The Elegance of VERTICAL FARMING

ARCHITECTURAL DESIGN OF BUILDING INTEGRATED PFAL

S.J.VERDEGAAL
MSc Architecture, Urbanism & Building Sciences
Delft University of Technology

Graduation Project Presentation
29-10-2021
Explore Lab 2020/2021

FASCINATION

Architecture & aesthetics

Entrepreneurship & innovation

Family background in floriculture

PHENOMENA & CHALLENGES

URBAN AGRICULTURE

Urban garden

Rooftop garden

Greenhouse

Barrel planters

Mushroom farm

Freight farm

Plant Factory

Automated Plant Factory

PLANT FACTORY WITH ARTIFICIAL LIGHTING (PFAL)

Automated & Controlled Environment

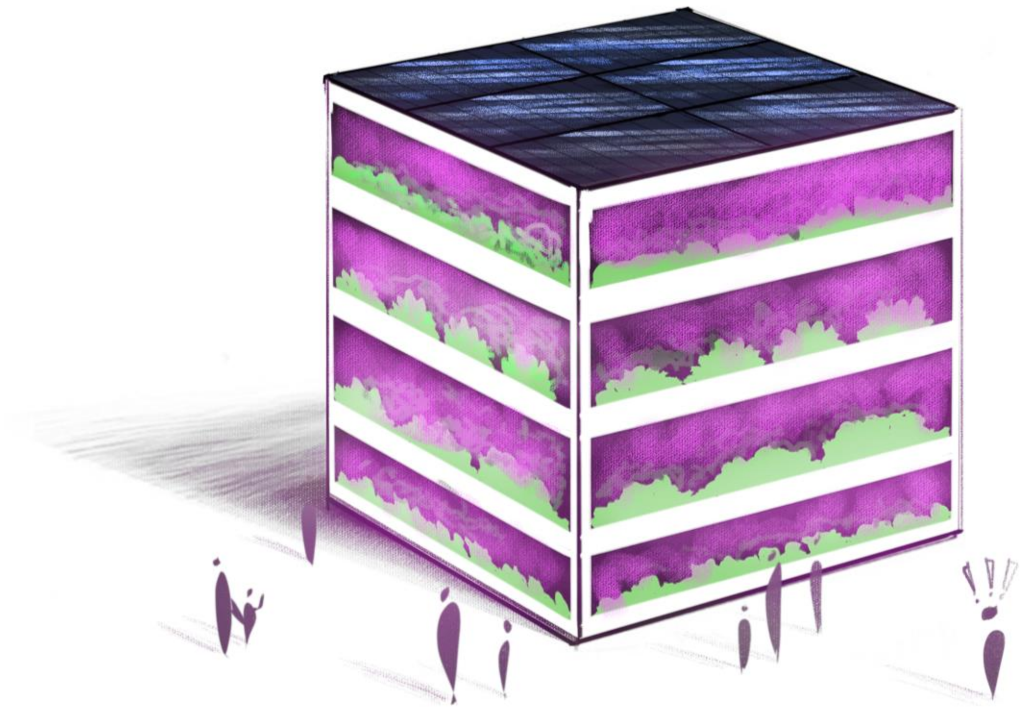
(water, nutrients, temperature, CO_2…)

PFAL. Aerofarms (USA)

Automated PFAL. Madar Farms (UAE), developed by Certhon.

PROBLEM STATEMENT

When approached from the perspective of production quality and efficiency, Plant Factories are at risk of being architecturally translated as a closed box.



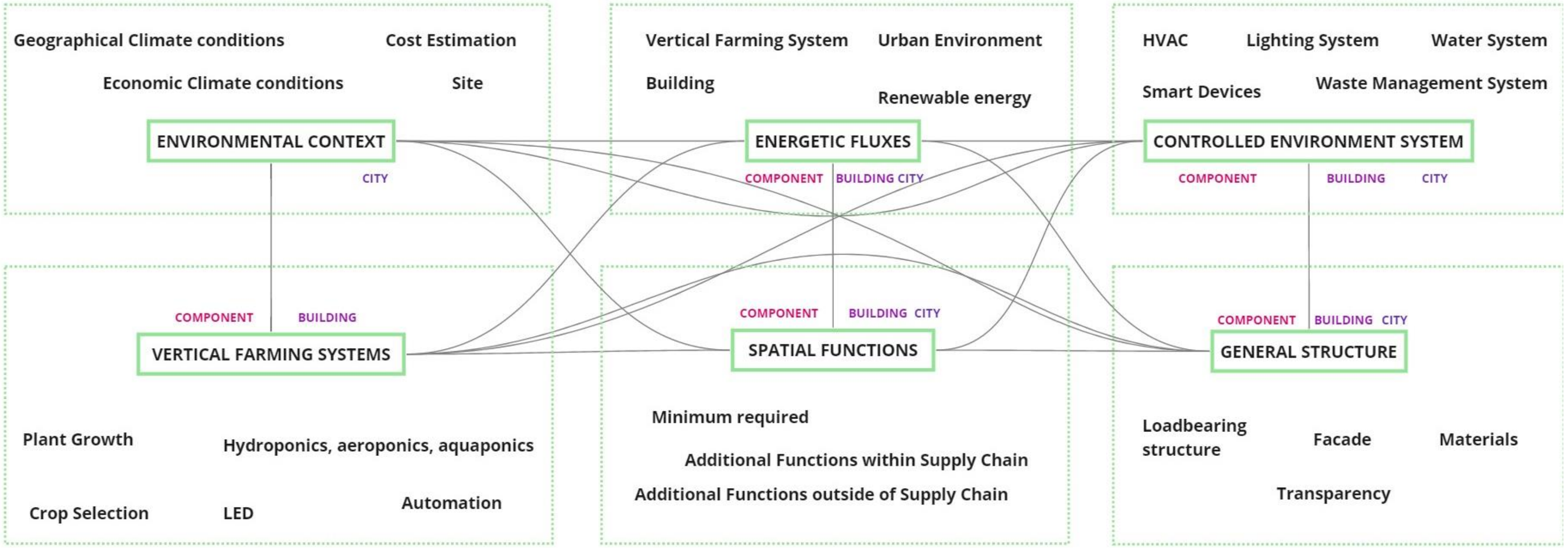
Instead, **Farming of the future** should be an **open box** to **experience.**
Not only the product, but also **the production process must interact with the consumer!**

Architectural Design of Building Integrated PFAL

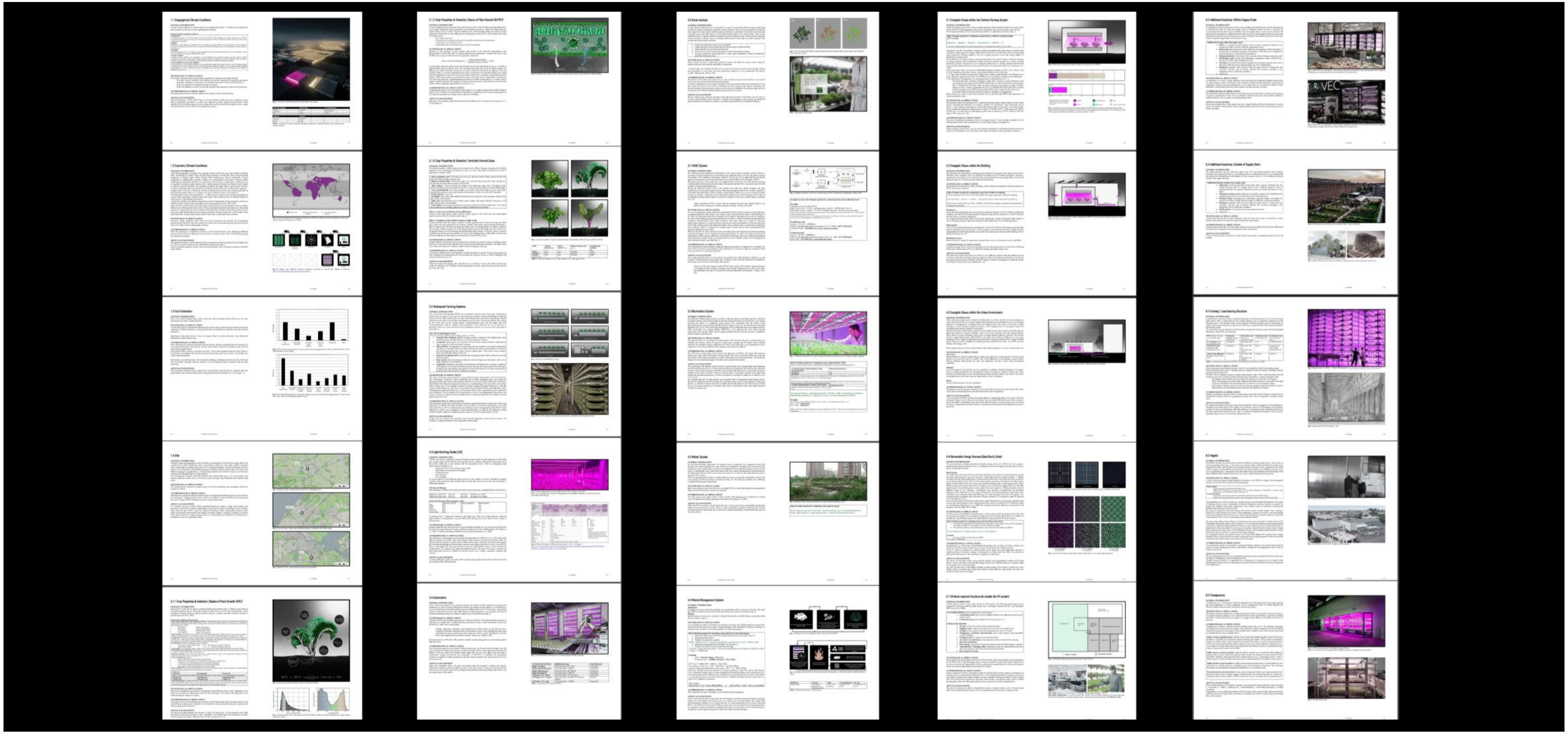
The **architectural integration** of **Plant Factories with Artificial Lighting** (PFAL)
into the **urban environment**,
optimising **social** and **aesthetic potentials** without **compromising on production quality and efficiency**.

RESEARCH QUESTION

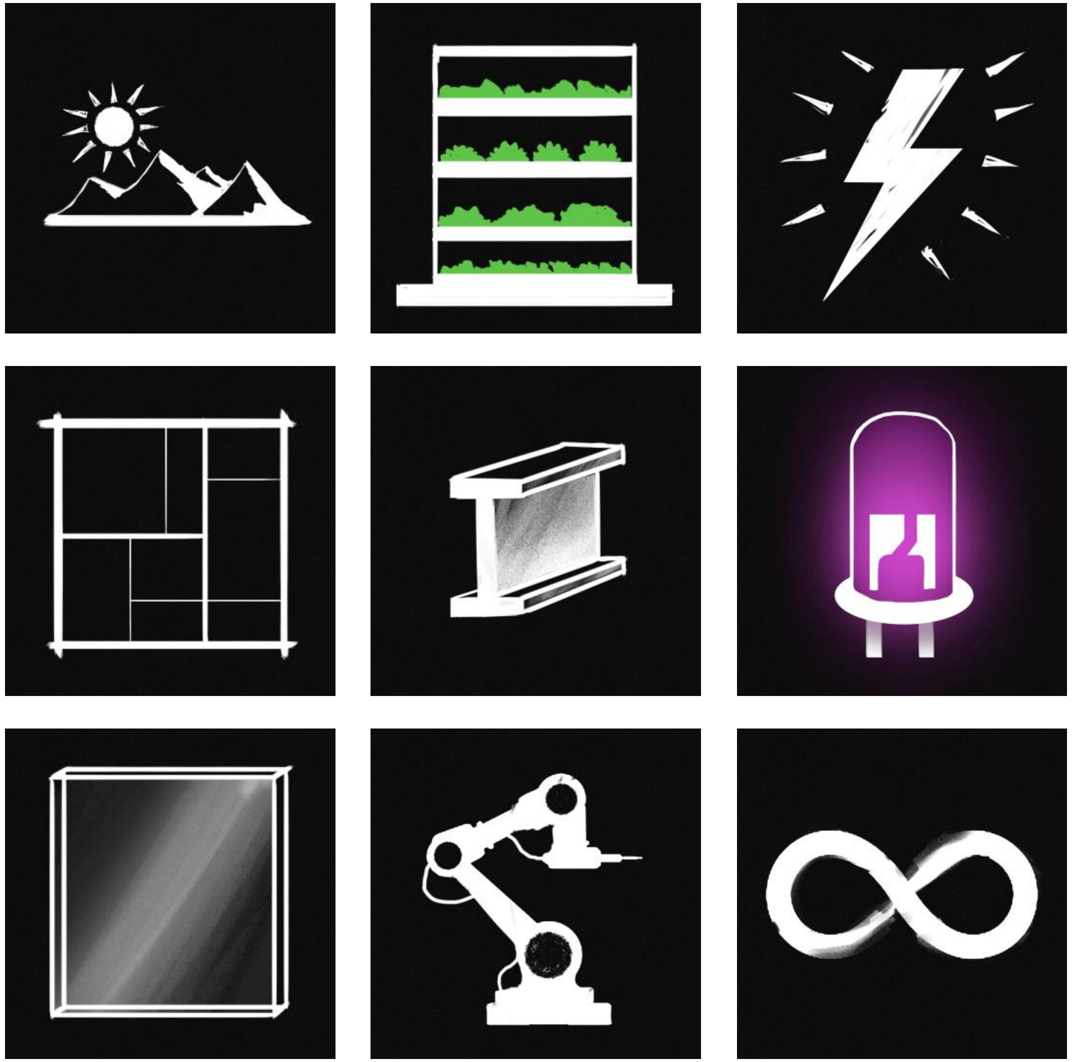
Which **factors** that enable **optimal production quality and efficiency**, are **relevant for architects** when designing **Building Integrated PFALs**?



RESULTS



RESEARCH CONCLUSIONS



RESEARCH CONCLUSIONS

INITIATION PHASE
INDIRECTLY RELEVANT

- In general, extreme climate conditions suit PFAL's better (1.1).
- Agriculture is a sector with tiny margins, when the project focusses around produce as the main source of income, the importance of economical decision making increases. However, additional functions could alleviate this grip (1.1, 5.2, 5.3).
- Understanding the supply chain can benefit the economic qualities of the design and integration with the urban environment (1.2, 5.2).
- For who do you design the PFAL, most consumers gladly make use of the convenience of an all in one supermarket. Determine if you want to combat this trend or work with it (1.4)?

DRAFT DESIGN PHASE (SO)
DIRECTLY RELEVANT

- **The functions within a PFAL are (5.1):**
    - **Culture rooms:** Germination room, Growing room.
    - **Operation rooms:** Packing, Storage(cooled), shipping, maintenance, changing room, disinfection rooms (air shower, wash basin, boot sole sterilization), data storage, administrative office, rest room, tea room.
- **Potential functions to integrate with a PFAL are:**
  1. Within the supply chain: e.g., office, restaurant, shop/supermarket, distribution centre (5.2).
  2. Outside the supply chain: e.g., education, museum/experience centre, train station/underground transportation (5.3).
- **Plants mostly use blue and red photons for photosynthesis. There is some emerging research on the impact of green and far-red photons but take into consideration that at least 50% of the time the LED's will emit a purple haze and perhaps only 20% white light (showing green plants instead of dark plants) (2.1.1, 2.3).**
- **When the PFAL exceeds 200m2 it is almost certain to be a stacked system of horizontal trays which enable relatively easy automation. If smaller, e.g. barrel shaped hydroponics can also be viable (2.2).**
- **Water dripping from hydroponic systems can have biophilic qualities. There are some differences per system how calm or constant this dripping is (2.2).**
- **In the climate of The Netherlands, it can be beneficial to integrate a greenhouse with the PFAL, especially when maximal control is not required. In particular non-leafy greens such as tomato's can benefit from a combined system reducing the energy demand from LED's (4.1).**
- **Solar is a very potent energy source to integrate on the roof of a PFAL, especially on a large-scale lightweight structure. In high density urban areas a rooftop garden or greenhouse provides more benefits. The technology of photovoltaic panels is quickly improving, with 170 kWh/m2/y currently at the high end of commercial availability (4.4).**
- **The average mass of a farming system per m3 is (6.1):**
  <200m2: *yet to calculate* **kg/m3 =** *xxx* **kN/m2**
  >200m2: *yet to calculate* **kg/m3 =** *xxx* **kN/m2**
- **Increasing the transparency (of the façade) tends to negatively influence (6.2, 6.3):**
  1. Controllability of the interior environment; internal climate, sterile environment. 2. Trade secrets.
  Use transparent materials that show the visual appearance but maintain an interior sterile environment (e.g., glass). Differentiate between protected IP (public) and testing grounds (private).
- **The different materials that resonate with a PFAL are studied during the Design Phase (6.3).**

DRAFT DESIGN PHASE (SO)
INDIRECTLY RELEVANT

- The major cost components of a PFAL are: Electricity 28%, Labour 26%. But, the cost of electricity (e.g. LED's) will greatly decrease in the next decennia and so could labour if automation is deployed. The question then also becomes of a social nature, when and where jobs may be more beneficial to maintain (1.3, 2.3).
- The main characteristics that consumers are willing to pay extra for when buying bagged lettuce are zero contaminants and a longer shelf-life (1.3).
- Not all crops are economically compatible with growing vertically. If the initiative to grow anything else other than leafy greens comes from a non-grower, make sure to validate its feasibility (2.1.3).
- When deploying data gathering to optimize the process, these skills must be learned. Especially in the next 10 years, PFAL structures may benefit from integrating an educational facility into the building. Educating the farmers of the future (3.5).

FINAL DESIGN PHASE (VO)
DIRECTLY RELEVANT

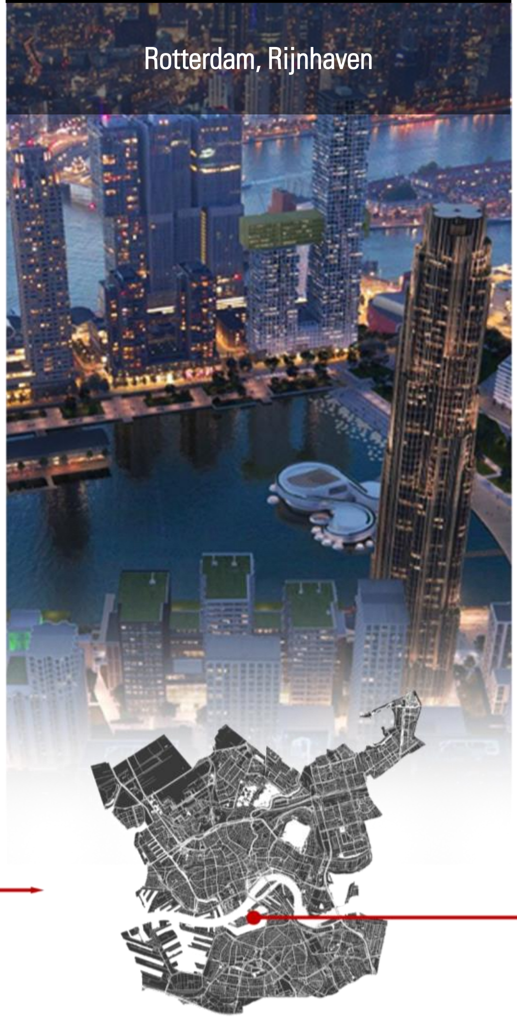
- **Indoor agriculture HVAC must be able to regulate much higher latent heat loads compared to comfort cooling for humans. Using the excess latent and sensible heat accumulated by the system for heating e.g. underfloor heating is vital. If all this energy is simply being disposed of the PFAL has little chance of being viable (3.1 4.2, 4.3).**
- **To obtain CO2 levels of around 1200 p/m, additional CO2 is added to the airflow. If reducible to pure CO2, surrounding infrastructure can be used to fulfil these needs (3.1).**
- **The water intake is minimalised compared to open land and greenhouse agriculture. There are systems that use natural filtering in a parc-like space next to the PFAL. Which is possible because there are no extreme pesticides needed within a PFAL (3.3).**

FINAL DESIGN PHASE (VO)
INDIRECTLY RELEVANT

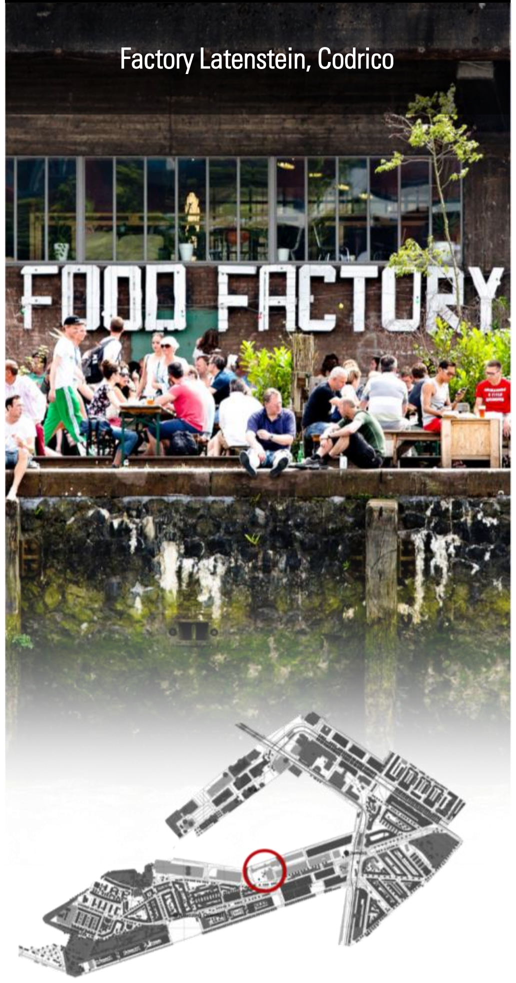
- Close the loop, but note that e.g. burning biomass is not worth it when deployed on a small scale. If the surface (growth) area is <5000 m2, instead look for composting at a nearby urban farm (2.1.2, 3.4).
- Advanced vertical farming systems minimalize light bleed by closing the sides with reflective material. On the sides visible to visitors or check-ups these sides should remain open, likely creating boxes which have one side left relatively transparent. The loss of PPFD efficiency is made up for by direct and indirect (economic and social) gains from consumers/visitors experiencing the PFAL (3.2, 2.3).

RURAL
Free-up land area

CITIES
Improve Resilience

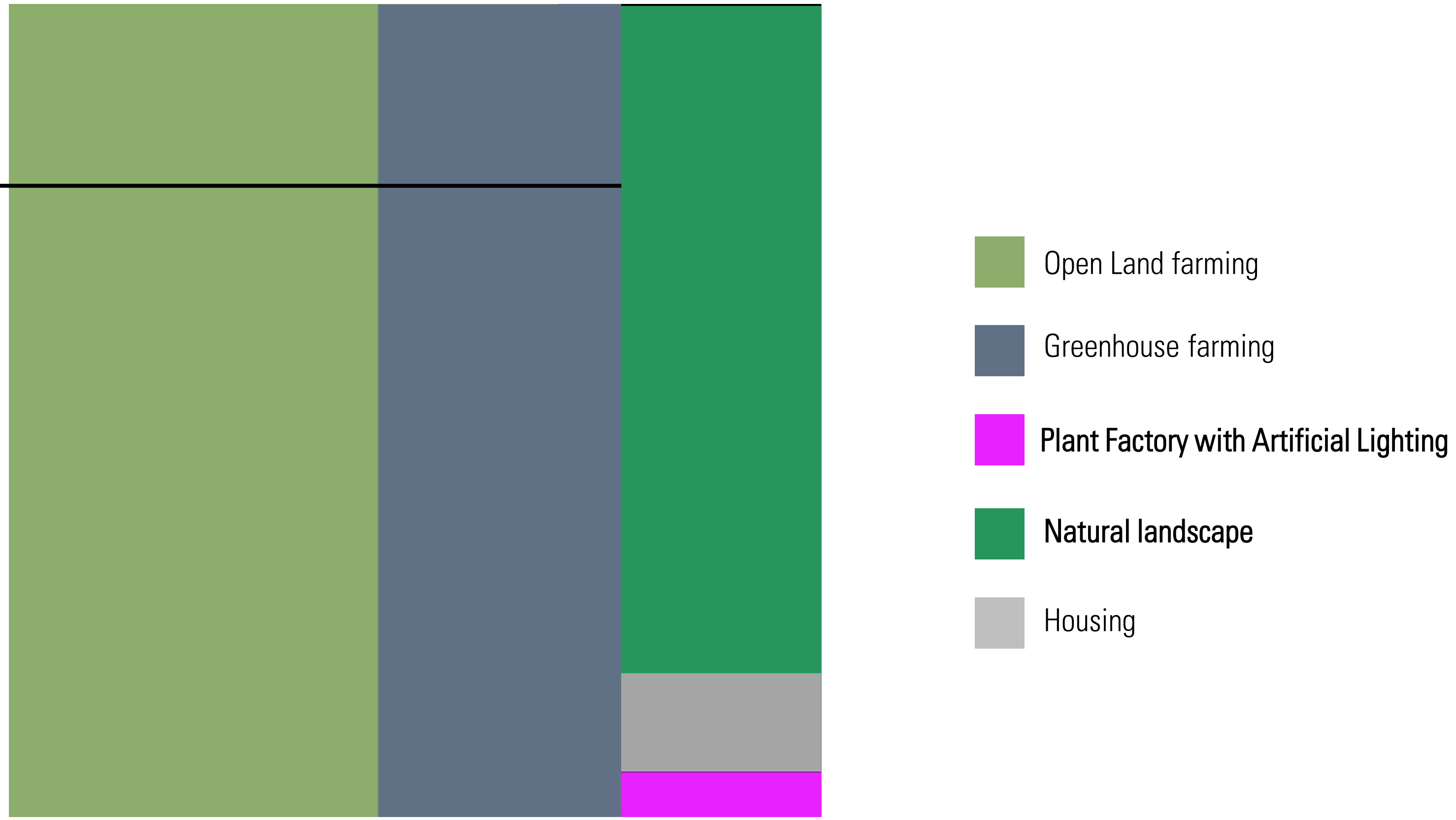


BUILDING
Reconnect the consumer with the growing of their food



RURAL | Free up land area

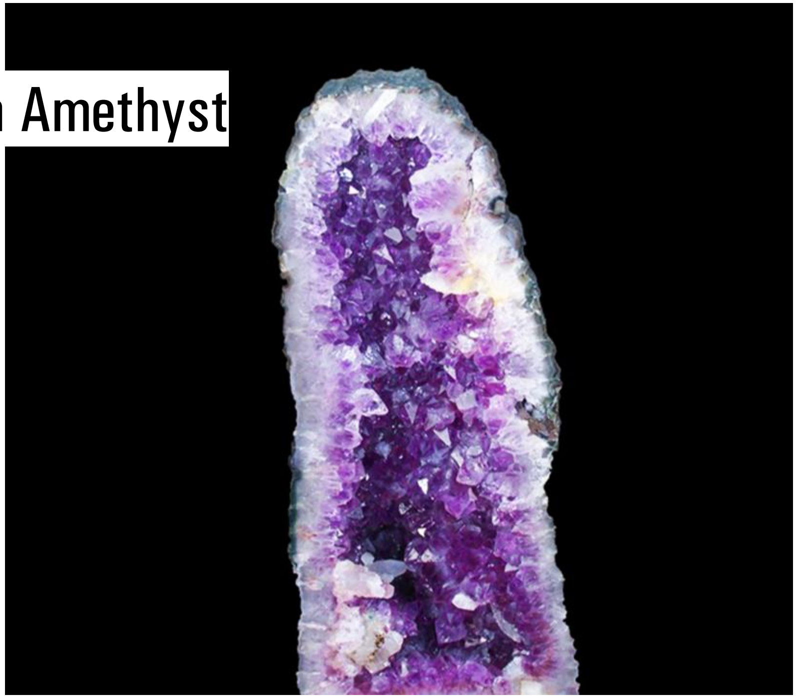
76 km2
Equal to 15 times the centre of Rotterdam



More ways than one

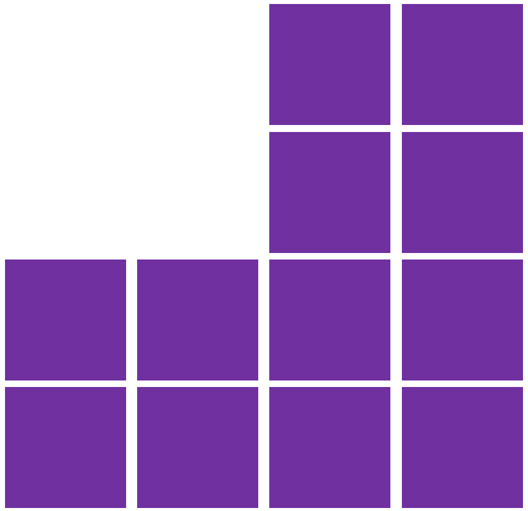
GROWMODULE SYSTEM PROTOTYPE

The Urban Amethyst



GROWMODULE | DESIGN STRATEGY

Tailormade Design



Standardised Design

GROWMODULE | DESIGN STRATEGY

User experience

- Experience the growing process
- User convenience through automation

Flexible fit in any building space

- Standardised building dimensions

Aesthetic

- Interplay between a high-tech industrial system and communicating the natural biophilic process of growing plants.

Production efficiency

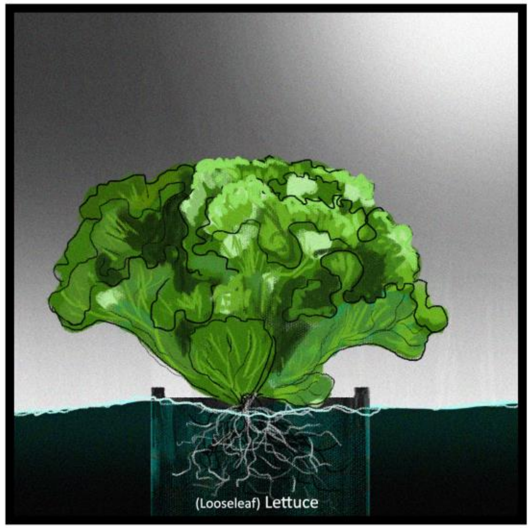
Result

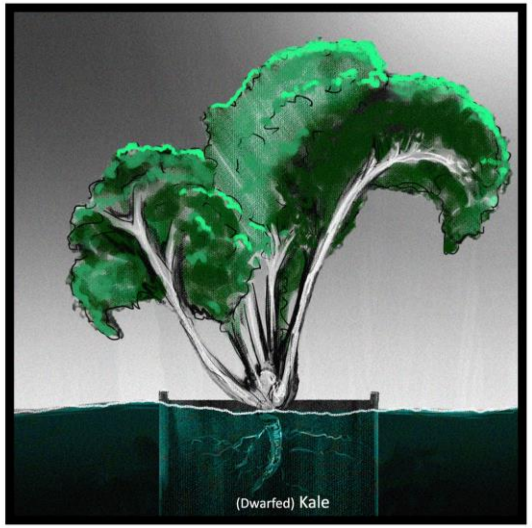
A growmodule providing up to 10 users with 250 g/day of tasty and nutritious leafy greens.

GROWMODULE | Edible Greens

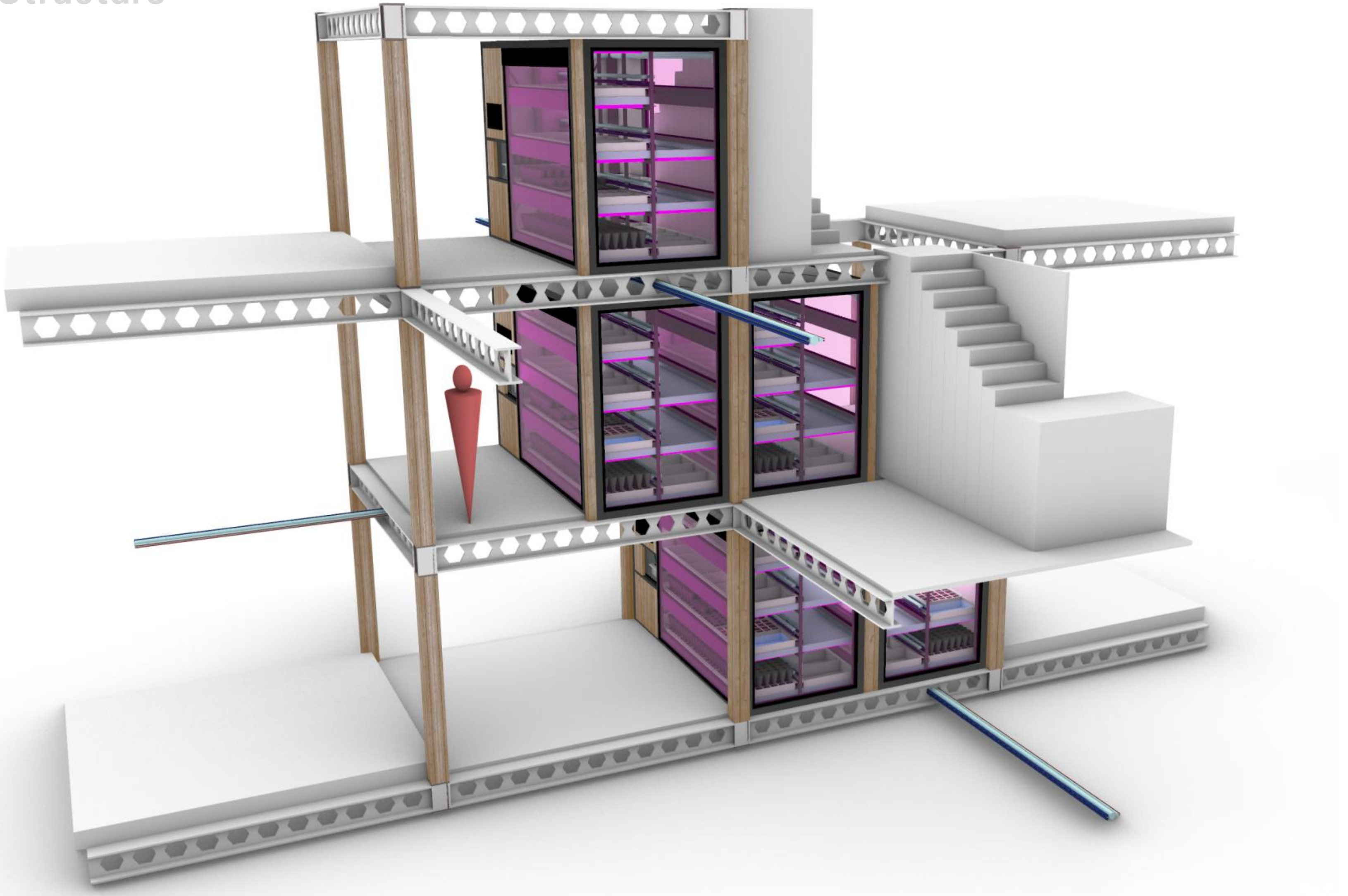
Plant types
Leafy greens make up the first stage of economically viable crops to be grown in plant factories. Research on making the second stage (strawberries, cucumbers, tomatoes) is quickly developing however generally require a different growing method and mechanism. Therefor the focus for this project lies on leafy greens, which with the right combinations can provide a complete meal in terms of required nutrients.

Examples:

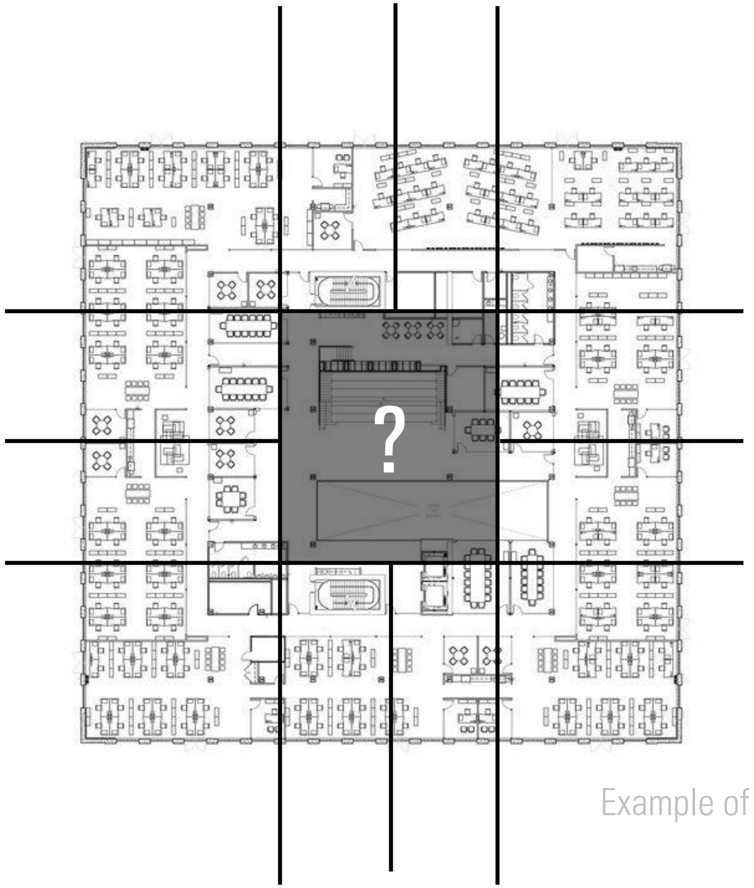


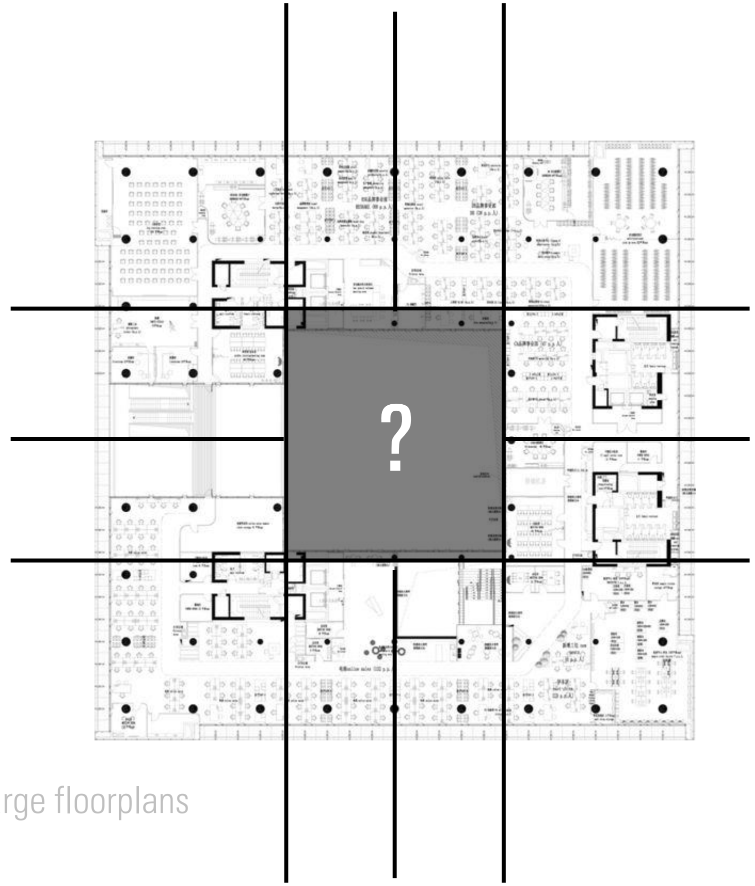


GROWMODULE | Structure



The dark problem of office/factory transformation



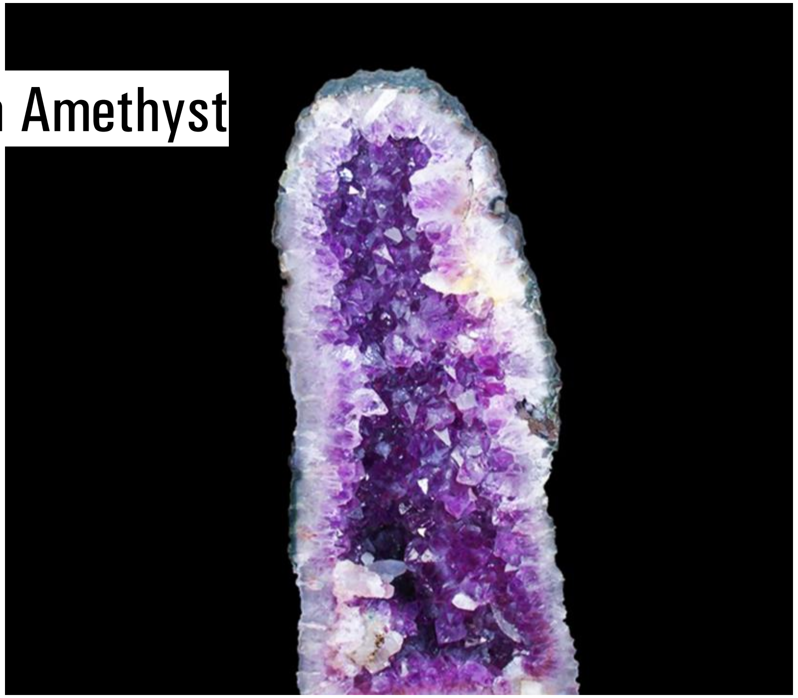


Example of large floorplans

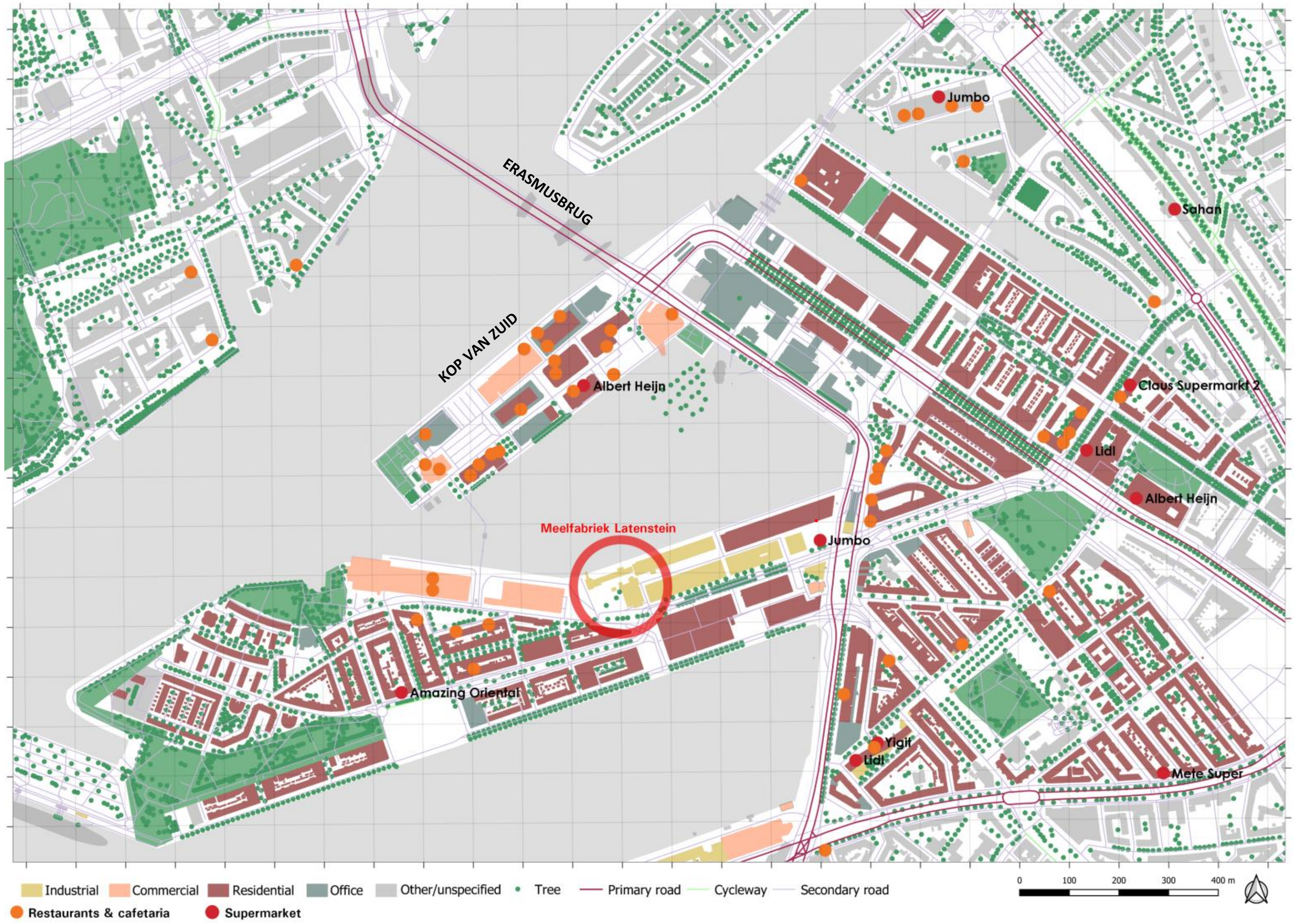
WHAT IF..?


GROWTH RECIPE
LETTUCE
BASIL
THYME
Albert Heijn
SAM VERDEGAAL

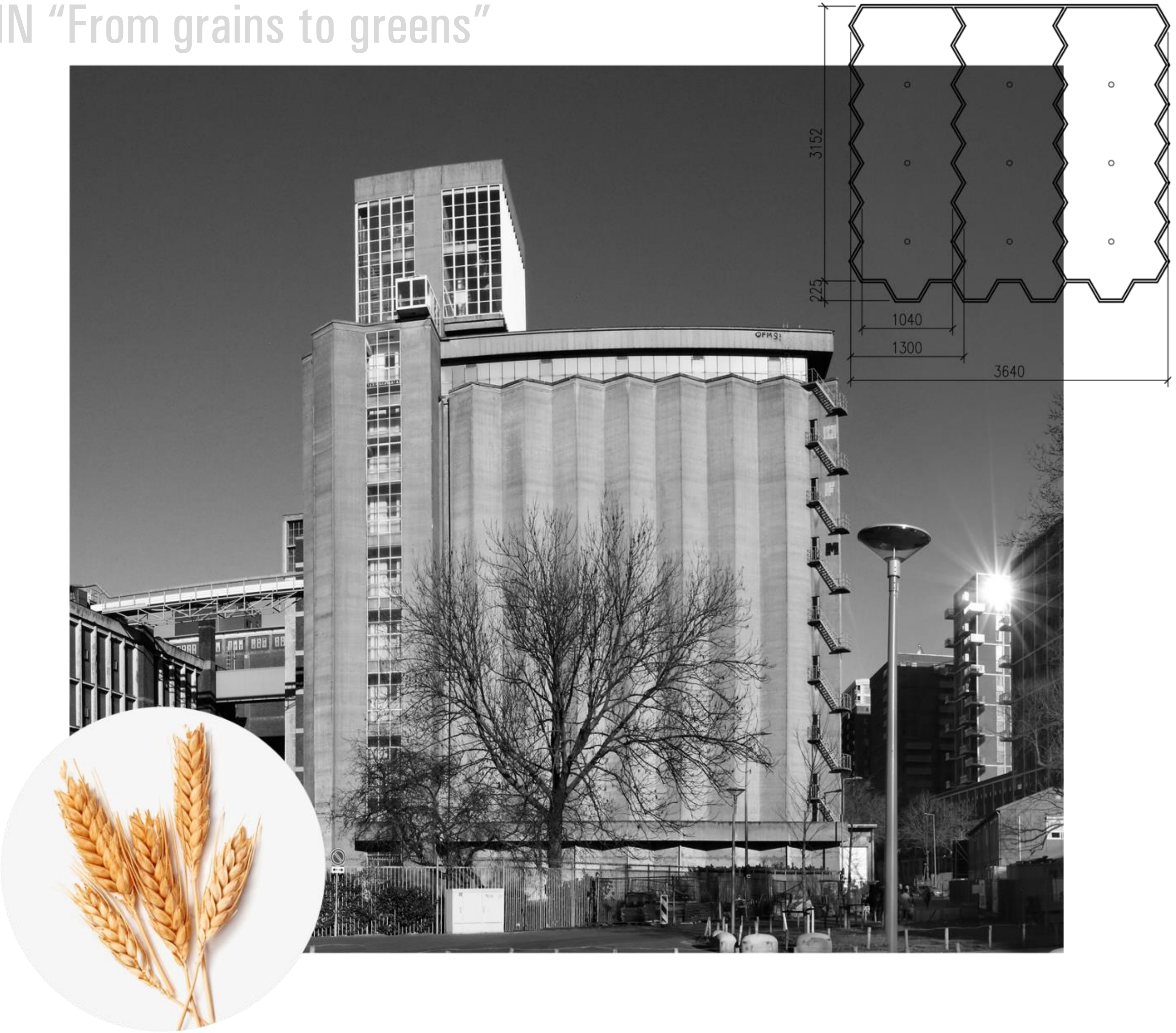
BUILDING AS A TESTCASE
The Urban Amethyst



RIJNHAVEN, ROTTERDAM



GRAIN SILO LATENSTEIN “From grains to greens”



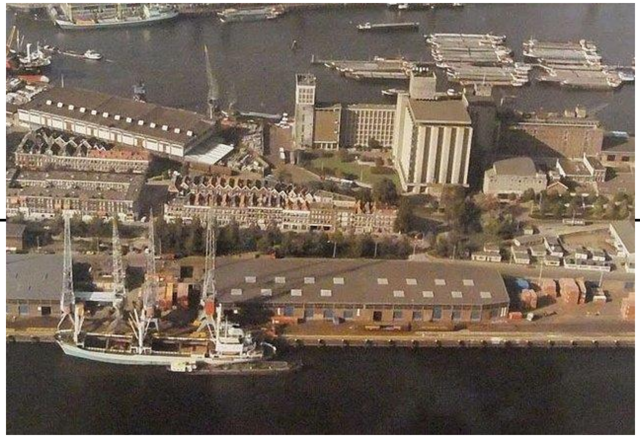
From grains to greens

1930 | Harbour Katendrecht

1960 | CO-OP Factory & Office

1964 | Grain silo extension

1969 | Codrico



1983

2021

BUILDING CONCEPT | THREE LAYERS

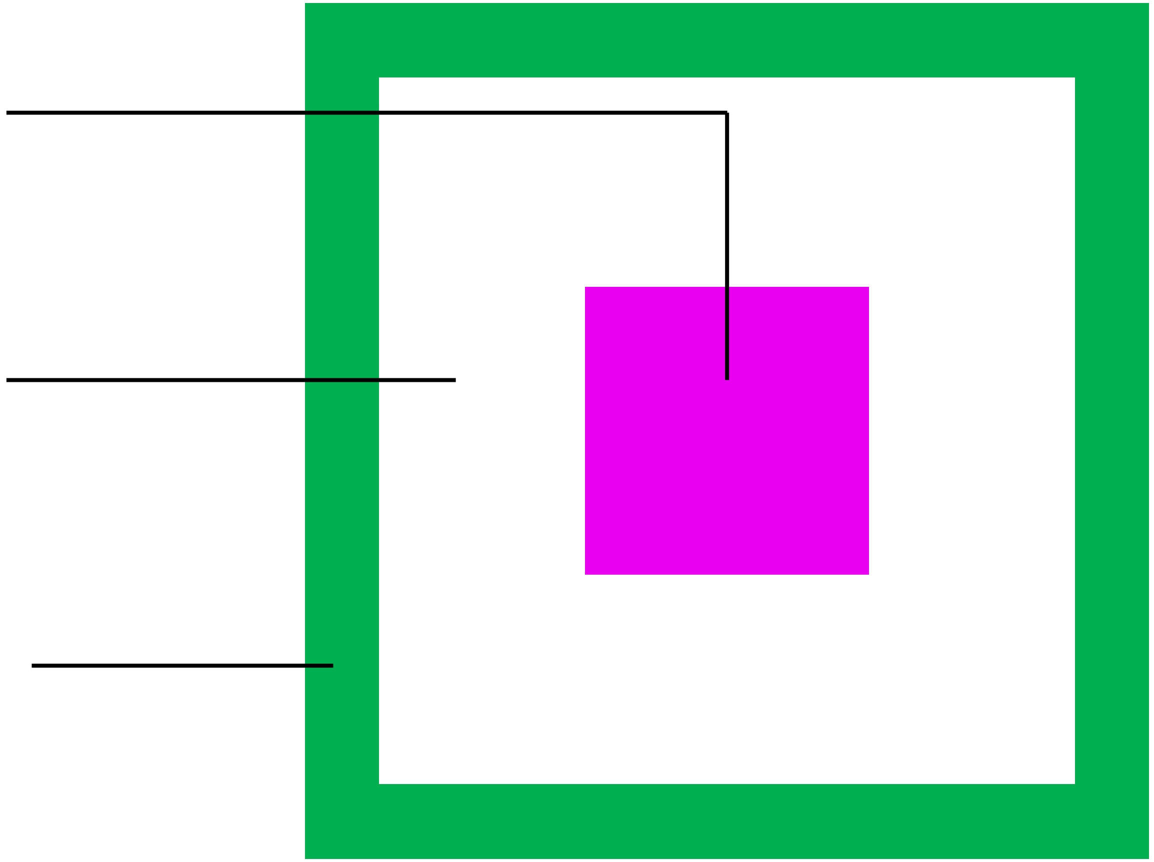
VERTICAL FARMING CORE

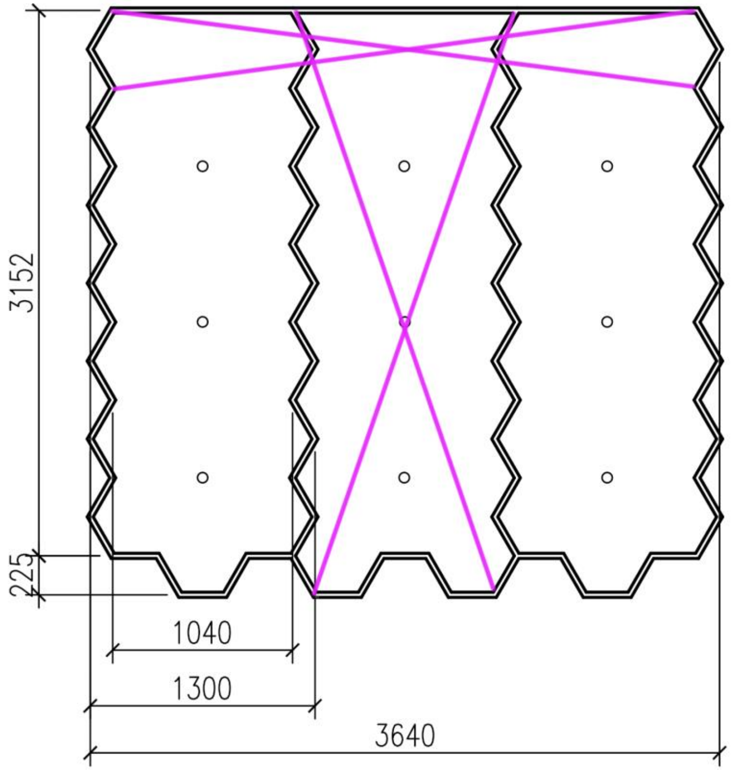
Experience growing your own food.
Controlled environment;
LEDs, water, nutrients.

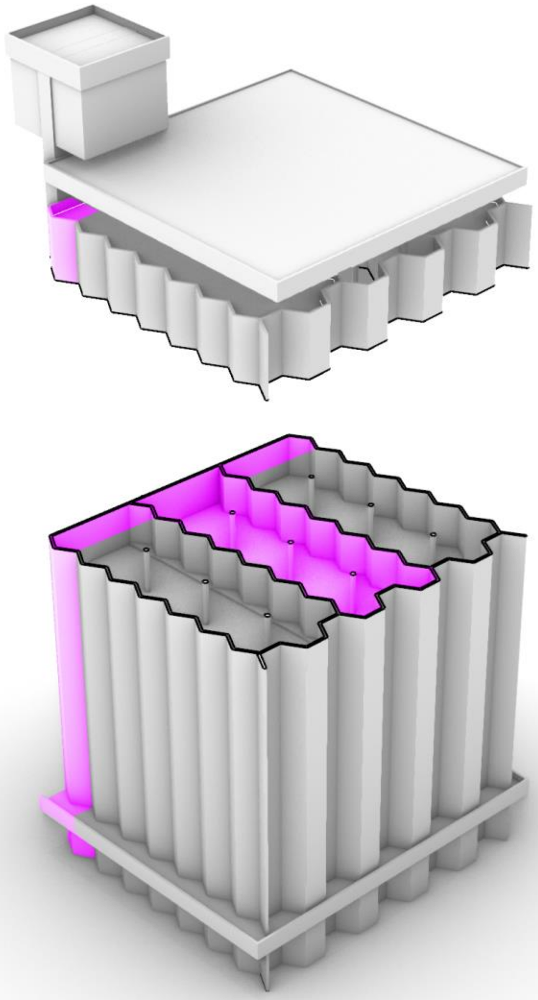
APARTMENTS

GREEN SHELL

Experience natural elements.
Exposed environment;
Sun, rain, wind.
Plants, birds, butterflies.

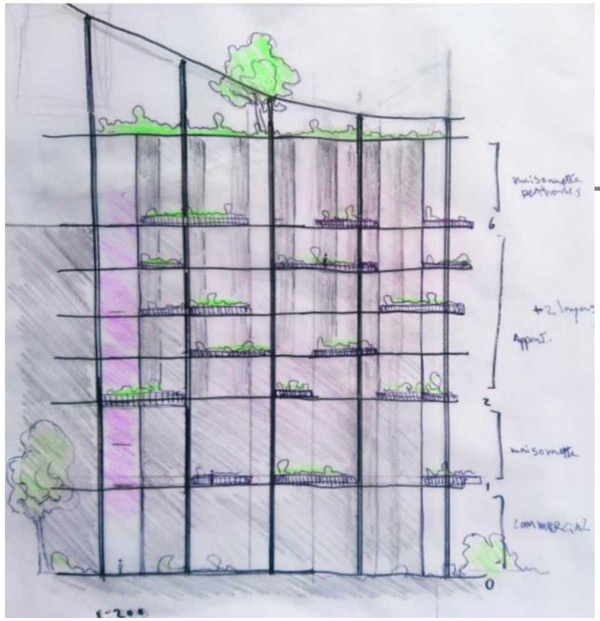



3152
225
1040
1300
3640

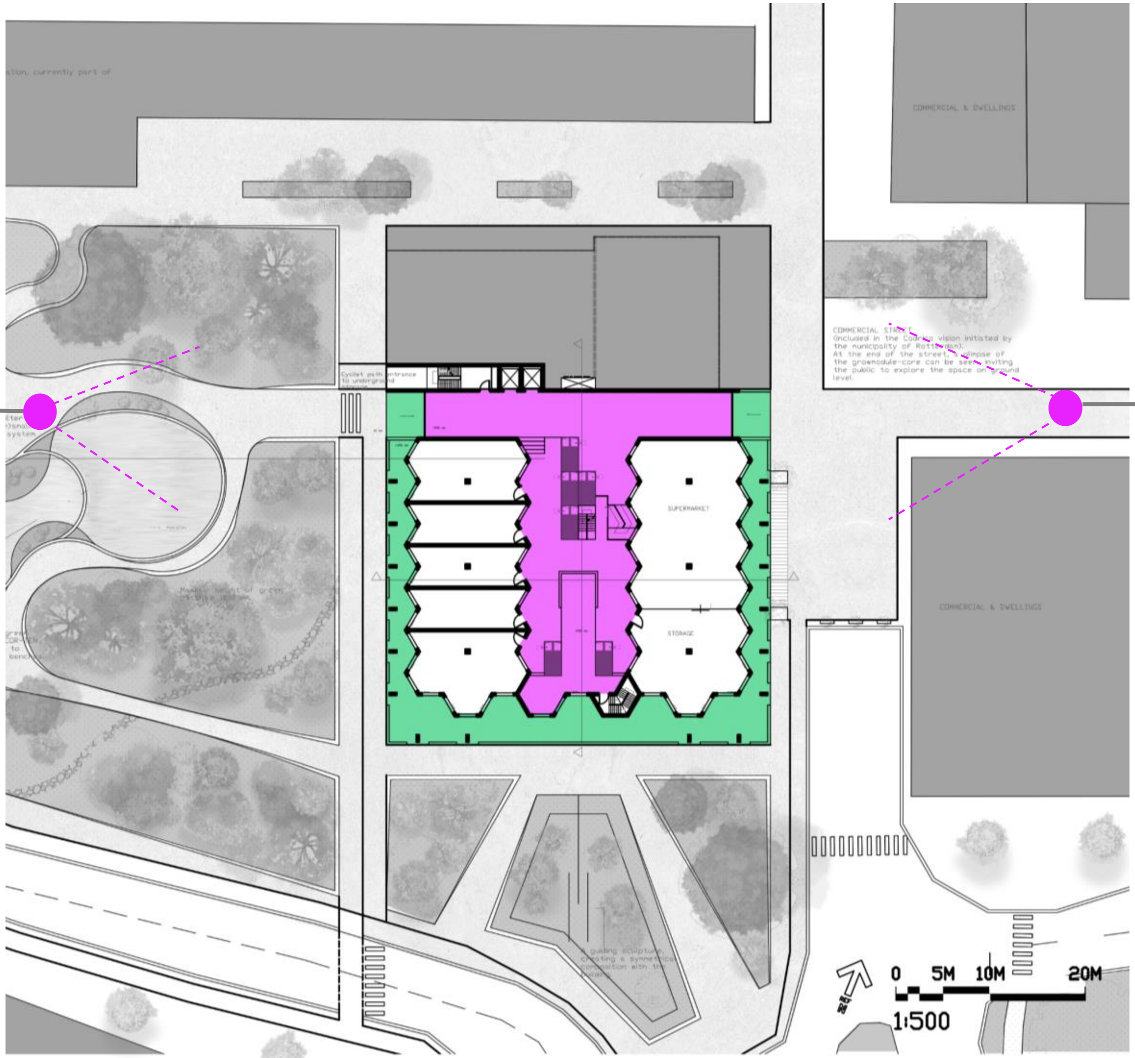


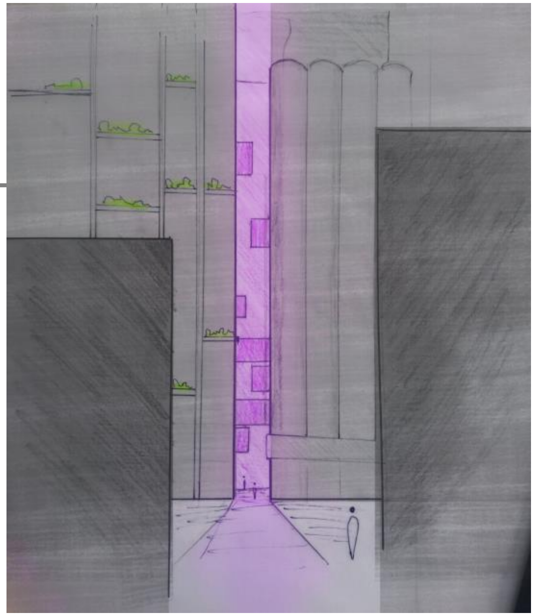
Building Design

CORE & SHELL



Initial concept sketch



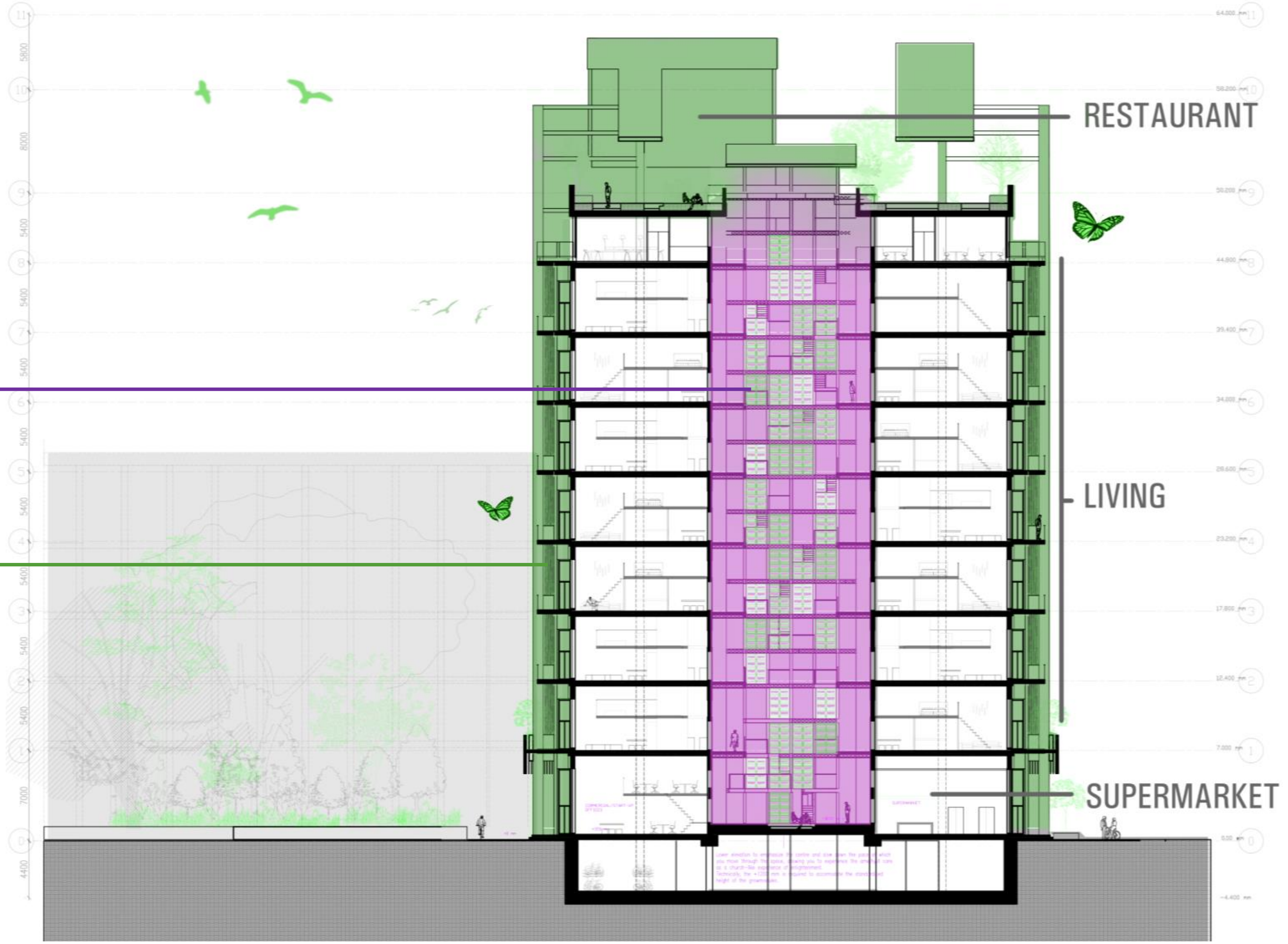


Initial concept sketch

Building Design

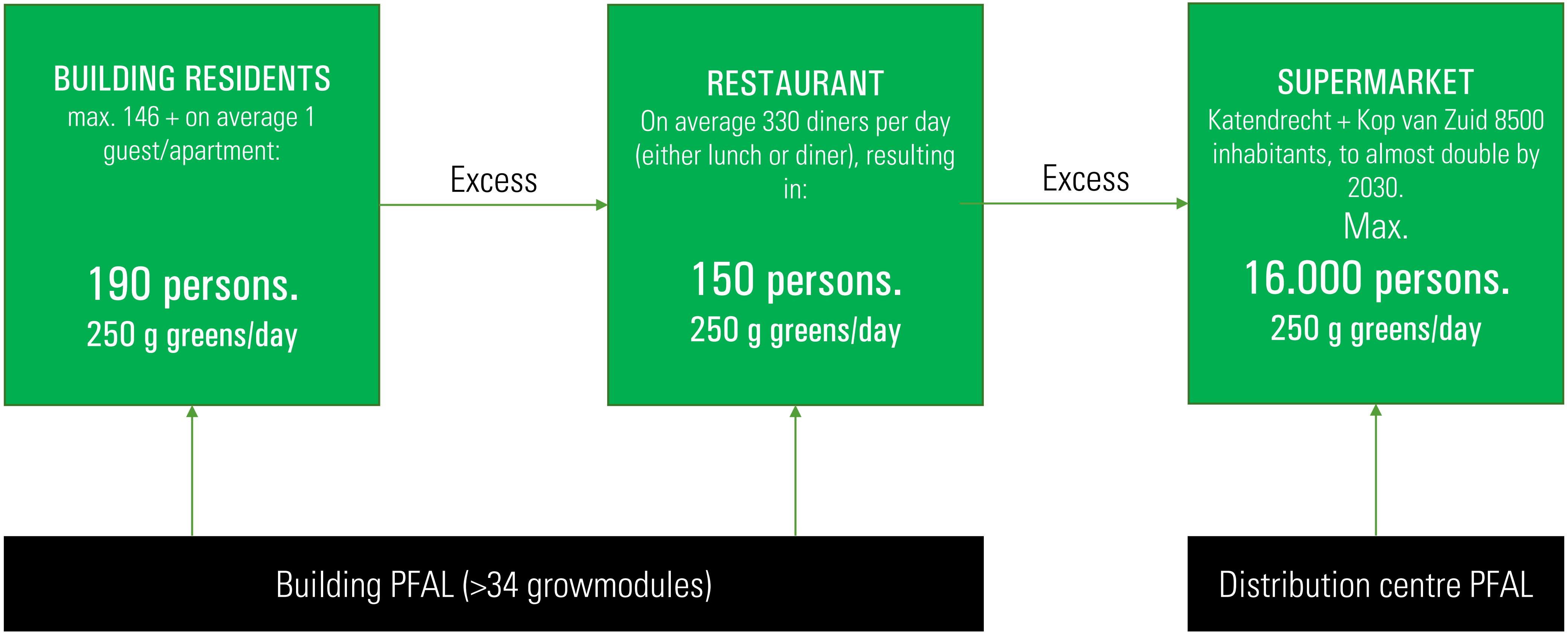
Vertical Farming Core
Controlled environment

Green Shell
Exposed environment



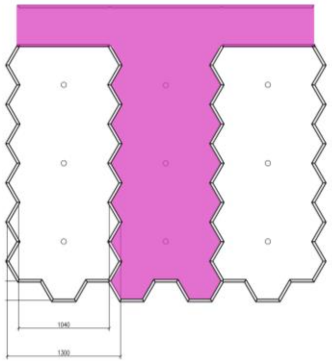
CORE | Food Demand

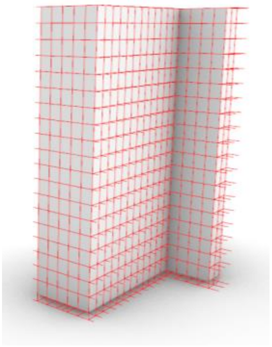
Building integrated PFAL
To produce for at least 340 pers. Which is equal to 250g*365days*340pers.= 31.000 kg greens per year. Excess greens are sold in supermarket.

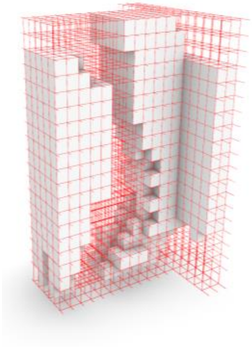


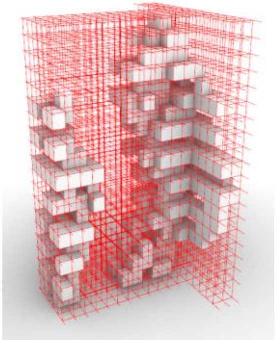
CORE | Carving out the Amethyst

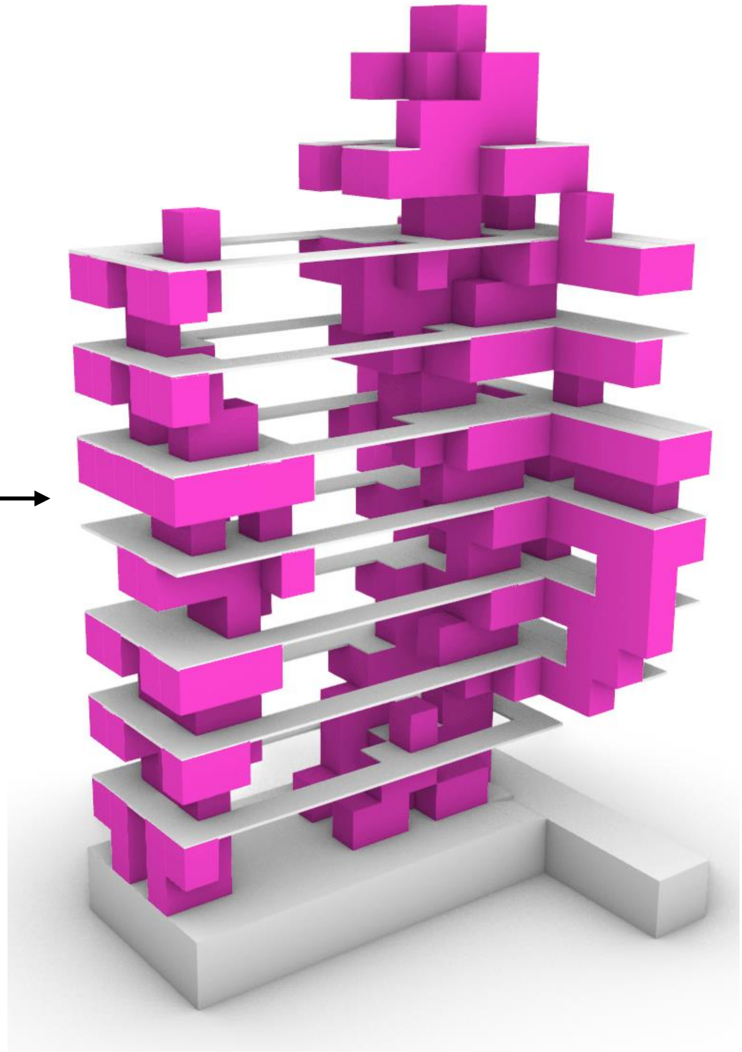
Parameters
- Aesthetic qualities of the guiding sketch.
- Accessibility of the apartments, incl. mezzanines having at least one opening towards the atrium.
- Access to growmodule from at least one side.



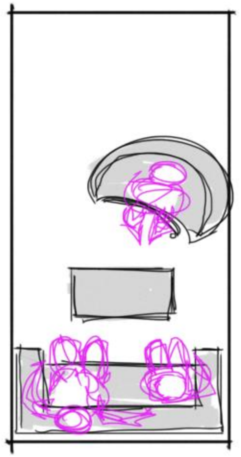


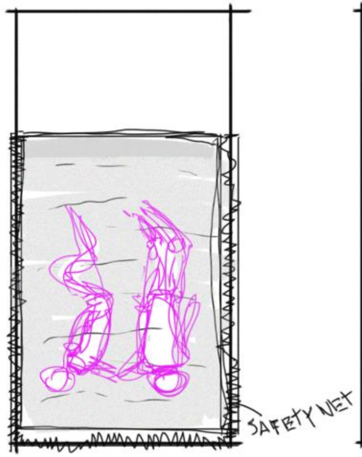




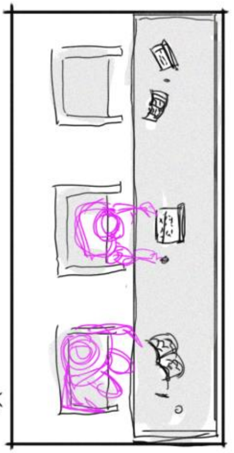


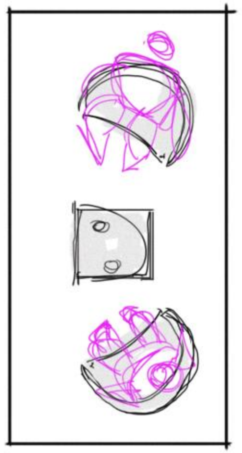
CORE | Space creation

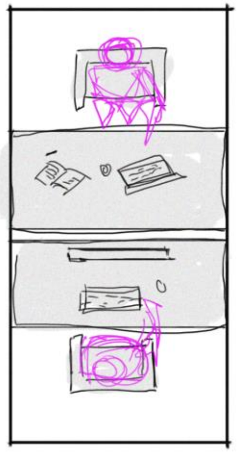

Chat

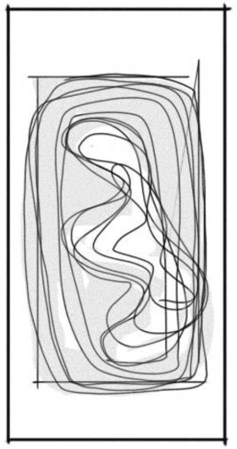


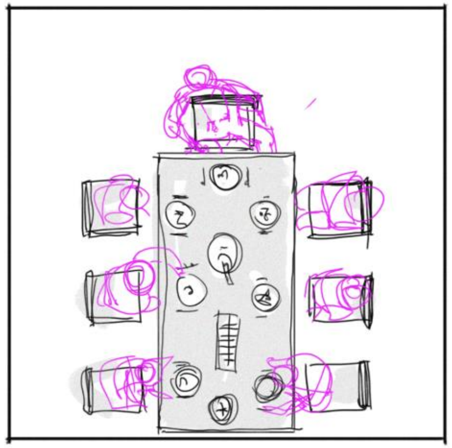
Relax / play
Coated mattress

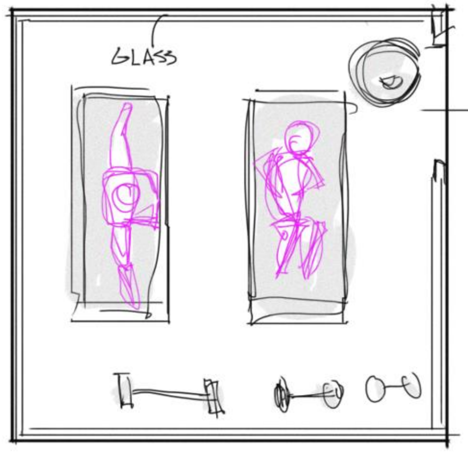

Work


Relax and brainstorm

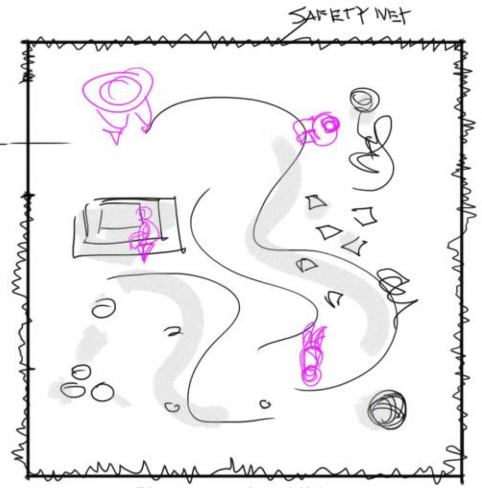

Work


Art installation

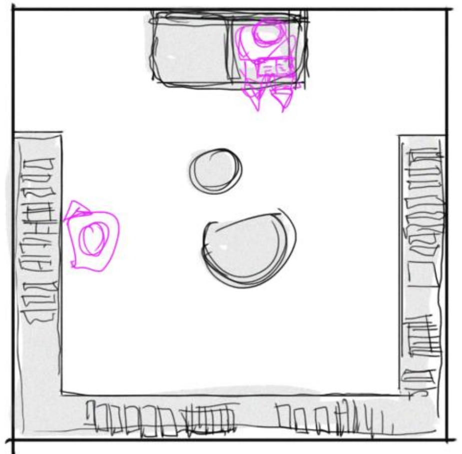

(spontaneous) diner



Yoga / workout



Play space for children


Shared books mini library


SAM VERDEGAAL

CORE | Food Production

Total crop production
Total surface area: 740 m2.
Total growth area: 1420 m2.
Average production capacity: 6.5 kg/m2/month*
*theoretical average for growmodule production, can differ in practise.

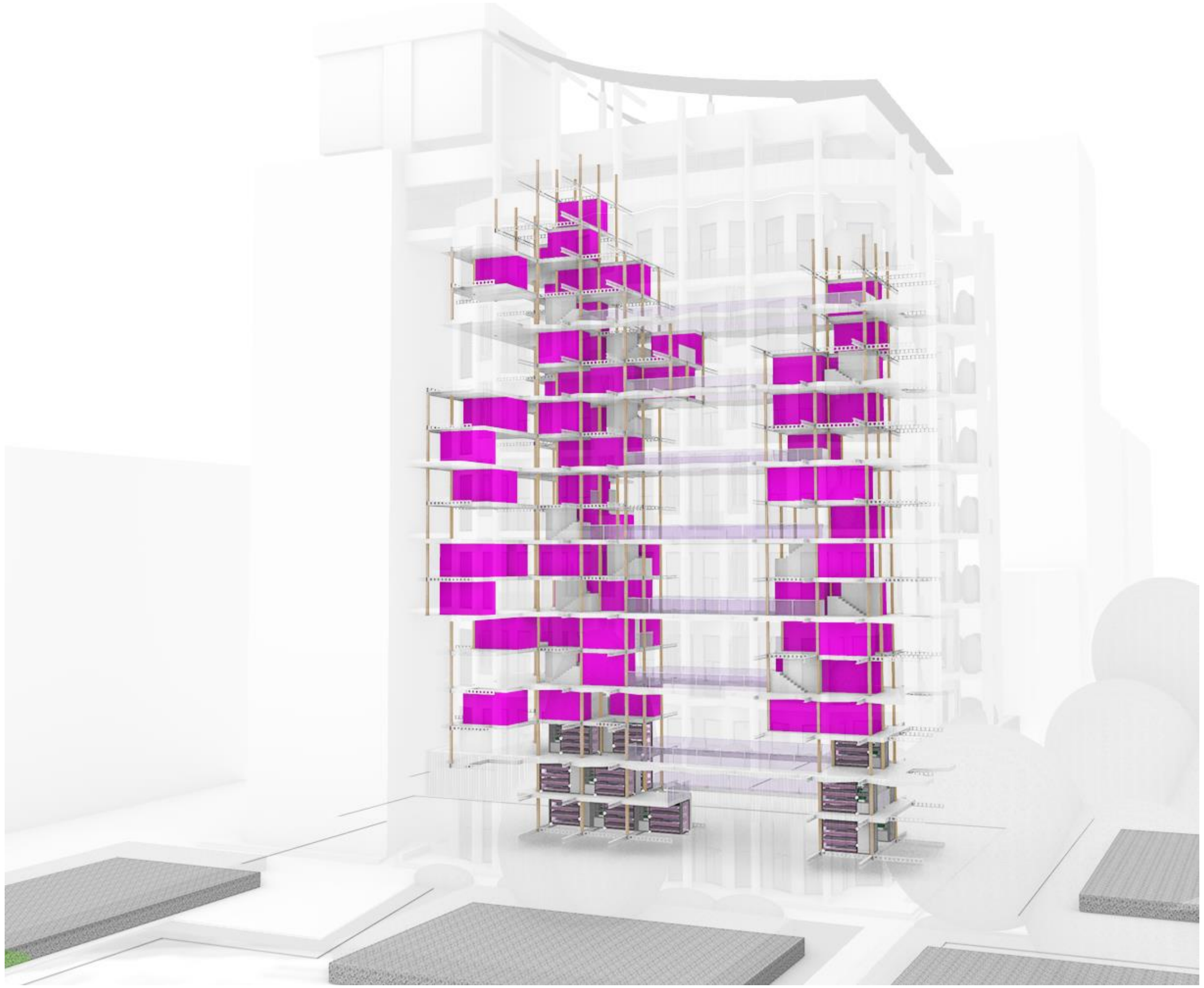
Edible Greens Production

110.000 kg/y

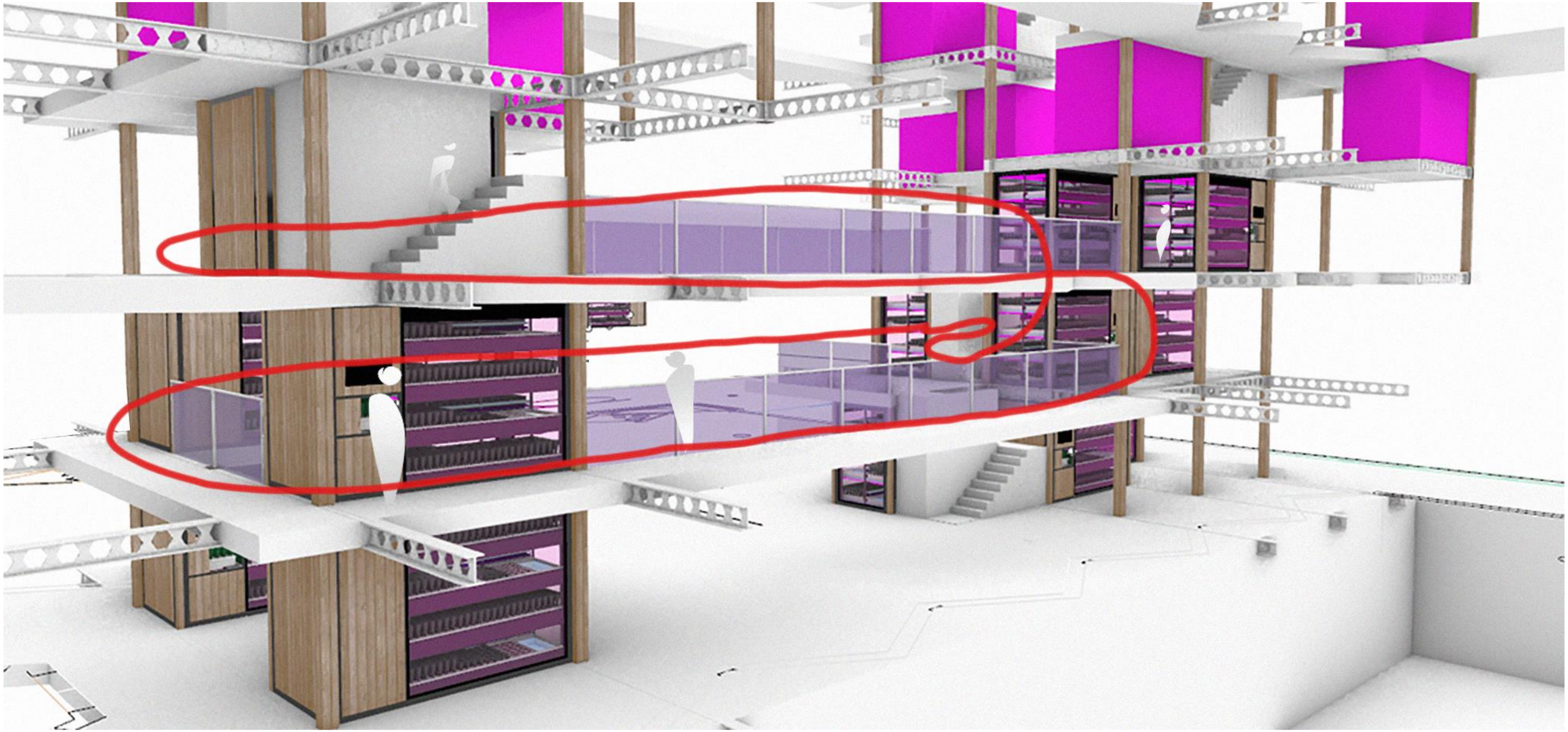
Providing over

1200 people

With 250 g of leafy greens each day.



CORE | Routing



SHELL | Outer structure

SHELL | Planting

Plant types
- Edible and/or stimulates the senses of touch and smell.
- Attracting birds, butterflies, bees.
- Low maintenance
- Including both evergreen and deciduous ivies (to allow the winter sun to enter the building).

Examples:

Star Jasmine (evergreen ivy)

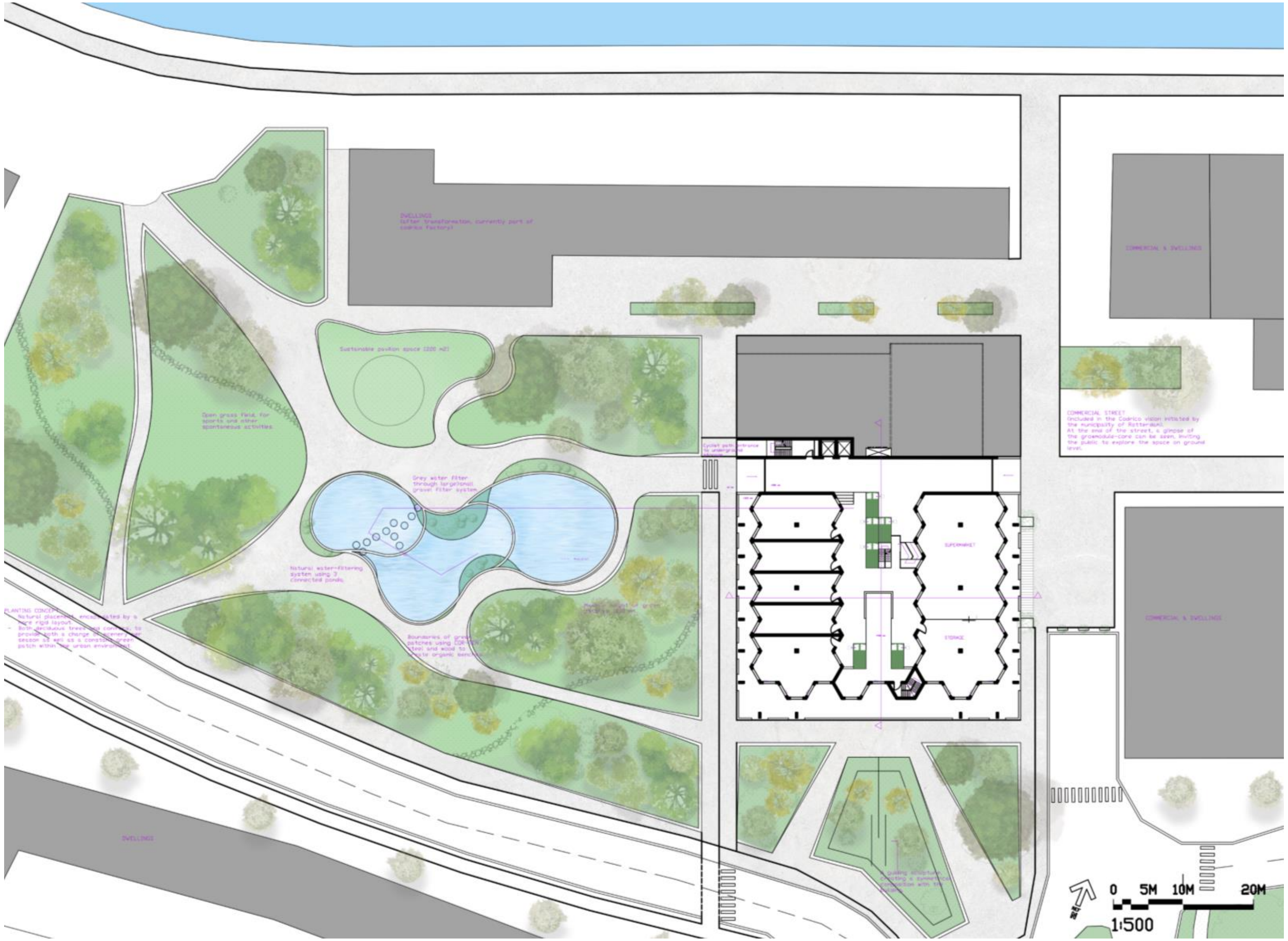
Lavender

Blackberry bush (dwarf cultivar)

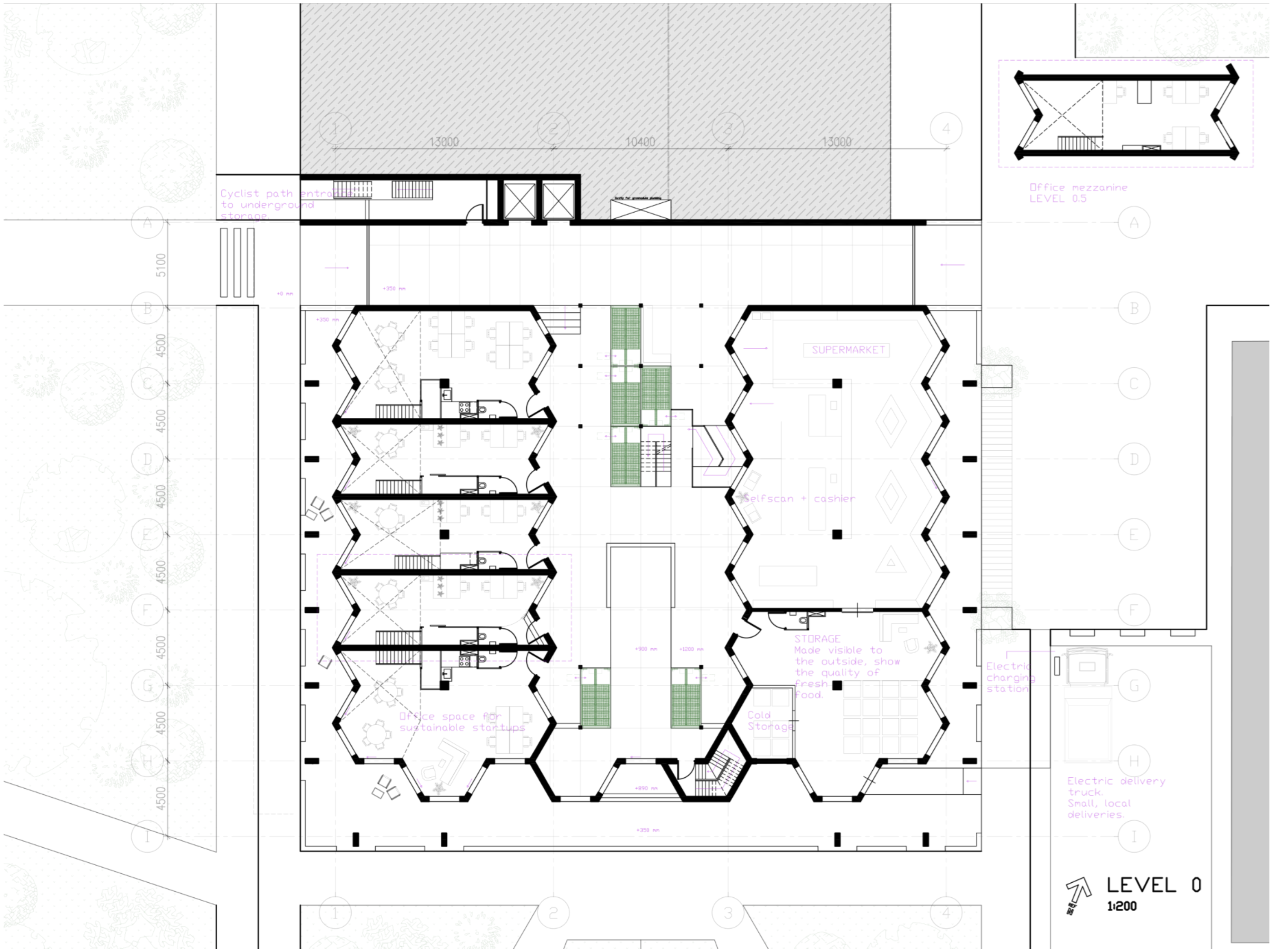
Butterfly bush (dwarf cultivar)

SHELL | Parc

Water filtering & storage
Natural greywater filtering and rainwater storage ponds.



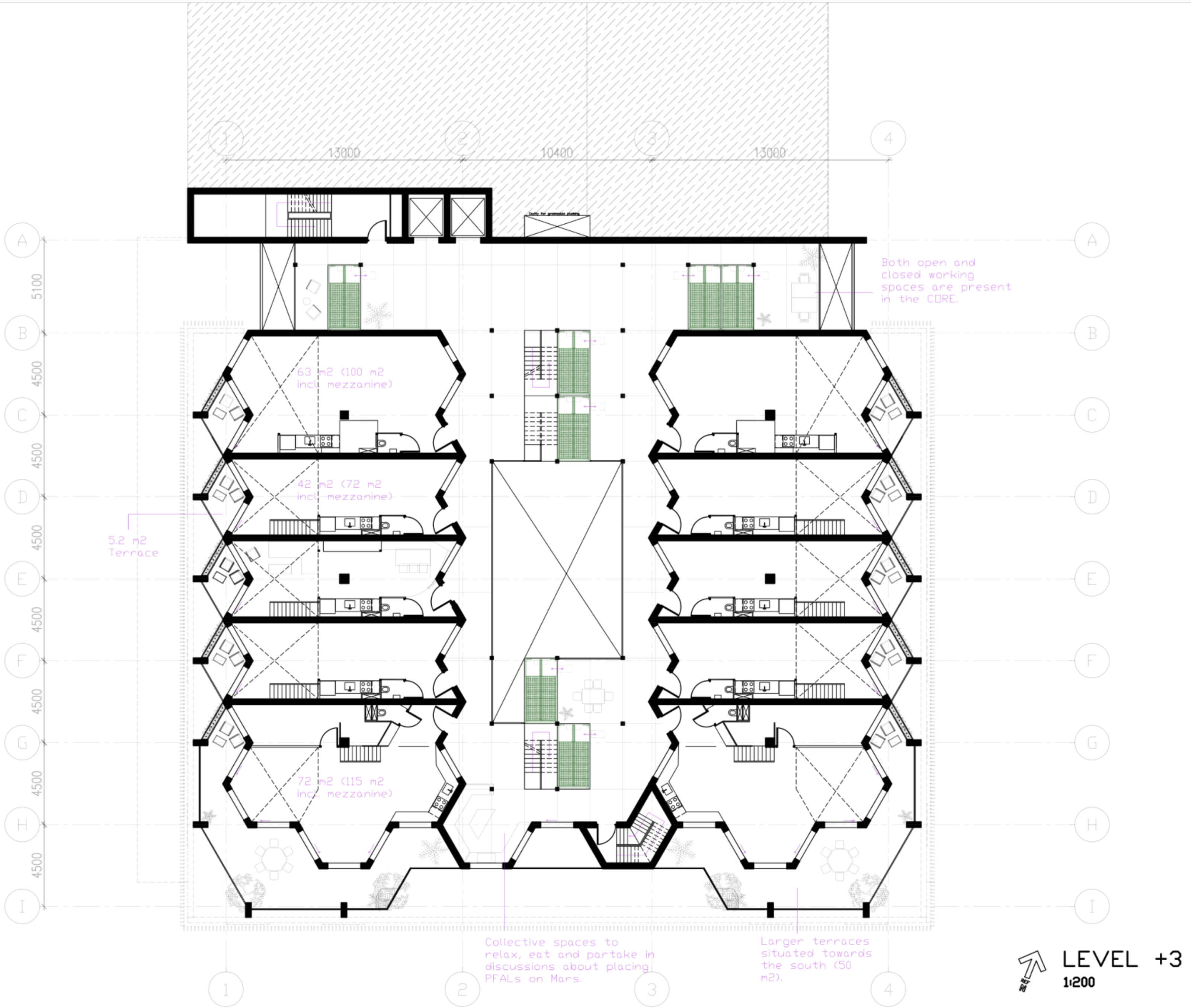
- **Office spaces**
- **Fresh shop** with both a transparent front- and back-end (storage), showcasing the short food supply chain.
- **Public atrium**,



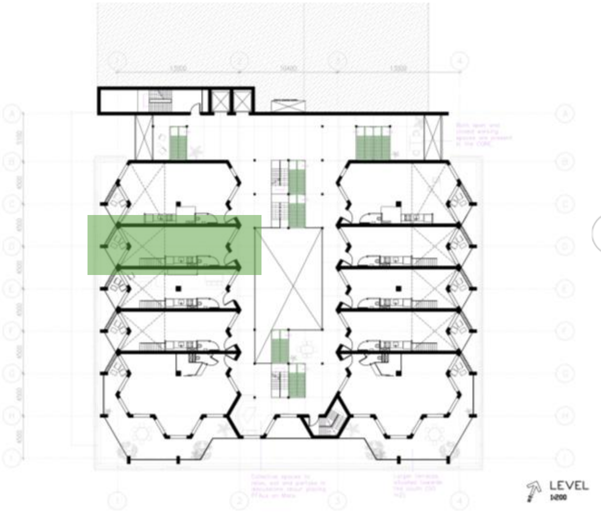
APARTMENTS

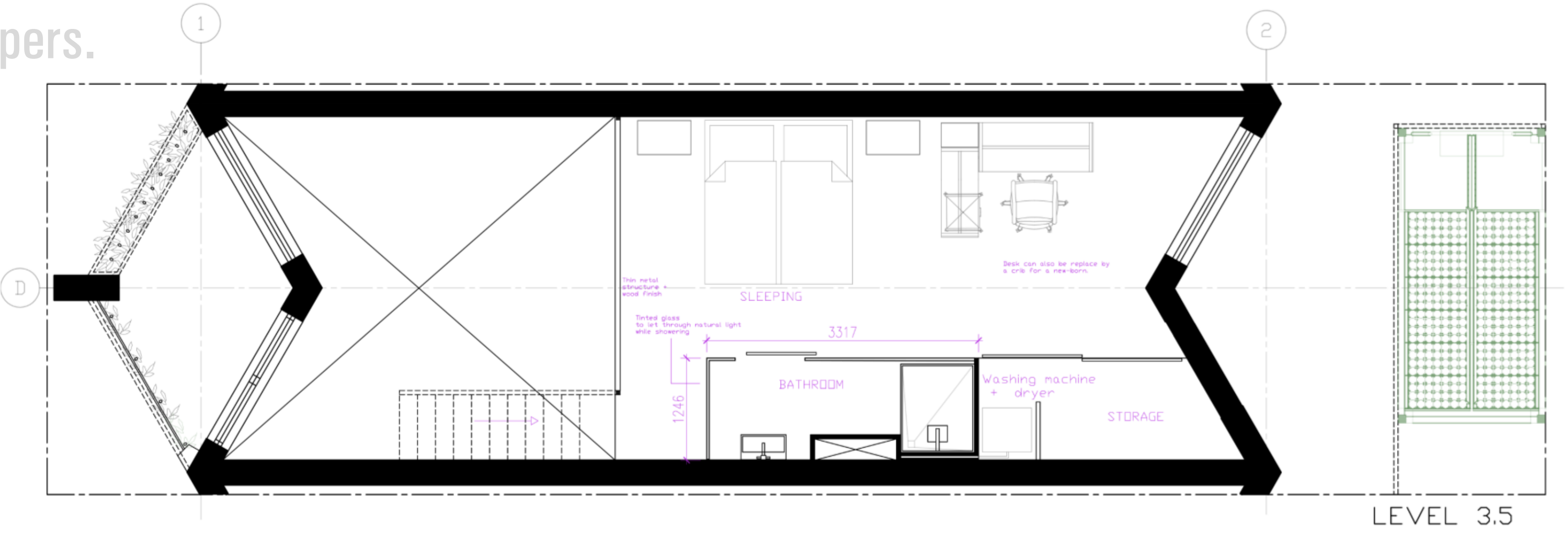
Type (persons)	Base m² (incl. mezzanine)	Terrace size m²
1 a 2	42 (72) m²	5.4 m²
2 a 3	63 (100) m²	5.4 m²
2 a 3	72 (115) m²	**50** m²
3 a 4	84 (134) m²	13.5 m²
4 a 5	105 (168) m²	13.5 m²
5 +	156 (240) m²	**70** m²

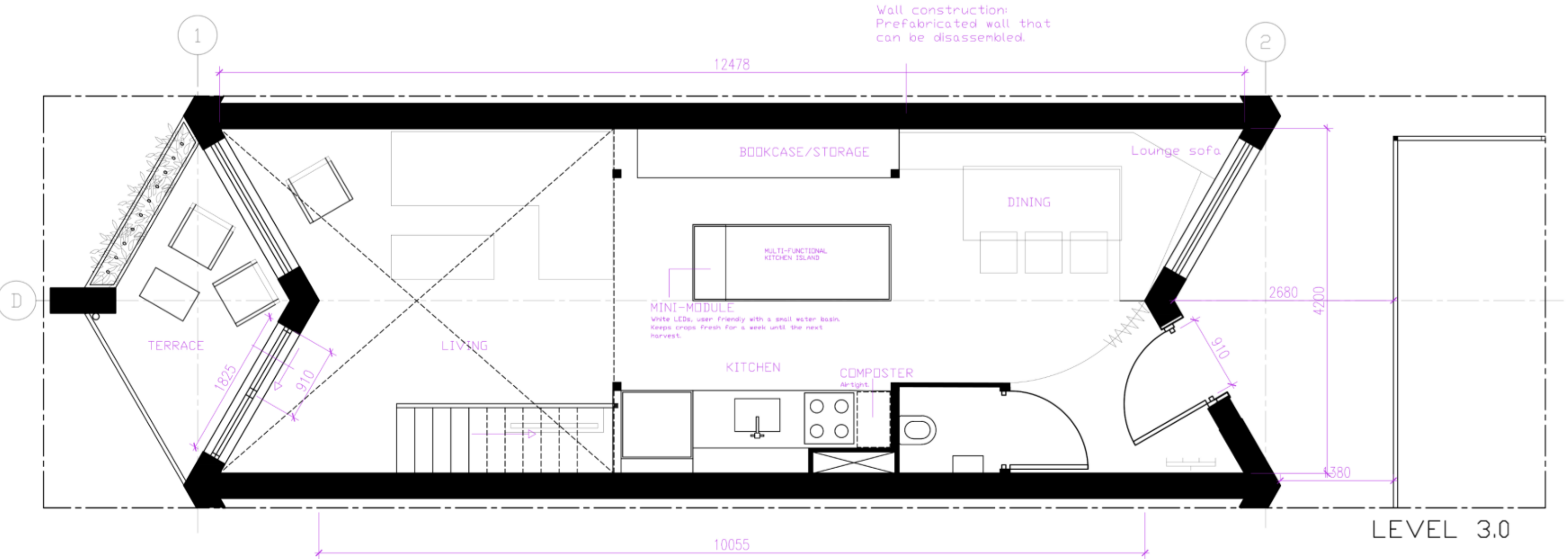
Small to medium apartments (1 a 2 pers. & 2 a 3 pers.



Apartment Floorplan 1 a 2 pers.

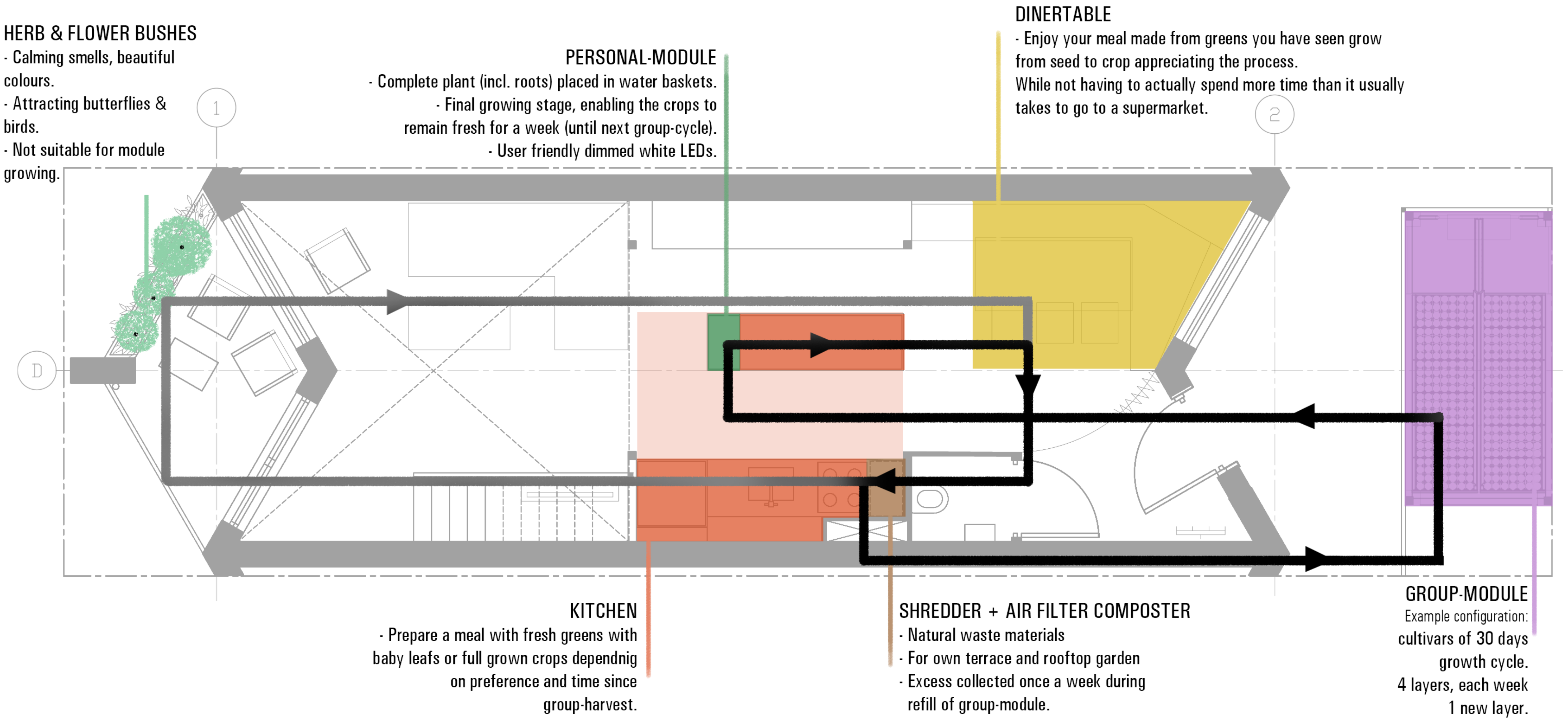


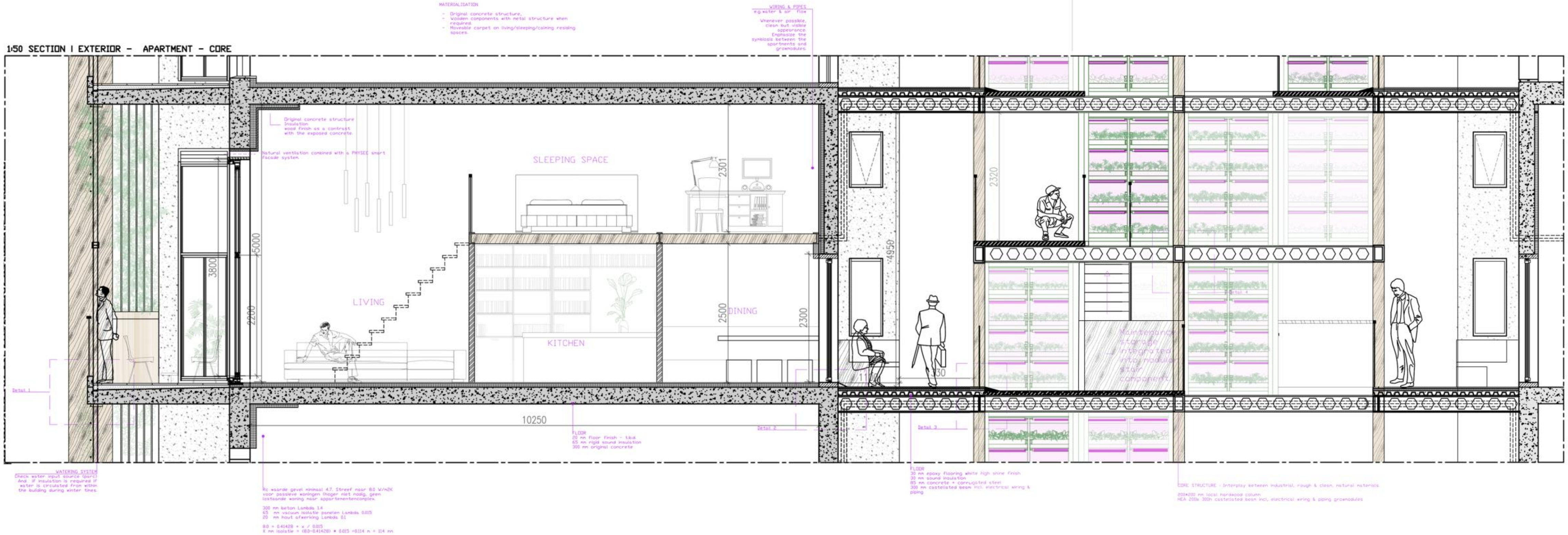


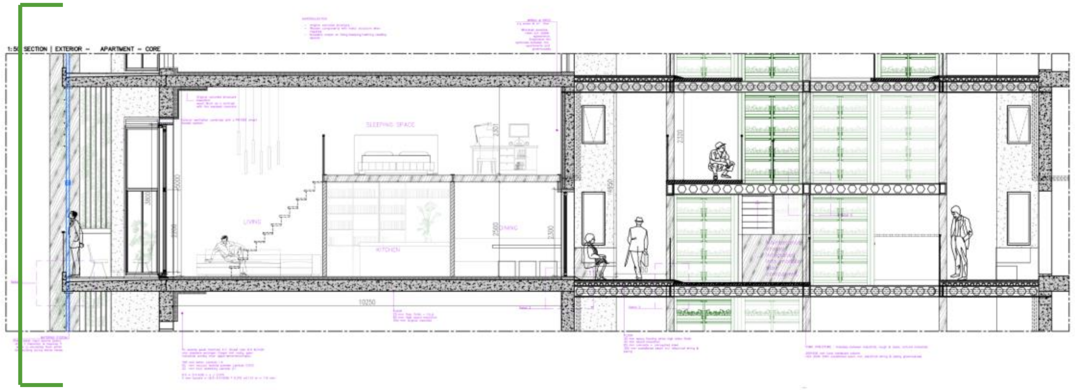


Growing
Cooking
Dining
Light

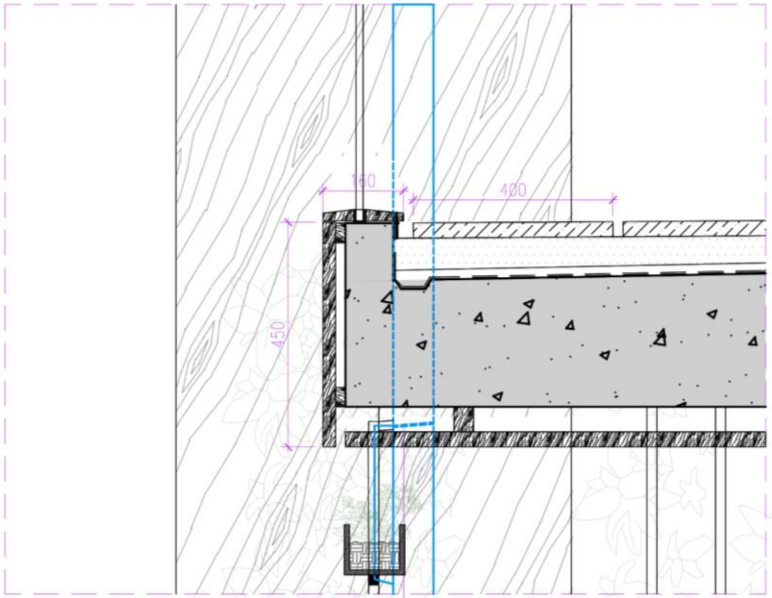
Circular food system



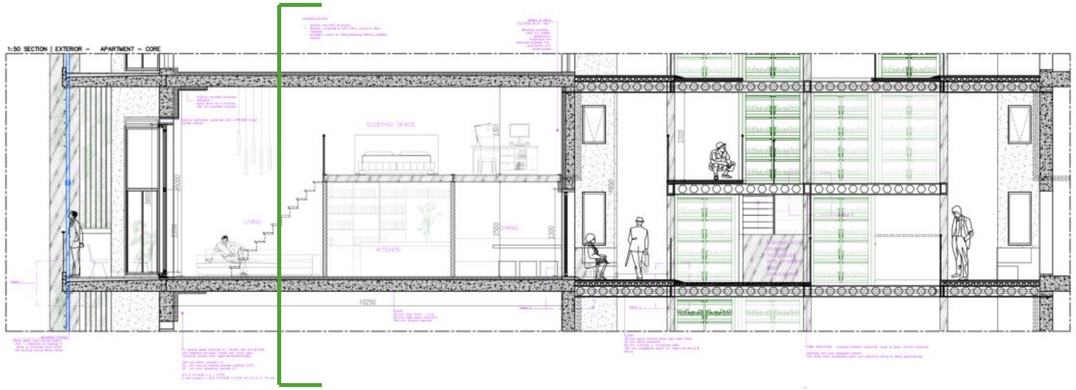

1:50 SECTION | EXTERIOR - APARTMENT - CORE
MATERIALISATION
- Original concrete structure.
- Wooden components with metal structure when required.
- Moveable carpet on living/sleeping/calming residing spaces.
WIRING & PIPES
e.g.water & air flow
Whenever possible, clean but visible appearance. Emphasize the symbiosis between the apartments and growmodules.
SLEEPING SPACE
LIVING
KITCHEN
DINING
10250
5000
3800
2200
2301
2500
2300
4950
2320



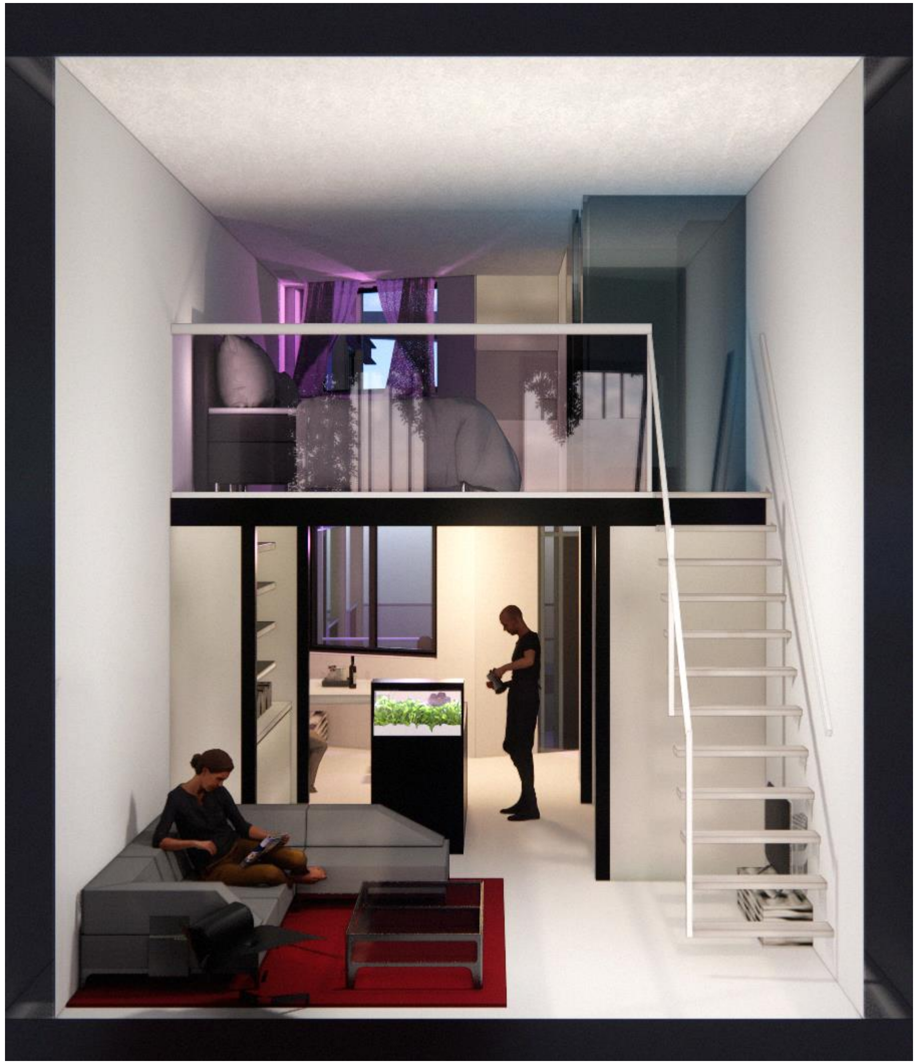
Terrace & rainwater drainage

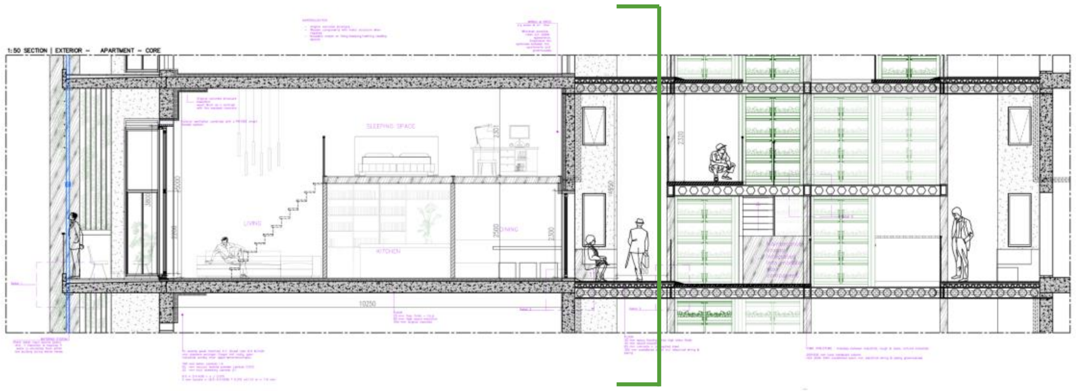


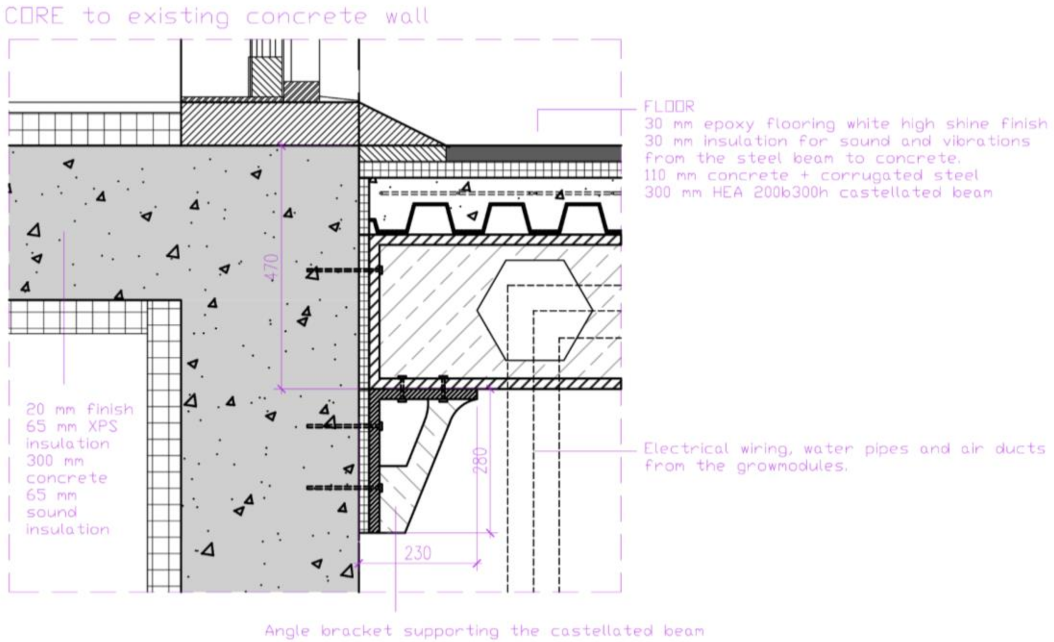
Watering system for facade planting.
Rainwater guided through downspouts, with a semi-permeable layer allowing water to flow into tubes that water the plants based on a dripping system.

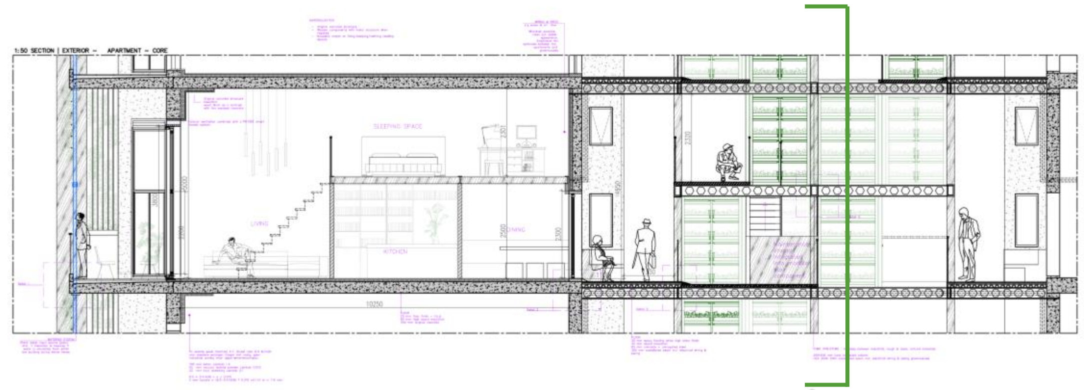


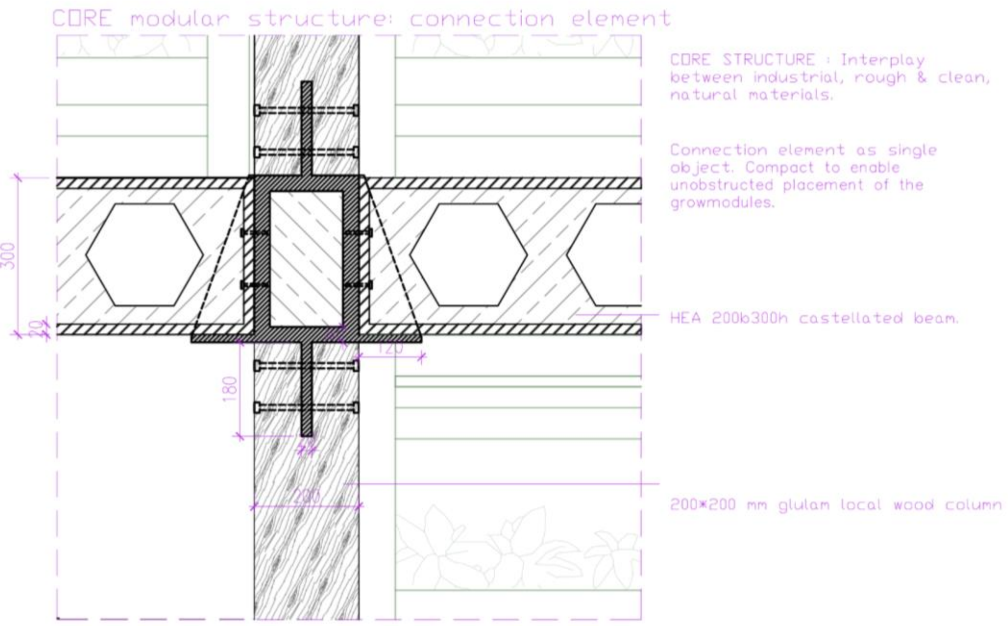
1:50 SECTION | EXTERIOR – APARTMENT – CORE
SLEEPING SPACE
LIVING
KITCHEN
DINING
10250

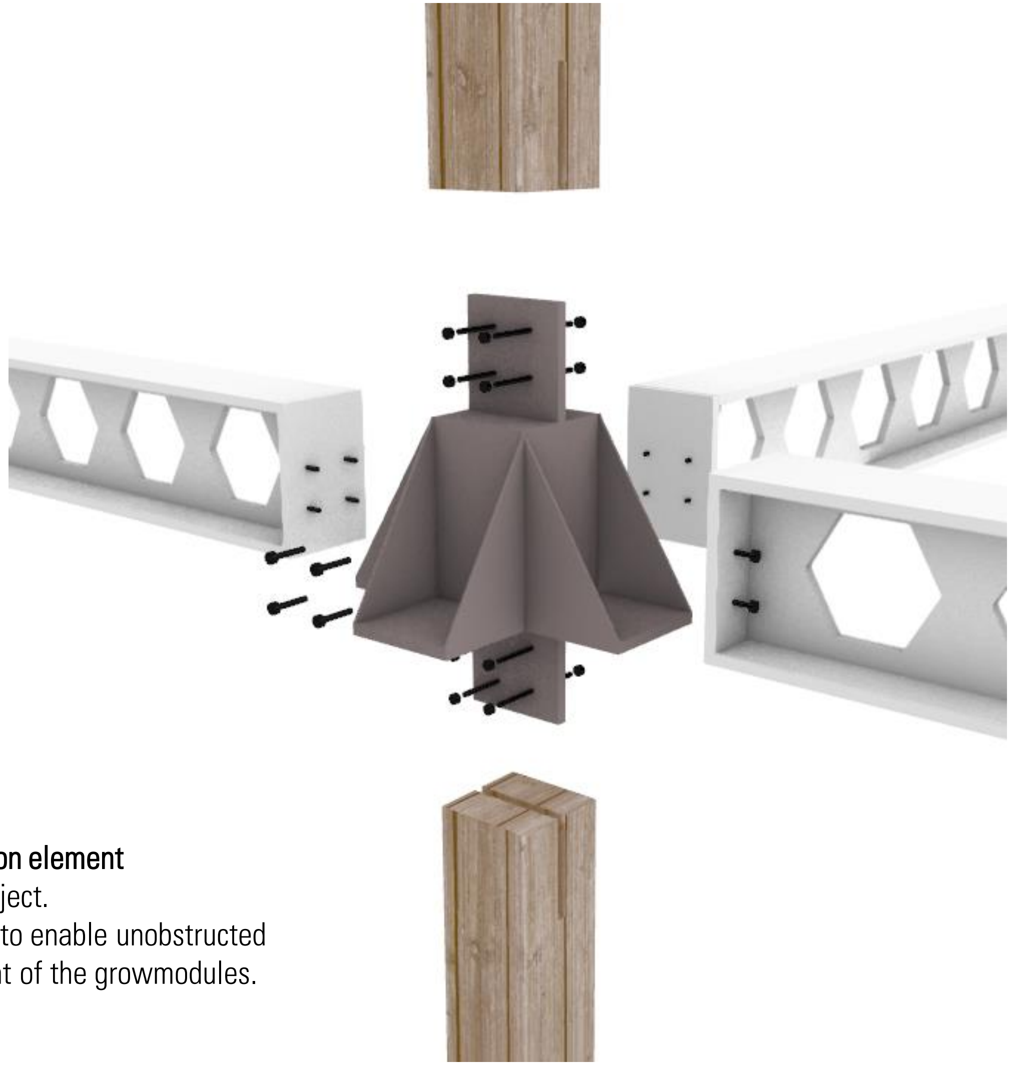





CORE to existing concrete wall
FLOOR
30 mm epoxy flooring white high shine finish
30 mm insulation for sound and vibrations
from the steel beam to concrete.
110 mm concrete + corrugated steel
300 mm HEA 200b300h castellated beam
470
20 mm finish
65 mm XPS
insulation
300 mm
concrete
65 mm
sound
insulation
280
230
Electrical wiring, water pipes and air ducts
from the growmodules.
Angle bracket supporting the castellated beam

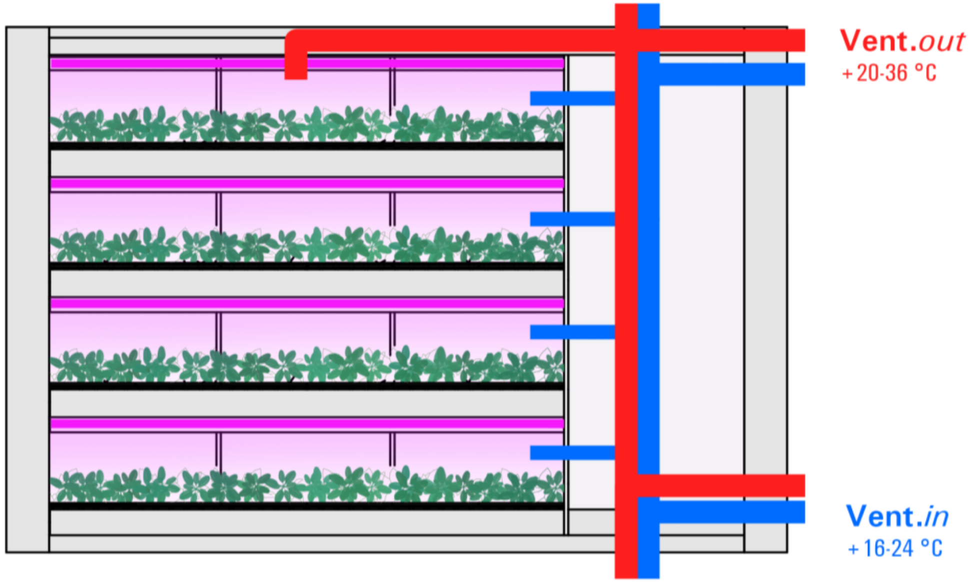




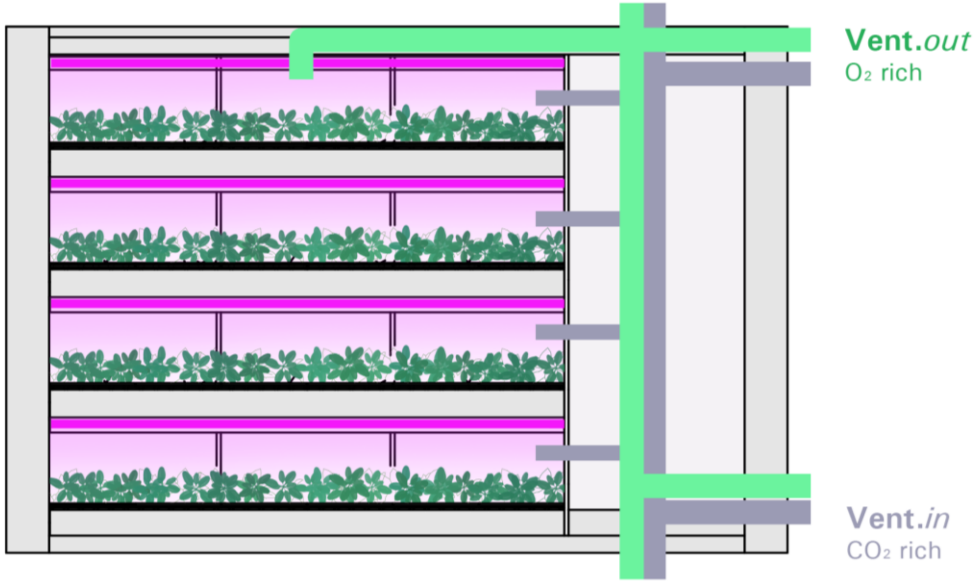


Connection element
Single object.
Compact to enable unobstructed placement of the growmodules.

CLIMATE DESIGN | Growmodule air circulation



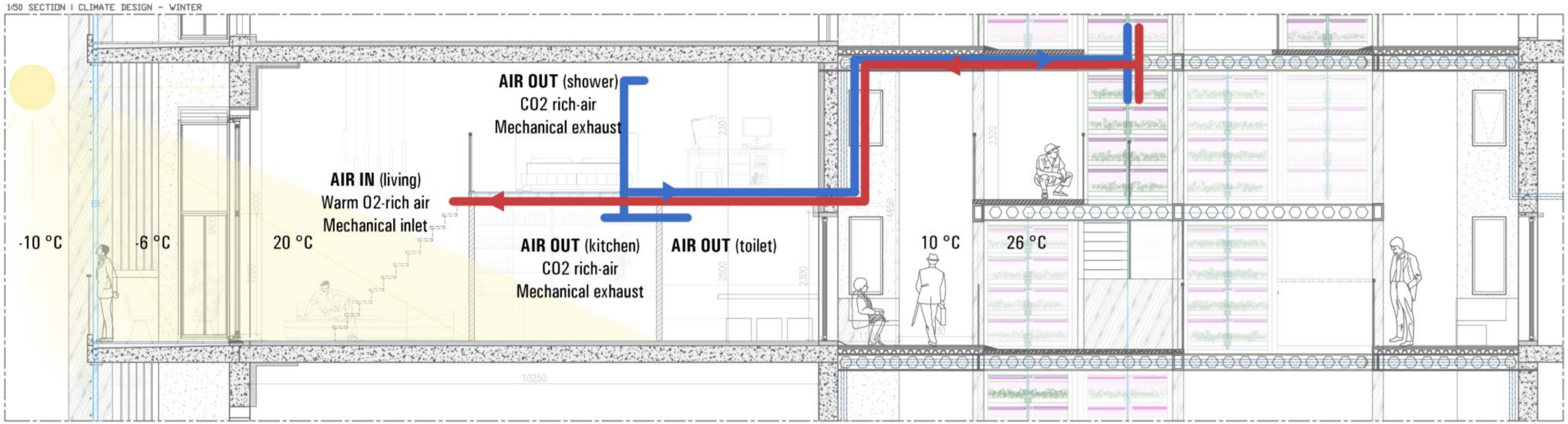
LEDs heat up air



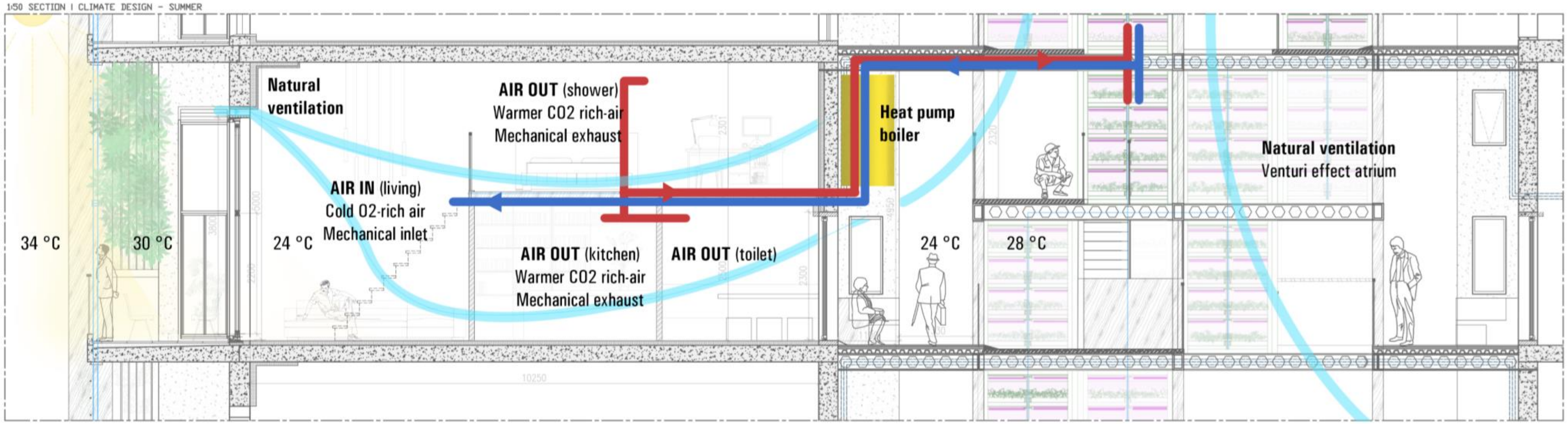
O_2 is lighter than CO_2

IN = cooler CO_2 rich air
OUT = warmer O_2 rich air

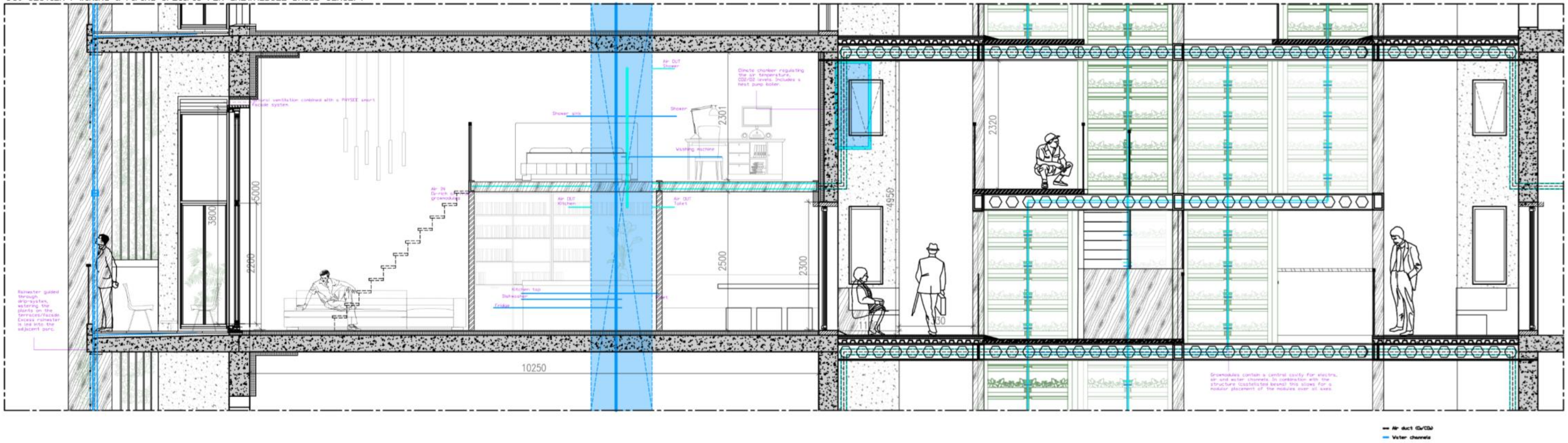
Winter
Extreme

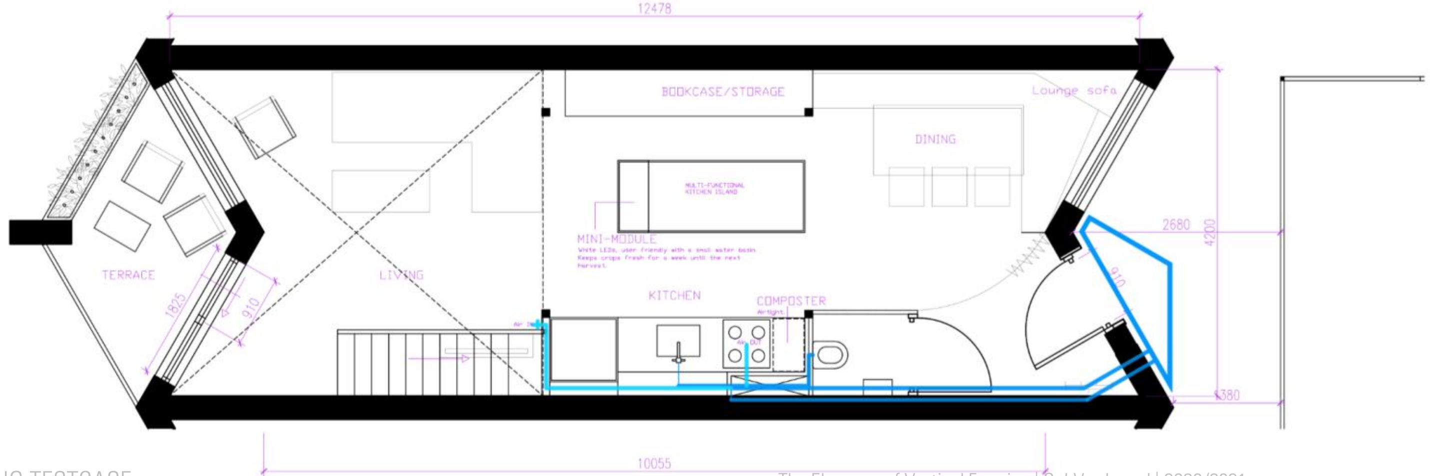


Summer
Extreme



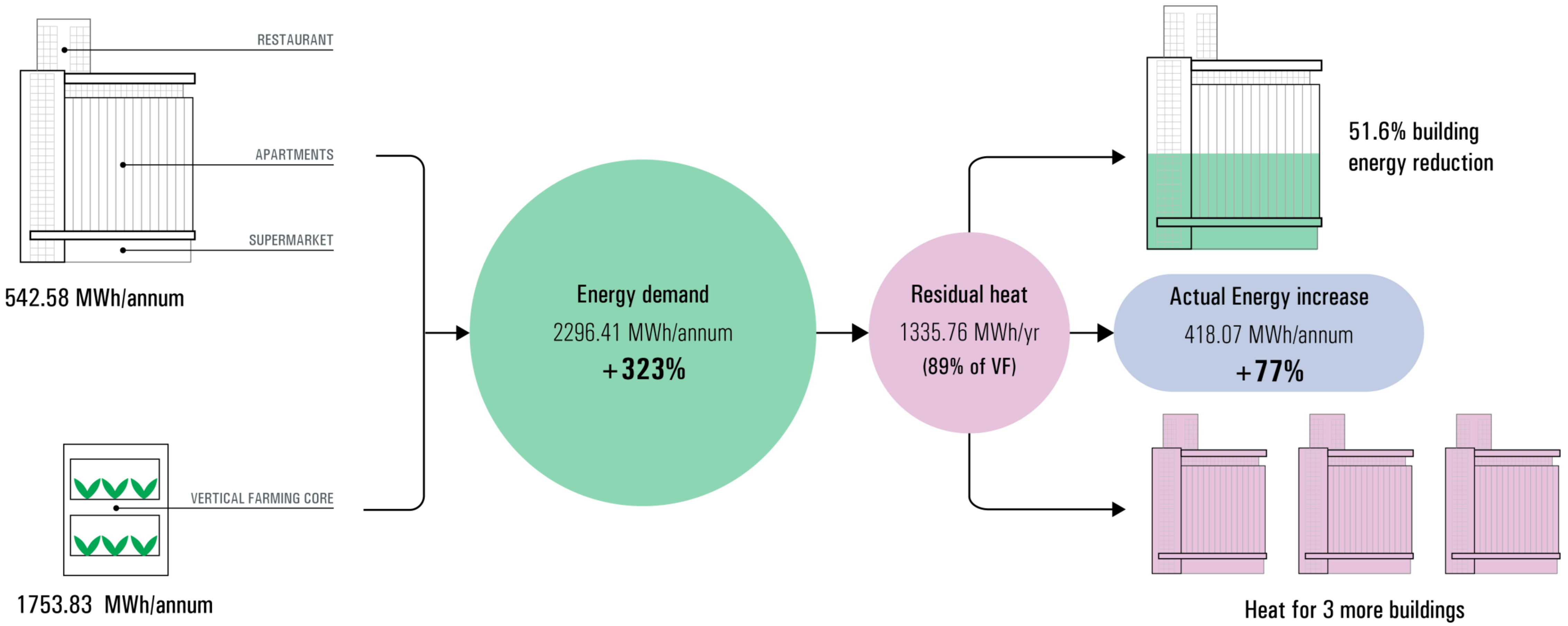
1:50 SECTION | WIRING & PIPING SPECIFIC FOR GROWMODULE-BASED CONCEPT





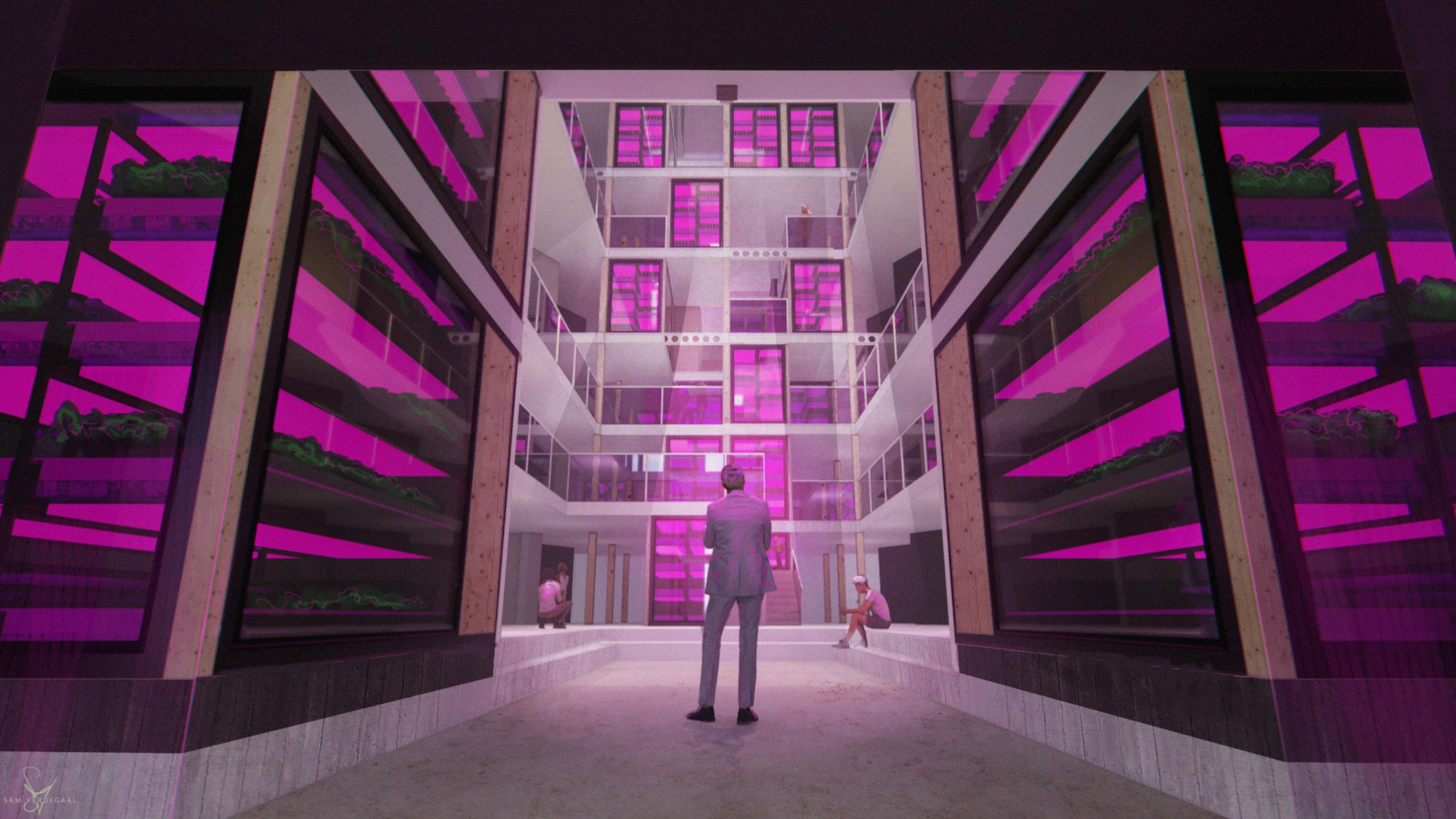
Placement of the water pipes and air ducts, focussed on maximising apartment height.

Energetic Symbiosis



Developed together with A. Jenkins & T. Blom for the
RAPS sustainability conference & Sky High NWO research project


SAM VERDEGAAL

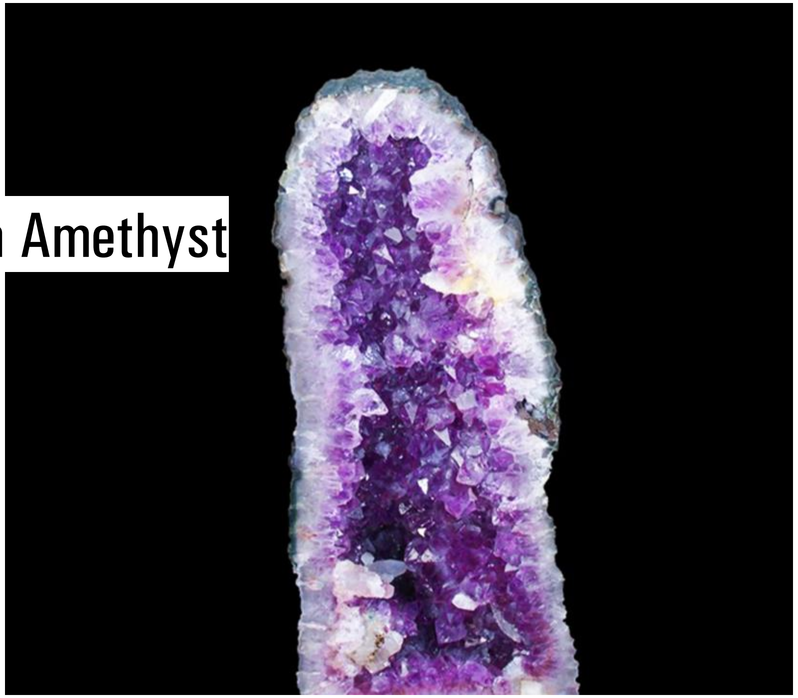

SAM VERDEGAAL


SAM VERDEGAAL

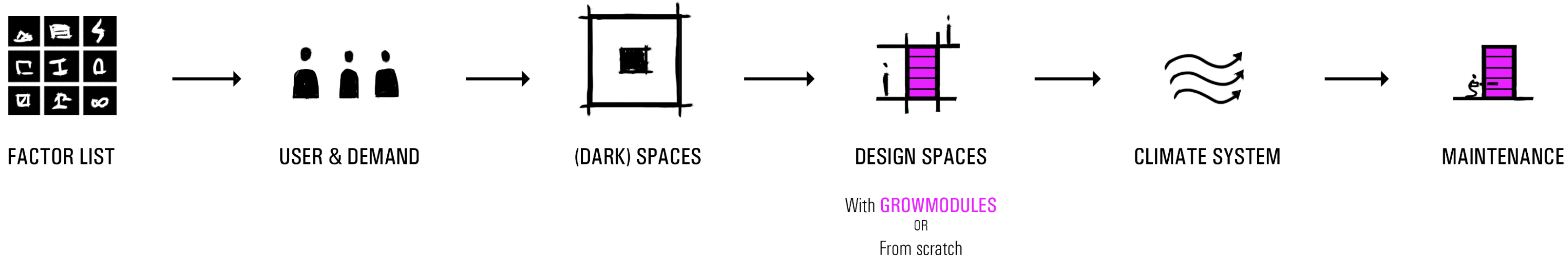

SAM VERDEGAAL

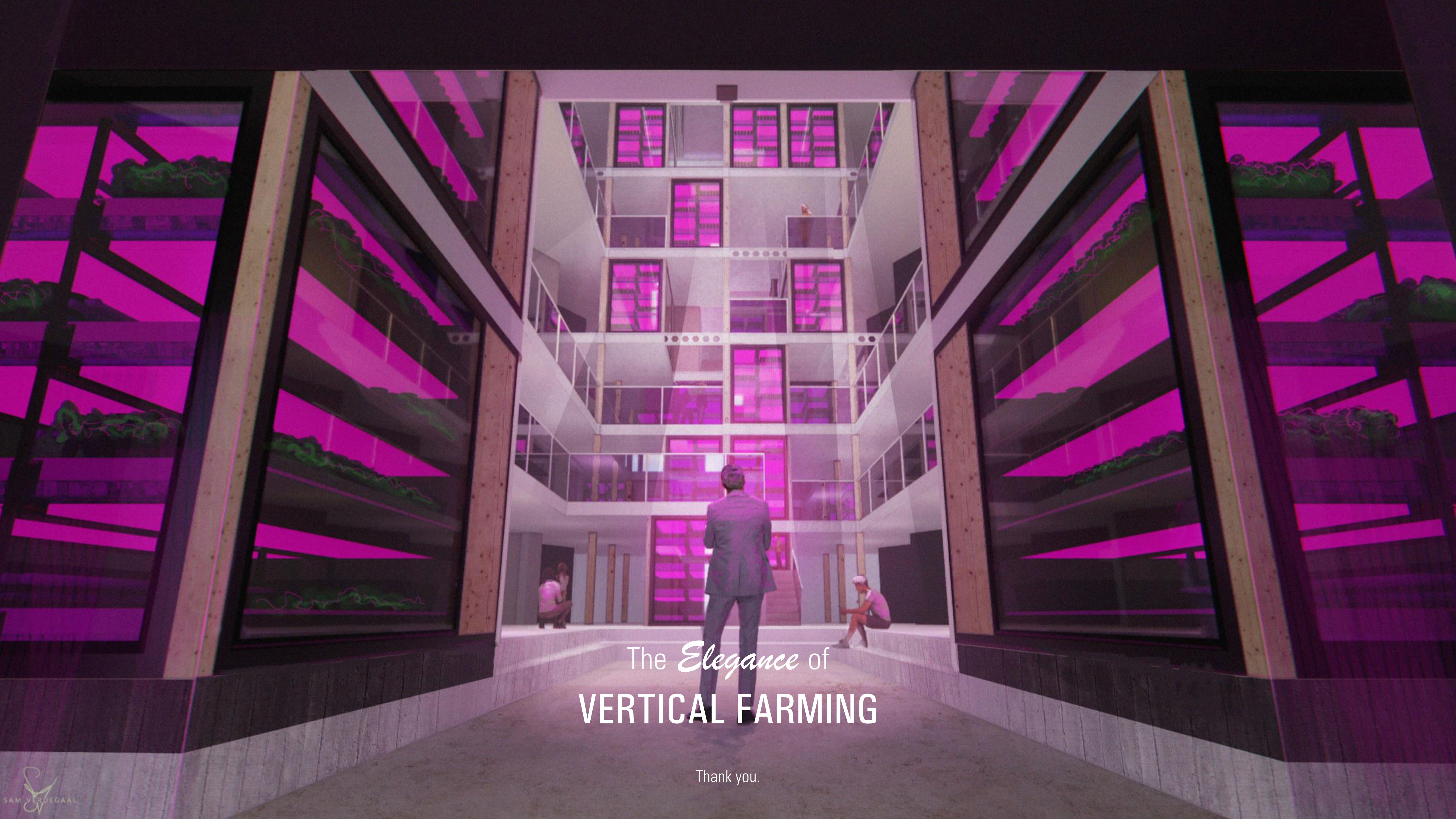
STRATEGY FOR FUTURE IMPLEMENTATION

The Urban Amethyst



Design approach Building Integrated PFAL in cities




The *Elegance* of
VERTICAL FARMING
Thank you.
SAM VERDEGAAL