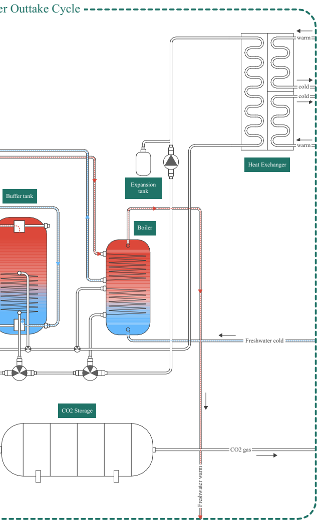
Cycle with Buffer Tanks



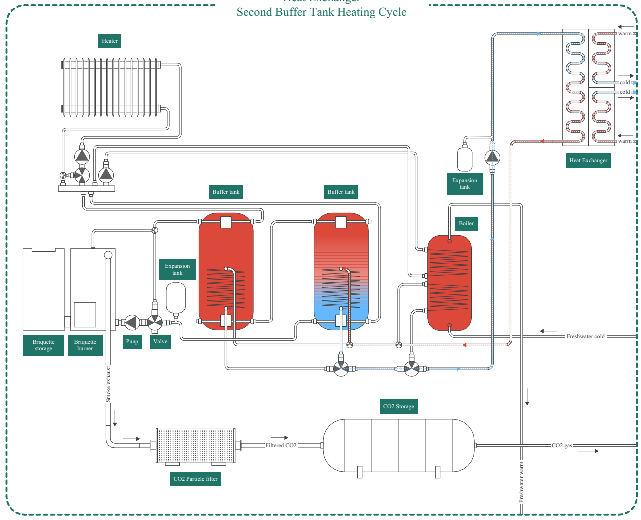
Heat Exchanger
First Buffer Tank Heating Cycle



er Outtake Cycle



Heat Exchanger
Second Buffer Tank Heating Cycle



WASTEWATER TREATMENT SYSTEM

The wastewater management system within the farm cycle architecture is not merely a disposal system but a regenerative infrastructure for harvesting, treating, and recirculating water resources among various agricultural and domestic subsystems. Such a multi-functional and decentralized strategy enhances the ecological intensity of water utilization within the system, as well as addresses the metabolic demands of food production systems.

GREYWATER

Comes from household sinks, showers, and laundry, and has little organic content and needs only low to modest levels of filtration processes. Based on Eawag's "Blue Diversion Autarky" system model, greywater (washing, bathing, laundry) is treated in a multi-stage biofiltration system. Mechanical sieving and sedimentation is the first stage, followed by a vertical flow constructed wetland or biochar-gravel filter. Following the biological treatment, the water is subjected to ultra filtration through membranes and UV disinfection, hence ensuring microbiological safety. This treated greywater can now be reused for applications such as irrigation, toilet flushing, or reuse in closed-loop aquaponics or hydroponic systems (Morgenroth et al., 2021).

BROWNWATER

Is produced from toilet solids and is rich in biodegradable organic material that needs anaerobic digestion and microbial treatment. Brownwater, or feces and toilet paper, is treated via decentralized anaerobic digestion, often via Up flow Anaerobic Sludge Blanket (UASB) reactors, which allow organic matter to break down while producing biogas, made up of methane and carbon dioxide. The stabilized solid residues are directed into the briquette burner. (Vogel et al., 2022).

YELLOWWATER

Or source-separated urine, contains high nitrogen and phosphorus levels and is therefore particularly suitable for nutrient recovery processes. Urine, when collected separately (source separation), is highly concentrated in nitrogen, phosphorus, and potassium. Eawag's Nutrient Recovery Module (e.g., VUNA project) includes a struvite precipitation treatment where magnesium salts are added to induce crystallization of magnesium ammonium phosphate. This crystalline fertilizer is collected and can be applied directly to algae culture or vertical farming systems. Moreover, urea stabilization averts the volatilization of ammonia, thus making safe storage and subsequent processing possible (Udert et at., 2019).

RAINWATER

Is collected from rooftops and treated by first-flush diversion and fine particulate filtration before being fed into the purification cycle. Harvested rainwater from the rooftop is treated using a first-flush diversion system to allow roof contaminants to be washed away. Sand and activated carbon are then used to filter out particulates and potential pollutants. Reverse osmosis or UV-C treatment is applied where required to achieve potable levels, especially when reintegration into the household supply is intended (Eawag, 2025).

PERFORMANCE VERIFICATION		Units	Person/day	Person/year	300P./year	Source
Input	Electricity	kWh	1,2	438	131 400	Eawag (2021)
	Heating	kWh	0,2	73	21 900	Eawag (2021)
	Greywater	l	50	18 250	5 475 000	Jönnson (2005)
	Yellowwater	l	0,4	146	43 800	Eawag (2021)
	Brouwnwater	l	19,6	7 154	2 146 200	Vogel et al. (2022)
	Rainwater	l	20,3	7 410	2 222 850	Eawag (2021)
Output	Freshwater	l	90	32 960	9 887 850	By Author
	Nitrogen	g	16	5 694	1 708 200	Jönnson (2005)
	Phosphorus	g	0,9	329	98 550	Jönnson (2005)
	Feces Briquetts	g	142	51 830	15 549 000	Vogel et al. (2022)

Tab. 2 Performance verification wastewater treatment system

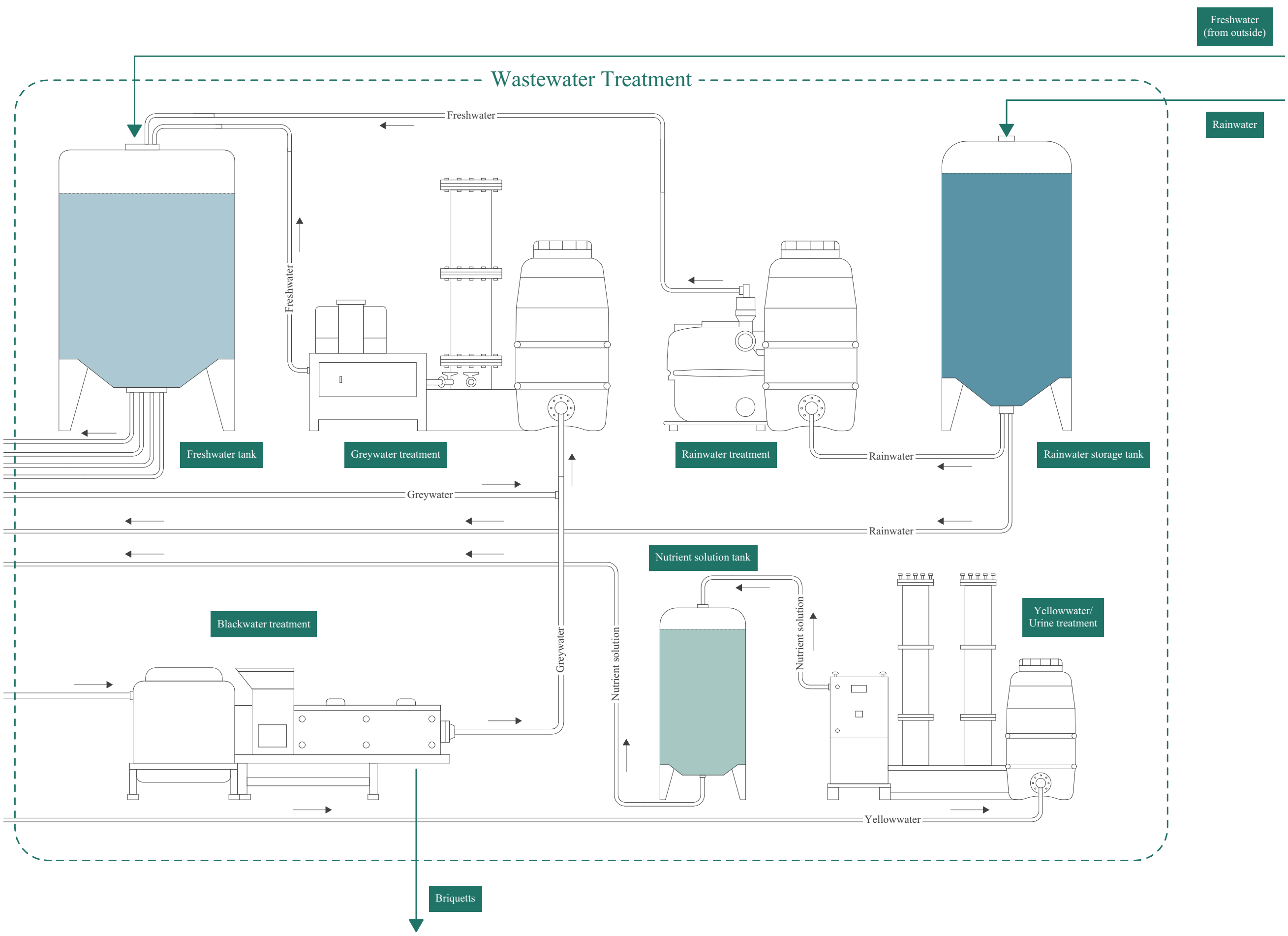


Fig. 61 Wastewater treatment system in detail

ALGAE CULTIVATION SYSTEM

This study investigates the incorporation of microalgae cultivation in building façades using closed-loop photobioreactors (PBRs) as bioactive membranes and productive components of architecture. These vertically integrated systems utilize solar energy and thermally regulated water to create an environment conducive to microalgae growth in a controlled system, thus making possible the cultivation of high-density biomass in minimal space. The façade design optimizes sunlight illumination for the building, and the internal circulation of water allows for thermal regulation, rendering the bioreactors a multifunctional element of the building envelope (Wurm et al., 2013).

The cycle process starts with the continuous circulation of a water-algae suspension pumped through the system. At maturity, the culture is harvested and subjected to a separation process in a skimming basin and a separator drum, where the algae are drained, cooled, and further processed into a concentrated biomass. The biomass is dried and purified into a high-protein powder for human consumption. The rest of the water, highly concentrated with nutrients (approximately 10%), is reused in the system, thereby closing the material loop and reducing waste generation (Wurm et al., 2013).

Apart from protein synthesis, the algal façade serves several important environmental purposes. It acts as an adaptive shading device, mitigating solar heat gain and fostering passive cooling. Furthermore, the thermally responsive water loop serves to modulate internal building temperatures. Notably, the algae culture continuously deploys the CO2 collected from the burned faeces pallet combustion of the house warm water cycle, in photosynthesis, which directly supports carbon capture and indoor air quality improvement. Thus, the system is an embodiment of the concepts of a regenerative urban metabolism, where biological productivity and infrastructural performance are spatially and functionally integrated (Wurm et at., 2013).

This example highlights the potential of bio-integrated façades to serve as decentralized systems of food production, while simultaneously enhancing several performance parameters of buildings. The system's modularity, its integration with urban infrastructure, and its potential to complement other water- and energy-related systems make it a prime example within the larger context of integrated architectural metabolism.

PERFORMANCE VERIFICATION		Units	100 g Algae Powder	Person/day	Person/year	300P./year	Source
Nutrients	Calories	kcal	326	92	33 419	10 025 680	RohKöstlich (2024)
	Carbs	g	18	5,2	1 896	568 717	RohKöstlich (2024)
	Protein	g	59	16,5	6 025	1 807 455	RohKöstlich (2024)
	Fat	g	1	0,2	82	24 633	RohKöstlich (2024)
Input	Electricity	kWh	6	1,7	616	184 748	Wurm et at. (2013)
	Heating (Winter)	kWh	7	2	718	215 540	Wurm et at. (2013)
	Water (in case of loss)	l	0,2	0,06	21	6 158	Wurm et at. (2013)
	CO2	g	410	115	42 082	12 624 474	Kammler et at. (2023)
	Nitrogen	g	50	14	5 132	1 539 570	Kammler et at. (2023)
	Phosphorus	g	1,5	0,4	154	46 187	Kammler et at. (2023)
	Sunlight	-	-	-	-	-	-
Output	Algae Biomass	g	1000	281	102 638	30 791 400	Wurm et at. (2013)
	Algae Powder	g	100	28	10 264	3 079 140	Wurm et at. (2013)
	Heat	kWh	1,4	0,4	140	42 147	Wurm et at. (2013)

Tab. 3 Performance verification algae cultivation system

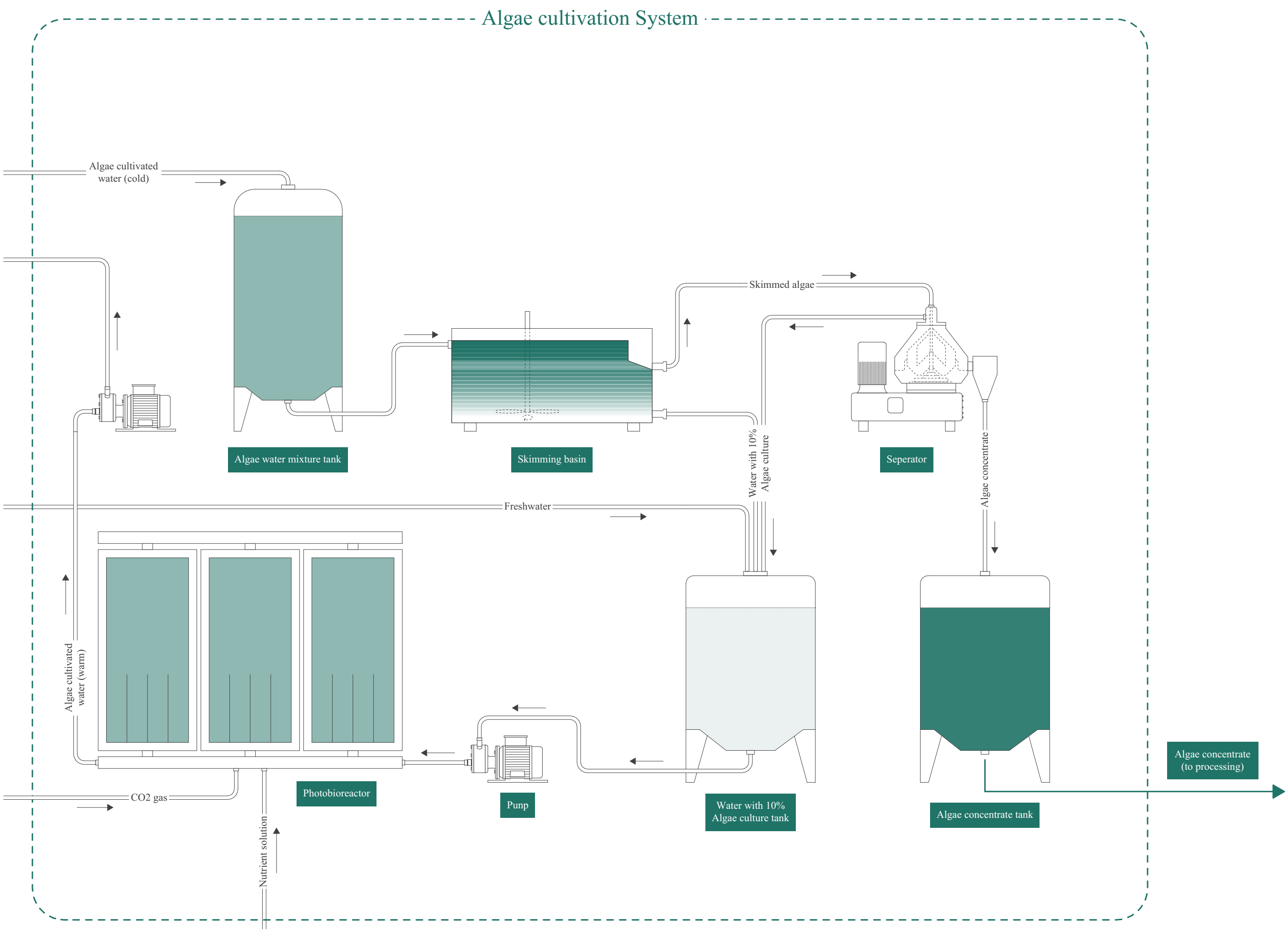


Fig. 62 Algae cultivation system in detail

AQUAPONICS SYSTEM

The aquaponic part of the system is based on a closed-loop hydrological cycle, which unites aquaculture and hydroponic agriculture in a self-closed, symbiotic ecosystem. This circularity is also supported by the use of filtered rainwater, which compensates for water loss in the system and preserves the water level balance (Goddek et al., 2016; Zhengxuan et al., 2024).

At the heart of the system are the fish tanks, where aquatic animals excrete metabolic by-products that result in nutrient enrichment, mainly comprising substances such as ammonia, nitrogen and phosphorous. While these substances can be toxic in high concentrations, they play a crucial role in plant growth stimulation. Water rich in nutrients is first run through a two-stage filtration system, a mechanical drum filter that removes particulate matter and solid wastes, then a biological filter where the ammonia is transformed into plant-available nitrates by nitrifying bacteria (Goddek et at., 2016; Zhengxuan et at., 2024).

Following the initial purification, the water is held briefly in an intermediary reservoir, where it stabilized before being directed into a hydroponic system. The plants are grown on vertically stacked trays in the system, thereby optimizing space utilization. The dissolved nutrients are absorbed by the plants, thereby filtering water via phytoremediation. A final stage of mechanical filtration ensures removal of any remaining particulates and sump before the water is recirculated back into the fish tanks, thereby completing the cycle (Goddek et al., 2016; Zhengxuan et al., 2024).

Solid residuals, such as sump material and sludge, are regularly removed from the filtration processes and placed into storage tanks specifically designed for this purpose. Rather than being discarded, these organic by-products serve as fuel for the pyrolysis subsystem, where they are thermochemically processed into syngas, biochar, and other valuable products, which are used to produce energy. This integration not only enhances the circularity of the system but also facilitates localized energy and material flows (Goddek et al., 2016; Zhengxuan et al., 2024).

The aquaponics system is a model of holistic synergy between biological productivity and technical infrastructure. It yields protein via fish farming and plant biomass via the cultivation of wheatgrass or microgreens, while maintaining internal ecological balance and minimizing dependence on external inputs.

PERFORMANCE VERIFICATION		Units	100 g Wheatgr. 100 g Fish	Person/day	Person/year	300P./year	Source
Nutrients	Calories	kcal	563	275	100 375	30 112 500	stueber (2025)
	Carbs	g	16	3,9	1 419	425 736	stueber (2025)
	Protein	g	86	49	17 885	5 365 500	stueber (2025)
	Fat	g	6,4	4,7	1 716	514 650	stueber (2025)
Input	Electricity	kWh	4,8	1,17	233	69 984	Zhengxuan et at. (2024)
	Heating	kWh	2,3	0,6	112	33 534	Zhengxuan et at. (2024)
	Water (Circ. System-from AP)	l	64,8	15,8	5 750	1 725 007	Zhengxuan et at. (2024)
	Wheat seeds	g	2 089	507,6	185 292	55 587 551	Zhengxuan et at. (2024)
	Fish food	g	100	153	55 772	16 731 600	Wolfhart et al. (2023)
	Nitrogen	g	30	7,3	2 679	803 577	Zhengxuan et at. (2024)
	Phosphorus	g	10	2,5	905	271 407	Zhengxuan et at. (2024)
	Sunlight	-	-	-	-	-	-
Output (VF)	Wheatgrass Biomass	g	6 739	1638	597 716	179 314 682	Zhengxuan et at. (2024)
	Wheatrgass Powder	g	100	24	8 870	2 660 850	Zhengxuan et at. (2024)
	Waste - Roots	g	3 976	966	352 652	105 795 662	Zhengxuan et at. (2024)
	Waste - Press cake	g	0,5	0,1	46	13 836	Zhengxuan et at. (2024)
	Water (Circ. System-to AP)	l	30	7	2 690	806 916	Zhengxuan et at. (2024)
	Water loss	l	35	8	3 060	918 091	Zhengxuan et at. (2024)
Output (Fish F.)	Tilapia Fish Meat	g	100	153	55 772	16 731 600	Love et at. (2014)
	Nitrogen	g	5,2	7,9	2 889	866 697	Forchino (2016)
	Phosphorus	g	2,3	3,5	1 283	384 827	Forchino (2016)
	Sump	g	9,3	14	5 200	1 560 001	Forchino (2016)

Tab. 4 Performance verification aquaponics system

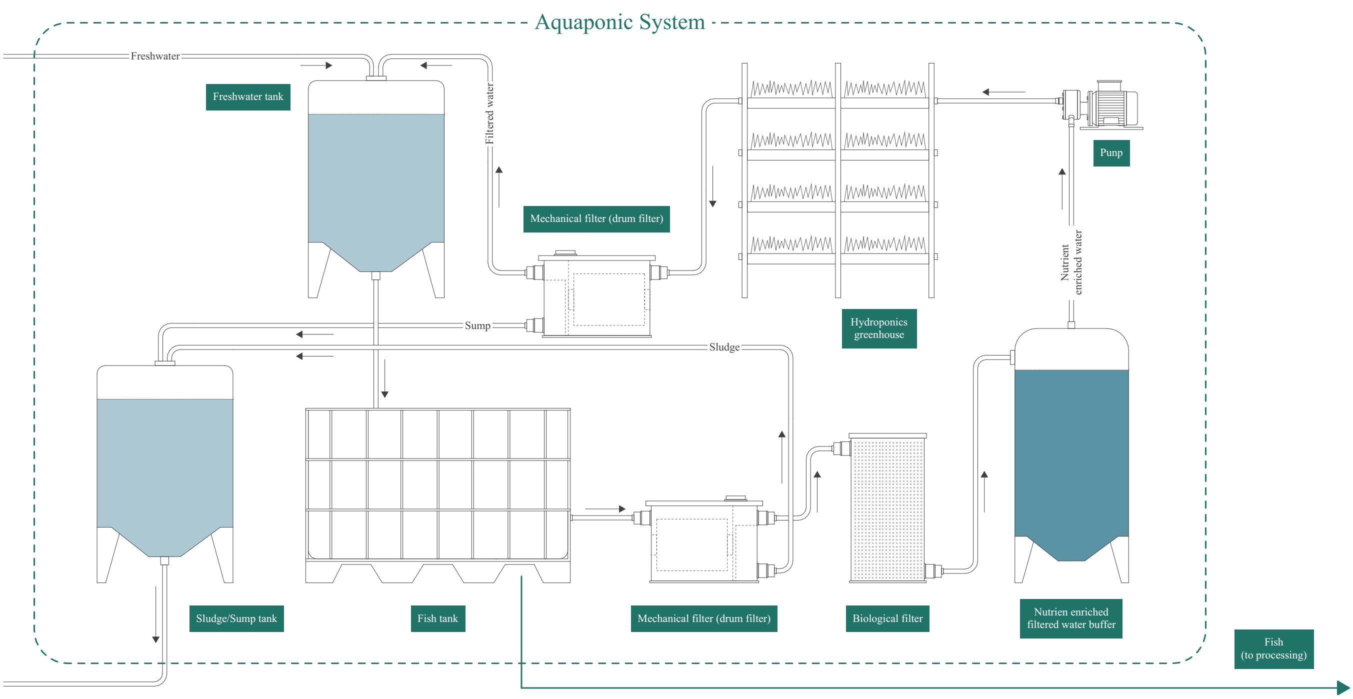


Fig. 63 Aquaponics system in detail

PYROLYSIS SYSTEM

The pyrolysis unit forms a critical node in the closed-loop infrastructure, offering a sustainable solution for organic waste management through thermochemical conversion. Operating in an oxygen-deprived environment, the system decomposes organic material at elevated temperatures, yielding three principal outputs: biochar, a carbon-rich residue with applications in soil enhancement and filtration; syngas, a combustible gas mixture; and thermal energy, a portion of which is recovered and re purposed within the building's energy systems (Kintek, 2025; HaiQi, 2025).

The process begins with the pre-treatment of organic biowaste from farming or the aquaponics system via a crushing unit that mechanically fragments and homogenizes the biomass. This increases surface area, improving thermal reactivity. The shredded material is then transferred to a waste compactor (wending machine), which densifies the mass for consistent feed into the reactor and may optionally dehydrate it, enhancing combustion efficiency (Kintek, 2025; HaiQi, 2025).

Subsequently, the material enters the pyrolysis or gasification chamber, where it is subjected to temperatures between 400°C and 800°C in a low-oxygen environment. Instead of complete combustion, this phase induces the breakdown of complex organic molecules into syngas, primarily composed of hydrogen, methane, and carbon monoxide. This gas is routed to a secondary combustion chamber, where it is fully oxidized, thereby maximizing energy extraction and neutralizing residual pollutants (Kintek, 2025; HaiQi, 2025).

The resulting high-temperature flue gases are harnessed to drive a Stirling engine, which converts external heat into mechanical motion and, subsequently, into electrical power. This decentralised energy generation system can support internal building loads or feed electricity into the local grid. Additional waste heat recovery units, such as heat exchangers, capture residual thermal energy for the building heating system or other integrated uses, improving overall system efficiency (Kintek, 2025; HaiQi, 2025).

Emissions are rigorously filtered before atmospheric release through a flue gas treatment system that includes particulate filtration, catalytic converters, and chemical scrubbers. The dominant emission is purified steam, underscoring the system's minimal environmental impact (Kintek, 2025; HaiQi, 2025).

The pyrolysis subsystem exemplifies how mechanical, chemical, and thermal processes can be synergistic-ally combined within a sustainable architectural framework. It closes material loops by transforming organic waste into energy and usable by-products, while simultaneously contributing to energy autonomy and carbon sequestration within the built environment.

PERFORMANCE VERIFICATION		Units	Person/day	Person/year	300P./year	Source
Input	Electricity	kWh	0,2	80	23 985	HaiQi (2025)
	Sump	g	21	7 667	2 300 000	HaiQi (2025)
	Sludge	g	14,2	5 200	1 560 000	HaiQi (2025)
	Waste-Prescake	g	0,1	43	13 000	HaiQi (2025)
	Waste-Roots	g	1 003	365 987	109 796 000	HaiQi (2025)
	Biowaste	g	276	100 667	30 200 000	HaiQi (2025)
Output	Electricity	kWh	0,9	320	95 940	HaiQi (2025)
	Heating	kWh	1,8	672	201 474	HaiQi (2025)
	Biochar	g	262,8	95 940	28 782 000	HaiQi (2025)

Tab. 5 Performance verification pyrolysis system

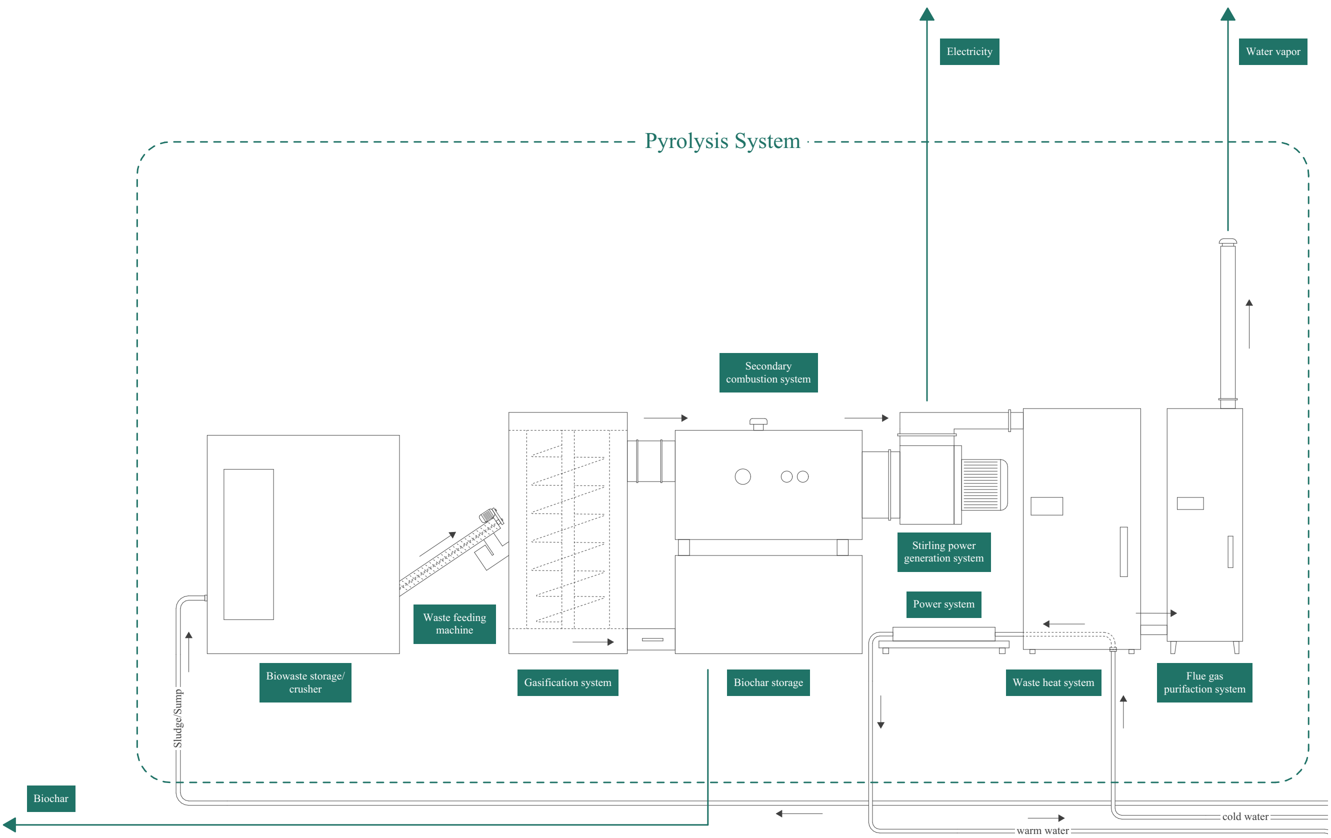


Fig. 64 Pyrolysis system in detail

VERTICAL WIND TURBINE

The FREEN-20 is a rated 20 kW, vertical-axis wind turbine of a vertical rotor type with nine metal cable and polyurethane foam blades, which have high durability. It has a variable speed of 35 to 108 rpm, starts producing power at 3.5 m/s wind speed, and reaches full capacity at 14.9 m/s, withstanding up to 36 m/s gusts. The turbine's direct-drive permanent magnet synchronous generator eliminates the gearbox, reducing mechanical losses and maintenance along with noise emission to just 45 dB at 100 meters (Freen, 2025).

At the average 7 m/s wind speed in Leith, a total of 18 turbines must be installed to achieve the targeted energy output of 813 585 kWh/year, to be energy self-sufficient.

This installation ensures proper operation and easy maintenance due to its modular and corrosion-proof design, which is expected to have a lifespan of around 20 years. Within building technology, the integration of these turbines enables efficient on-site renewable energy generation, thus reducing reliance on external energy supplies and lowering operating costs. This setup maintains essential building infrastructures, heating, ventilation, lighting, and with intelligent energy management, stabilizes supply and optimizes consumption, making the building's energy system more robust and sustainable (Freen, 2025).

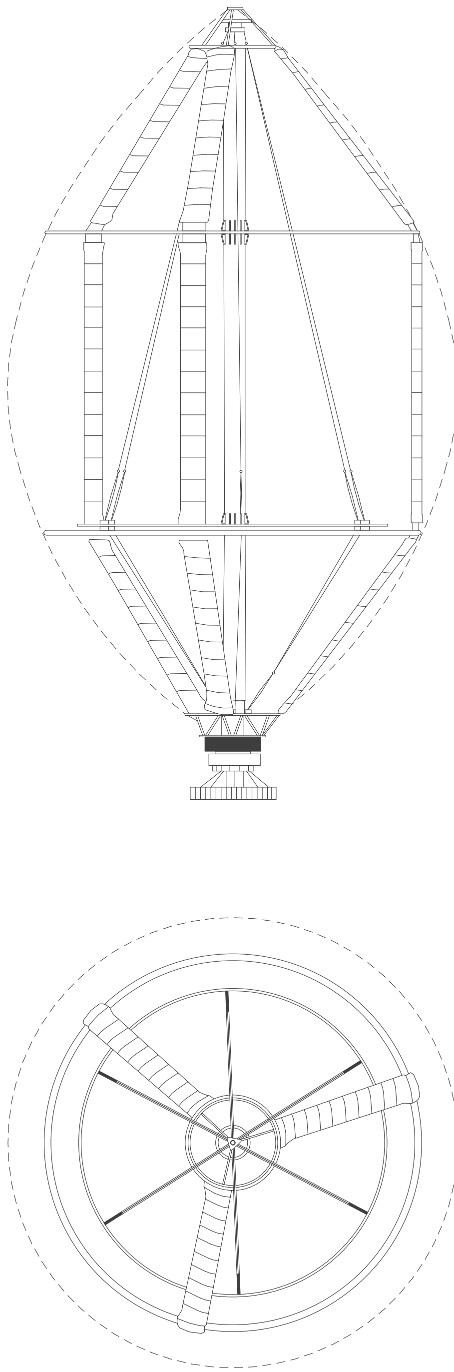


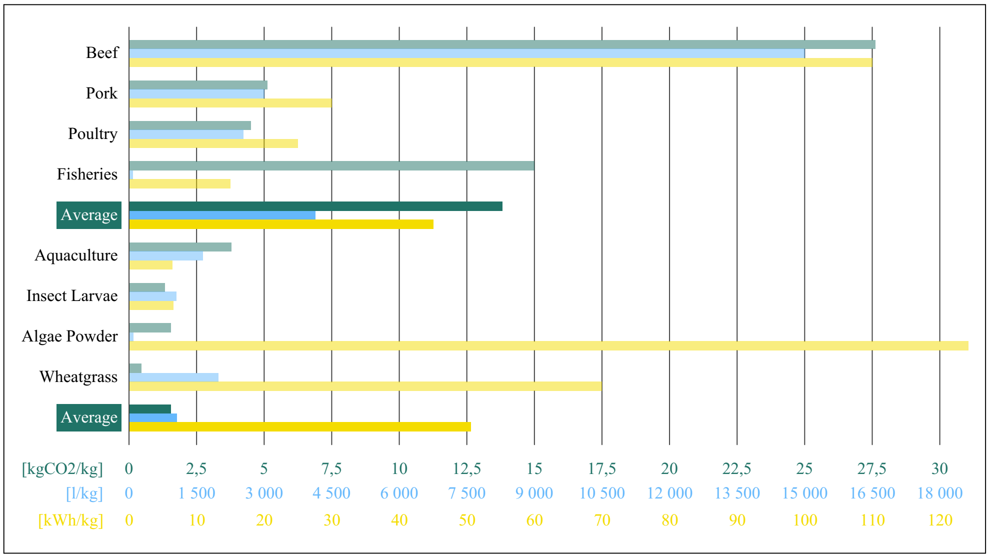
Fig. 65 Vertical wind turbine detail

3.2 MASS BALANCE STRATEGY

In order to guarantee the operating equilibrium of mass flows at the various inputs and outputs of the individual systems, a comparative analysis is conducted. The comparative analysis is established from the result achieved in the preliminary study, which is detailed in Chapter 5.3. The calculation considers a resident population of 300 inhabitants. This strategy enables comprehensive consideration of the requirements and outputs of resources across several subsystems, thereby promoting strengthening of material and energy interactions in the coherent system.

This evaluation employs mass balance to quantify principal inflows and outflows, Water, nutrients, biomass, energy, waste, and illustrates system synergies and limitations. It enables sustainable subsystem operation, detects feedback loops, and offers guidelines for design, operation, and coordination. It, finally, demonstrates the potential for resilient, circular infrastructure incorporating food, energy, and waste systems into urban housing.

In a direct 1:1 comparison based on output mass, it becomes evident that both CO2 emissions and water consumption are significantly lower in the newly proposed system compared to conventional protein-rich foods. Only the energy demand may be higher in certain cases, such as in algae cultivation. However, this must be considered in context, as algae powder accounts for only about 15% of the protein consumption of a human and is therefore not required in large quantities.



Tab. 6 CO2 emission, water and Energy consumption comparison

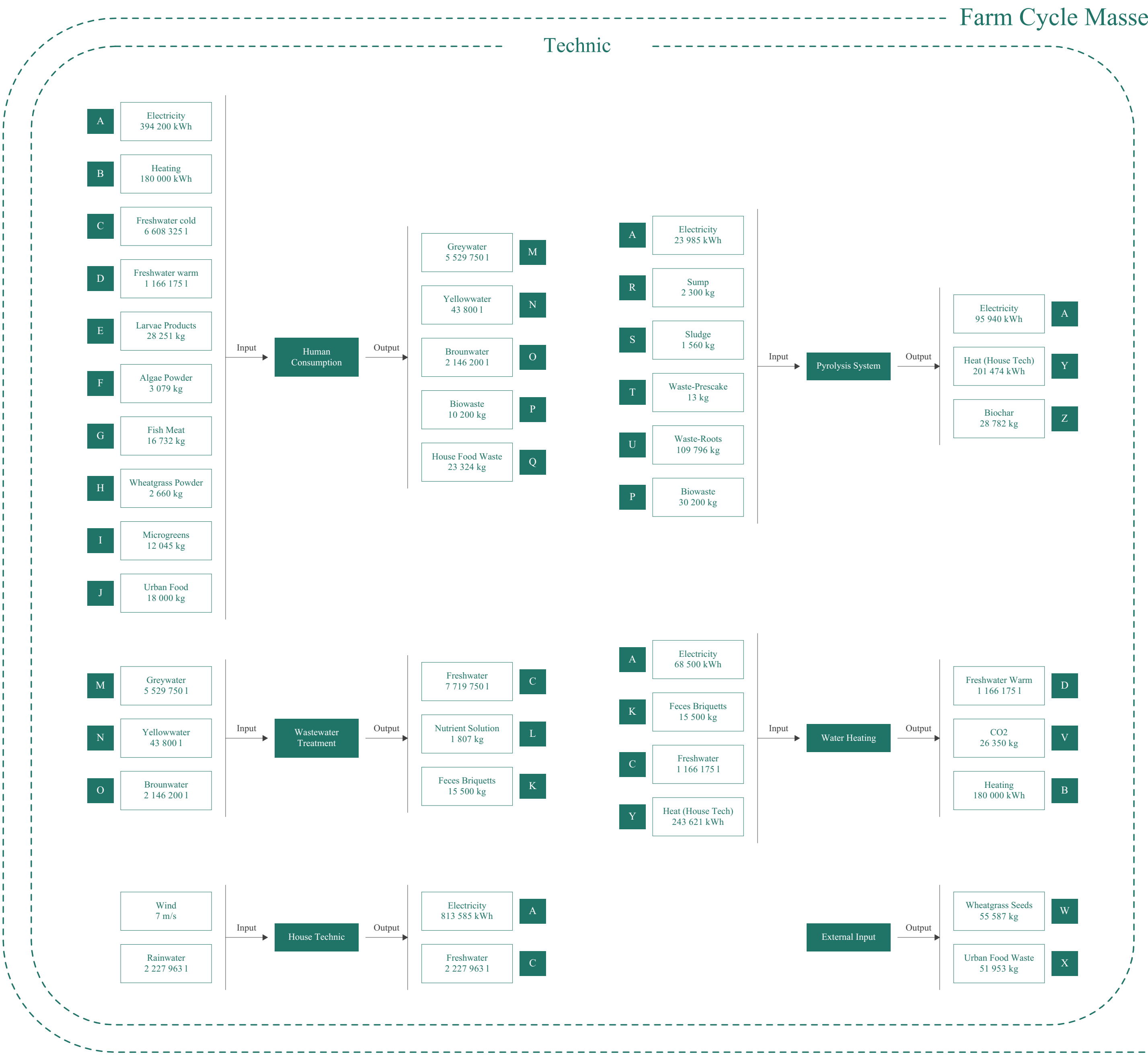
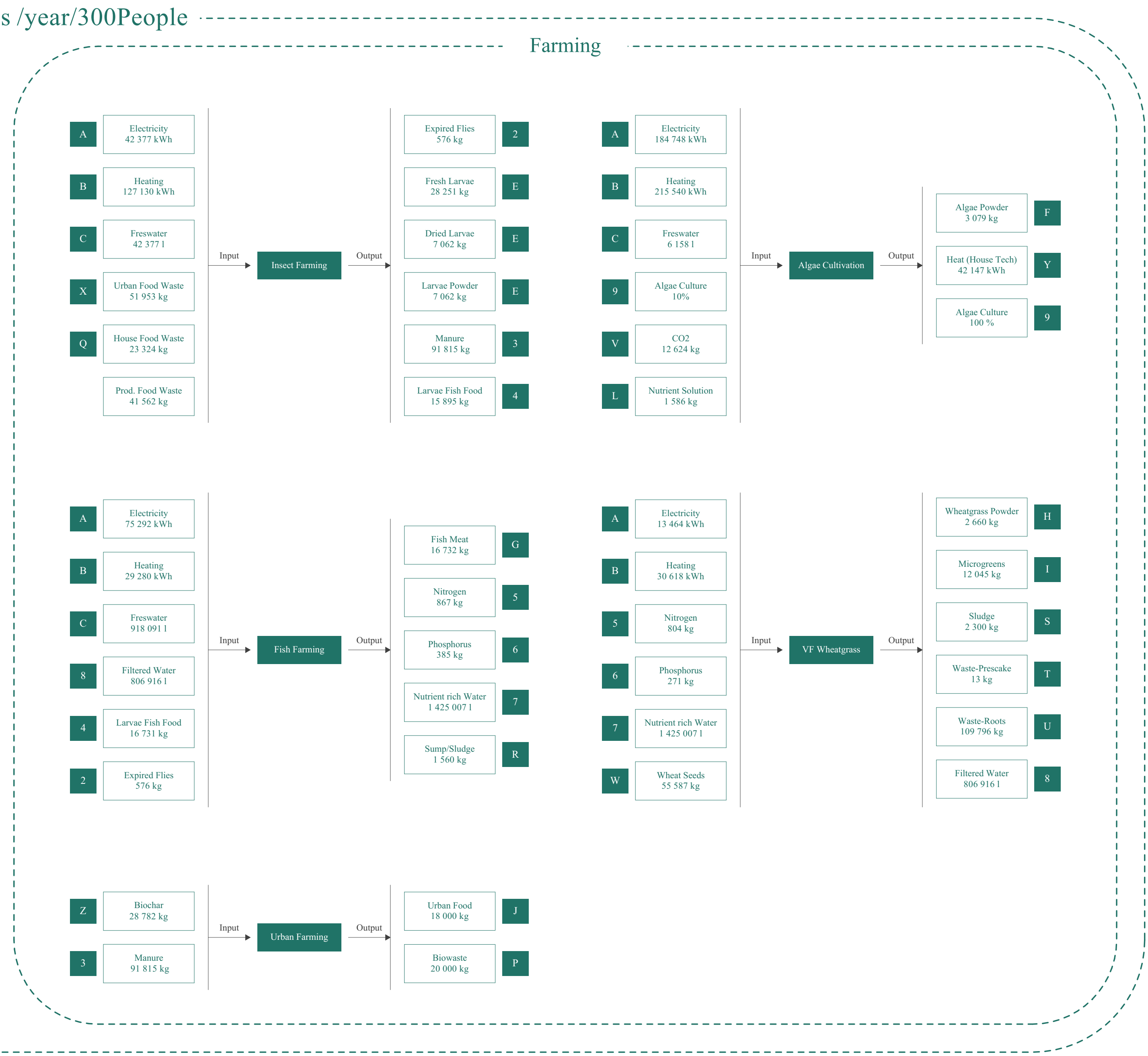


Fig. 66 Farm cycle masses [year/300 people]


s /year/300People
Farming
A Electricity 42 377 kWh
B Heating 127 130 kWh
C Freswater 42 377 l
X Urban Food Waste 51 953 kg
Q House Food Waste 23 324 kg
Prod. Food Waste 41 562 kg
Input
Insect Farming
Output
Expired Flies 576 kg 2
Fresh Larvae 28 251 kg E
Dried Larvae 7 062 kg E
Larvae Powder 7 062 kg E
Manure 91 815 kg 3
Larvae Fish Food 15 895 kg 4
A Electricity 184 748 kWh
B Heating 215 540 kWh
C Freswater 6 158 l
9 Algae Culture 10%
V CO2 12 624 kg
L Nutrient Solution 1 586 kg
Input
Algae Cultivation
Output
Algae Powder 3 079 kg F
Heat (House Tech) 42 147 kWh Y
Algae Culture 100 % 9
A Electricity 75 292 kWh
B Heating 29 280 kWh
C Freswater 918 091 l
8 Filtered Water 806 916 l
4 Larvae Fish Food 16 731 kg
2 Expired Flies 576 kg
Input
Fish Farming
Output
Fish Meat 16 732 kg G
Nitrogen 867 kg 5
Phosphorus 385 kg 6
Nutrient rich Water 1 425 007 l 7
Sump/Sludge 1 560 kg R
A Electricity 13 464 kWh
B Heating 30 618 kWh
5 Nitrogen 804 kg
6 Phosphorus 271 kg
7 Nutrient rich Water 1 425 007 l
W Wheat Seeds 55 587 kg
Input
VF Wheatgrass
Output
Wheatgrass Powder 2 660 kg H
Microgreens 12 045 kg I
Sludge 2 300 kg S
Waste-Prescake 13 kg T
Waste-Roots 109 796 kg U
Filtered Water 806 916 l 8
Z Biochar 28 782 kg
3 Manure 91 815 kg
Input
Urban Farming
Output
Urban Food 18 000 kg J
Biowaste 20 000 kg P

3.3 KEY ACTORS IN BUILDING SERVICES ENGINEERING

To realize such an integrated and closed building services vision, a multidisciplinary group of actors must collaborate across disciplinary boundaries. At the core are building systems engineers and MEP planners, who are responsible for integrating the thermal, hydraulic, and energy interfaces. These must work in close collaboration with environmental and process engineers, who conceive and optimize the wastewater treatment, nutrient recovery, and pyrolysis subsystems.

Architects and façade designers are responsible for incorporating productive systems like algae photobioreactors into the building envelope without sacrificing spatial quality and aesthetics. Experts in agriculture and aquaculture guarantee the biological feasibility of incorporated systems like aquaponics and vertical farming, and biotechnologists streamline processes involved with the cultivation of algae, microbial digestion, and nutrient recycling.

In addition, energy systems engineers must integrate thermal and electric flows to match on-site generation with demand profiles, while control systems engineers install the smart sensor-based automation that manages water, nutrient, and energy cycles in real time. Component development, particularly for filtration, separation, and bioreactor technologies, is achieved by material scientists and industrial designers.

Lastly, urban planners, regulatory bodies, and sustainability experts have the challenge of incorporating the systems within large-scale infrastructural, regulatory, and ecological systems, thereby guaranteeing compliance, sustainable feasibility, and harmony with the objectives of a circular economy. Together, these actors form the transdisciplinary foundation necessary to implement a regenerative model of building services engineering.

3.4 CONCLUSION

To summarise the topic the research question can now be answered:

"How can building technology be re imagined as a dynamic infrastructure that integrates new food production systems to establish a regenerative, circular urban metabolism between food, waste and energy that promote sustainable urban living and ecological consciousness?"

The combination of aquaponics, façade-mounted algae bioreactors, decentralized wastewater treatment plants, and pyrolysis technologies creates a metabolically intense and circular infrastructure that re scripts the function of building services. Instead of passive supply and disposal systems, the subsystems are engaged in dynamic and interdependent exchange. Nutrient cycles, energy streams, and water flows are no longer viewed as linear inputs and outputs, but rather continually revalorized in a closed-loop process.

The complex combination of biological, thermal, and chemical processes gives rise to an essentially new paradigm in building services engineering. The established methods of residential buildings, which are largely concerned with comfort, sanitation, and efficiency, are extended to include such considerations as food production, carbon sequestration, nutrient recovery, and local energy generation. The building becomes not only a consumer of resources, but a productive agent embedded in urban ecological cycles.

This strategy demands a reconsideration of architectural infrastructure as an interactive system, one that has the capacity to adapt, provide feedback, and be integrated through various scales of materiality. It resists the separation of technical disciplines and promotes cross-disciplinary design ideals where engineering, ecology, and architecture blend. Ultimately, this model lays the groundwork for a regenerative urban metabolism, in which the building technology serves as a basis for biotechnical symbiosis between human, energy, waste and food production, rather than static containers of consumption.

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3.6 LIST OF FIGURES

3.7 LIST OF TABLES

3.8 LIST OF AIDS

AI-TOOL	USE	AFFECTED PARTS
Chat GPT	Checking for grammatical correctness of text	All chapters
Deepl	Translation of text passages	All chapters

4.0 DECLARATION OF AUTHORSHIP

ARCHITECTURAL FOOD LAYER
- Urbanised Protein Production

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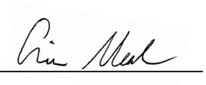

Lustenau, 23.06.2025 Lion Maul

05

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APPENDIX

PRELIMINARY STUDY -
Urbanised Protein Production

ABSTRACT

This work deals with the problems of feeding humanity in the face of climatic change, population growth, political crises, and careless handling of food. The high demand for cheap ready goods has stretched the food production chain to its limits, making it prone to environmental crisis like droughts, floods, and political unrest. This has led to highly processed foods, inflation, and a decline in product quality while overstepping planetary boundaries by a wide margin, especially in biosphere integrity and oceanic nutrient levels such as phosphorus and nitrogen. The study researches the relevance of the current food production system and investigates how architectural interventions can respond to these challenges. Therefore the research question is asked:

"How can new food production methods be integrated into an architectural project to promote a more sustainable relationship with food and raise awareness among people?"

This question is addressed in the following work. Building on the necessary elements for plant growth, the definition of nutrition, and the indication of the most climate-damaging foods, the research concludes with the focus on protein-rich foods. Different alternative foods production methods of protein rich food are analysed, production flows, datasets for nutritional needs of 300 people, and a spatial program. This is then going to be used as a basis for an architectural project in Leith, Edinburgh.

The study highlights the importance of integrating different production methods into a cohesive and sustainable circular system that connects with humans and nature. The proposed solution is a "living machine" where "waste" and "products" circulate within a closed-loop system, maintaining its functionality. It produces the daily requirement of 110g of protein a day per person for 300 people and aspires to raise awareness of better food practices within the living machine and beyond it.

This work forms the basis for a master's thesis that will extend the subject to a greater architectural scale, further investigating the relationship between food production, sustainability, and human interaction.

TABLE OF CONTENT

INTRODUCTION

Due to climate change, ever-increasing demographics, political crises, and the wasteful handling of food, it is becoming increasingly difficult to feed humanity in a healthy way. The rising demand for material goods also extends to the food industry. More and more goods are needed in ever shorter periods to satisfy the "hunger" of the population. Over the decades, this has led to the emergence of a massive production chain. However, this chain is increasingly reaching its limits due to even the smallest environmental changes, such as droughts, hailstorms, floods, and political crises. From a human perspective, the consequences are highly processed foods, high inflation, and lower-quality products.

The hunger for quick and cheap food also leaves its mark on nature. Food production significantly contributes to the overexploitation of planetary boundaries. The planetary boundaries newly established in 2023 show that, in particular, biosphere integrity and the nutrient content of the oceans, especially phosphorus and nitrogen, are under greater threat than climate change. These factors are primarily attributed to food production.

The following preliminary study examines to what extent this food production chain is still timely and how it can be adapted to the contemporary "Zeitgeist" through an architectural intervention.

The work is divided into four sections. Research on the cycles of nature identifies what plants need for growth, focusing on the carbon and water cycles. Research on nutrition and food explains what food is and what constitutes a healthy diet. Food is broken down into its components - carbohydrates, proteins, and fats - and allocated proportionally for a balanced diet. A life cycle assessment with a focus on CO_2 emissions and water consumption for various foods identifies protein-rich foods as the most environmentally harmful. Subsequently, sustainable protein production methods are analysed, and spatial programs are developed. These serve as the basis for an architectural project that integrates the findings into a master thesis.

5.1 THE CYCLES OF NATURES

THE CARBON CYCLE

The carbon cycle is one of the major complex systems, showing the exchange of carbon between atmosphere, oceans, biosphere, and geosphere. It consists of two major components: the fast biological cycle, which includes processes such as photosynthesis, respiration, decomposition, and carbon exchange with oceans, running on a very short time-scale of days to thousands of years, and the slow geological cycle running on time-scales of millions of years, where rock weathering, volcanic activity, and the formation of fossil fuels are involved. Oceans are a tremendous carbon sink whereby carbon is utilized by phytoplankton that, upon dying and sinking, bind carbon (Archer, 2010).

Human activities, such as burning fossil fuels, deforestation, and land-use changes, disrupted that balance and allowed for a sudden rise in atmospheric CO2, thus accelerating global warming and affecting natural carbon sinks. For example, the thawing of permafrost releases additional greenhouse gases, further worsening the problem. Understanding these processes is important for mitigating climate change by reducing carbon emissions to stabilize Earth's climate system (Archer, 2010).

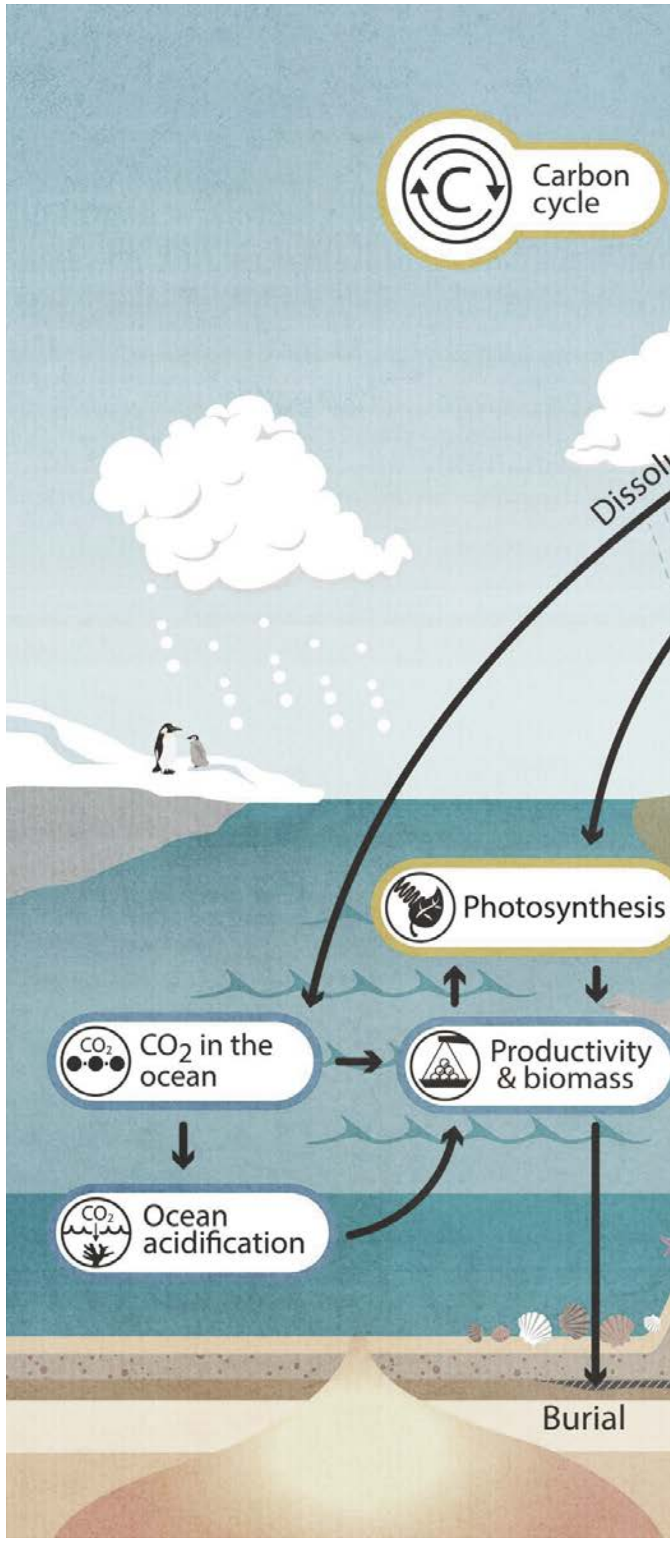
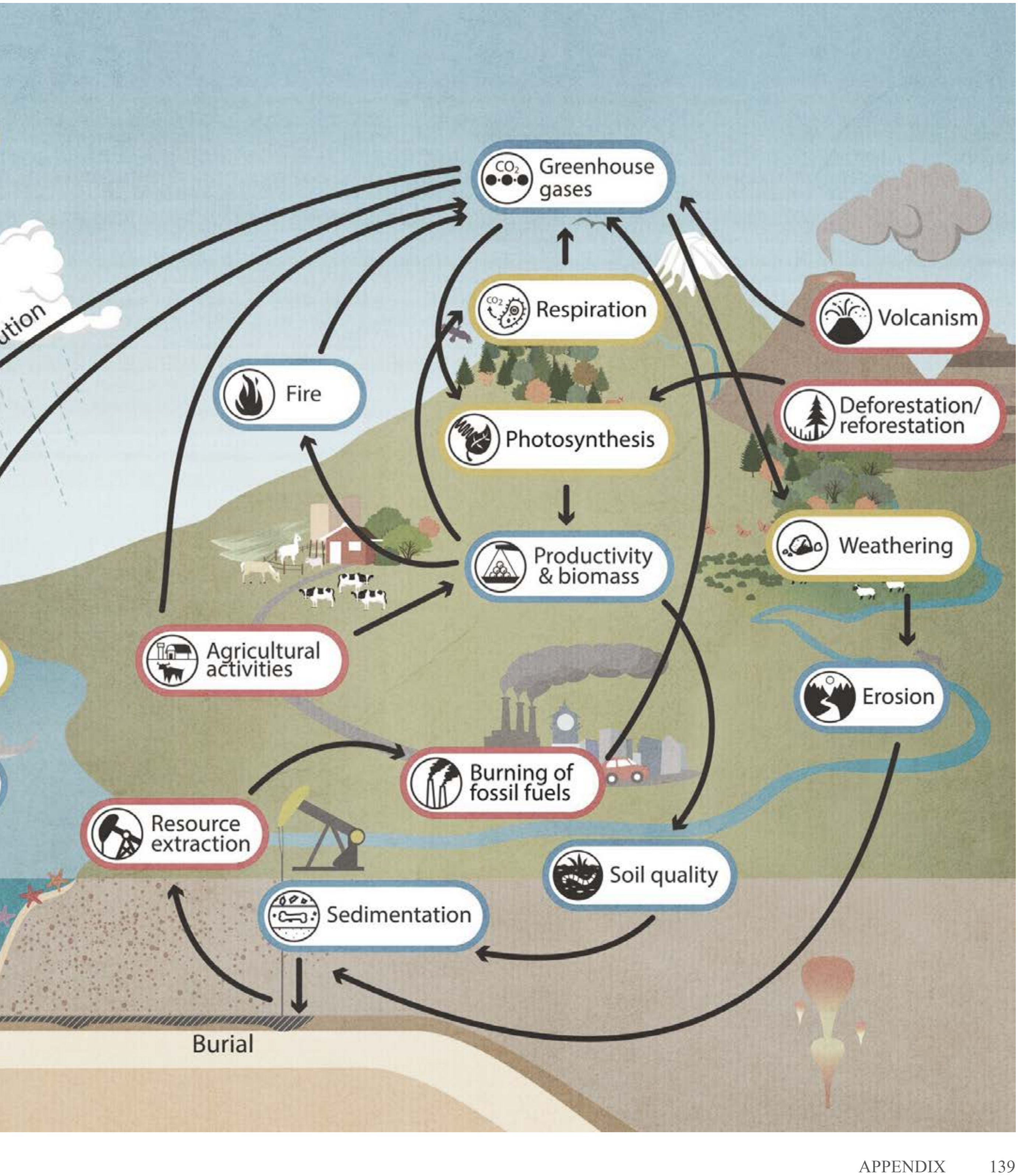


Fig. 67 Carbon cycle diagram


Greenhouse gases
CO_2
Respiration
Volcanism
Fire
Deforestation/ reforestation
Photosynthesis
Productivity & biomass
Weathering
Agricultural activities
Erosion
Burning of fossil fuels
Resource extraction
Soil quality
Sedimentation
Burial

THE WATER CYCLE

Around 75% of Earth's surface is taken up by water, which continuously circulates or recycles between atmosphere, land, and oceans. It also plays an important role in climate, weather, and energy storage. However, the growing population and global warming increased demands on water and reduced the amount of available freshwater, thereby disturbing the hydrologic cycle, causing more extreme droughts and floods. The driving agent of the hydrologic cycle-a process including evaporation and plant transpiration of water-is provided through solar energy, water vapour happens to be the most common greenhouse gas. It does stay in the atmosphere, albeit temporarily, as well as feed into global warming processes through some reinforcing feedback. Precipitation falls as rainfall or snow and is stored in glaciers, rivers, and even groundwater (University of California Regents, 2024).

Water cycling affects human activities and the environment in the context of climate patterns, freshwater availability, biodiversity, weathering, ocean currents, and extreme weather events. Global warming amplifies this impact, resulting in more frequent droughts, hurricanes, and floods (University of California Regents, 2024).

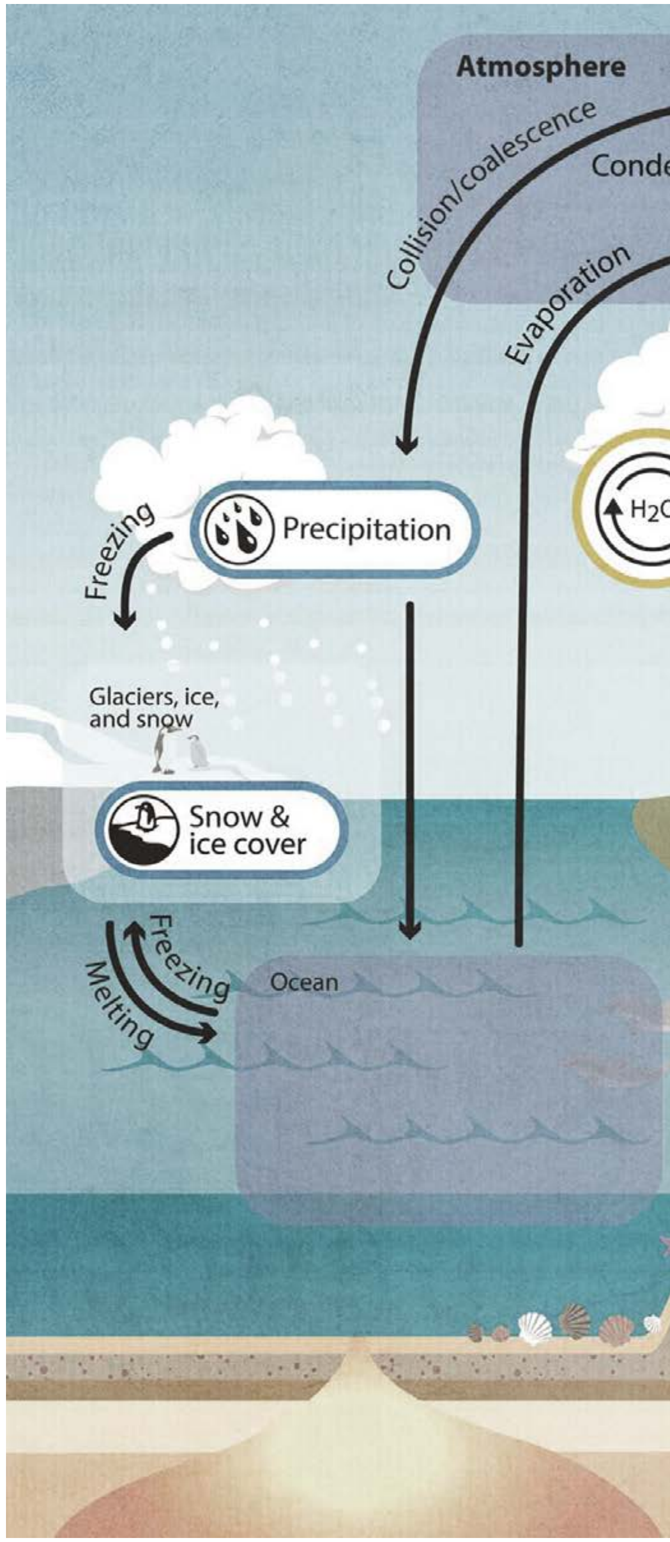
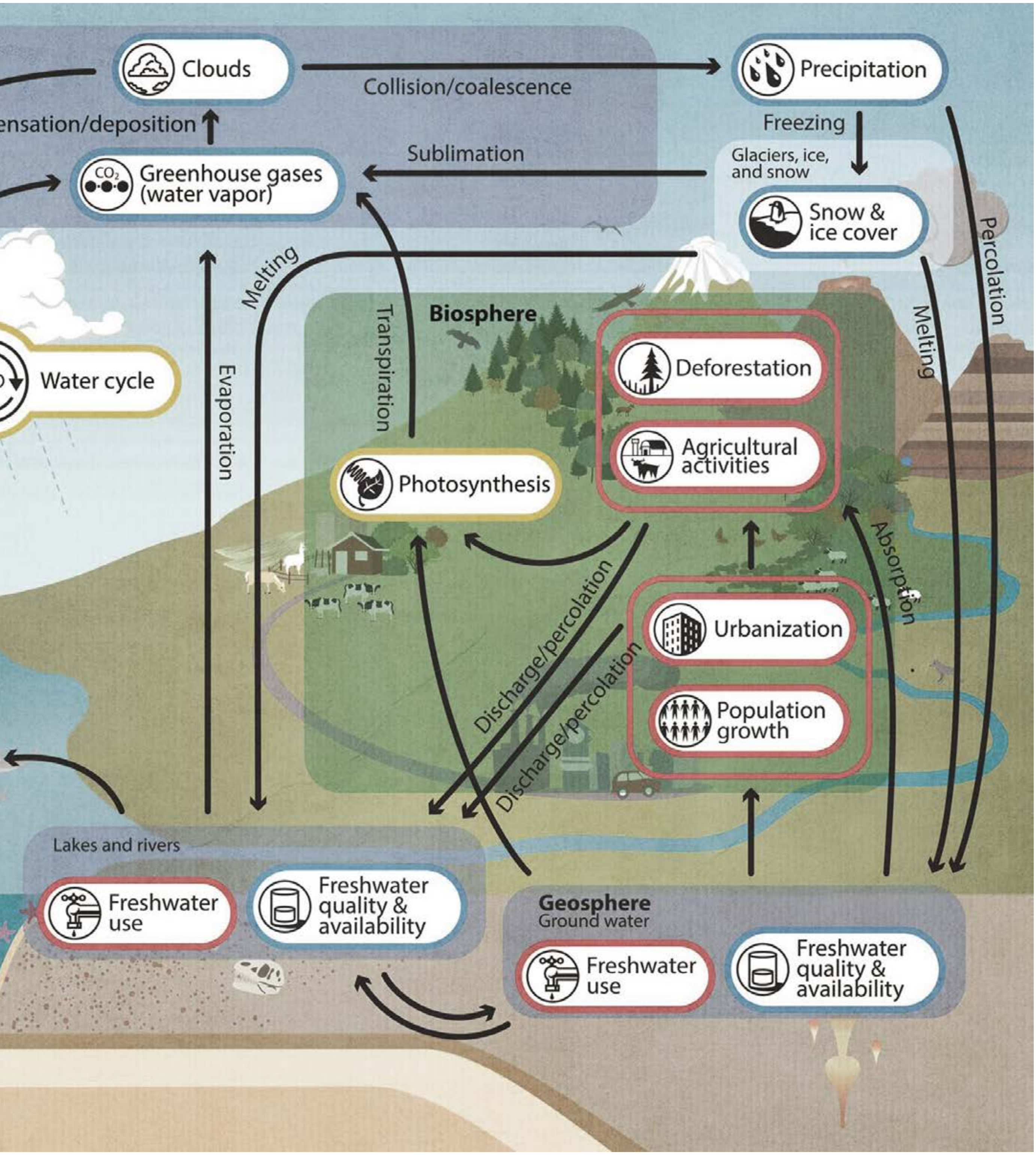


Fig. 68 Water cycle diagram


Clouds
Collision/coalescence
Precipitation
ensation/deposition
Freezing
Sublimation
Glaciers, ice, and snow
Greenhouse gases (water vapor)
Snow & ice cover
Melting
Percolation
Melting
Transpiration
Biosphere
Deforestation
Water cycle
Evaporation
Agricultural activities
Photosynthesis
Absorption
Discharge/percolation
Discharge/percolation
Urbanization
Population growth
Lakes and rivers
Freshwater use
Freshwater quality & availability
Geosphere
Ground water
Freshwater use
Freshwater quality & availability

NUTRITION AND THE CYCLES

The carbon and water cycles are among the most important components of food production, as they provide critical processes and resources that enable plant development and help maintain stability in agriculture. Each one of them participates distinctly in the various stages of food production, hence ensuring that plant growth, fertility in soils, and a constant supply of water occur both in plants and animals.

CARBON CYCLE

The carbon cycle is essential for food production because it affects the process of photosynthesis. During photosynthesis, plants absorb carbon dioxide (CO_2) from the atmosphere and convert it into glucose and other organic materials, which in turn become vital for growth and development. This mechanism generates not only the energy that is essential for plant growth but also food that forms the base of the food chain.

In addition, carbon sequestered in soil as organic matter enhances soil fertility and structure, which promotes increased crop yields. Soils containing more organic carbon will retain more water, have more nutrients available, and better microbial activity, all parts of growing plants healthily. Disruptions in the carbon cycle due to high CO_2 emissions will likely affect climate patterns, which impact crop productivity as temperature and rainfall patterns change.

WATER CYCLE

This cycle is also essential in food production, since water is required for the life of plants and animals. Plants need water for photosynthesis, transport of nutrients, and maintaining their structure. The water cycle enables water from seas, rivers, and lakes to evaporate and to form clouds that eventually precipitate back on to land, thus replenishing the water supplies used in agriculture by irrigation.

First, the distribution of rainfall is determining the availability of fresh water for crops and animals. Ground and surface water sources also depend on the regularity of the water cycle. Additionally, soil moisture, required for root growth and nutrient absorption, is maintained by the water cycle.

INTERACTION OF THE CYCLES

Both carbon and water cycles are connected and have an influential role in regulating climate, further affecting the productivity of food. For photosynthesis and the production of food by plants, both CO_2 from the carbon cycle and water from the water cycle are needed. Disruption in these due to extremity in related events of drought and flood brought about by change in climate leads to crop failure and deterioration of soil quality, decreasing food availability. This balance in the nutrient cycles needs to be maintained for the future of agricultural productivity, so that global food systems may achieve long-term stability and resilience.

5.2 BASIS OF NUTRITION

HUMAN NEEDS

First, one needs to define what food is, and where does the human body obtain energy from. The major source of energy for the body emerges from three primary nutrient groups: carbohydrates, proteins, and fats; named as macronutrients since they make up big portions of our diet. While other nutrients like vitamins or trace elements do not provide energy. The energy contained in food is also known as calorific value and is measured in units of calories or joules. When referring to calories or joules in everyday language, this actually means kilocalories (1000 calories) or kilojoules (1000 joules). The abbreviations for kilocalories are kcal and for kilojoules, kJ (IQWiG, 2022):

1 kcal = 4,2 kJ
10 kJ = 2,4 kcal
Carbs: 1g = 4 kcal
Protein: 1g = 4 kcal
Fats: 1g = 9 kcal

Balancing these macronutrients in the diet ensures that the body has a consistent energy supply and the necessary components for muscle maintenance, cellular repair, and overall health. Each macronutrient plays a unique role, and the body's needs can vary depending on factors like age, activity level, metabolism, and health goals.
Understanding these foundational principles of macronutrients and calorific value is key to managing energy intake effectively, supporting health, and maintaining balanced nutrition in daily life (IQWiG, 2022).

CARBOHYDRATES

Carbohydrates are small sugar molecules that chemically bond to one another and, hence, can also form long chains. There is, therefore, a difference between: Monosaccharides, Disaccharides, Oligosaccharides, Polysaccharides (Morris et at., 2021).

Household sugar, which is the combination of glucose and fructose, is a disaccharide. More so, lactose, or milk sugar, is made out of glucose and galactose. On the contrary, in the case of starch, the two compounds amylose and amylopectin correspond to long chains of glucose molecules. Thus, starch is regarded as 'complex carbohydrates. All the carbohydrates that are taken in our diet both in simple and complex forms are digested and absorbed as sugars. Later these are absorbed by the intestinal wall, which raises the blood sugar level. Blood sugar has to be transported inside the cells by releasing insulin. Insulin is a hormone linked with anabolism that carries carbohydrates and amino acids into cells, lowering the blood sugar level. Carbohydrates have one major function, which is to provide energy. In fact, only a few tissues such as red blood cells and liver cells require or need the consumption of carbohydrates. All the other tissues can be completely satisfied in terms of energy requirements with fats when needed. Because carbohydrates can be synthesized from proteins in the body to a certain extent, carbohydrates do not have to be essentially needed. They are particularly crucial during high-intensity exercise, as they can be metabolized quickly (Macdougall et at., 1999).

PROTEINS

Proteins consist of amino acids linked together in long chains. The specific composition, sequence, and three-dimensional folding of amino acids determine the functions of the protein in the body. Unlike the other two macronutrients, protein is only converted into energy when necessary. If the intake of protein exceeds the body's needs, it is first converted into carbohydrates and can then either be used as energy or stored as glycogen (Trumbo et at., 2002).

Protein is also the only macronutrient that the human body cannot produce from other substances. Therefore, it is necessary to consume protein through our diet in sufficient quantities. Twenty amino acids are important for building the most essential proteins in the body. Out of these 20, a healthy adult can synthesize 11 from other amino acids. However, the remaining 9 amino acids are so unique that the body cannot produce them, thus classifying them as essential amino acids, abbreviated as EAAs. The composition of amino acids in a dietary protein is a significant factor determining the protein's quality. A dietary protein is considered 'complete' if it contains sufficient amounts of each essential amino acid in proportion to its total amino acid content (Wolfe et at., 2016).

Animal proteins generally have a more balanced proportion of essential amino acids compared to plant-based protein sources. Therefore, they tend to have higher quality on average (Gorissen et at., 2018).

FATS

Despite being the body's major energy reservoir and primary energy source, the importance of fats is extended by their other functions, which make them an indispensable macronutrient. Examples include the production of sex hormones and tissue hormones and their cell membrane constituent role. Furthermore, there is the so-called essential adipose tissue, which acts as a cushion for major organs and protects them against shocks and impacts. The major form of fat in our diet is triglyceride, consisting of a molecule of glycerol linked with three fatty acids (Morris et at., 2020).

Fatty acids are classified according to the length of their carbon chains and how many double bonds they contain. Fatty acids that do not contain double bonds are known as 'saturated fatty acids." Monounsaturated fatty acids have one double bond; polyunsaturated fatty acids have more than one double bond. Omega-3 and Omega-6 fatty acids are the only two essential fatty acids, so although all other fatty acids can be manufactured in the body from other fats, these two must be obtained from the diet. The major difference between the Omega-3 and Omega-6 fatty acids is that there is a distinction between the two, in that Omega-6 fatty acids are already found in abundant amounts in our diet, whereas most people take relatively fewer Omega-3 fatty acids. Alpha-linolenic acid or ALA is found in plant-based food; this needs to be converted in the body to longer-chain EPA and DHA. (Mariamenatu et at., 2021).

VITAMINS

A good distribution of the various vitamins is important for a balanced diet. This aspect also plays a role in basic research. In the vitamin table, the different foods to be produced are listed. In this way, one obtains an overview of the different vitamins of the foods. Vitamins are organic substances needed to maintain overall health and well-being. They are nutritional elements necessary in moderate quantity but highly required in physiological body functions. The human body cannot synthesize adequate amounts, and therefore supplementation is required through proper diet (Krank, 2024).

The vitamins are of importance on various grounds concerning body functions. Each vitamin performs certain roles, thereby helping many body functions. For example, Vitamin A is relatedly helpful in relation to vision, as it supports eye health and low light adaptation. Vitamin D is very helpful for the functions of bones as it helps in the assimilation of calcium that results in strong bones and healthy teeth. Vitamin E serves as an antioxidant, protecting cells from damage caused by free radicals and, in turn, immune function and skin health. Vitamin K plays a very vital role in the coagulation of blood, which is quite indispensable in wound healing processes in order to prevent excessive bleeding (Krank, 2024).

The B-complex vitamins include thiamine or vitamin B1, riboflavin or vitamin B2, niacin or vitamin B3, pantothenic acid or vitamin B5, pyridoxine or vitamin B6, biotin or vitamin B7, folate or folic acid or vitamin B9, and cobalamin or vitamin B12. These are critical in the metabolic processes of energy conversion in the body, enabling the conversion of food into usable energy. They also participate in nerve function, the creation of red blood cells, and DNA synthesis (Krank, 2024).

Vitamin C, otherwise known as ascorbic acid, is a powerful antioxidant that promotes and stimulates the immune system to help prevent infections and support wound healing. It is also necessary for the development of collagen, which is required for healthy skin, cartilage, and blood vessels (Krank, 2024).

The absence or deficiency of certain vitamins can lead to various health issues and deficiencies. Such shortages can be seen in various ways: for instance Vitamin D can cause bones weakened and diseases such as osteoporosis, Vitamin C triggers scurvy, which results in exhaustion, weakness, and swollen gums; hence, Vitamin A shortage arouses a decay in vision or night blindness (Krank, 2024).

An adequate intake of vitamins through a well-balanced diet, including fruits, vegetables, whole grains, lean proteins, and dairy, is highly instrumental in pursuing optimum health. Supplements may, however, be helpful in bridging some of the nutritional deficiencies one suffers from (Krank, 2024).

DISTRIBUTION

Daily caloric needs vary for the individual based on variables such as sex, age, and type of physical activity engaged in. Typically, males need more calories than females simply because usually males have bigger and larger muscular bodies, which automatically need higher energy to sustain. Likewise, people with a higher level of fitness or those with larger muscles require more intake because muscle tissue uses more energy even at rest. Taking the average of these variables into account, the day-to-day intake of calories for an average person, depending on the gender and the age, is calculated to be around 2200 kcal a day (Goedecke, 2024).

The second important component of a proper and healthy diet is the apportionment of nutrients. While in the past, dietary guidelines often focused on high carbohydrate intake, more recent findings suggest that a diet heavy in carbohydrates, especially simple sugars, may raise a predisposition to illnesses like obesity and diabetes. This new thought has now brought a rise in emphasis toward a diet of moderation in carbohydrate consumption, focusing more on complex carbohydrates, and a rise in proteins and healthy fats. Particularly in the field of sports nutrition, there have been growing recommendations for diets with higher protein and a high content of healthy fats, which would allow the muscles to recover properly and provide energy that does not spike blood sugar (Goedecke, 2024).

The macronutrient distribution of balanced diet recommendations at an intake level of 2200 kcal per day is:

Carbs:	3 - 3,4 g/kg body weight
	50% of total calories
Proteins:	1,3 - 1,6 g/kg body weight
	20% of total calories
Fats:	1,2 – 1,4 g/kg body weight
	30% of total calories

Carbs:	1100 kcal	=	275 g/Person
Proteins:	440 kcal	=	110 g/Person
Fats:	660 kcal	=	73 g/Person

A balanced intake of macronutrients ensures sustained energy, maintains muscle, and manages body weight without raising the risk of metabolic disorders. Of course, these ratios can be changed depending on specific goals, whether to lose weight, gain muscle, or take other health considerations into account (Goedecke, 2024).

FOOD GHG EMISSION

Life Cycle Assessment is an ISO-standardized method for evaluating the environmental impacts of products from “cradle-to-grave.” It examines impacts such as climate change, eutrophication, and resource useg, water, land, energy-along production, processing, and distribution stages (Sonesson et al., 2010, p. 2).

Production systems are complex, featuring many interdependencies, and there is some flexibility in setting system boundaries and allocating environmental burdens to products. The consequence is that LCA studies on similar systems can reveal apparently divergent results, not because of errors but because of differing methodological choices. In this way, results from an LCA should be interpreted knowing the level of their uncertainties, but they still have much value for determining hot spots and potential areas of improvement. In food production chains, the early stages (primary production and processing) differ significantly between product types, while later stages are more uniform. Thus, the report first focuses on primary production across various product groups.

BEEF

Beef production-both from specialized herds and dairy by-products-is considered one of the largest GHG emitters due to the high amount of methane produced via enteric fermentation. Feeding practices with roughages decrease methane emission but increase the production of CO2 and N2O. Faster animal growth reduces methanogenic activity, however, lower reproduction rates in cows compensate for this improvement, making beef quite emissions-intensive (Sonesson et al., 2010, p. 2-3).

Study	CO_2-equiv./kg bone-free meat				MJ/kg bone-free meat
	Total	CH_4	N_2O	CO_2	
Ogino et al. (2007) Japan	32	23	2	7	
Casey & Holden (2006a, b), Suckler, Ireland	28-32				
Williams et al., (2006), ”Average UK beef”	16				28
Williams et al., (2006), ”100% suckler”, UK	25				41
Verge, et al., (2008) , ”Average Canadian beef”	30	15	11	4	
Cederberg et al. (2009a), ”Average Brazilian beef”	40	31	9	0	5
Cederberg et al. (2009b), ”Average Swedish beef 2005” [a]	28	17.5	7	3.5	
Cederberg & Darelius (2000), ”Swedish beef from combined systems dairy-beef”	17-19	9-10	5-6	3	44

[a]64% of the meat originates from combined dairy-beef production (surplus calves and culled cows).

Tab. 7 GHG emissions for beef reported in different studies. Note that the studies cannot be com pared directly due to differences in design and weighting factors used.

PORK

Pigs are monogastric, producing negligible amounts of methane. Their feed competes with human food. So, feed accounts for 60–70% of all emissions, while manure handling is also important. Pork has a lower GHG intensity than beef because of higher efficiency in feed use and reproduction rates of sows (Sonesson et al., 2010, p. 5).

POULTRY

Chickens are also monogastric and feed-efficient. GHG emissions are relatively low, with most emissions resulting from high-protein feed production. Energy for barn heating or cooling can influence emissions depending on energy sources (Sonesson et al., 2010, p. 6).

Study	CO_2-equiv./kg bone-free meat				MJ/kg bone-free meat
	Total	CH_4	N_2O	CO_2	
Williams et al., 2006	5.6-6.4				14-17
Basset Mens & van der Werf (2003) [a]	5.3-8.0				37-42
Cederberg & Flysjö (2004),	4.1-3.6	1.1	1.6-2.1	0.9-1.2	15-18
Strid Eriksson et al. (2005) [b]	3.2-3.5				13-16
Cederberg m.fl. (2009b) [c]	5.2	1.3	2.6	1.3	

[a] The results have been recalculated from ”Live weight” to “bone-free meat” using a yield factor of 43%
[b] Only the fattening phase was included, not rearing of piglets
[c] The results have been recalculated from ”Carcass weigh” to “bone-free meat” using a yield factor of 59%

Tab. 8 GHG emissions for pork as reported in different studies. Note that the studies cannot be compared directly due to differences in design and weighting factors used.

Study	CO_2-equiv./kg bone-free meat			
	Total	CH_4	N_2O	CO_2
Thynelius, 2008 [a] 1.5	1.5			
Pelletier (2008) [b] 2.6	2.6			
Cederberg et al. (2009b) [c] 2.5	2.5	0.1	1.2	1.2
Williams et al. (2006), conventional [c] 6.1	6.1			
Williams et al. (2006), free-range [c] 7.3	7.3			

[a] Emissions per substance was not presented
[b] The results have been recalculated from ”Live weight” to “bone-free meat” using a yield factor of 54%
[c] The results have been recalculated from ”Carcass weight” to “bone-free meat” using a yield factor of 77%

Tab. 9 GHG emissions for chicken as reported in different studies. Note that the studies cannot be compared directly due to differences in design and weighting factors used.

FISHERIES

Fisheries are a source of considerable CO2 emissions, mainly from diesel combustion on vessels, but also from refrigerant leaks. Low-impact refrigerants are available but rarely used. Emissions during seafood production mainly take place in the fishing process. Energy-efficient methods, such as purse seine's and pelagic trawls, are superior to energy-intensive techniques, such as beam trawling. Fuel efficiency is lowered by low or overfished stocks, even though the development of fish detection methods has improved, overfishing has reduced energy efficiency over recent decades (Sonesson et al., 2010, p. 7).

SEAFOOD

Wild fisheries mainly contribute to the GHG emissions by diesel combustion on vessels. Overfishing decreases energy efficiency, but gear type and stock density also play a determining role in emissions. In aquaculture, feed production dominated the GHG footprints especially for carnivorous fish with marine-based feed (Sonesson et al. 2010, p. 6-8).

Product	Climate impact (kg CO_2equiv./kg)	Production region	Reference
Herring frozen	1.2	Fished by Norwegian fishermen	FHL 2009
Cod	3.8 - 4.8 [a]	Fished by Norwegian fishermen	Findus 2008
Salmon	1.8 - 4.2 [b]	Farmed in Canada	Pelletier & Tyedmers 2007

[a] depending on fishing method and location of processing plant
[b] depending on feed composition

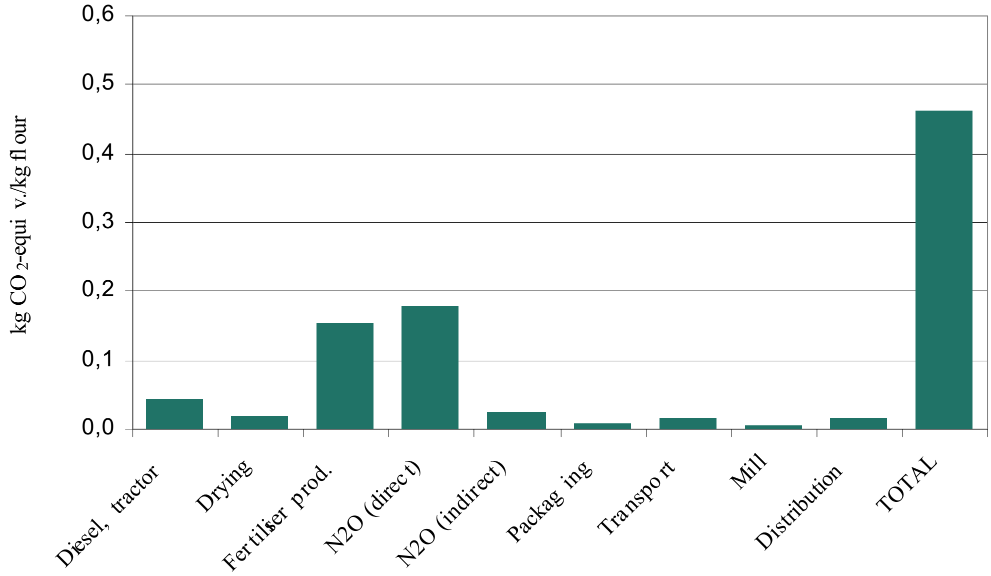
Tab. 10 Climate impact of a number of common seafood products per edible kilo (with nonedible parts given zero impact).

GRAINS AND LEGUMES

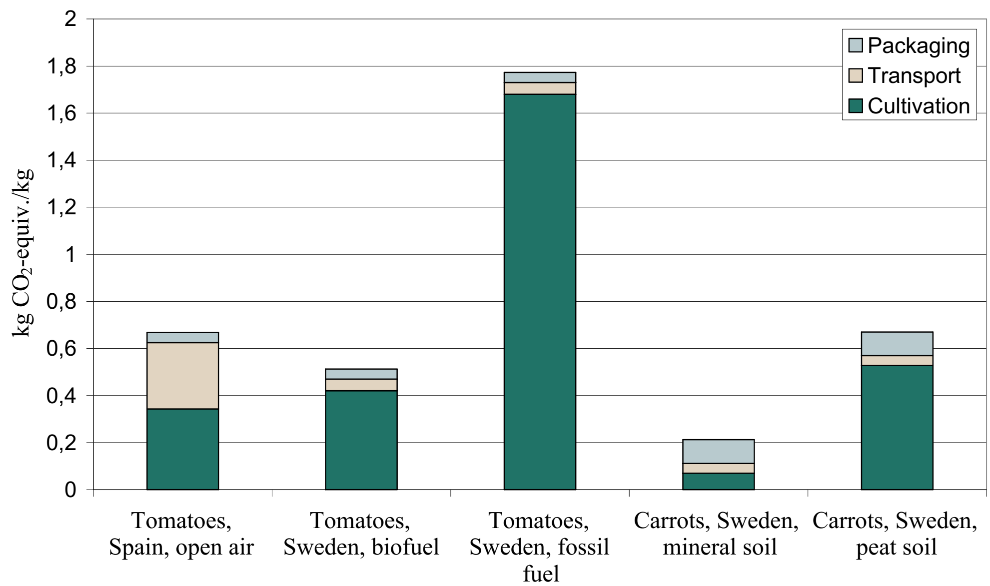
Nitrogen fertilizers are the largest GHG source for grains, while legumes fix nitrogen, reducing fertilizer needs. Legumes like soy beans and peas have lower climate impacts compared to animal proteins. Diesel use and packaging also contribute to emissions (Sonesson et al., 2010, p. 8-10).

RICE

Paddy rice represents 10–13% of global methane emissions and has a higher GHG footprint than dry land rice. The major contributors are methane from flooded fields and fossil energy in processing (Belengini 2009, p. 1512-1522).



Tab. 11 Climate impact of a number of common seafood products per edible kilo (with nonedible parts given zero impact).



Tab. 12 Climate impact of a number of common seafood products per edible kilo (with nonedible parts given zero impact).

FRUITS AND VEGETABLES

GHG emissions are mainly due to diesel and fertilizer use. For greenhouse-grown crops, the emission varies with heating methods. Biofuels are a more viable alternative than fossil fuels. Waste enhances emission, especially for perishables (Sonesson et al., 2010, p. 10-11).

TRANSPORTATION

GHG emissions from transportation of food are relatively low. However, there are significant airfreight and refrigeration. In addition, although bulk transport is efficient, retail distribution and consumer trips have higher emissions due to smaller loads and stop-start driving (Sonesson et al., 2010, p. 10-11).

FOOD WASTE

33% of food are wasted globally due to perish ability, poor storage, and consumer behaviour. Waste management is also important as landfilled food generates methane. Furthermore, reducing waste from high-impact foods, such as meat and dairy, massively reduces emissions (Stuart, 2009; Ventour, 2008).

RETAIL AND PACKAGING

The retail refrigeration and food waste are the main contributors, though the sector can influence the supply chains to lower waste. The packaging limits the spoilage but again results in emission through production and disposal processes (Sonesson et al., 2010, p. 13).

CONSUMPTION

In the consumer stage, the most significant impacts on total life cycle GHG emissions come from food wastage and home transportation. However, cooking also plays a role, particularly for vegetables with low emissions in earlier stages but which need extended boiling times. (Sonesson et al., 2010, p. 13).

CONCLUSION

Food production cycles are very carbon- and water-intensive, but animal-based foods are considerably more harmful to the environment than plant-based foods. For instance, meat and dairy products produce up to 70 times more GHG emissions and use 15 times more water than crops or vegetables. Animal-based foods are responsible for more than 40% of the diet-related GHG emissions in Germany, while plant-based foods contribute to only about 8%, as shown by Koerber et al. (2009).

While animal-based foods contain high-quality protein, supplying up to 20-25% of daily calories, their production is far more environmentally damaging than carbohydrate sources, which are less impactful in terms of CO2, GHG emissions, and water use.

The following work focuses on the production of protein-rich foods to reduce CO2 emissions and water consumption. It examines different production methods and explores their underlying mechanisms.

Tab. 13 CO2-equiv. comparison dataset

CO2-equiv. Comparison		**CO2-equiv./kg**				**l Water/kg**
Product	Source	CO2	CH4	N2O	Total	CO2
Beef	Ogino et al. (2007) Japan	7	23	2	32	15 000
	Casey & Holden. (2006a, b), Suckler, Ireland				32	15 000
	Williams et al. (2006), ”Average UK beef”				16	15 000
	Williams et al. (2006), ”100% suckler”, UK				25	15 000
	Verge, et al. (2008) , ”Average Canadian beef”	4	15	11	30	15 000
	Cederberg et al. (2009a), ”Average Brazilian beef”	0	31	9	40	15 000
	Cederberg et al. (2009b), ”Average Swedish beef 2005”	3,5	17,5	7	28	15 000
	Cederberg & Darelius. (2000), ”Swedish beef"	3	10	6	19	15 000
	AVERAGE				27,75	15 000
Pork	Williams. et al. (2006)				6,4	5 000
	Basset Mens & van der Werf. (2003)				8	5 000
	Cederberg & Flysjö. (2004)	1,2	1,1	2,1	3,6	5 000
	Strid Eriksson. et al. (2005)				3,5	5 000
	Cederberg. et at. (2009)	1,3	1,3	2,6	5,2	5 000
	AVERAGE				5,34	5 000
Poultry	Thynelius. et at. (2008)				1,5	3 900
	Pelletier. et at. (2008)				2,6	3 900
	Cederberg et al. (2009)	1,2	0,1	1,2	2,5	3 900
	Williams et al. (2006), conventional				6,1	3 900
	Williams et al. (2006), free-range				7,3	3 900
	AVERAGE				4	3 900
Fisheries	FHL. (2009)				15	0
	AVERAGE				15	0
Aquaculture	FHL. (2009), Hering frozen				1,2	1 500
	Findus. et at. (2008), Cod				4,8	3 500
	Pelletier & Tyedmers. (2007), Salmon				4,2	3 000
	AVERAGE				3,4	2 666,67
Grains	Cederberg. et al. 2008)				0,46	700
Garin Legumes	Blengini & Busto. (2009), Soy				0,8	1 500
	Blengini & Busto. (2009), Peas				0,3	500
	AVERAGE				0,55	1000
Vegetables	Sonneson. et at. (2010), Tomatoes				0,45	700
	Sonneson. et at. (2010), Carrots				0,2	500
	AVERAGE				0,33	600

5.3 PROTEIN-RICH FOOD PRODUCTION | INSECT FARMING

INTRODUCTION

Insect farming, especially for the Black Soldier Fly (Hermetia illucens) involves a series of steps in rearing, breeding, and harvesting larvae. It has received extensive attention due to its great potential in waste treatment and the production of high-value proteins and fats for animal feed and industrial purposes. Successful farming is based on efficient colony management, environmental control, and constant monitoring of the fly's life cycle.

REARING CONDITIONS

Under appropriate conditions, the generation cycle from egg to egg takes about six weeks. Adults live 1.5 to 3 weeks; after laying eggs, females die. The control of temperature and humidity is very important for good breeding. For flies, eggs, and larvae, temperatures must be between 27-30°C with high humidity above 60%; the larvae will thrive in temperatures from 25-28°C. Below 23°C, it reduces the development of the insect; below 17°C, it stops. Temperatures above 32°C can harm development (Wolfhart et al., 2023, p. 4).

FEEDING DURING FATTENING

Waste substrates can be used for larvae fattening, but poor feeding has also been identified as a cause of mortality up to 80%. Protein- and carbohydrate-enriched feeding with substrates like grain leads to larvae that are 25% larger. Diets high in protein produce the highest biomass; too high a proportion of fat impairs development. Feeds should contain at least 7% protein for good development (Wolfhart et al., 2023, p. 5-6).

Optimal Fattening Period:

- Start: Begin with 5–9-day-old young larvae, following their most sensitive phase.
- End: Approximately 10–14 days of fattening (larvae aged 15–23 days after hatching), identifiable by the appearance of 10–20% dark prepupae (6th larval stage).

Tab. 14 Optimal Fattening Period

Recipe for Fattening Feed:

- 40% grain products
- 32% surplus fruit and vegetable waste
- 28% residual materials from reuse/recycling

Tab. 15 Recipe for Fattening Feed

FEEDING TIMES

Feeding is carried out on days 1, 4, 7, and 10 of the fattening cycle. A single larva consumes approximately 0.0714 g of fresh matter per day. In a fattening period of 14 days, 1 gram of feed per larva is needed (Wolfhart et al., 2023, p. 7).

Feeding/Day	% Of the total ration
1	20
4	26
7	32
10	22
Total	100

Tab. 16 Feeding During a Fattening Period

g/Larvae	Larvae	Day	kg feed
0,071	1	14	0,001
0,071	5 000	14	5
0,071	70 000	14	70
0,071	100 000	14	100

Tab. 17 Feed Amount During Fattening Per.

STOCKING DENSITY

Larger surface areas enable higher larval densities and more flexible feeding strategies. Pallet boxes can handle 50,000 to 90,000 larvae. Above 100,000 larvae/m² problems might occur with harvesting and ventilation. The best feed efficiency is attained at 8.5–9 larvae/cm². (Wolfhart et al., 2023, p. 9).

HARVESTING AND PROCESSING

Simple sieving techniques can be used to separate larvae from feed residues, but more sophisticated techniques such as centrifugation are too expensive. For larger quantities, either vibrating sieves or composting may be applied. For humane killing, larvae should be frozen at –18°C for at least two days and then dried at 60°C for 30-36 hours to be properly dried without affecting the quality of the proteins (Wolfhart et al., 2023, p. 10).

Compartments	Length [cm]	Width [cm]	Hight [cm]	Area [m²]	Larvae number
Palox	110	74	30-50	0,814	70 000
Euro-box	57	36,5	22	0,208	10 000
Tupperbox	39	26,5	10	0,103	3 000

Tab. 18 Interior Dimensions and Stocking Densities

Larvae number	Larvae fresh [kg]	Larvae dry [kg]	Larvae flour [kg]	Required food [kg]	Palox´s number
70 000	11,6	5,2	3,1	66,5	1
100 000	16,5	7,4	4,5	95	2
5 000 000	825	371	223	4750	70

Tab. 19 Conversion of Fresh Fattening Larvae to Hermetia Meal

EGG LAYING

Female Hermetia illucens lays eggs two to three days after copulation in dry, decaying food locations. Egg laying is done in corners or openings and takes at least 10 minutes. Fresh egg collections every two to three days ensure efficient egg production, preventing uncontrolled laying in cracks (Wolfhart et al., 2023, p. 14).

Occupancy of Large Nets:
Dimensions: 200 × 180 cm floor area, 170 cm height, Volume: 6 m^3
Optimal Capacity: 4,000 to 8,000 flies

Tab. 20 Occupancy of Large Nets

CONCLUSION

Larvae are a sustainable food source due to their highly resource-efficient production. Compared to traditional meat sources, they require significantly less land, water, and feed while producing considerably lower greenhouse gas emissions, reducing their carbon footprint. Additionally, they can convert organic waste into high-quality protein, supporting circular economy practices. Rich in protein, vitamins, and minerals, larvae are an environmentally friendly and healthy alternative.

Insect larvae can be reared as an ideal protein medium on very minimal space. Having a growth cycle of only two weeks, 20-24 harvests in a year's time on an average is achievable. Cultivation can be done in standardized Palox boxes bearing a footprint of 1 m^2 each which are stackable up to 2 meters high and yield about 11.6 kg of larvae per harvest. Only 15% of the larvae are needed for breeding in fly cages to guarantee egg supply. The biological waste of the process is converted into biochar and thermal energy by pyrolysis. Storage, processing, technical, and hygiene room sizes are scaled proportionally to the required annual production area.

Larvae are not only cultivated for human consumption but also serve as fish feed, reducing dependency on traditional feed sources. However, this application entails additional spatial requirements, which are accounted for in subsequent calculations.

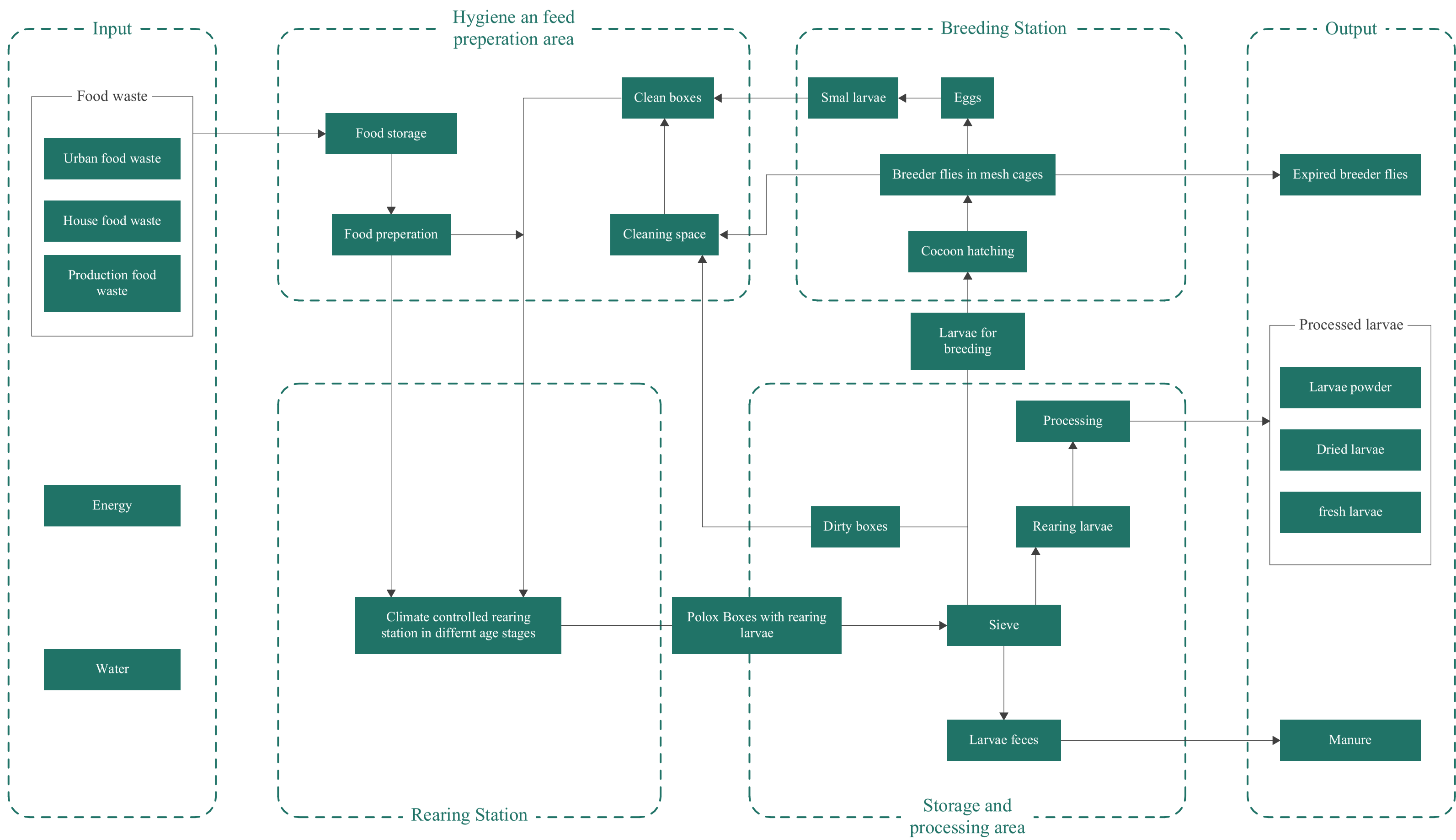


Fig. 69 Insect farming process flow

INSECT FARMING | 40% of Protein demand		Units	100 g Larvae	44 g Protein/Person/day 258 g Larvae/Person/day	16 060 g Protein/Person/year 94 170 g Larvae/Person/year	4 818 kg Protein/300P./year 28 251 kg Larvae/300P./year	Usage	Source
Nutrients	Calories	kcal	162	418	148 794	44 638 128	Human needs	Goedecke (2023)
	Carbs	g	1	2,6	942	282 510	Human needs	Goedecke (2023)
	Protein	g	17	44	16 009	4 802 670	Human needs	Goedecke (2023)
	Fat	g	10	26	9 417	2 825 100	Human needs	Goedecke (2023)
Input	Electricity	kWh	0,2	0,4	141	42 377	Energy demand	Wolfhart et al. (2023)
	Heating	kWh	0,45	1,2	424	127 130	Energy demand	Wolfhart et al. (2023)
	Water	l	0,15	0,4	141	42 377	Energy demand	Wolfhart et al. (2023)
	Agricultural Waste (40%)	g	184	474	173 179	51 953 589	Larvae Food demand	Wolfhart et al. (2023)
	House Food Waste (28%)	g	129	332	121 225	36 367 512	Larvae Food demand	Wolfhart et al. (2023)
	Production Food Waste (32%)	g	147	380	138 543	41 562 871	Larvae Food demand	Wolfhart et al. (2023)
Sapce	Rearing Station	m²/y	0,00020	0,0006	0,2	66	Production	Wolfhart et al. (2023)
	Storage Space	m²/y	0,0005	0,0012	0,4	45	Production	Wolfhart et al. (2023)
	Processing Space	m²/y	0,0004	0,0010	0,4	105	Production	Wolfhart et al. (2023)
	Breeding Station	m²/y	0,0008	0,0003	0,1	33	Production	Wolfhart et al. (2023)
	Hygiene Station	m²/y	0,0003	0,0008	0,3	30	Production	Wolfhart et al. (2023)
	Feed preperation Station	m²/y	0,0003	0,0008	0,3	31	Production	Wolfhart et al. (2023)
	TOTAL	m²/y	0,0026	0,005	1,8	309	Total Production area	By Author
Output	Larvae Breeding (15% of Larvae)	g	15	39	14 125,50	4 237 650	Breeding	Wolfhart et al. (2023)
	Expired breeder Flies	g	2,0	5,3	1 920,00	576 000	Fish Food	Wolfhart et al. (2023)
	Fresh Larvae	g	100	258	94 170,00	28 251 000	Human Food	Wolfhart et al. (2023)
	(or) Dried Larvae (25% fresh)	g	25	65	23 542,50	7 062 750	Human Food	Wolfhart et al. (2023)
	(or) Larvae Powder (25% fresh)	g	25	65	23 542,50	7 062 750	Human Food	Wolfhart et al. (2023)
	Manure	g	325	839	306 052,50	91 815 750	Vertical Farming	Wolfhart et al. (2023)
Fish Food (+ 50% Production)		Units	100 g Food	152,8 g Fish/Person/day	55 772 g Fish/Person/year	55 772 kg Fish/300P./year	Usage	Source
Fish Food	Rearing Station	m²/y	0,00009	0,0001	0,05	16	Fish Food	Love et at. (2014)
	Breeding Station	m²/y	0,00004	0,0001	0,03	8	Fish Food	Love et at. (2014)
	Fresh Larvae	g	95	145	52 983	15 895 020	Fish Food	Love et at. (2014)

Tab. 21 Insect Farming dataset

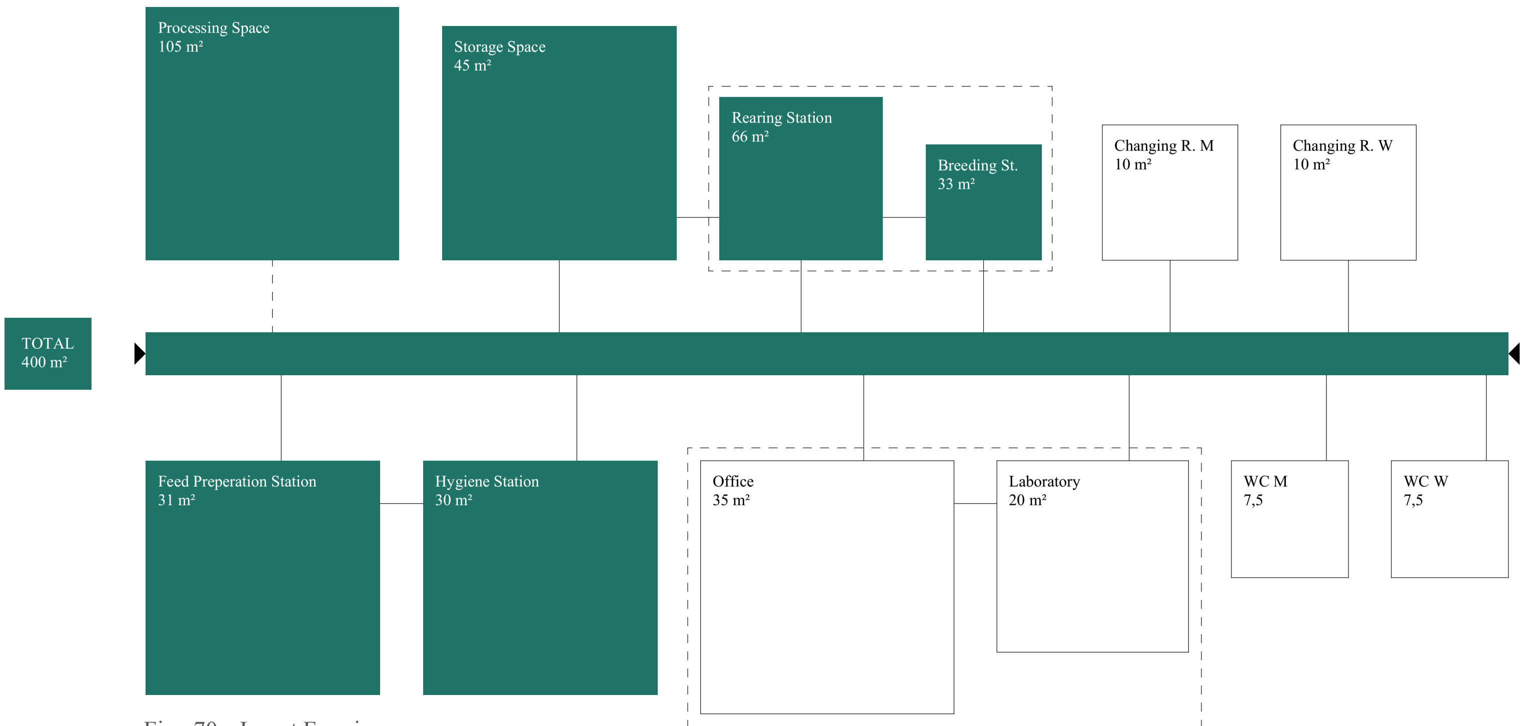


Fig. 70 Insect Farming space program

ALGAE CULTIVATION

INTRODUCTION

Microalgae biomass represents an efficient substitute for traditional crops as it makes use of the sun's energy to sequester CO2 and produce O2. This process is essential to nutrient cycles and provides almost 90% of Earth's oxygen. These unicellular organisms grow quickly in controlled conditions, doubling in biomass daily. Being cost-effective, land-independent, and water-efficient, they represent a very sustainable source of protein, especially in urban environments, according to Petrick (2013).

PRODUCTION

Microalgae biomass systems can be either open or closed. The closed ones, such as PBRs, are designed for optimal surface-to-volume ratio and circulation to maximize efficiency and reduce biofouling. It allows precise control over nutrients, water, and temperature for year-round operation in most diverse climates while minimizing contamination (Wurm et al., 2013, p. 13-14).

TECHNOLOGY

This makes urban algae integration, apart from photovoltaic and solar thermal systems, serve the energy, food, and resource supply demands. As Prof. Peter Head mentions, "The use of algae will play a very important role in urban sustainability into the future" (Wurm et al., 2013, p. 16).

Requirement	Value
Medium	Water
Operating temp.	8-32°C
Spectral angle	680 mm
Nutrients	CO2, N, P
Dimension	Full story hight
Depth	15-25 mm
Width	Variable up to 1,5 m
Distance AirLift	50-100 mm
AirLift Channel	150 mm
Supply System	Circulation system

Tab. 22 Requirements - Photobioreactor

Requirement	Value
Building Physics	• Rain protection
Structural Planning	• Load transfer • Serviceability • Durability • Residual load-bearing capacity
Energy Design	• Optimization of biomass yield/CO2 • Optimization of heat input
Building Services	• Heat storage • External CO2 source required
Design	• Translucency/ partial transparency • Profiling of the frames

Tab. 23 Requirements - Residential Building

PHOTOBIOREACTOR

Plate-type PBR of SSC GmbH - AirLift with high-flow turbulence, biofilm formation is prevented. Floating scrubbers ensure self-cleaning. System allows for light optimization and heat recovery at 35°C. Biomass yields of up to 100 g/m²/day can be achieved with 70% CO2 saturation from flue gas. The transparent walls, airtight spacers, valves, and airlift channels ensure circulation without overflow. The rotating support structure enables optimal solar orientation, with integrated thermal insulation and hidden supply lines (Wurm et al., 2013, p. 24-27).

BUILDING TECHNOLOGY

PBRs facing south produce biomass and heat from solar energy. Nutrients and CO2 originate from a central system, while the flue gas reduces carbon emission. Flotation harvests surplus algae, which can be treated to produce biogas. The heat exchangers in the façade transfer the energy to domestic heating, geothermal storage, and solar-powered circulating pumps according to Wurm et al. (2013, p. 42-43).

LARGE-SCALE APPLICATIONS

Serially connected PBRs provide equal distribution of the medium flow. Tests by SSC GmbH recommend a flow rate of 1 l/min per reactor. The harvested algae are enriched to 50-80 g TS/kg and can be stored for up to 10 days before methanation or hydrogenation. Waste heat is used for space heating and water preheating, and geothermal storage increases the efficiency of this process (Wurm et al., 2013, p. 55-56).

PROCESSING

Harvesting of algae involves gentle centrifugation or filtration to preserve the nutrients, followed by washing and dehydration through spray or freeze-drying. The resultant dried biomass, rich in proteins, vitamins, omega-3 fatty acids, and antioxidants, is incorporated into powders, tablets, or food products such as smoothies and snacks, conferring dietary benefits (Becker, 2007).

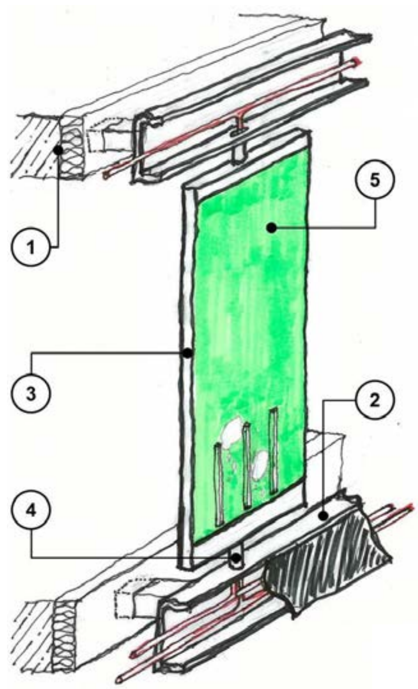


Fig. 71 Ventilated PBR façade system
1 - Primary supporting structure
2 - Secondary support system
3 - Tertiary support system
4 - Tracking system
5 - Photobioreactor unit (PBR)

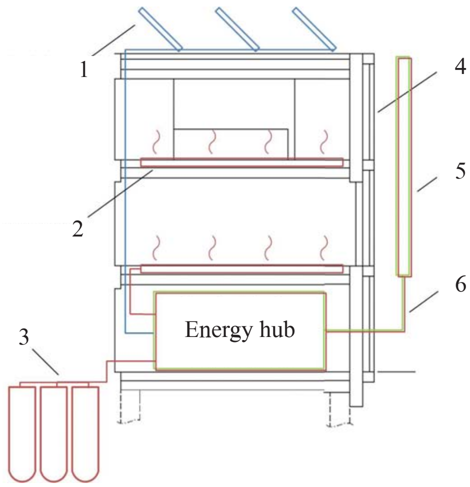


Fig. 72 Overall building System
1 - Photovoltaic
2 - Building Heat Supply
3 - Heat Storage
4 - Primary Facade
5 - Bioreactor Facade
6 - Piping System

Average Biomass Yield: • 100 g/m²/day Algae Powder After Processing: • 10% of the Biomass = 10 g/m²/day

Tab. 24 Algae processing numbers

CONCLUSION

Algae in bioreactor façades are considered a sustainable food option since they can grow in extremely small spaces and with very limited resources, like water and nutrients. They give a high yield of nutrient-rich biomass, rich in proteins, vitamins, and omega-3 fatty acids. Furthermore, they can be cultivated within an urban context, reducing transport distances and further improving their carbon footprint.

Algae farming on otherwise unused façades is one very good solution for space-efficient algae powder production. The energy hub takes the largest part of space that the system needs. This powder can be taken in small quantities as a supplement in shakes or other preparations. The system must be integrated very closely with the building's infrastructure so that heat generated within the bioreactors could be converted to warm water. This undergoes conversion into heat and charcoal through the pyrolysis system in the transformed biomass waste products of filtration as earlier explained.

It is important to note the supply of CO_2 to the water medium. Partially, it occurs through the pyrolysis and the water heating process, though mainly through the combustion of compressed manure in a Briquette furnace, discussed in detail further on. Nutrients required for the algae are supplied by filtered yellow water, which is derived from human urine.

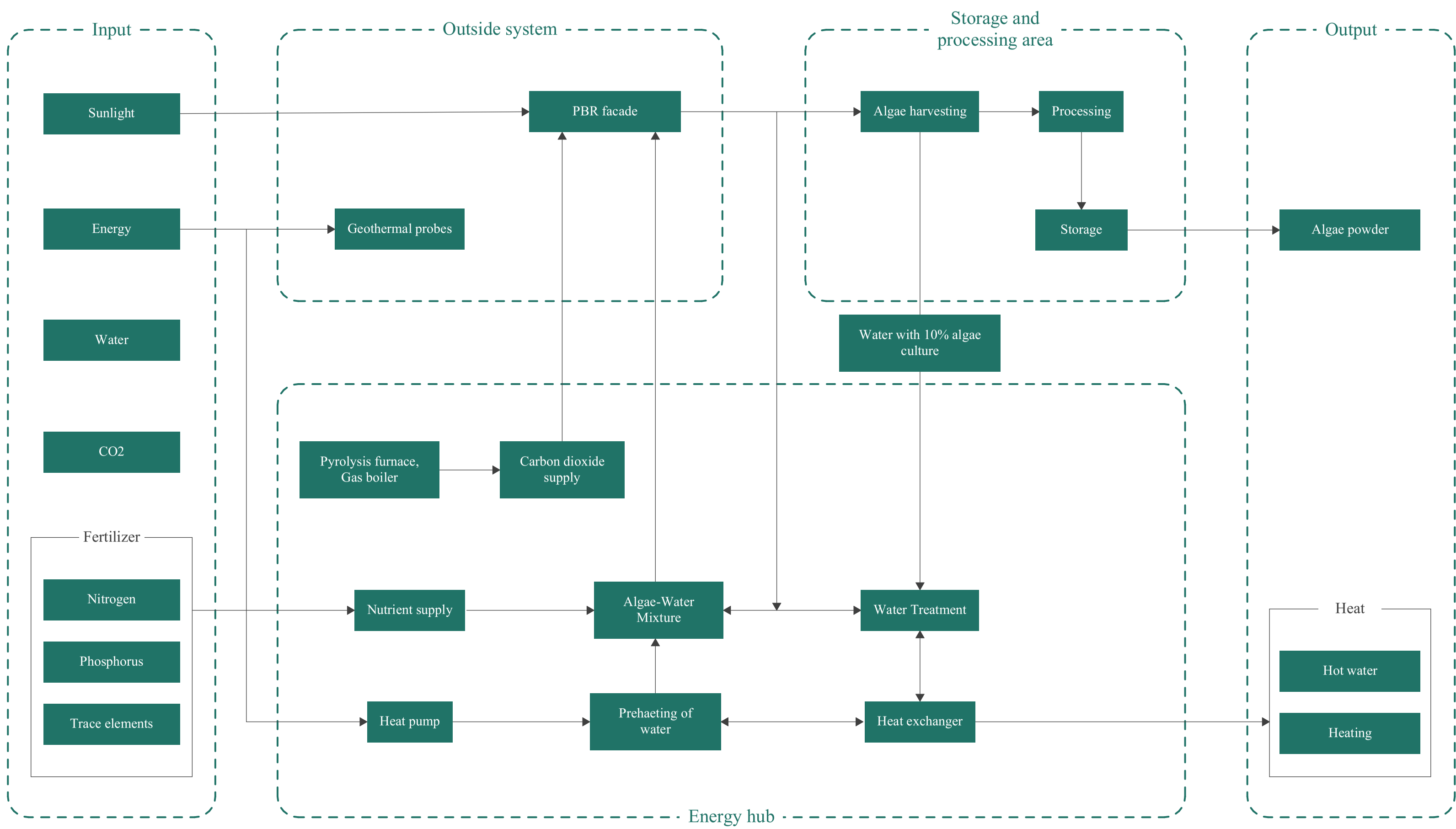


Fig. 73 Algae cultivation process flow

ALGAE CULTIVATION | 15% of Protein demand		Units	100 g Algae Powder	16,5 g Protein/Person/day 28,12 g Algae/Person/day	6 022,5 g Protein/Person/year 10 263,8 g Algae/Person/year	1 807 kg Protein/300P./year 3 079 kg Algae/300P./year	Usage	Source
Nutrients	Calories	kcal	326	92	33 419	10 025 680	Human needs	RohKöstlich (2024)
	Carbs	g	18	5,2	1 896	568 717	Human needs	RohKöstlich (2024)
	Protein	g	59	16,5	6 025	1 807 455	Human needs	RohKöstlich (2024)
	Fat	g	1	0,2	82	24 633	Human needs	RohKöstlich (2024)
Input	Electricity	kWh	6	1,7	616	184 748	Energy demand	Wurm et at. (2013)
	Heating (Winter)	kWh	7	2	718	215 540	Energy demand	Wurm et at. (2013)
	Water (in case of loss)	l	0,2	0,06	21	6 158	Energy demand	Wurm et at. (2013)
	CO2	g	410,00	115	42 082	12 624 474	Nutrients	Kammler et at. (2023)
	Nitrogen	g	50,00	14	5 132	1 539 570	Nutrients	Kammler et at. (2023)
	Phosphorus	g	1,5	0,4	154	46 187	Nutrients	Kammler et at. (2023)
	Sunlight	-	-	-	-	-	Nutrients	-
Space	Facade area	m²/y	10	2,8	2,8	281	Production	Wurm et at. (2013)
	Energy hub	m²/y	0,01	0,002	0,6	63	Production	Wurm et at. (2013)
	Processing area	m²/y	0,003	0,001	0,3	30	Production	Wurm et at. (2013)
	Storage area	m²/y	0,001	0,000	0,1	15	Production	Wurm et at. (2013)
	TOTAL	m²/y	0,010	0,003	1,1	108	Total Production area	By Author
Output	Algae Biomass	g	1000	281	102 638	30 791 400	Raw Product	Wurm et at. (2013)
	Algae Powder	g	100	28	10 264	3 079 140	Human Food	Wurm et at. (2013)
	Heat	kWh	1,4	0,4	140	42 147	Human Consumption	Wurm et at. (2013)

Tab. 25 Algae Farming dataset

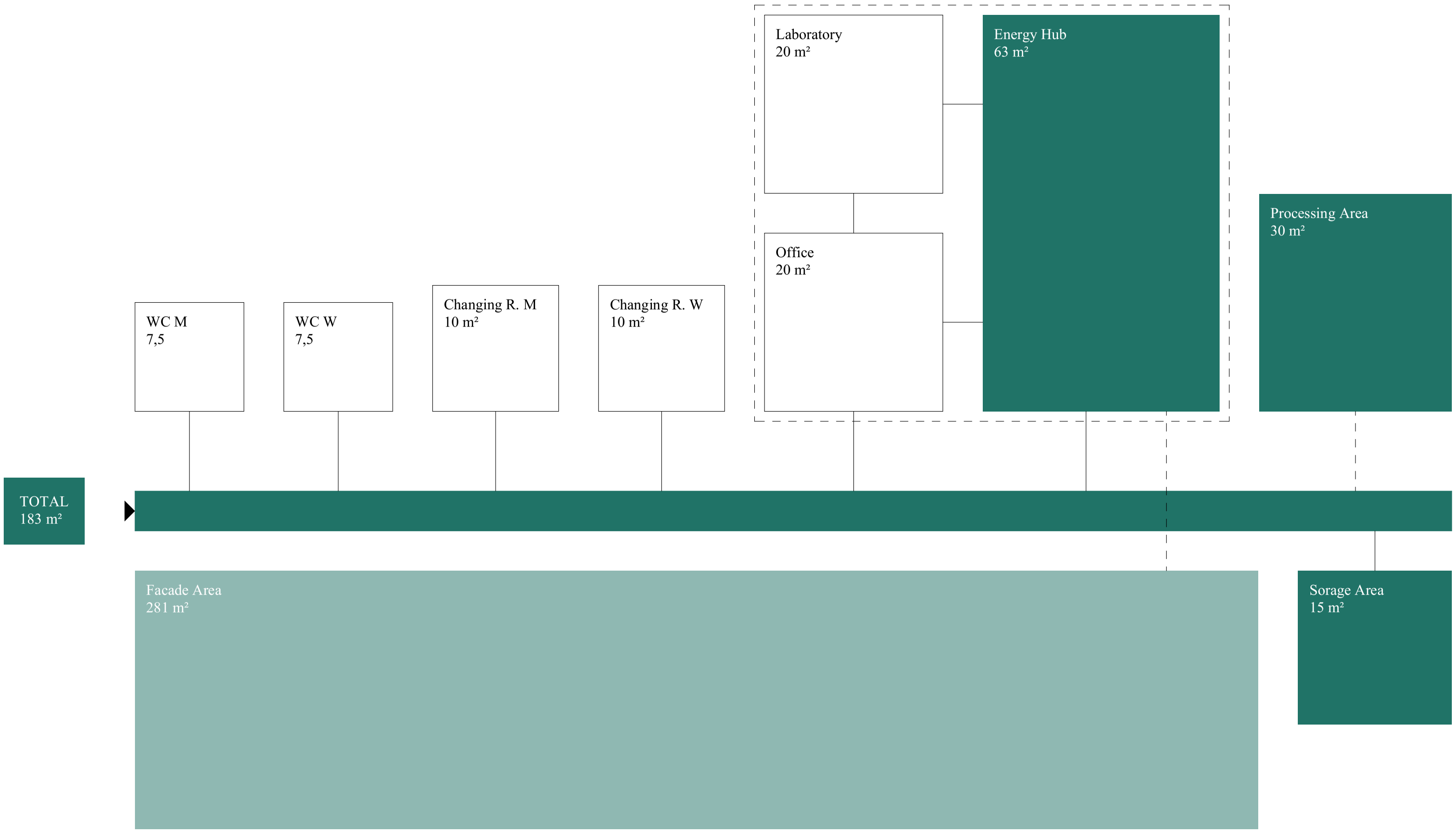


Fig. 74 Algae Farming space program

FISH FARMING

INTRODUCTION

With increased efficiency, urban methods of production are minimizing environmental impacts that result from food production, transportation, and shortages of labor. Aquaponics combines RAS technology with soilless farming, enabling the production of local organic food. This system satisfies both the needs of the environment and consumers. Hence, it attracts the attention of researchers, entrepreneurs, and producers (Vermeulen et al., 2013, p. 71–77). Aquaponics is a closed-loop ecosystem that integrates aquaculture, hydroponics, and beneficial bacteria and hence turns the disadvantages of other conventional methods into its advantages by minimizing nutrient input and waste disposal. It advances sustainable food production by using huge volumes of reused water and recycled nutrients (Endut et al., 2010, p. 1511-1517).

FUNCTION

Aquaponics make use of a recirculation aquaculture system (RAS) that integrates fish tanks, solid waste filters, biofilters, and hydroponic plant beds. Water flows from the fish tank to the filter, then through plant beds and back into the fish tank. The RAS maintains optimum conditions for high-density fish rearing (Losordo et al., 1999; Medina, 2014). Nitrates are removed by water exchange, plant uptake, or denitrification by anoxic bacteria, with removal rates depending on plant and reactor configurations. Key nutrients are primarily supplied by waste feed and feces from the fish (Goddeck, 2016).

SYSTEM TYPES

Aquaponic systems differ: Integrated systems allow for continuous water flow from fish to plants but offer limited control over water parameters. Deep Water Culture involves the use of floating platforms in oxygen-rich water for large-scale farming. Media-based systems utilize substrates such as gravel, which filter waste and make the system easy to maintain. The Decoupled Aquaponic System, DAPS, separates the fish and plant water circuits, thus enabling independent control of each system's water quality (Goddeck, 2016).

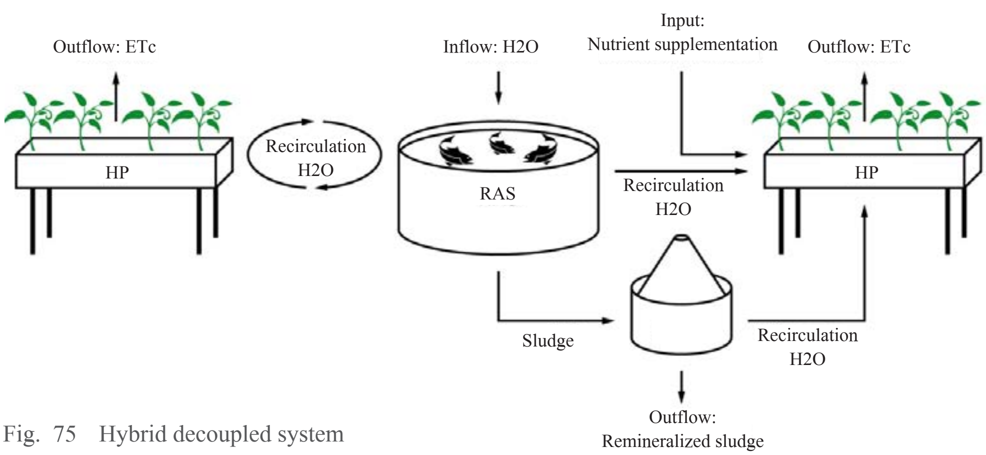


Fig. 75 Hybrid decoupled system

DAPS optimizes water quality both for fish and plants, hence improving productivity and health. It also simplifies the management of nutrients since plant fertilization does not affect fish. The decoupling minimizes the risk of failure since each subsystem runs independently; this permits scaling and crop diversification. The hybrid system involves mixing one-loop and decoupled-loop designs; in fish-oriented systems, it serves to maintain high nitrate levels without denitrification (Goddeck et al., 2016).

AQUACULTURE

Tilapia is commonly used in aquaponics due to its omnivorous diet, rapid growth, and tolerance to various water parameters, such as 15-30°C and ammonia concentrations from 0.2 to 3.0 mg/L (Rakocy et al., 2004). Nutrient inputs should be steady to maintain system balance. Using fish at different growth stages ensures continuous nutrient supply, preventing imbalances and improving efficiency (Goddeck, 2016).

An example is where an integrated system of tilapia and tomato production can give 1kg of tilapia and 5kg of tomatoes from only 1kg of fish feed-a sustainable cycle of production (Rakocy et al., 2004). A parameter variation experiment found that a stocking density of 50 kg•m-3 requires about 100 fish per tank to maintain optimal conditions. Regular fish monitoring ensures balanced nutrient cycling, proper oxygen levels, and growth, improving system sustainability and productivity (Goddeck, 2016).

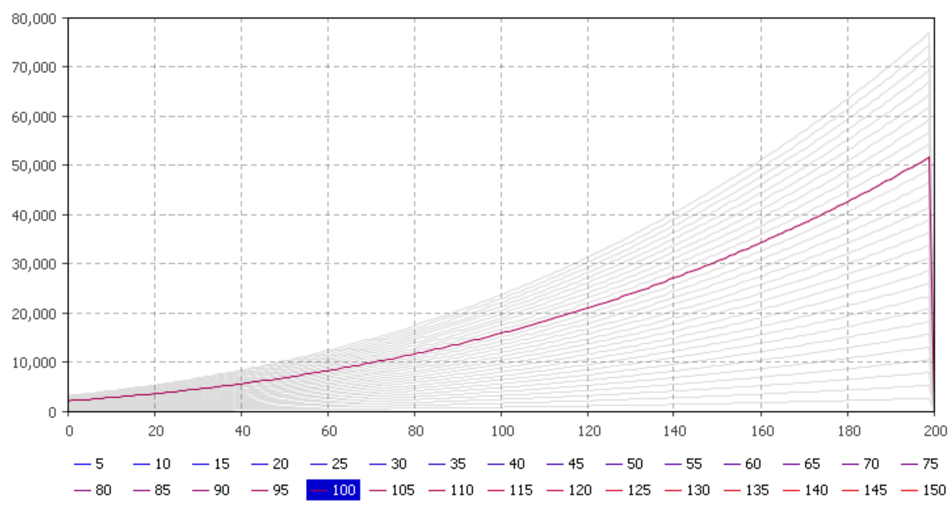


Fig. 76 Fish outcome

Name	%	Feed/kg fish	Space[kg/m³] | Fish number	Reference
Nile tilapia	55	1 kg	50 | 100 fish	Love et at., 2014
Ornamental fish	48	1,5 - 2 kg	15 | 50 fish	Love et at., 2014
European catfish	25	1,2 - 1,8 kg	30 | 67 fish	Love et at., 2014

Tab. 26 Most commonly farmed fish in aquaponics

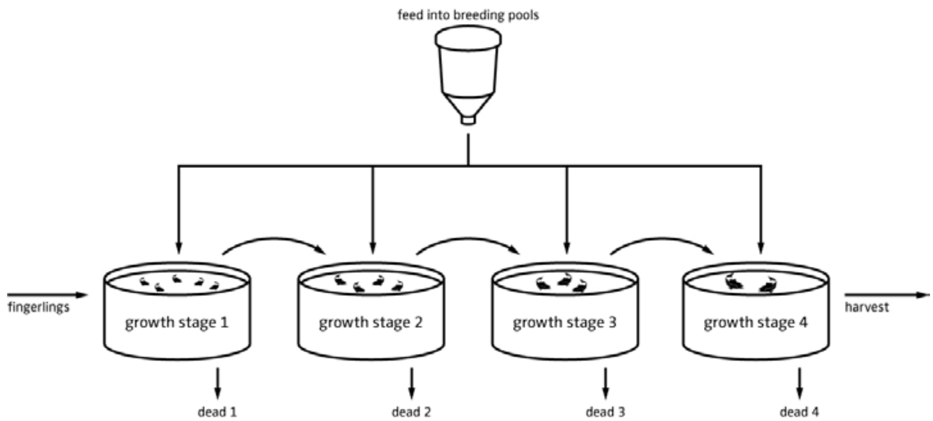


Fig. 77 Growth stages tanks

CONCLUSION

Aquaculture is an important and sustainable food source, as it tends to be less threatening to natural fish stocks than wild fishing does, with better control over resources. Besides that, fish farming demands less land and water than land-based animal husbandry, and in many cases has a lower CO2 footprint. Environmental impacts continue to be reduced with innovative techniques such as recirculating systems and insect- and fly-based fish feeds in producing a consistent supply of nutrient-rich fish.

The tilapia is used symbolically to study the system of fish farming. The aquaponics system is integrated with a vertical framing system, creating a closed loop of nutrients. Additional required nutrients are supplemented, as in algae cultivation, with filtered human wastewater. It must be noted that different growth stages must be divided into four tanks to achieve optimal fish growth. 8% of catch is used by the circular economy for fish eggs. Technical, processing, and storage rooms do have a proportional dependence on the production facility size. Sludge produced is treated by pyrolysis.

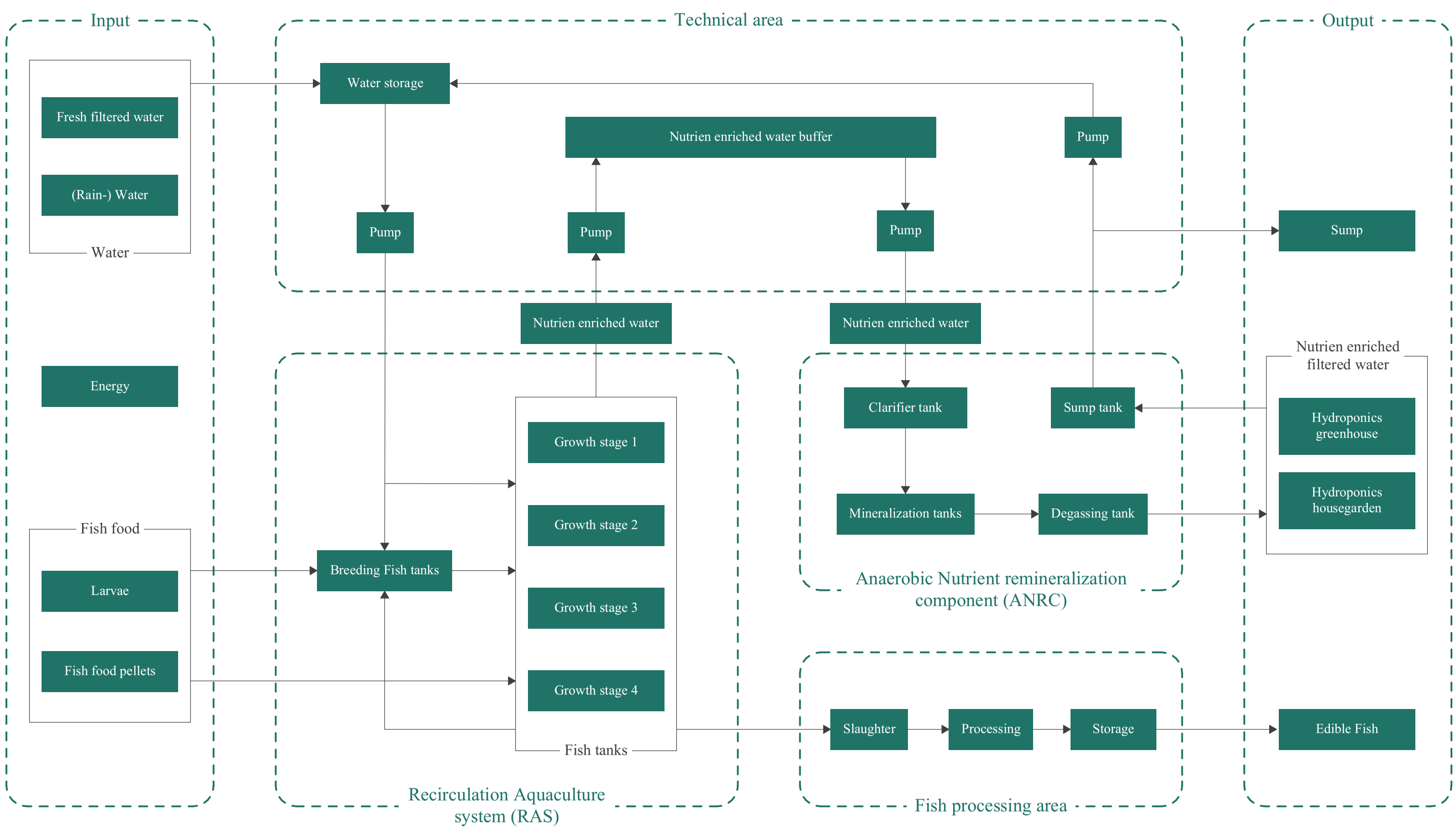


Fig. 78 Fish farming process flow

FISH FARMING | 25% of Protein demand		Units	100 g Fish (Tilapia)	27,5 g Protein/Person/day 152,8 g Fish/Person/day	10 037,5 g Protein/Person/year 55 772 g Fish/Person/year	3 011 kg Protein/300P./year 16 732 kg Fish/300P./year	Usage	Source
Nutrients	Calories	kcal	90	138	50 195	15 058 440	Human needs	Eat Smarter (2024)
	Carbs	g	0	0	0	0	Human needs	Eat Smarter (2024)
	Protein	g	18	28	10 039	3 011 688	Human needs	Eat Smarter (2024)
	Fat	g	2	3,1	1 115	334 632	Human needs	Eat Smarter (2024)
Input	Electricity	kWh	0,5	0,7	251	75 292	Energy demand	Water proved (2025)
	Heating	kWh	0,2	0,3	98	29 280	Energy demand	SustainAqua (2009)
	Water (Circular System)	l	1,7	2,5	926	277 740	Energy demand	Love et at. (2014)
	Water (in case of loss)	l	5,5	8,4	3 060	918 091	Vertical Farming	Zhengxuan et at. (2024)
	Fish food	g	100	153	55 772	16 731 600	Fish Food demand	Wolfhart et al. (2023)
Space	Fish Tank (Stage 1, 1,5m depth)	m²/y	0,0001	0,0002	0,1	11	Production	Love et at. (2014)
	Fish Tank (Stage 2, 1,5m depth)	m²/y	0,0002	0,0003	0,1	20	Production	Love et at. (2014)
	Fish Tank (Stage 3, 1,5m depth)	m²/y	0,0003	0,0005	0,2	33	Production	Love et at. (2014)
	Fish Tank (Stage 4, 1,5m depth)	m²/y	0,001	0,002	0,6	112	Production	Love et at. (2014)
	Breeding tank (8%, 1,5m depth)	m²/y	0,0001	0,0001	0,0	9	Production	Love et at. (2014)
	Processing area	m²/y	0,0008	0,001	0,4	132	Production	Goddek (2016)
	Storage room	m²/y	0,0005	0,0007	0,3	40	Production	Goddek (2016)
	Technical area	m²/y	0,0007	0,001	0,4	36	Production	Goddek (2016)
	TOTAL	m²/y	0,004	0,006	2,0	394	Total Production area	By Author
Output	Tilapia Fish Meat	g	100	153	55 772	16 731 600	Human Food	Love et at. (2014)
	Tilapia Breeding Fish	g	1,3	1,9	700	210 000	Fish Breeding	Love et at. (2014)
	Nitrogen	g	5,2	7,9	2 889	866 697	Vertical Farming	Forchino (2016)
	Phosphorus	g	2,3	3,5	1 283	384 827	Vertical Farming	Forchino (2016)
	Sump	g	9,3	14	5 200	1 560 001	Urban Farming	Forchino (2016)

Tab. 27 Fish farming dataset

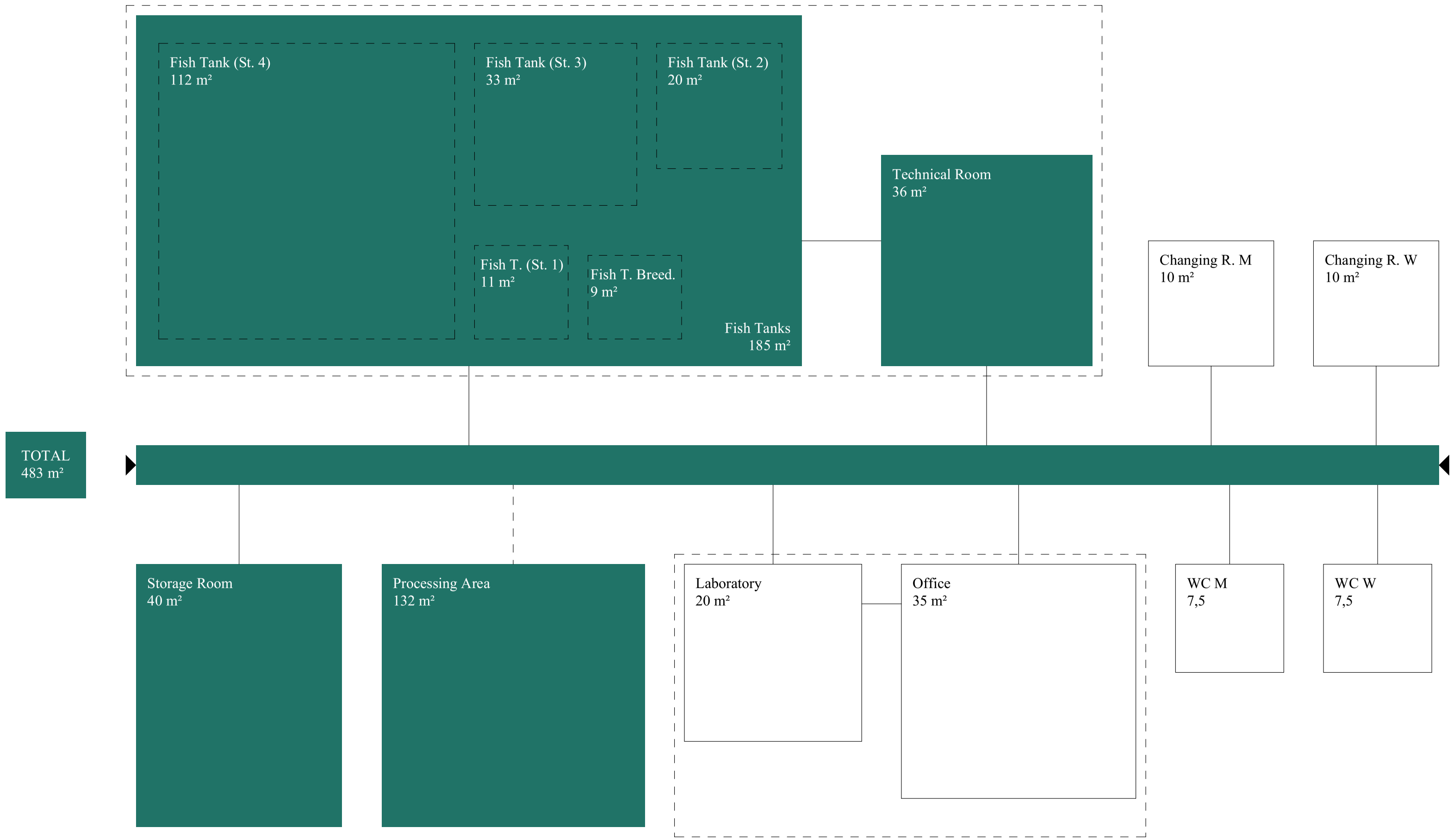


Fig. 79 Fish farming space program

VERTICAL FARMING

INTRODUCTION

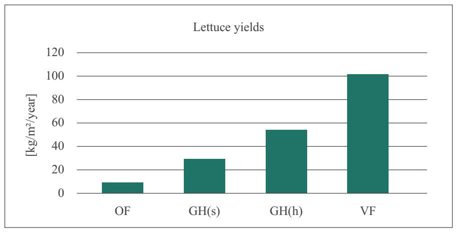
Vertical farming is a modern agricultural method that grows plants in vertically stacked structures using hydroponics or aeroponics, and artificial lighting in controlled environments. Advantages of the practice involve land use efficiency, water usage reduction, pesticide-free crop cultivation, and local food production all year round. There are still a few drawbacks as a high energy demand, and technological complexity (Blom, 2022). The given project evaluates agricultural systems and crops with the aim of optimizing crops that are rich in proteins.

FARMING SYSTEMS

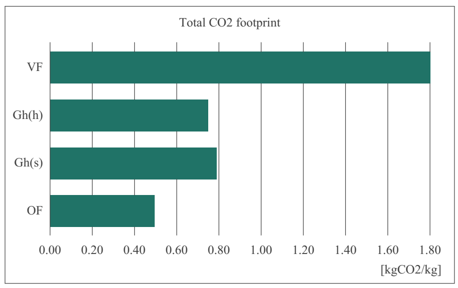
Hydroponic Greenhouse Horticulture (GHh): Lettuce is grown indoors using a nutrient film technique (NFT) and LED light providing 87 µmol/m²/s for 2,000 hours/yr, giving the yield of 53.2 kg/m²/y wheatgrass, with one layer. LEDs increase the temperature by 10°C thus providing favourable conditions for good growth of lettuce plants as stated by Blom (2022).

Vertical Farming:
It is constituted by a growth compartment with hydroponic multilayer trolleys and a processing room. Climate control is assured with air conditioning and dehumidification. Produces 2,068 kg basil and 4,550 kg of lettuce yearly in an area of 122 m² which translates into 101 kg/m²/year for lettuce (Blom, 2022).

Integrated System:
The project combines VF and GHh to overcome the limitations. VF structures are set up in greenhouses or urban areas such as rooftops, supplementing natural sunlight with LED lighting. Efficiency is ensured by a hydroponic system fed through an aquaponic nutrient supply (Blom, 2022).



Tab. 29 Lettuce yields in the different systems



Tab. 28 Total CO2 footprint in the different systems

CROPS

Spinach, kale, bok choy, and Swiss chard are the best for hydroponic vertical farming, with high yields and fast growth. Microgreens such as sunflower, pea, radish, and lentil sprouts thrive with rapid growth, minimal resources, and high protein content (Gustario, 2024).

Wheatgrass is high in protein and thrives in vertical farming, maturing in 7–10 days with space requirements being minimal. It is nutrient-rich, providing 8 g of protein per 100 g, along with vitamins and antioxidants. This will make it not only sustainable but highly efficient for both urban farming and health-conscious consumers (Zhengxuan et al., 2024).

HYDROPONICS

Nutrient Film Technique (NFT): A thin continuous nutrient film, 1-2 cm in thickness, provides less substrate and highly mechanized cultivation with optimum plant density. The disadvantages include being susceptible to pump failure, temperature stress, and unsuitable for long-cycle crops (>4-5 months). Multi layered NFT systems overcome the inefficiency for densely rooting crops like tomatoes due to root clogging (Doddek et al., 2019).

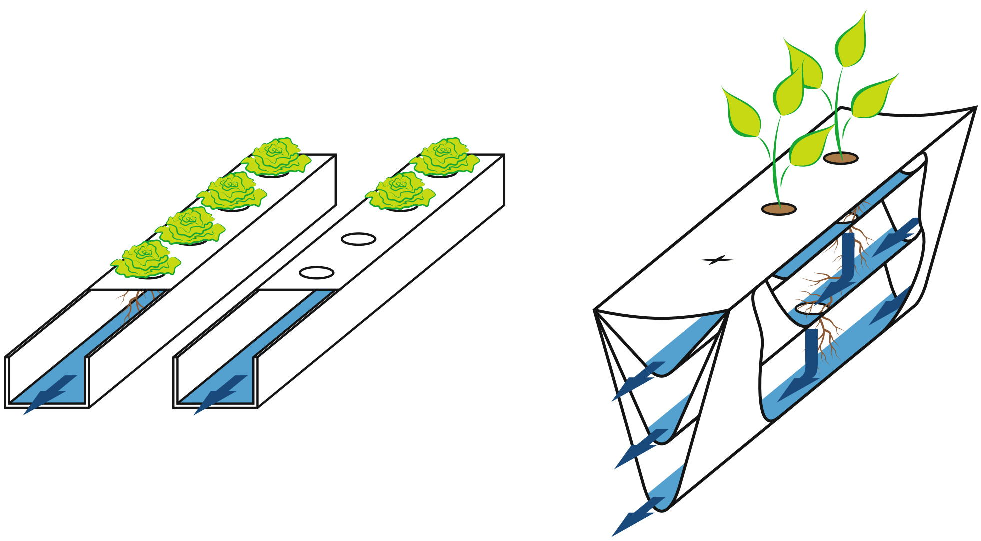


Fig. 80 NFT system (left) and a multilayer NFT (right)

Crop	Yields [kg/m²/y]	Electricity [kWh/kg]
Tomato	74	3,3
Basil	50	20,8
Lettuce	68,9	14,8

Tab. 30 Vegetables/Microgreens Output

Category	Mass	Amount
Seeds	Wheat seed	0,31 kg
Fertilizer	Nitrogen	0,44 g
	Phosphor	0,145 g
Electricity	Lighting	6,33 kWh
	HVAC	1,69 kWh
	Other	0,37 kWh
Water	Water (AP)	9,62 kg
Products	Wheatgrass	1 kg
Remaining	Roots, Stalks	0,59 kg
	Wastewater	4,5 kg
Space Requ.	VF area	73,3 kg/m²/y

Tab. 31 Wheatgrass Output

CONCLUSION

Greenhouse vertical farming is a very sustainable food production option, as land use is minimal by using vertical layers and the productivity is already high on a small footprint. This controlled environment vastly reduces the usage of water, pesticides, and fertilizers, having assured yields all year round. In addition, proximity to the urban centres reduces transport distances, further reducing CO2 emissions.

The vertical farming system will be applied for large-scale production of wheatgrass powder and decentralized growing of microgreens.
In the greenhouse, a hydroponic system of wheatgrass production is designed to have two layers, doubling the production rate to create a more energy-efficient growing environment. The UV lamps that replace sunlight in vertical farming are major energy consumers. To address this, they will only be used during the winter months when natural sunlight is limited. The rooftop of the building is the best place as it receives maximum sunlight.

Wheat grass production accounts for a smaller percentage of human protein consumption, regarding the other methods. It, however, plays a pivotal role in creating awareness in healthy consumption of food. It is a decentralized system that can be used directly by the resident who may use it to grow microgreens or other vegetables and fruits without reliance on another person. Such systems may be located on corridors or balconies.

This will further extend to the system within the urban context to raise awareness of healthy and sustainable nutrition outside of the building complex through the involvement of the larger community.

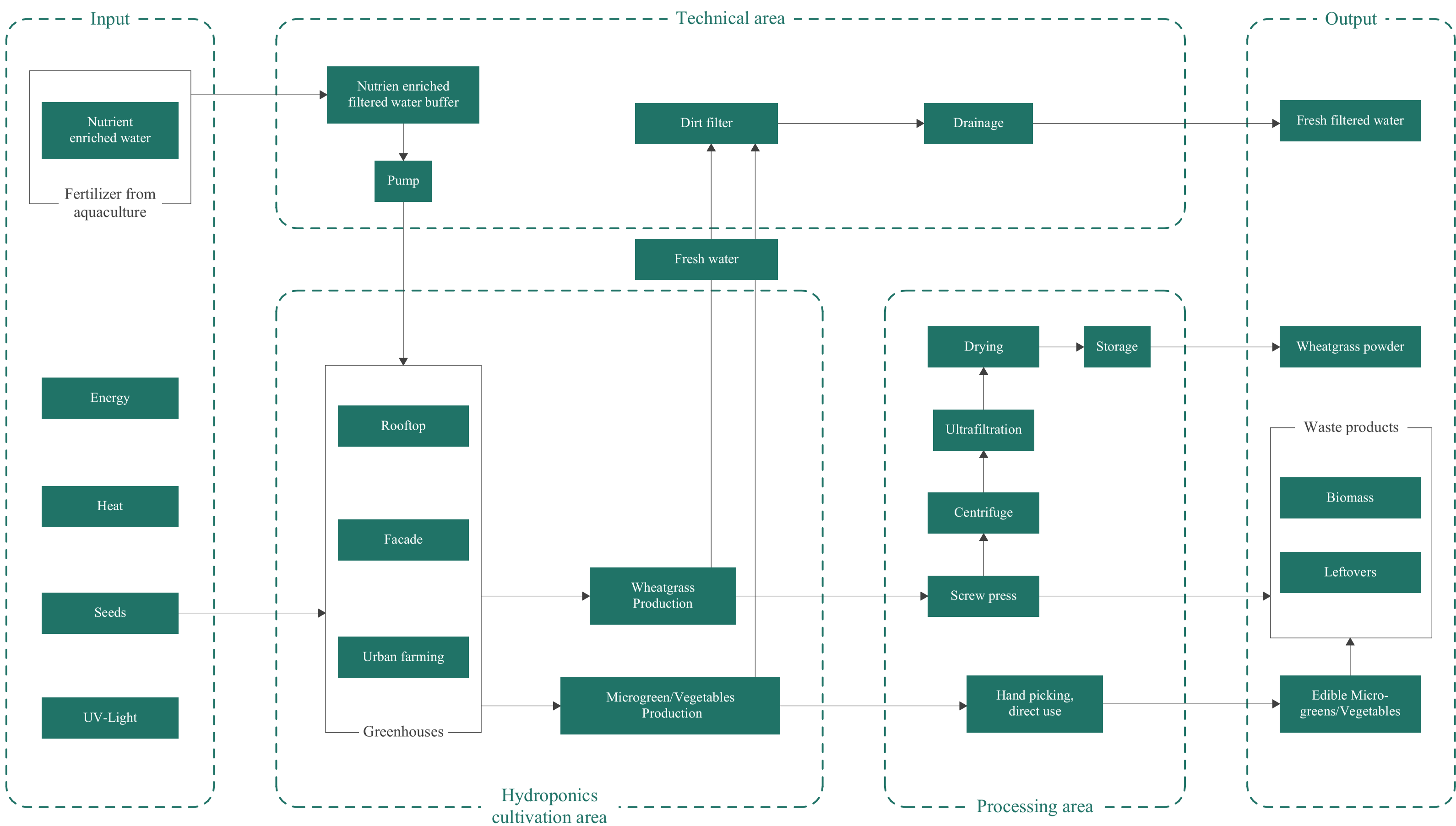


Fig. 81 Vertical Farming process flow

VF WHEATGRASS | 15% of Protein demand		Units	100 g Wheatgr. Powder	16,5 g Protein/Person/day 24,3 g Wheatgr./Person/day	6 022,5 g Protein/Person/year 8 856,6 g Wheatgr./Person/year	1 806 kg Protein/300P./year 2 657 kg Wheatgr./300P./year	Usage	Source
Nutrients	Calories	kcal	473	115	41 953	12 585 821	Human needs	stueber (2025)
	Carbs	g	16	3,9	1 419	425 736	Human needs	stueber (2025)
	Protein	g	68	17	6 031	1 809 378	Human needs	stueber (2025)
	Fat	g	4,4	1,1	390	117 077	Human needs	stueber (2025)
Input	Electricity (Processing)	kWh	0,5	0,1	45	13 464	Energy demand	Zhengxuan et at. (2024)
	Heating (Processing)	kWh	20	4,8	1 763	528 977	Energy demand	Zhengxuan et at. (2024)
	Electricity UV-light (Winter)	kWh	4,3	1,04	209	62 694	Energy demand (Winter)	Zhengxuan et at. (2024)
	Heating (Winter)	kWh	2,1	0,5	102	30 618	Energy demand (Winter)	Zhengxuan et at. (2024)
	Water (Circ. System-from AP)	l	64,8	15,8	5 750	1 725 007	VF Hydroponic System	Zhengxuan et at. (2024)
	Wheat seeds	g	2 089	507,6	185 292	55 587 551	Plants	Zhengxuan et at. (2024)
	Nitrogen	g	30	7,3	2 679	803 577	Nutrients	Zhengxuan et at. (2024)
	Phosphorus	g	10	2,5	905	271 407	Nutrients	Zhengxuan et at. (2024)
	Sunlight	-	-	-	-	-	Nutrients	-
Space	Vertical Framing (VF, 5 Storeys)	m²/y	0,02	0,00	1,6	489	Production	Zhengxuan et at. (2024)
	Technical area	m²/y	0,01	0,00	1,0	39	Production	Zhengxuan et at. (2024)
	Processing area	m²/y	0,04	0,01	3,7	55	Production	Zhengxuan et at. (2024)
	Storage area	m²/y	0,02	0,01	2,0	39	Production	Zhengxuan et at. (2024)
	TOTAL	m²/y	0,1	0,0	8	623	Total Production area	By Author
Output	Wheatgrass Biomass	g	6 739	1638	597 716	179 314 682	Raw Product	Zhengxuan et at. (2024)
	Wheatrgass Powder	g	100	24	8 870	2 660 850	Human Food	Zhengxuan et at. (2024)
	Waste - Roots	g	3 976	966	352 652	105 795 662	Larvae Food, Pyrolysis	Zhengxuan et at. (2024)
	Waste - Press cake	g	0,5	0,1	46	13 836	Larvae Food, Pyrolysis	Zhengxuan et at. (2024)
	Water (Circ. System-to AP)	l	30	7	2 690	806 916	Aquaponics	Zhengxuan et at. (2024)
	Water loss	l	35	8	3 060	918 091	Plant consumption	Zhengxuan et at. (2024)

Tab. 32 Vertical Farming Wheatgrass dataset

VF MICROGREENS | 5% of Protein demand		Units	100 g Microgreens	5,5 g Protein/Person/day 110 g Microgreens/Person/day	2 007,5 g Protein/Person/year 40 150 g Microgreens/Person/year	623 kg Protein/300P./year 12 045 kg Microgreens/300P./year	Usage	Source
Nutrients	Calories	kcal	53	58	21 280	6 383 850	Human needs	AOK (2025)
	Carbs	g	6,0	6,6	2 409	722 700	Human needs	AOK (2025)
	Protein	g	5,0	5,5	2 008	602 250	Human needs	AOK (2025)
	Fat	g	0,5	0,6	201	60 225	Human needs	AOK (2025)
Input	Electricity	kWh	-	-	-	-	-	-
	Heating	kWh	-	-	-	-	-	-
	Water (Circ. System-from AP)	l	0,5	0,6	201	60 225	VF Hydroponic System	Tavan et at. (2021)
	Microgrees Seed	g	15	17	6 023	1 806 750	Seeds	Tavan et at. (2021)
	Nitrogen	g	3,3	3,6	1 325	397 485	Nutrients	Zhengxuan et at. (2024)

	Phosphorus	g	0,4	0,4	141	42 158	Nutrients	Zhengxuan et at. (2024)
	Sunlight	-	-	-	-	-	Nutrients	-
Space	Vertical Framing (VF)	m²/y	0,003	0,0	1	396	Production	Tavan et at. (2021)
	Technical area (In Apartment)	m²/y	-	-	-	-	Production	-
	Processing area (In Apartment)	m²/y	-	-	-	-	Production	-
	Storage area (In Apartment)	m²/y	-	-	-	-	-	-
	TOTAL	m²/y	0,003	0,0	1	396	Total Production area	By Author
Output	Microgreens Biomass	g	100	110	40 150	12 045 000	Human Food	Tavan et at. (2021)
	Waste - Roots	g	40	44	16 060	4 818 000	Larvae Food, Pyrolysis	Tavan et at. (2021)
	Water (Circ. System-to AP)	l	0,5	0,5	181	54 203	Aquaponics	Tavan et at. (2021)
	Water loss	l	0,05	0,1	20	6 023	Plant consumption	Tavan et at. (2021)

Tab. 33 Vertical Farming Microgreens/Vegetables dataset

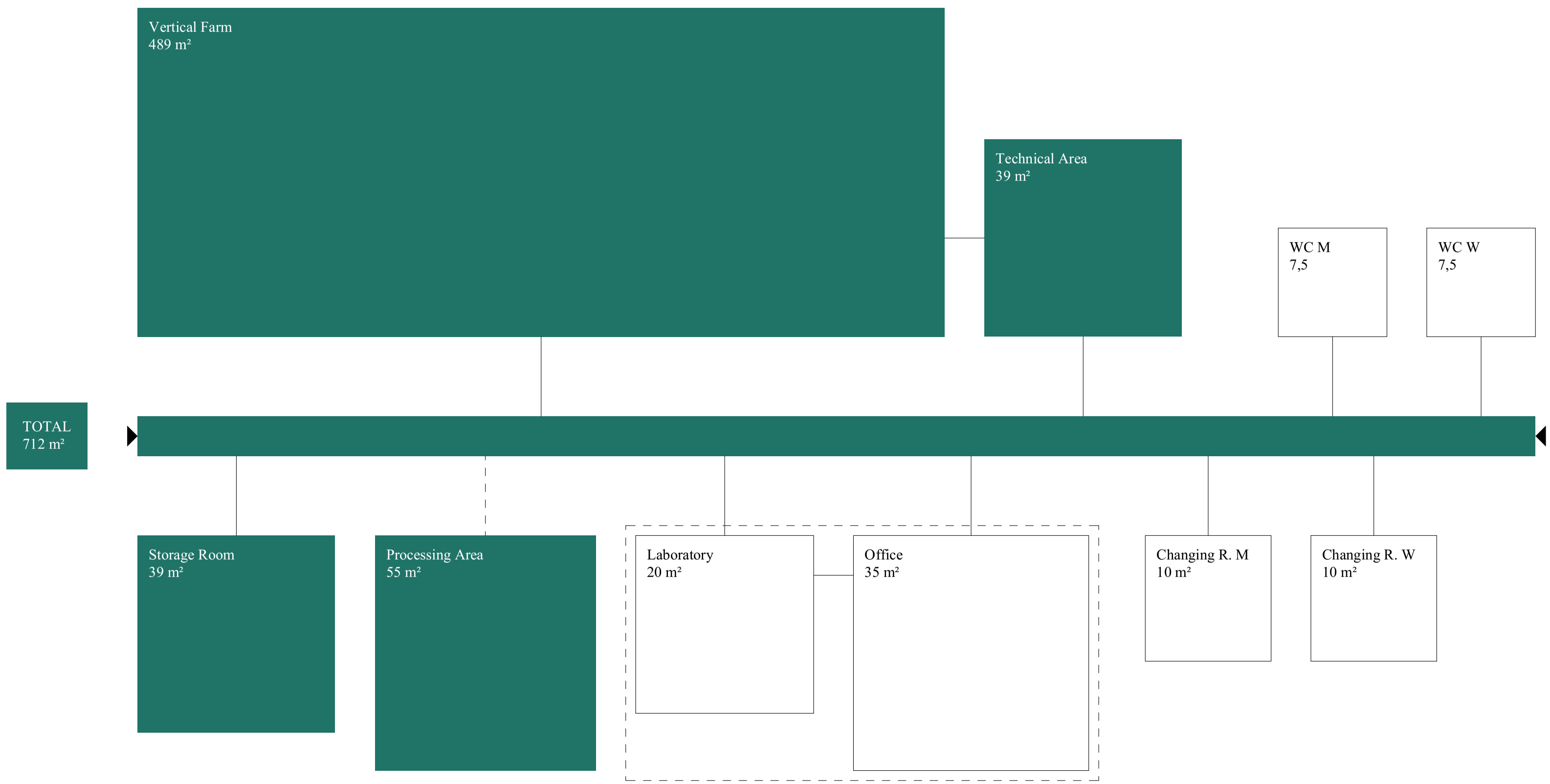


Fig. 82 Vertical Framing space program

HUMAN CONSUMPTION

INTRODUCTION

Humans are the last link in the protein production cycle, utilizing resources-food, water, energy, and heat-harvested from the essential resources. These resources are vital for the function and to keep the circular food production system running. Waste products, such as food scraps and wastewater, become important contributors to maintaining such a system.

This section describes the sorting of food waste into feeding fish and insect larvae, aside from studying a wastewater system. This is segregated into gray water, black water, and rainwater to recycle water within the system by filtering out pollutants that have to be used as fertilizers for plant growth.

WASTEWATER

Household wastewater is divided into blackwater (from toilets) and greywater (from bathrooms, kitchens, washing machines). On average, 40 liters of blackwater and 75 liters of greywater are generated per person daily, totaling 115 liters (Jönsson et al., 2005). Feces and urine separation is crucial for nutrient recovery, as they contain essential fertilizers like nitrogen, phosphate, and potassium.

RAINWATER TREATMENT

Rainwater is collected from non-toxic roofs, filtered to remove debris, stored in light-protected tanks for sedimentation, and then treated with fine filtration, activated carbon, and UV light or membrane filtration to meet potable water standards (Ravndal et al., 2015).

GREYWATER TREATMENT

The Water Wall System applies a BAMBi for core treatment, with polishing and disinfection occurring in a clean water tank. BAMBi uses ultrafiltration membranes in concert with aeration to enable nitrification-denitrification while operating in a gravity-driven configuration without sludge removal (Ravndal et al., 2015).

YELLOWWATER TREATMENT

The Vuna system treats urine to recover nitrogen, phosphorus, and potassium, which is sterilized and used as fertilizers. The urine is separately collected, filtered for removing the solids, and then treated by either struvite precipitation or ammonia stripping (Udert et al., 2019).

BROWNWATER TREATMENT

Brownwater treatment employs composting toilets or mechanical filters, where solid removal is performed in combination with drying of the residual solids to below 20%. In both, pyrolysis or combustion at low temperature of the air-dried raw material provides pellets used as biomass for heating (Seodigeng et at., 2022).

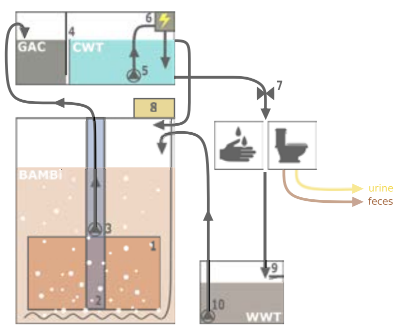
PYROLYSIS

Pyrolysis is the thermal treatment of biomass in an oxygen-free environment at high temperatures, producing biochar and heat. The process starts with the heating of biomass. This will drive off the volatile components as gases and leave a solid carbonaceous residual-the biochar. The volatilized gases may be combusted with low emissions to produce

Category	H2O [g/P./d]	N [g/P/d]	P [g/P/d]	K [g/P/d]
Urine	1 487	11	0,9	2,4
Feces	110,6	1,5	0,5	0,9
Greywater	75 000	-	-	-
Blackwater	40 000	-	-	-
Wastewater	101 000	-	-	-

Tab. 34 Wastewater sub streams

Fig. 83 Vuna urine recycling process in detail



1 Ultrafiltration membrane
2 Permeate collection
3 Permeate pump
4 Overflow
5 Electrolysis recirculation pump
6 Electrode
7 Valve
8 Aeration pump
9 Float switch
10 Wastewater pump

Fig. 84 Wastewater treatment

heat, which again can be used to sustain the pyrolysis process itself or for any other purpose such as heating the housing.
The procedure enables the effective conversion of woody residues into biochar, with the produced heat being concurrently and efficiently transformed into electrical energy (Pyropower GmbH, 2025).

A pyrolysis machine thermally decomposes organic materials like biomass, plastics, or rubber into commercially useful products in an oxygen-free atmosphere. The process begins by feeding the raw material into the reactor, which can be either rotary or stationary. Inside the reactor, the material is heated to high temperatures that break down large molecules into smaller components. This process avoids combustion and allows the production of bio-oil, biochar, and syngas. Examples of their use include bio-oil, which can be used as a fuel or as a feedstock for chemical production, biochar, which serves as a soil enhancer or energy source, and syngas can be used directly as fuel for heating (Kintek, 2025).

CONCLUSION

The human, together with the four various methods of producing proteins, is the last unit of the circular economy researched. They consume goods, thereby producing “waste products”. They are recycled in nutrients and resources like nitrogen and phosphorus to build a circular economy. The human is therefore the last link in the chain of the system.

Wastes that can not be reused are treated with the pyrolysis system, which avoids the entrance of harmful wastes into the environment while producing biochar and heat that could be used for plant cultivation or generating hot water.

Residential space should be designed using minimum footprint. Given that per person 40 m^2 can be provided, the following concept of living space can be highly flexible and user-friendly. The entire system is a combination of low-tech and high-tech solutions. The latter requires proper space in technical rooms for hosting devices. Toilets that can separate yellowwater and brownwater are installed for an easier treatment process.

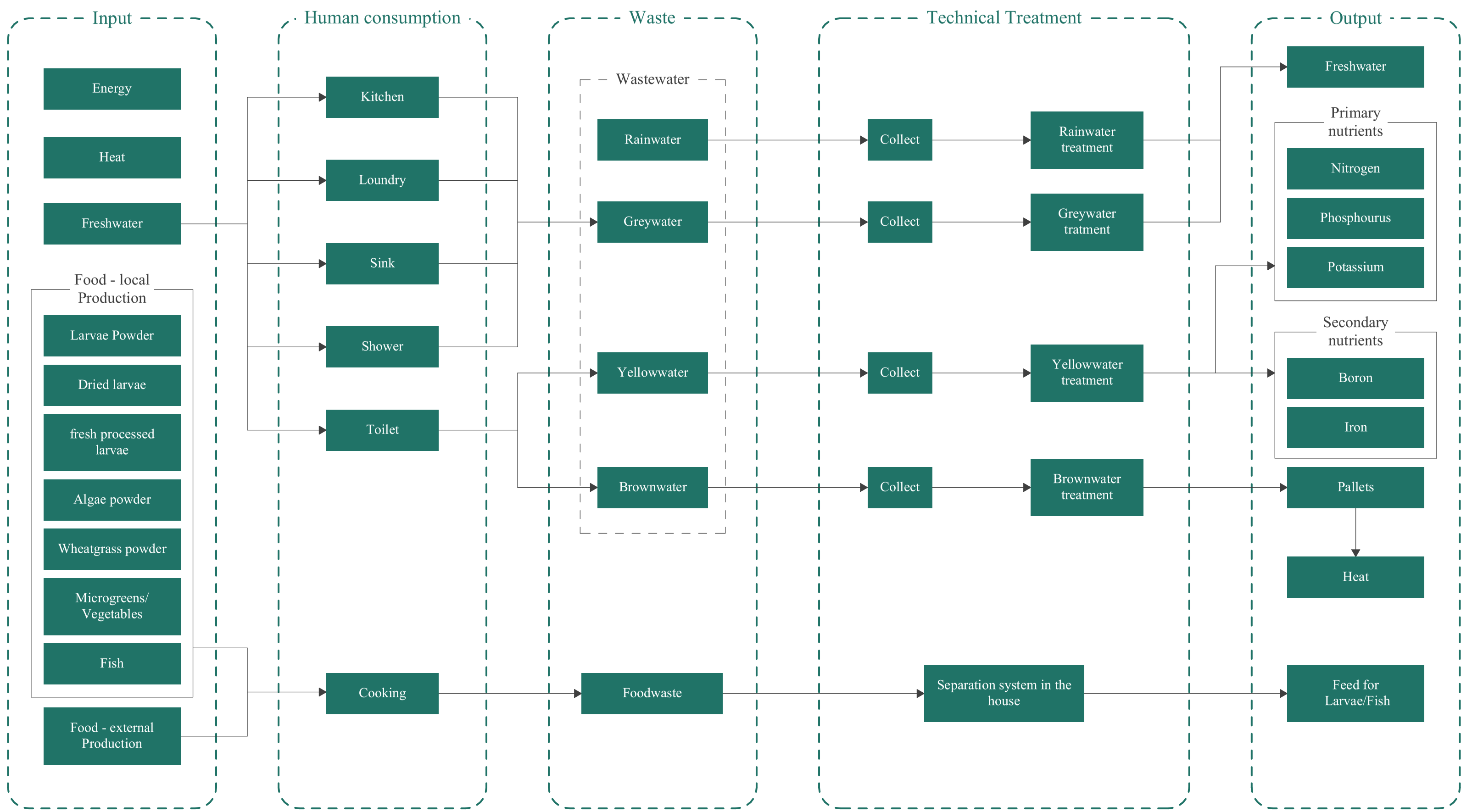


Fig. 85 Human process flow

HUMAN | 100% of Protein demand		Units	Protein/Person/day	Protein/Person/year	Protein/100P./year	Usage	Source
Nutrients	Calories	kcal	2 200	803 000	80 300 000	Human needs	Goedecke (2023)
	Carbs	g	275	100 375	10 037 500	Human needs	Goedecke (2023)
	Protein	g	110	40 150	4 015 000	Human needs	Goedecke (2023)
	Fat	g	73	26 645	2 664 500	Human needs	Goedecke (2023)
Input	Electricity	kWh	3,60	1 314	131 400	Energy demand	Gasag (2025)
	Heating	kWh	1,64	600	60 000	Energy demand	Kümpel (2023)
	Freshwater	l	71	25 915	2 591 500	Energy demand	Eawag (2021)
	Larvae Products	g	258	94 170	9 417 000	Human Food	By Author
	Algae Powder	g	28,12	10 263,80	1 026 380	Human Food	By Author
	Fish	g	152,80	55 772	5 577 200	Human Food	By Author
	VF Wheatgrass Powder	g	24,30	8 869,50	886 950	Human Food	By Author
	VF Microgrees	g	110	40 150	4 015 000	Human Food	By Author
	External Products	g	-	-	-	Human Food	By Author
Space	Living	m^2/y	40	40	4 000	Living	By Author
	Technical area	m^2/y	0,002	0,83	83	Production	Eawag (2025)
	TOTAL	m^2/y	40,002	40,835	4083,5	Total Production area	By Author
Output	Nitrogen	g	11	4 015	401 500	Verical Farming	Jönnson (2005)
	Phosphorus	g	0,9	329	32 850	Verical Farming	Jönnson (2005)
	Blackwater	l	20	7 300	730 000	Vertical farming, Heating	Eawag (2021)
	Greywater	l	51	18 433	1 843 250	Reprocessing	Jönnson (2005)
	Food Waste	g	213	77 745	7 774 500	Insect Farming, Pyrolysis	Hummel (2025)

Tab. 35 Human dataset

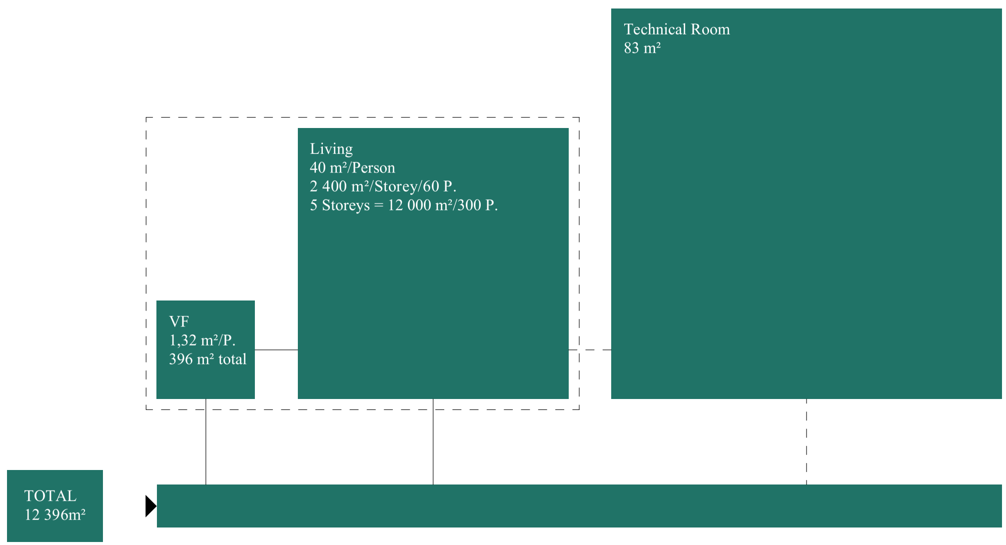


Fig. 86 Human space program

5.4 FARM CYCLE

SUMMARY

From the analysed and researched methodologies for protein production through insect farming, algae cultivation, fish farming, and wheatgrass/microgreens production, together with the human component, comes a completely self-sustaining circular economy. The starting point is the researched production flow, the resultant data on inputs, spatial requirements, and outputs, as well as the spatial plans made for each methodology. This agricultural cycle has the least amount of external inputs required for its operation. It represents the methodologies and their relationships to one another.

The research serves as the groundwork for the coming architectural project where it integrates and develops the research results to design a protein-food production cycle in an architectural setting wherein human beings are a part of the system, hence a part of this machinery. This is not a concept that stops at the production facilities within the building but extends to the inhabitants themselves. They are meant to interact with the system actively to derive greater benefits beyond mere sustenance.

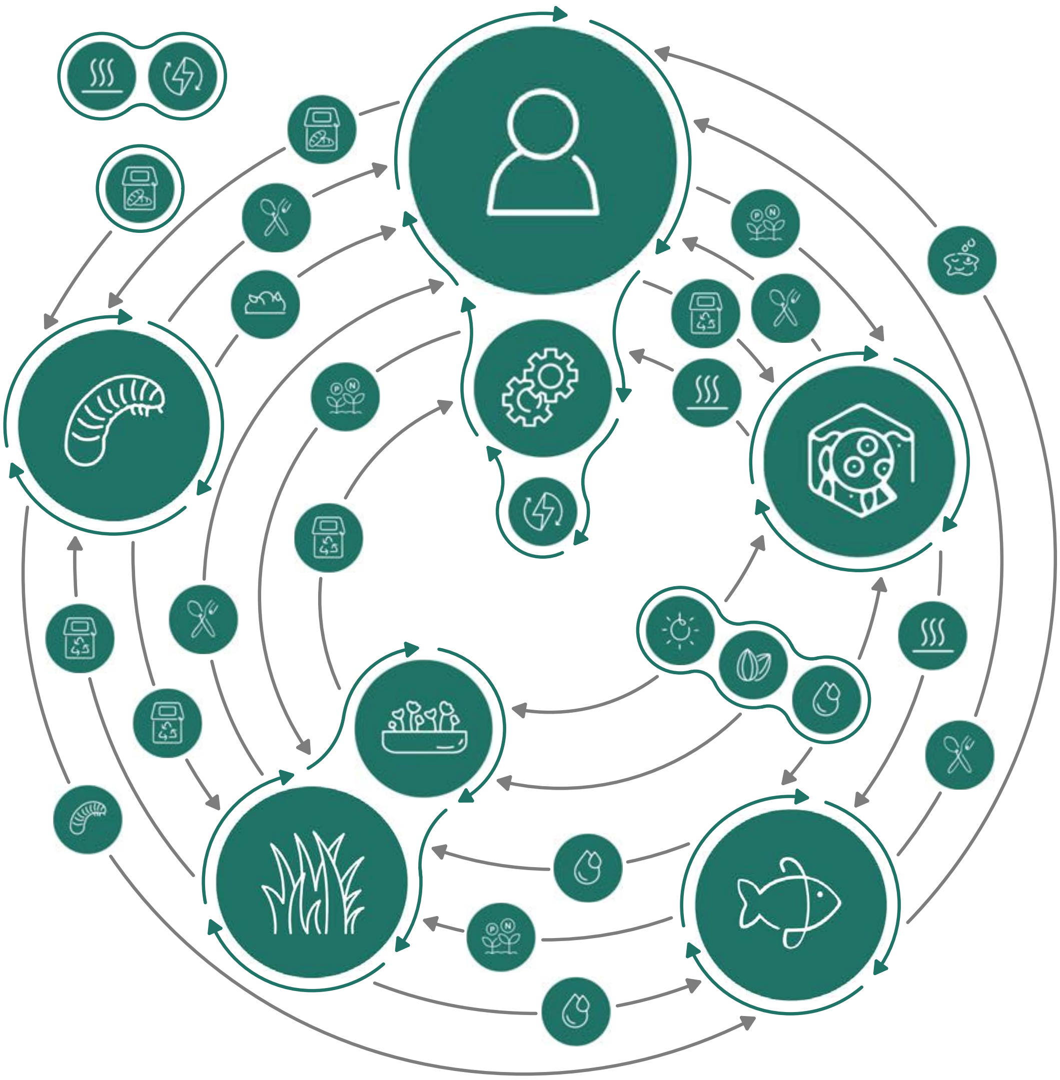
This is a vision to be reflected in newly developed residential forms, in open cultivation gardens both within and outside the building complex, free for anyone. The community should be limited to about 100 people, which can be a quantity large enough to test such a system theoretically, more residents would be possible, but inadvisable to make sure that the scope of feasibility is not outgrown by this work.

This theoretical implementation and test of the residential machine will be done in successive site analysis. Usually, every city centre around the world could be a candidate for implementation, but this work will deal exclusively with the narrower European context.

<table>
<tr><th>Product</th><th>CO2-equiv./kg</th><th>CO2 average</th><th>l Water/kg</th><th>l Water average</th></tr>
<tr><td>Beef</td><td>27,75</td><td rowspan="4">13,02</td><td>15 000</td><td rowspan="4">5 975</td></tr>
<tr><td>Pork</td><td>5,34</td><td>5 000</td></tr>
<tr><td>Poultry</td><td>4</td><td>3 900</td></tr>
<tr><td>Fisheries</td><td>15</td><td>-</td></tr>
<tr><td>Aquaculture</td><td>3,4</td><td rowspan="2">1,80</td><td>2 666</td><td rowspan="2">1 909</td></tr>
<tr><td>Insect Larvae</td><td>1,5</td><td>1 500</td></tr>
<tr><td>Algae Powder</td><td>1,8</td><td rowspan="2">7,2 times
less emissions</td><td>20</td><td rowspan="2">3,1 times
less emissions</td></tr>
<tr><td>Wheatgrass Pow.</td><td>0,5</td><td>3 450</td></tr>
</table>

Tab. 36 CO2 emission and water consumption comparison

Fig. 87 Farm Cycle scheme



5.5 LIST OF REFERENCES

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5.6 LIST OF FIGURES

5.7 LIST OF TABLES

5.8 LIST OF AIDS

AI-TOOL	USE	AFFECTED PARTS
Chat GPT	Checking for grammatical correctness of text	All chapters
Deepl	Translation of text passages	All chapters

“You are, what you eat” - Ludwig Feuerbach