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Exploring the opportunities for building a rooftop greenhouse

Case study from Bergen, Norway

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Anna Birgitte Milford, Signe Kårstad, Michel Verheul
Divisjon for matproduksjon og samfunn/Divisjon for kart og statistikk

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FORFATTER(E)/AUTHOR(S)

Anna Birgitte Milford, Signe Kårstad, Michel Verheul

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SAMMENDRAG/SUMMARY:

Å bygge veksthus på tak i byer kan ha flere fordeler. Redusert avstand til forbrukere gir ferskere varer og mindre kostnader og forurensing forbundet med transport og lagring. Dette er spesielt viktig for byer som ligger langt fra der maten produseres. Veksthus i byer kan også gi den urbane befolkningen muligheten til å lære mer om hvordan mat dyrkes. Ved å bygge veksthus på tak istedenfor på bakken spares arealer som i stedet kan brukes til jordbruk, grøntområder eller andre typer boliger. Et veksthus på tak som er integrert med den øvrige bygningen, kan også utnytte varmen fra etasjene under, noe som vil være energibesparende.

I stadig flere byer i verden bygges det veksthus på tak. En del av disse veksthusene er kommersielle og selger det de produserer gjennom supermarkeder, restauranter, egne butikker eller abonnementsordninger. Noen veksthus på tak er også bygget på universiteter og skoler og brukes i undervisning. De fleste av disse veksthusene bruker hydroponiske systemer for vanning og gjødsling av planter.

Men et veksthus på tak kan by på bygningsmessige utfordringer. Hvis veksthuset skal bygges på en eksisterende bygning som ikke er dimensjonert for en ekstra etasje, krever det at bygningen styrkes, noe som kan være kostbart. Andre forhold som vil øke kostnadene i forhold til et veksthus på bakken, er bygging av adkomst og integrering med øvrig bygning for utveksling av varme og luft. Det kan også være vanskelig å få tillatelse til å bygge et veksthus på tak i et bysentrum av estetiske hensyn og av hensyn til beboere i området og fordi reguleringsplaner angir et maksimum antall

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etasjer på bygningene i et område, som det kan være krevende å få unntak fra. I tillegg kan det også være nødvendig å betale leie for bruk av arealene veksthuset er bygget på.

For å kompensere for høyere kostnader kan et veksthus på tak generere inntekter gjennom større betalingsvilje hos forbrukere på grunn av ekstra ferske produkter, eller fordi veksthuset fremstår som et lokalt, miljøvennlig konsept som genererer arbeidsplasser i nærmiljøet. Andre aktiviteter som omvisning og undervisning kan bidra til å gjøre veksthuset til mer enn en kommersiell produsent. Direktesalg til forbruker gjennom egen butikk, abonnementsordning eller egen restaurant kan også øke inntektene fordi en større andel av utsalgsprisen tilfaller produsenten.

I dette prosjektet har tre forskere samarbeidet med en prosjektgruppe bestående av arkitekter, eiendomsselskap, gartnere, kokker og representanter for myndigheter, samt Bybonden i Bergen. Foreløpige resultater har blitt presentert og diskutert gjennom prosjektperioden. Det er utviklet en case studie basert på bygningen «Bontelabo» i Bergen sentrum, hvor det er gjort analyse av kostnader og markedsmuligheter. I tillegg er det laget en arkitekttegning av et veksthus på tak på dette bygget.

Prosjektet viser at det å bygge et veksthus på tak innebærer ekstra investeringskostnader sammenlignet med et veksthus på bakken. Men økt fokus på de sosiale og miljømessige fordelene med veksthus på tak kan både kan gi økte muligheter for investeringsstøtte fra for eksempel myndigheter, og økt betalingsvilje hos forbrukere for varer produsert i veksthuset. Dette kan gi bedre grunnlag for lønnsomhet. Med økt fokus på klimaendringer og ekstremvær kan vi forvente økt verdsetting av de fordelene veksthus på tak har både for miljø og for muligheter for byers muligheter til å produsere egen mat.

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KOMMUNE/MUNICIPALITY:	Bergen
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GODKJENT /APPROVED	**PROSJEKTLEDER /PROJECT LEADER**
Sjur Spildo Prestegard	Anna Birgitte Milford
NAVN/NAME	**NAVN/NAME**

Foreword

The project that this report is based on was financed by Hordaland Fylkeskommune (Hordaland County Council) and Fylkesmannen Vestland (County Governor of Vestland) as well as by Solheimsviken Næringspark and by in-kind contributions from TAG arkitekter, Toppe Gartneri, Bybonden i Bergen (the Bergen City Farmer), Bergen Kommune (Municipality of Bergen), Den lille Gartner, Stine Vikne Blomster and chefs from the restaurant Bare Vestland.

The project leader and main author of the report was Anna Birgitte Milford (Department of Economics and Society). She was aided by Signe Kårstad (Department of Agricultural Economics) and Michel Verheul (Department of Horticulture).

The aim of the project was to present relevant information about building and running a rooftop greenhouse. The project was implemented in collaboration with stakeholders in Bergen with relevant competence on this topic, in order to also build networks and create more interest for this type of project.

We would like to thank all the project members for their valuable contributions to this report.

Bergen, 05.11.19

Anna Birgitte Milford

Innhold

1 Introduction and methodology

Putting greenhouses on rooftops has several potential benefits. Mainly for the environment but also in terms of education and social interaction. But food producing rooftop greenhouses are still rather uncommon. There are not many in Europe, and in Bergen, Norway's second largest city, there are so far none. The inspiration to this project came from the idea that a rooftop greenhouse should be built in Bergen, providing the city with fresh, short travelled, sustainably produced vegetables, as well as a new and interesting construction. But the fact that such a greenhouse had not already been built in Bergen, and that there were so few in other places as well, led us to think that there must be certain challenges in constructing and running a rooftop greenhouse, and that it is important to provide all relevant information for anyone who should be interested in launching such a project.

This research project was led by three researchers: two economists (Anna Birgitte Milford and Signe Kårstad) and a plant physiologist (Michel Verheul). A Bergen based project a group was put together, consisting of people representing various trades relevant for a rooftop greenhouse project: A representative from a real estate company, two architects, three greenhouse gardeners, two chefs, one representative from the city municipality and one representative from the regional municipality, as well as the Bergen "City Farmer". The idea was to use Bergen as a case study, representing a city where a rooftop greenhouse could be built, and from the discussions around where and how to build it, we could learn about what would be the most advantageous manners of doing it, and the potential challenges that would be faced. The hope was also that this process could also help instigate a new project where an actual rooftop greenhouse would be built in Bergen.

The project group had 3 project meetings during the process, where preliminary results were presented and discussed. At one of the meetings an employee for the planning authorities at the municipality of Bergen was invited to present the laws and regulations relevant for the building of a rooftop greenhouse. In addition, we had two field trips in Bergen, to the greenhouse of Toppe Gartneri and to the rooftop garden of landscaper Svein Boasson A/S at Sandsli. A field trip to Berlin, Germany was organised in June 2019, visiting five different greenhouse and urban agriculture projects.

The work with the report started with a review of scientific literature, using primarily search engines such as Google Scholar and Web of Science. The next phase was to look at concrete examples of existing rooftop greenhouses, and gather relevant information about these, primarily from the internet. It became clear that rooftop greenhouses are a popular topic in the media, as many of the greenhouses were described in several articles in both popular and professional journals, newspapers, magazines, YouTube films etc. In addition to the information found here we also performed some interviews via telephone and e-mail to gather further information about some of the greenhouse projects.

The last part of the report is an economic assessment of the costs of constructing and running a rooftop greenhouse, using an existing building in Bergen as a case study. For this part of the study we use price estimates from greenhouse companies and a recently built greenhouse in Norway, as well as estimates of gross margin based on numbers from NIBIO and greenhouse cultivation advisors (Norsk Landbruksrådgivning).

2 Why build a rooftop greenhouse?

Previous studies have identified several advantages from building a food producing greenhouse on a rooftop in a city, instead of on the ground outside of the city. This chapter describes some of them.

2.1 Proximity to consumers

Having a greenhouse in a central, urban area close to where people live or pass by has several advantages. Reduced food transport means savings in both financial costs and CO2 emissions. The savings will be larger for cities that have little food production nearby, and therefore need to have food transported from far away. Likewise, financial and environmental benefits can be obtained because the energy needed for storing the produce, and possible also packaging, will be lower with production taking place near to the consumers (Al-Kodmany 2018). The proximity to the consumers also means that they will be provided with fresher products all year round, possibly leading to more consumption of healthy greens with a low carbon footprint. Closeness to consumers may also reduce the risk of contamination during transport and storage (Al-Kodmany 2018), and the shorter time span from harvest to consumption can also reduce the amount of food waste, which is also an important source of greenhouse gas emissions. Furthermore, temperatures in cities are on average higher than in the countryside, which is an advantage in periods of cold weather when greenhouses need heating. Another advantage of the urban proximity is the possibility to find urban waste sources to create soil or fertiliser for plants, including waste water from households.

2.2 Using rooftops instead of urban or fertile ground

The advantages mentioned in the section above could also have been obtained with an urban greenhouse on the ground instead of a rooftop. But in most urban areas the land availability is constrained, and there could also be soil contamination risks (Sanye-Mengual et al. 2018). Using rooftops could be a way of taking unexploited urban space into usage, instead of using some of the scarce ground level space. Using rooftops for food production also has the advantage that it could save fertile agricultural soil outside of the city, making the overall food production potential larger, or possibly reducing agricultural activities and instead restoring natural ecological systems for the preservation of biodiversity (Al-Kodmany 2018). With continuous, year-round production, greenhouses can generate high yields per m^2: According to Caplow (2009) each hectare of a recirculating hydroponic greenhouse has the potential to replace 10 hectares of rural land (Caplow 2009, cited in Specht et al. 2014). This could potentially become very important in an uncertain future with possible food scarcity because of population growth and loss of agricultural land due to construction and climate change.

2.3 Energy saving

When a rooftop greenhouse is integrated with the air circulation system of the building below, heat loss from the building can be used to heat the greenhouse, thus providing important savings in energy (Caputo et al 2017). It is also possible for an urban greenhouse to use residual heat energy from for instance a factory (Mejjer 2015, Freisinger 2015). Rooftop greenhouses also add an insulation layer to the building below, which reduces the heat loss from the building in the winter and protect against the impact of heat in summer (Specht 2014, Freisinger 2015). A study mentioned by Sanye-Mengual (2018) also finds that a rooftop greenhouse can possibly benefit from the CO2 generated from the building below.

In comparison with indoors container cultivation, which can have some of the same advantages as urban rooftop greenhouses (proximity to consumers and use of unexploited urban space), rooftop greenhouses require less energy as it can use natural light and do not rely entirely on artificial lighting the way container cultivation does.

2.4 Other advantages: less pesticide use, less vulnerable to extreme climate events, and education and social integration

Most greenhouse production today uses limited amounts of pesticides and relies instead to a large extent on biological pest control, such as predator insects. This could be an advantage compared to outdoor cultivation, where plants are more vulnerable to attacks from various plant diseases and harmful insects, and where chemical pesticides are more often applied.

Most rooftop greenhouses use hydroponic production systems, where plants are grown in water with nutrients, instead of soil. This has some advantages: there is less weight, which is especially important for growing on rooftops, as there is less weight for construction and transport to the roof, and it is also easier to install. With hydroponics it is easier to regulate the supply of water and nutrients to the needs of the plants, which results in higher yield. The product quality is also easier to regulate. When using recirculation there is also reduced water consumption. Finally, hydroponically grown plants have less problems with soil borne diseases.

With climate change and more extreme weather events such as droughts and hurricanes, greenhouses also have the advantage that they have irrigation systems and protect the plants behind walls and roofs, and they can therefore be important for food security. For example: after the Hurricane Sandy Gotham Greens rooftop greenhouse was the only fresh food provider in the New York area (Al-Kodmany 2018).

Another advantage of urban greenhouses is that they can give city dwellers the opportunity to see and experience how food is grown. This is important for the education of children and adolescents, but also to increase general knowledge in societies where most people are used to only seeing food as it looks like when purchased. A rooftop greenhouse can also contribute to a revival of the local economy and remove stigma from neighbourhoods (Al-Kodmany 2018). By making the greenhouse project not merely a business for profit, but also creating other benefits to the society such as knowledge and education, jobs in deprived areas and opportunities for social interaction, it is also possible to gain support from authorities, including financial.

3 Examples of existing rooftop greenhouses

Although they are not yet widespread and common, there are many examples of rooftop greenhouses which have been built in different places in the world. In this chapter we will present some examples of existing rooftop greenhouses in the US, Canada and Europe. A summary of some of the characteristics of the greenhouses can be found in table 1.

3.1 Lufa Farms

The first of the three Lufa farms greenhouses was built in Montreal in 2011 by the young couple Mohamed Hage and Lauren Rathmell, who have a background in information technology and biochemistry (Gutnick 2018). They rented the rooftop of a renovated two-story building designed to hold an additional floor that was never built. The total greenhouse area was 2900 m². Their second greenhouse was 4000 m² and was built on a warehouse under construction in 2013. Their third greenhouse is their largest, 5900 m² and built on an industrial building (Schwartz 2017).

For the first greenhouse, Lufa Farms managed to gather an investment of 2 million Canadian dollars (1,35 million Euros) from family, friends and others (Schwartz 2017). The two last greenhouses were built in collaboration with Dutch greenhouse producer KUBO and Belgian greenhouse automation experts, Hortiplan. The costs of the last greenhouse was estimated to 5 million Canadian dollars. This greenhouse was co-funded by Fonds de solidarité FTQ and La Financière agricole du Québec (Cision 2017).

The Lufa Farms greenhouses all use hydroponic production systems with rainwater from the rooftops. The systems' lighting and heating is "fairly automated" and controlled via apps (Swartz 2017). The greenhouses have an all-year production of a wide range of different vegetables: Tomatoes, eggplants, cucumbers, peppers, leafy greens, herbs and microgreens. All the produce is sold in food baskets to subscribing consumers in the Montreal area. Lufa farms collaborates with other local farmers in the area, which means that subscribers can also buy food products such as dairy, meat and fish through their system. Every week 10,000 food baskets are delivered either at one of the 300 pick-up points (for example cafés, yoga studios or pharmacies in Montreal), or at people's houses (Schwartz 2018).

The Lufa farms greenhouses are all integrated with the building below and thereby benefitting from the heat lost through its roof. Their web pages say that their greenhouses use approximately half of the heating energy of equivalent ground-level greenhouses. Because the greenhouses serve as protective buffers they reduce the buildings' energy needs, both for heating in winter and for cooling in summer, when the plant transpiration cools the air and reduces the heat island effect created by typical black tar roof (Lufa Farms 2018). In cold winter nights the Lufa Farm greenhouses use natural gas heaters.

Lufa farms offer free tours as organised events (open doors) several times a year.

Lufa Farms rooftop greenhouse Ahuntsic, built 2011. Photo: Lufa Farms

3.2 Gotham Greens

Gotham Greens is a fresh produce and food company offering a line of leafy greens, herbs, salad dressings and sauces. The company builds and operates ecologically sustainable greenhouses in cities across the United States, where it grows its year-round supply of produce for retail, restaurant and foodservice customers. With more than 46,452 m² of high-tech greenhouses under operation in five U.S. states by the end of 2019, Gotham Greens is one of the largest and fastest growing greenhouse producers of leafy greens in North America (Gotham Greens e-mail, 2019).

The company currently has six rooftop greenhouses in New York City and Chicago and ground-up greenhouses in Chicago, Illinois; Providence, Rhode Island; and Baltimore, Maryland. Founded in 2009 by Viraj Puri (CEO) and Eric Haley (CFO), the company opened its first 1,400 m² rooftop greenhouse in Greenpoint, Brooklyn, in 2011. Gotham Greens built its second 1900 m² greenhouse on the rooftop of a Whole Foods Market in Gowanus, Brooklyn, in 2013. Its third rooftop greenhouse is 5,600 m² and was built on an old toy factory building in Queens, New York, in 2015. In the same year, Gotham Greens expanded to Chicago and built a 7,000 m² rooftop greenhouse on top of the Method Products soap manufacturing plant in the historic Pullman district. The company will open three 9000+ m² greenhouses in Chicago, Providence and Baltimore by the end of 2019 and additional locations thereafter.

All of their greenhouse projects are financed by private funding (Bond street 2019). The greenhouses were built by multiple greenhouse system providers, including Nexus Greenhouses Systems from the USA.

Gotham Greens uses hydroponic techniques for cultivation, which enables the greenhouses to be 20-30 times more productive than field production while using 95% less water (Gotham Greens e-mail, 2019). The greenhouses produce mainly leafy greens (lettuce, herbs), which are packaged and sold to retailers and restaurants.

In a report to the New York State Energy Research and Development Authority from 2011, describing its first greenhouse in Greenpoint, Brooklyn, Gotham Greens writes: "*Due to site constraints, waste heat capture is not feasible at the site. The building has a relatively small space forced air heating system considering the size of the building i.e. 80,000 ft². Common areas of the building are rarely heated during regular work hours and the building is never heated on weekends and evenings when the building is not usually occupied. There are no hot water boilers in the building.*" (Gotham Greens 2011). Heat capturing is not mentioned on the company's Web site. The company has installed solar PV panels and LED lighting but relies mainly on sunlight and utilizes only a small amount of artificial lighting in its greenhouses, which it powers with 100 percent renewable electricity and some on-site renewable energy (Gotham Greens e-mail, 2019). Just like Lufa Farms, Gotham Greens operates computer control systems for climate control.

Gotham Greens greenhouse in Gowanus, Brooklyn, New York. Photo: Ari Burling, Gotham Greens

3.3 Sky vegetables

Sky Vegetables is a greenhouse with 743 m² growing space built on a residential, affordable housing building in Bronx, New York City in 2013. The construction was made in relation to a major refurbishing of the building. According to one the founders the idea was to introduce greenhouse farming method and its produce to the underserved community (Zeldovich 2018). The project is the result of a public-private partnership between New York City Housing Authorities, the Department of Housing Preservation and Development, a private development company and other organisations (Velsey 2013).

The greenhouse uses a hydroponic production system and produces herbs and leafy greens, of which a portion is distributed to the residents of the buildings or donated to local food. The rest is sold to the private market, mainly restaurants. The greenhouse has 4 full time employees (interview with Agrictecture Consulting).

The greenhouse does not rely on any artificial lighting except for certain areas of the farm in the winter time. It is only partially integrated with the heating system of the rest of the building and in order to keep the greenhouse warm enough in winter it became necessary to install an extra heater, which is driving up the production costs. But according to a consultant at Agritecture Consulting the facility was meant as a pilot to test the technology, and the aim of the project was not merely economic profitability, but also information and education. The project offers free tours every week for educational institutions.

3.4 Vertical Harvest Jackson Hole

Vertical Harvest is a greenhouse built next to a car parking garage in Jackson Hole, Wyoming, USA. It is a vertical greenhouse, not on a rooftop, which functions as three greenhouses stacked on top of each other, where each floor has its own microclimate (Havens 2017). The surface it is built on is 46 meters long and 9 meters wide, and the total greenhouse area is approximately 1250 m^2.

Jackson Hole is a small town of less than 10,000 inhabitants, but most of the area is protected as national parks, and the scarcity of available land for construction is driving the real estate prices up. Furthermore, the cold climate as well as the protected status means that most fruits and vegetables are transported from afar (Henderson 2015). One of the founders of the greenhouse project, who is today CEO, was architect Nona Yehia, and her incentives for creating the project seem to come to some extent from the wish to create a higher degree of food self-sufficiency for the town. Another important element of Vertical Harvest is that it uses an inclusive employment model, which means it provides jobs for developmentally disabled people in Jackson Hole. The project was financed by both private and public funding.

The cultivation method is hydroponic, with tomatoes and lettuce grown on different floors of the greenhouse. Mechanical carousels rotate the crops, which reduces the amount of lighting needed, balances artificial and natural light, and facilitates access to the plants (Havens 2017). The greenhouse is not integrated with any other building, and the environmental benefits compared to traditional agriculture are mainly from less waste of crops and less need for water and transport (Vertical Harvest 2019).

The products are sold directly from the greenhouse where there is an onsite retail store, which also sells locally crafted foods and gifts from around the area. They also sell to local restaurants, hotels etc. in Jackson Hole.

3.5 Sous les fraises

"Sous les fraises" is a private company founded by biologist Yohan Hubert in 2013, which today runs eighteen different roof gardens in the Paris area as well as one in both Lyon, Marseille and Annecy, France. The gardens produce a large variety of edible plants, grown organically. The company consists of a group of around ten collaborators with complementary skills: architects, urban planners, computer scientists, engineers, market gardeners and so on. In September 2018 they constructed their first rooftop greenhouse in a residential area in Paris. In this 400 m^2 greenhouse they cultivate mainly tomatoes (Hasse 2018).

In a phone interview Yohan Hubert explains that he and his company built the greenhouse mainly themselves without hiring a building company. This was hard work, especially as the building below had to be strengthened in order to hold the new greenhouse construction. The greenhouse is not integrated with the building below, and it is not heated artificially, nor does it use any artificial lighting. The tomatoes grow in bags of soil that that are being made by the company from urban organic waste material.

The produce of the greenhouse is mainly sold in the same manner as the produce from the roof gardens: in “pop-up stores” using available retail space near the cultivation place, at prices close to what they are sold at in ordinary supermarkets. Their produce from the greenhouse is also transformed into high value added grocery products. Some of the rarer plants are also bought by restaurant owners and chefs. “Sous les fraises” also organize workshops and awareness-raising events about ecology, open to the public.

Rooftop greenhouse in the 20th arrondissement, Paris. Photo: Sous les Fraises

3.6 Ferme Abbatoir

The “Ferme Abbatoir”, or BIGH (Building Integrated GreenHouses), is an urban agriculture project in Brussels, founded by architect Steven Beckers. The greenhouse has a total area of 2000 m^2 and was completed in 2018. The investment costs for the project were 2,7 million euros, which included 2000 m^2 external rooftop productive gardens (Gamberini 2018). It is built on the roof of a food market hall and according to their web page their heat pump captures heat, allowing year-long production, while offering refrigeration to the butchers and retailers’ cold rooms (BIGH 2019). The greenhouse herb area uses LED lighting for support to naturally exposed year-long production.

BIGH also uses aquaponics and has a closed system for fish farming where the water from the fish tanks’ biofilter is used for fertilising the greenhouse plants. The greenhouse is divided into two horticultural zones producing herbs and tomatoes. These products, and the fish, are sold via their web pages, as well as to retail and restaurants.

The project has two social partners, TRAVIE and Atelier Groote Eiland, who employ local disabled people. BIGH also offers tours to the public and the possibility to organise social events on the premises.

Ferme Abbatoir (BIGH) Brussels. Photo: BIGH ISOPIX

Table 3-1 Overview examples of rooftop greenhouses

	Lufa Farms	Gotham Greens	Sky vegetables	Vertical* Harvest	Sous les fraises	Ferme abbatoir
Where	Montreal	New York and Chicago	New York	Jackson Hole, Wyoming	Paris	Brussels
When built	2010	2011	2013	2016	2018	2018
Size of greenhouse	2900, 4000 and 5900 m^2	1400, 1900, 5600 and 7000 m^2	743 m^2	1250 m^2	400 m^2	2000 m^2
Type of building	Factory, mixed use commercial space	Toy Factory, Supermarket, Method Products manufacturing plant	Residential house	Not attached to other building	Residential house	Food market
Heat saving from integration with building	Yes	Partly	Partly	Not attached to other building	No	Yes
Type of cultivation	Hydroponic	Hydroponic	Hydroponic	Hydroponic	Soil	Aquaponic
Products	Vegetables, herbs, microgreens	Herbs and leafy greens	Herbs and leafy greens	Tomatoes and leafy greens	Tomatoes	Herbs, tomatoes, microgreens and fish
Sales methods	Subscription to food basket	Retail and restaurants	Residents (10%) and restaurants	Onsite store + restaurants	Mainly pop-up stores	Web shop, retail and restaurants
Other activities than cultivation	Tours/open house	Tours	Tours	Tours Employment of disabled	Tours	Tours, events. Employment of disabled

*Vertical Harvest is not a rooftop greenhouse, but still mentioned because of its interesting construction and business model

3.7 Restaurant greenhouses

There are also examples of restaurants with greenhouses integrated into their concept. One such case is Eli Zabar's vinegar factory in New York City, where four greenhouses are installed on the rooftop of a market place. Using waste heat from a bakery they produce greens, tomatoes, berries and figs year-round. The greenhouse employs two people who cultivate in soil made from composted organic waste from the food market (Carrot City 2019).

Another example is The Green House, a restaurant for 150 people which opened in Utrecht in 2018, and which has a 80 m² greenhouse on its first floor. The greenhouse is run in collaboration with the company Hrbs, who grow vegetables and herbs in carts that are lit up artificially. Hrbs supply trays of plants to The Green House greenhouse on a regular basis, and collects the empty trays when the plants have been used (Hrbs 2019).

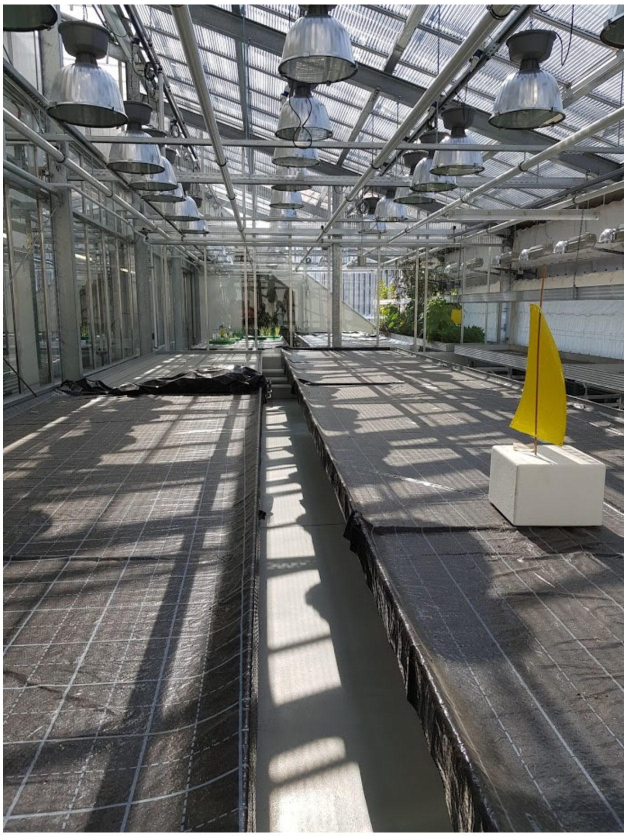
3.8 School and university rooftop greenhouses

In a number of cities there are examples of rooftop greenhouses built by universities for educational purposes. Examples of universities with rooftop greenhouses are Research Centre ICTA-ICP in Barcelona; Institute of Environmental Sustainability, Loyola University, Chicago; Department of biological science, Florida State University and Humboldt University, Berlin. We have also found some examples of primary schools with rooftop greenhouses: the Williamsburg's PS 84 in Brooklyn, and Manhattan school for children. Rooftop greenhouses built for educational purposes have the advantage that they are not so tied to the season, and the whole material cycle can be recreated and observed in a controlled setting (Freisinger 2015).

The Humboldt University rooftop greenhouse in Berlin was visited during the project field trip in June 2019 and has many interesting features. The rooftop greenhouse was built as part of a major renovation and reconstruction which was done at the university, on a building which was built in 1918 as a military- veterinary laboratory. According to Dr Bernard Grimm, the old university greenhouse, which was on the ground, had to give space to a new, taller building and the solution was to build a new greenhouse in the loft area of one of the old buildings. This loft area was not in use for decades, and it was to some extent in a state of decay. A greenhouse of 600 m2 was built in this loft area, divided into various compartments and smaller cabins. The walls facing the street were not replaced with glass, due to partial prevention of too much light pollution during night time for the adjacent residents. The roof angle of the loft was made slightly flatter, so that the height of the greenhouse area is somewhat higher than the original loft area. The construction costs went higher than expected, due to constraints and the need for a complete renewal of the roof because of wooden fungus in the entablature and asbestos. In total 2,1 million euros were spent on the project, and this included creating a new fundament/base plate for the greenhouse, as well as the renewal of the entire roof. According to Dr Grimm, the result has been "surprisingly good", and there are only a few technical problems today. A potential challenge is when outside repairs have to be made, as it will require someone to climb outside on the roof. The greenhouse is a classical research greenhouse (and not a show greenhouse), currently used mainly for basic research, but also for applied research. It is not used to cultivate crop plants for the harvest of fruits and vegetables, but mainly model plants (Arabidopsis thaliana, tobacco, tomato, and potato for research in molecular biology.

All the cultivation is on table tops with an ebb and flood system.

Humboldt University rooftop greenhouse seen from the ground below. Photo: A.B. Milford



Humboldt University greenhouse from the inside. Photo: A.B. Milford

4 Factors to consider when building a rooftop greenhouse

So far, we have only mentioned the advantages of rooftop greenhouses, and we have presented cases of existing rooftop greenhouses around the world that all seem to be doing pretty well economically. But this does not mean that building and running a rooftop greenhouse is easily done. The lack of more rooftop greenhouses in the world is a clear indication of that. Searching the web, one also finds a large number of drawings of urban greenhouse projects which never seem to have left the desk. Furthermore, one famous European rooftop greenhouse, Urban Farmers in The Hague, went bankrupt after running for a couple of years. Hence, both building and running a rooftop greenhouse profitably seem to have its challenges. In this section we look at some of these challenges and try to provide some advice.

4.1 Business model

Building a rooftop greenhouse requires large investments. According to e-mail correspondence with Kubo, the Dutch greenhouse producer who helped build two of the Lufa Farm greenhouses, a greenhouse is "easily 3 to 4 times more expensive to build on a rooftop and you can never get to the large scale as on the ground". One reason for the high investment costs is the need for strengthening the building so that it can carry the greenhouse, which often will be necessary. Furthermore, as pointed out by Al-Kodmany (2018), access to a rooftop greenhouse might impose logistical issues, possibly driving up investment and operational costs. A rooftop greenhouse might also imply land rent payment to the owner of the building, which can be significantly high, particularly on more central locations.

For a rooftop greenhouse to run profitably it is, as with any greenhouse, important to minimize production costs and maximise income by running efficiently with low use of energy, labour and other inputs and high yields per m^2. The reduced need for transport can to some extent lower the total costs, as is for instance the case with the Gotham Greens greenhouse located on top of a Whole Food Market in Gowanus, Brooklyn, New York. But transport costs generally do not constitute a large share of total costs. It may be necessary for the greenhouse to have incomes that will compensate for the extra investment and running costs. The freshness of the produce, and the possibility to produce rare varieties of products that are not available in ordinary supermarkets, may generate a higher willingness to pay among consumers and restaurant chefs, and hence a higher price (Milford et al. 2019). According to the beliefs of one of the chefs in the project group, restaurants in cities with a cold climate like Bergen who are branding themselves with locally produced ingredients on their menu have a problem in the winter season, when the only locally produced vegetables available are root vegetables. Fresh tomatoes, cucumbers and lettuce locally produced in a rooftop greenhouse could therefore be highly valued by these restaurants.

A rooftop greenhouse may also give the harvested food an interesting story generating extra value for consumers, whether they are purchasing it directly or from a restaurant. A higher willingness to pay can possibly be generated if the rooftop greenhouse manages to brand itself as a sustainable alternative to products arriving from far away, providing job opportunities for the local population, as well as education about plant production from greenhouse tours etc.

Cutting links in the supply chain is another way to increase incomes, as some of the case study greenhouses do by selling directly to consumers in food baskets schemes or their own stores or restaurants, instead of through retail and other restaurants. Having a greenhouse store or a food basket scheme could require, as is the case with Lufa Farms and Vertical Harvest, also selling other products than only what comes from the greenhouse, in order to have a larger variety to attract customers.

The choice of products is an important part of a business model. Rooftop greenhouses generally produce lettuce, microgreens, herbs, tomatoes, cucumbers, bell peppers or eggplants. If the plan is to sell directly to consumers through a shop, restaurant or food basket scheme, one might need to have a variety of products. But different plants have different requirements regarding building height and temperature: for instance, tomatoes need both a higher temperature and a higher ceiling than lettuce and microgreens. Producing different varieties of plants will require that the greenhouse is divided into different sections, or that several different greenhouses are built, and this drives both investment and operational costs upwards.

During the group meetings of this research project, there were discussions about the possibility to operate a commercial rooftop greenhouse business and to generate an extra willingness to pay if the product is sold through the mainstream supermarket chains in Bergen. The example of Gotham Greens, which sells produce and fresh food products to retail and restaurants, proves that this type of business model is possible for urban greenhouses. During the field trip to Berlin the project group also visited ECF Aquaponic Farm system, a greenhouse situated in the centre of Berlin, who produces basil plants and fish, selling it to one of the main supermarket chains in Berlin. In the case of ECF and Gotham Greens, the companies' products are clearly branded and distinguishable from other similar products, with information about the sustainability qualities of their products, which might be enough to generate a higher willingness to pay.

4.2 Rooftop greenhouses for residents

In the literature on vertical farming and rooftop greenhouses there is little information about greenhouses built on top of residential buildings where the residents are responsible for cultivation and share the harvest between them. Among our examples of rooftop greenhouses there are two built on top of residential houses (Sky Vegetables and Sous Les Fraises), but these are run by companies with mainly commercial purposes. In the case of Sky Vegetables, the greenhouse practices an open-door policy for the people in the building. According to Agritecture Consulting this type of interaction between residents and greenhouse is "easier said than done", it takes time and it has to be done right with the community in mind, and integrating it into a project requires that the related costs are included in the budgets.

A Master thesis from the Netherlands gives several examples of greenhouses where the consumers themselves are responsible for the cultivation, more or less in the manner of allotment gardens where people harvest what they grow (Bros 2017). These types of communal cultivation greenhouses are also similar to allotment gardens in the sense that not only food production is in focus, but also the social values of meeting people while cultivating, as well as the learning process on how to grow food. However, these greenhouses were neither on rooftops nor newly constructed, and they were cultivating in soil instead of using more advanced technology such as hydroponics. When a greenhouse is using hydroponics, such as Sky Vegetables, not only will the investment costs be much higher than with soil cultivation, but expertise knowledge and surveillance is necessary, making the participation of ordinary people more difficult.

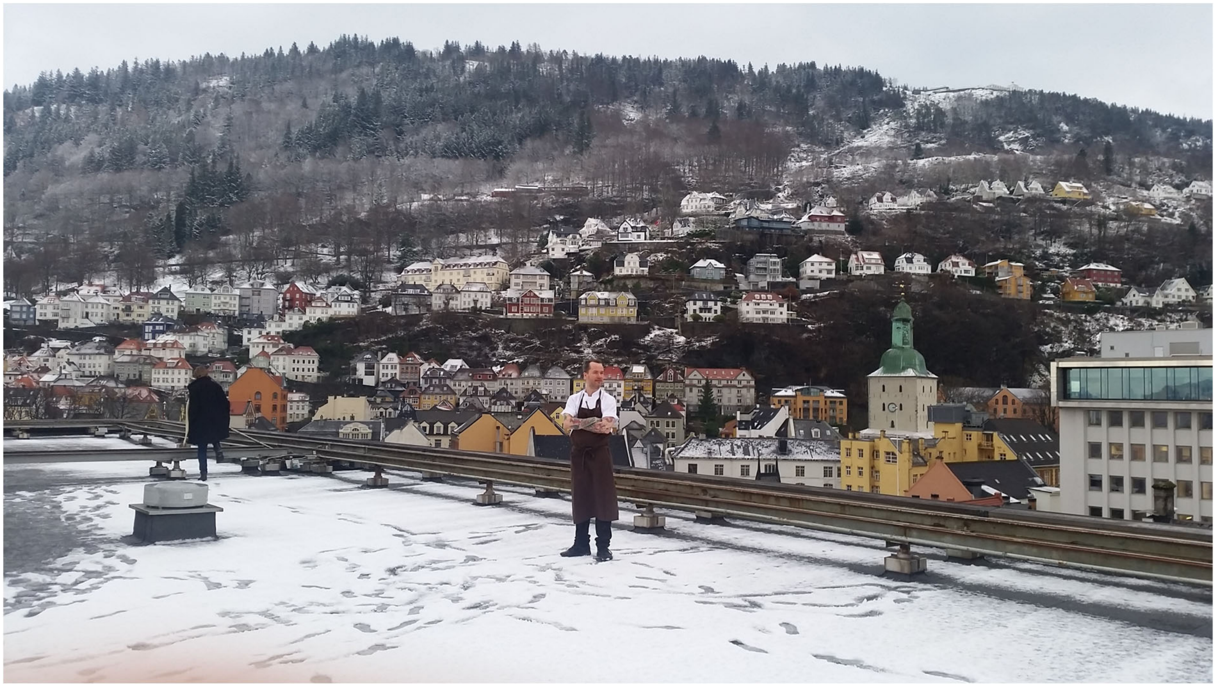
Although rooftop greenhouses for residents of the building are seemingly very rare, we have come across some examples. One is the Augustenborg residential building in Malmø, Sweden, and there is also a rooftop greenhouse at the Leopold residence hall of the University of Wisconsin-Madison, USA.

4.3 Suitable areas for building a rooftop greenhouse

In order to benefit from reduced transport needs a rooftop greenhouse should be located close to consumers. But most greenhouses will rely on certain inputs which need to be delivered; hence industrial areas or retail parks at the outskirts of a city can also have advantages. These are often well connected to infrastructure, trucks have easily access, and for a greenhouse selling to retail and restaurants it can be an advantage to be situated near a food distribution centre, typically located in such an area (Sanyé-Mengal et al. 2015). Sanye-Mengual et al. (2018) recommend rooftop greenhouses to be built in retail parks with supermarkets, as they often have buildings with large flat roofs, and the product could then be sold directly from the supermarkets.

The most suitable area for the construction of a greenhouse will, at least in the case of Bergen, depend largely on the local urban planning legislation. These legislations give for instance restrictions to building height, and, according to the planning authorities in Bergen, if a greenhouse is built on the rooftop of a house the legislation will be the same as for an extra floor was built on that house. However, the legislation is different for different areas of the city, and typically stricter for instance in the historic centre, where aesthetic concerns are more important than in a more industrial area at the outskirts of the city. In the case of Bergen, where the centre is surrounded by mountains from where people can enjoy a view of the city from above, it is particularly important how the building structure is valued from an aesthetic point of view. The visual qualities of a project will be estimated by the planning authorities.

The urban planning authorities are reluctant to let industry into residential areas, to avoid conflict with the aim of creating a pleasant living environment for the inhabitants. Light or noise pollution from a greenhouse could become a nuisance for the neighbours. For that reason, a commercial rooftop greenhouse will more easily be allowed built in an industrial or commercial than a residential area.



A chef in the project group on one of the rooftops in centre of Bergen. (Photo: A.B. Milford)

4.4 Suitable buildings to for a rooftop greenhouse

Several factors need to be considered when choosing the right type of building for a rooftop greenhouse. One of these is that the roof should be sufficiently exposed to the sun and not in the shadow of other, taller buildings (Freisinger 2015). This is particularly important in a city as far north as Bergen, where winter days are short.

Another important factor is the capacity of the building to carry a greenhouse on its roof, which can depend on the building material, and the age of the building. If the building dimensions are not right, extra strengthening of the existing building structure is necessary. According to Sanye-Mengual et al. (2018) buildings made of concrete are more resistant than buildings made of metal sheet, and therefore more likely to accomplish requirements for building a rooftop greenhouse. Another consideration is the wind load, which becomes bigger the higher the building is, requiring particular attention to the robustness of the greenhouse and its connection to the existing building structure. The potential load of snow is also important to consider.

For a commercial greenhouse of a certain size, the most advantageous type of building is one with a large, flat roof. However, the case of the Humboldt University greenhouse shows that it is also possible to build greenhouses in old buildings with pitched roofs, by putting the greenhouse in the loft areas. It is difficult to construct very large greenhouses in this way (the Humboldt greenhouse is 600 m^2) which makes it more difficult to obtain economies of scale, but on the other hand legal permissions can be more easily obtained because the greenhouse is only replacing an already existing construction. It might also already have access via stairs and elevators, and the necessary capacity to carry a greenhouse, which means that expensive upgrading of the building, may not be necessary.

Building the greenhouse on top of a house that is being built, and not an already existing one, has the advantage that the building will from the start be built strong enough to carry the greenhouse, and it will also be easier to integrate air circulation for heat and CO_2 exchange between building and greenhouse, as well as to make constructions for access to the greenhouse via elevators and stairs.

The case study greenhouses presented here were mainly built on top of existing buildings, but in the case of some of the Lufa farms greenhouses and Sky vegetables, the rooftop greenhouses were constructed in relation to major restorations of the buildings that were anyway taking place. This has some of the same advantages as constructing a completely new building.

However, the building company and architects in our project group pointed out that when constructing a rooftop greenhouse on a new or existing building, the planning legislation will put a limit to the number of floors a building can have. The constructor might find it more profitable to construct an extra floor for other commercial use, such as offices or residents, instead of a greenhouse.

4.5 Legal questions and public acceptance of the rooftop greenhouse

In any area, urban as well as rural, permissions from authorities must be given before a greenhouse can be constructed. The planning authorities make sure that a city is developed in the way most beneficial to society. Paragraph 11 of the Norwegian Plan and building law states: “The law will promote sustainable development for the benefit of the individual, society and future generations”. Although rooftop greenhouses may have many advantages, it may not be popular among the people living in the area. In April 2018 Le Parisien writes about a group of neighbours protesting against the construction of a rooftop greenhouse outside their windows, by blocking for the construction workers (Le Parisien 2018). The planned greenhouse of 1500 m^2 was given permission by the maire of Paris to be built in a residential area, but the neighbours complained to the administrative court.

Permission to construct on a rooftop may be difficult to obtain because the building in question is listed as worthy of preservation, for historical reasons or because it has special features and characteristics. The visibility of the new greenhouse will also matter, and whether or not it fits in aesthetically with the landscape of houses around it.

When existing regulations do not allow for a rooftop greenhouse, for instance because of restrictions regarding the number of floors to the building, it is possible to apply for an exemption. In such cases the authorities will weigh the advantages of the greenhouse, such as greater food self-sufficiency, creation of local jobs and a place for education and socialisation, against drawbacks such as neighbours losing their view or light pollution. If the greenhouse has social purposes such as education, the authorities might claim that it should have access for wheelchairs. If the greenhouse is not integrated with the building below but placed on top with the possibility to remove it, exemptions to the law can be more easily given, as it can be given temporarily for a limited number of years at the time.

The greenhouses which have been looked at in this project have all had their prime focus on functionality, but it is possible to imagine an urban, food producing greenhouse where aesthetic values are at the forefront. There are many examples of greenhouses with strong visual qualities, for instance in old botanical gardens. A modern example is the greenhouse of the Bombay Sapphire gin distillery in Hampshire, UK, described on many architect and tourist internet sites on the internet and praised for its curves and Art Nouveau style. According to the information on these sites the greenhouse uses surplus heat from the distillery and grows exotic plants for the gin production. Clearly, a greenhouse project with strong aesthetic qualities will be far more costly than a more ordinary one, but it could also become a landmark in an urban area, an interesting place for people to come and see, and perhaps help build an image of a green, environmentally concerned and progressive city, inspiring both its citizens and visitors. It could therefore be in the interest of the authorities to have such a greenhouse built. However, the aesthetic qualities of such a greenhouse must be balanced with its functionality and its ability to produce efficiently, which would be a challenge that architects and biologists would need to solve together.

Other factors that will involve the authorities are questions of using piped water, and waste water management. According to the Bergen planning authorities, if a hydroponic greenhouse is connected with the municipality's water network they will want to know about it, and they will want to know if the waste water from the greenhouse can be let directly into the municipality network, or if it needs to be cleaned first.

5 Explorative case study from Bergen

Bergen is a city of approximately 282 000 inhabitants in the west coast of Norway. Its location is by the sea, but the landscape is rocky and mountainous, and the municipality has relatively little agricultural land. The climate is not particularly favourable for plant production, with more than 2000 mm of rainfall per year. Presently there is hardly any commercial vegetable or potato production in the municipality, and also not in the surrounding municipalities, apart from some small-scale farmers selling directly to consumers. There are also hardly any food producing greenhouses in the area. Most of the city's berries and vegetables are therefore transported from other places, and since the harvest season in Norway is short, most of the year much of it is imported. Hence, an urban greenhouse would be beneficial for Bergen as it would reduce transport emissions and provide the population with fresh vegetable products.

Compared with North America, where rooftop greenhouses have had success, Bergen has the advantage that the winters are less cold because of its coastal climate and the golf stream. The disadvantage is that winters are darker because it is nearer to the polar circle, and year-round production without artificial lighting would be impossible.

A rooftop greenhouse can be built in many areas of the city. The most central areas pose some challenges because of historical/aesthetical values and limitations to number of floors on existing buildings. But as shown with the case of Humboldt University in Berlin, it is also possible to use loft areas on old buildings to construct rooftop greenhouses. There are also plans for major new constructions in some of the central districts of Bergen, such as Mindemyren immediately north of the centre, and on a more long term perspective there will also be constructions in the Dokken district at the harbour. New constructions are also made in the districts further away from the centre, such as Åsane, Fana and Fyllingsdalen. Having a rooftop greenhouse near the main fruit and vegetable warehouse in Arna is a possibility that could have some logistical advantages.

In this part of the report we have chosen a specific building in Bergen as a case study for a rooftop greenhouse project: Bontelabo in the city centre. Through the case study we will learn about the different factors that must be considered when projecting rooftop greenhouses, including regulatory barriers, investment costs, choice of business model and potential profits.

5.1 Description of case study: Bontelabo

Bontelabo is a very small area in the harbour of Bergen, very near, but not in the middle of the centre of the city. There is only one main building structure in the area, which used to house Europe's largest freezer, used for fish. Next to the freezer there is a lower building with offices and a parking lot on the rooftop. The freezer was turned off in 2011, and the real estate company GC Rieber AS is planning for new use of the buildings. The plans are to turn the taller freezer building into a hotel, and in the lower building there will be galleries, shops, bakeries, cafés and restaurants. One of the plans for the rooftop is to turn it into a park and recreation area.

The total area of the parking lot on the rooftop is 3400 m^2. The building is not regulated for having an extra floor on the rooftop and building a greenhouse on top of it would require getting an exemption from these regulations from the Bergen municipality. The building is not in a residential area, which speaks for increased likelihood of getting the exemption. Furthermore, the building itself is not old with particularly important historical values. But it is situated in a historical area, near one of the oldest buildings in Bergen, Håkonshallen, a stone castle from the 12^{th} century, which could argue against new, large, dominating, modern building structures in the area.

The present plans for the building includes both a glass blowing workshop and a bakery, which both generate excess heat that could be canalised into the rooftop greenhouse, saving energy in the cold months of the year. Examples of other greenhouses in the world are benefitting from heat generating industries are L'Abbatoir in Belgium, Eli Zabar's in New York and Lufa farms in Montreal. Another possibility is to use excess heat from freezers, if this is to be installed in the building below.

Case study building at Bontelabo. Photo: GC Rieber Eiendom

5.2 Possible business models for a rooftop greenhouse in Bontelabo

There are several business models that may be used for a rooftop greenhouse at Bontelabo. On the one side, there is the business model of a greenhouse gaining its profits only from what is harvested at the greenhouse and maximising the yields. With such a model the greenhouse will be built on as much as possible of the rooftop area, to gain from economies of scale. It will be built with standard greenhouse measures and material, as this will maximise yields and minimize construction costs. Choosing only one type of product (for instance only tomatoes) will have advantages in terms of minimizing technical, knowledge and labour costs related to climate, temperature, CO_2 levels, artificial lighting, growth medium and fertilising, as this will then be specialised and the same in the entire greenhouse. But there could be reasons related to market opportunities and customer willingness to pay, which could outweigh the potential extra costs of having more than one variety. In such a case it might be more beneficial to have several different types of species, such as tomatoes, cucumbers and lettuce or microgreens.

On the other side of the spectre there is what we could call a multifunctional business model, where yield from the greenhouse is only one of several income sources. A greenhouse run with a multifunctional business model also aims to be profitable, but profits will also come from activities such as guided tours, education, social events, serving food from a restaurant, in addition to yields from the greenhouse.

Looking at the existing greenhouses we have presented earlier, Gotham Greens is perhaps the one that is closest to a pure, yield maximising business model. The others have more elements of multifunctionality, creating arenas for social interaction and other values such as job opportunities for disabled citizens.

5.3 Economic assessment

The costs of constructing and running a rooftop greenhouse relies on a number of factors such as wind conditions, access to rooftop, utilization of waste heat from the building below, costs of strengthening the building below etc., and it is not possible to estimate exact numbers for economic profitability. However, in the following we will provide a broad estimate of the costs of building a 1 000 m^2 greenhouse on the roof parking lot of Bontelabo, highlighting the uncertain factors. We will also assess the running costs and the total gross margin, as well as energy sources and marketing.

5.3.1 Construction costs

When building a greenhouse there are costs related to the structure (the framework, the covers and the floor) as well as costs for the specific technical inputs/equipment chosen. This will be addressed in the following.

For the construction cost estimates we will use two examples, one is a greenhouse which was constructed on the ground for NIBIO at Særheim, Jæren, in 2018, the other is an estimate provided by the Dutch greenhouse constructor Smiemans Projecten[1] for a rooftop greenhouse in Bergen. The examples are shown in table 5-1. The rooftop greenhouse in Bergen is capable to withstand a snow load of 160 kg/m^2 and a wind load of 1,5 KN/ m^2. The greenhouse in Jæren is to be kept snow-free by using a heating system, and the wind load is according to the international standard, NEN 3859[2]. Both estimates include costs of the structure, i.e. the costs of the framework and the covers of sides and walls, built and delivered on site. The costs of the foundation are not included in the examples.

The listed specifications of the two greenhouses are different and also the total cost estimate of 600 000 euros in Bergen and 212 000 euros in Jæren. The estimate for the rooftop greenhouse in Bergen is roughly 3 times higher than the estimate for Jæren. The higher costs for the rooftop greenhouse have several explanations. One is the building material, which needs to be stronger on the Bergen rooftop because the wind and snow load is higher (Bergen is further north than Jæren, and therefore has more snow). The proposed rooftop greenhouse in Bergen also has safety glasses and high insulation clear PC panels instead of simple horticultural glasses in the side walls, and better ventilation capacity and stronger mechanisms with ridge ventilation. The other explanation is that building on the rooftop instead of on the ground requires the need for special high cranes, different safety measures, special foundation connections, and complex material storage facilities. This will also require a longer building time, with corresponding extra labour costs.

[1] https://www.smiemansprojecten.nl/en

[2] NEN 3859, third edition 2004, type A15, article 8.8.2 table 2

Table 5-1 Costs of building a 1000 m2 greenhouse in Jæren, Norway, and a 1000 m2 greenhouse on the roof in Bergen, Norway

Design element	Greenhouse estimate Bergen	Jæren
Structure	Galvanised steel construction	Galvanised steel construction
Ventilation on roof	Double ridge	
Covers on roof	Single safety glass on roof	Diffuse glass, 4 mm
Covers on sides	Polycarbonate, 16 mm	Diffuse glass, 4 mm
Covers on interior wall	-	Float glass, clear, 4 mm
Doors	Swing doors	Sliding doors
Foundation	-	-
Total costs*	€ 600 000	€ 212 000

Source: Smiemans Projecten and NIBIO.

There are some uncertainties when considering building a rooftop greenhouse at Bontelabo. We do not know the full costs of gaining access to the main power grid, and the costs of creating a system for the collection of rain water is also not included. Integration with the building below to benefit from excess heat from the heated building below, and particularly the projected bakery and the glass workshop, will increase the costs of construction. But it will reduce running costs for electricity and make the greenhouse more environmentally friendly. This is not only important in itself, but it can also increase public support for the project, and willingness to pay among consumers. But these are uncertain factors.

Most of the rooftop in Bontelabo is a parking lot, which means that extra strengthening of the building structure is most likely not necessary. A complete renovation of the building is already planned for, which is an advantage, compared to constructing a greenhouse on the top of a building that should otherwise not go through any changes. It will for instance be easier to plan for and build a functional access to a rooftop greenhouse. Although there are many factors making greenhouse construction on rooftops more expensive, it should be noted that greenhouse construction on the ground also have certain costs. There might be other building structures to tear down first, or the ground might not be flat and needs to be levelled out. If the ground is rocky (as is often the case in the Bergen area) this could for instance require the use of explosives.

5.3.2 Costs of technical equipment

With a modern hydroponic cultivation system, the costs of the technical equipment of a greenhouse will in general be higher than the construction itself. An operational greenhouse often has a climate computer, thermal screen, heating system, cooling system (fogging), grow lights, CO_2-supply, and water, irrigation, fertilizing systems, and more.

For the greenhouse in Jæren the costs of the technical equipment amount to around 872 324 euros, see Table 5-2. However, it is important to stress the fact that the specific technical equipment chosen, affects the costs. Thus, the example from Jæren is not necessarily transferable to the considerations and choices needed to make a rooftop greenhouse fully operational.

For heating the greenhouse it is possible to use a heating pump, supplemented by an electrical boiler for the really cold days. It might also be necessary to build a water collection tank due to possible changes in regulation (it is expected that new regulations concerning reuse of water are going to be implemented). Collecting rain water has some agronomic benefits compared to treated drinking water, and also saves costs related to use of drinking water. Furthermore, a thermal screen, a climate computer, a lighting system (150 W/m² when using LED-lights), a drip irrigation system, fertilizing dosing system, emergency power supply and packaging equipment are necessary. In addition to this a functional CO2-supply should be installed.

A greenhouse can be divided into different sections with for instance cucumbers, tomatoes, lettuce and microgreens. The climate requirements are different for lettuce and tomatoes and cucumbers, so the sections need to be separated with a wall. But there will still only be need for one climate control computer.

Table 5-2 List of technical equipment in a greenhouse, a cost estimate for Jæren, in euros (1 Euro ≈ 10 NOK)

List of elements	
Water and fertilizers	
Gutters	
Crop protection	
Fertilizer dosing system	
Drip irrigation system	
Climate computer	
Thermal screen	
Heating system	
Heating pumb/Boiler	
Heating pipes	
CO2 supply and distribution system	
Cooling system (fogging)	
Other costs	
Emergency power supply	
Packing and others	
Lighting	
Total costs	€ 872 324

5.3.3 Running costs and gross margin

In our case study we use tomato production as an example. Tomatoes are the second most common vegetable in Norway, after carrots. Other common greenhouse vegetables produced in Norway are cucumbers, lettuce and herbs. Other typical greenhouse vegetables such as bell peppers are mainly imported.

Variable costs are often referred to as running costs as the costs vary with the level of production.

Table 5-3 shows the running costs of a 1000 m² greenhouse with tomato production, taken from NIBIO's published running cost estimates[3]. The running costs for greenhouse tomato cultivation in Norway are related to the number of tomato plants needed in the production process, and the need for fertilizer, cultivation substrate, analysis of nutrient solution, crop protection, heating, the light requirement, plant ties and bumblebees.

In hydroponic cultivation different cultivation substrates can be used, such as perlite, rock-wool, coconut coir, peat, etc. In the running cost example rockwool is used as cultivation substrate.

[3] Handbok i driftsplanlegging

Furthermore, it is assumed that the greenhouse has invested in a thermal screen as this reduces the need for heating from around 550 000 kWh per year to around 440 000 kWh per year. The variable costs of fertilizers could also be reduced if drainage water is recycled, and this will also have environmental benefits.

Table 5-3 Variable costs of tomato cultivation for a 1000 m² greenhouse in Norway with year-round production, in NOK (1 Euro ≈ 10 NOK)

	Volume	Unit	Price (NOK)	Variable costs (NOK)
Tomato plants	2 500	plants	27	67 500
Fertilizer[1)]				60 000
Cultivation substrate[2)]	625	pcs	26	16 250
Analysis of nutrient solution	3	samples	400	1 200
Crop protection				15 000
Heating	440 000	kWh/year	0,5	220 000
Light requirement	840 000	kWh/year	0,5	420 000
Plant ties				6 000
Bumblebees	8	nests	3 000	24 000
Other variable costs				6 000
Total variable costs				**835 950**

1) 42 200 NOK if drainage water is recycled
2) Rockwool

Source: Handbook for driftsplanlegging 2019 and own calculations

In order to ensure a profit, the revenues must be greater than the costs of production. The gross margin is the net revenue from selling tomatoes minus the running costs of producing the tomatoes. In other words, the total gross margin shows how much is left to cover labour costs, fixed costs and interests on invested capital.

In order to calculate the gross margin, the net revenue must be estimated. The net revenue is the amount of tomatoes sold, times the producer price. The producer price for tomatoes in Norway is roughly the target price minus the costs of packing, sorting and transport. The target price is set in the Agricultural Agreement, and in 2019 it has so far ranged between 21,9-22,76 NOK. The costs of packing, sorting and transport were estimated to around 3,5-4 NOK in 2019 (Handbok i driftsplanlegging, NIBIO). This indicates a producer price of 18 NOK in 2019.

Table 5-4 shows the total gross margin for a 1000 m² greenhouse cultivating tomato in Norway with the latest technology. If we assume that 120 000 kg of tomatoes is produced and sold for 18 NOK per kg, then with a total variable cost of 835 950 NOK, the total annual gross margin is 1324 050 NOK.

Table 5-4 Total gross margin per 1000 m2 of tomato cultivation in Norway, in NOK

Tomatoes sold, kg	Producer price, NOK per kg[1)] 16	17	18	19	20
80 000	444 050	524 050	604 050	684 050	764 050
90 000	604 050	694 050	784 050	874 050	964 050
100 000	764 050	864 050	964 050	1 064 050	1 164 050
120 000	1 084 050	1 204 050	1 324 050	1 444 050	1 564 050
150 000	1 564 050	1 714 050	1 864 050	2 014 050	2 164 050

1) Producer price is approx. the target price [21,9-22,76 NOK in 2019] excl. packing, sorting and transport [3,5-4 NOK]. Subsidies are not included.

Source: Handbok for driftsplanlegging 2019, Verheul et al. 2012 and own calculations

To estimate the net profits of a greenhouse, labour costs, instalments and interest must be deducted from the gross margins. An advisor on greenhouse cultivation from the Norwegian Agricultural Extension Service (NLR) estimates that the labour use per 1000 m² for year-round greenhouse production of tomatoes is approximately 2000 hours. In the case of rooftop greenhouses, it might also be necessary to deduct house rent, as the producer might be a tenant of the site where the greenhouse is constructed. The area at Bontelabo where the greenhouse is projected is today rented out for car parking, giving an estimated yearly income of approximately 540 000 NOK for the owner.

5.3.4 Energy sources

The greenhouse will need artificial lighting and heating, particularly in the winter. This will require electricity, which one can get by connecting to the local grid. In the Bergen area most of the electricity comes from hydro energy from dams and waterfalls. But the fact that Norway can export energy to other countries with less clean energy sources, argues for minimising energy use also here.

Lufa farms claim that their energy consumption is half of that of an ordinary greenhouse because of their integration with the building below. There are also possibilities for taking advantage of excess heat from the building below at Bontelabo, although we have not explored these possibilities technically.

In addition to lighting and heating, plants need CO_2 and an environment with relatively high humidity (75-85%). In order to keep an optimal climate for plant growth, a ventilation system is required. Often a roof ventilation system is used. The problem with a roof ventilation system is that, when opened, heat and CO_2 is lost to the atmosphere. A more energy saving solution is to integrate the greenhouse ventilation to the ventilation in the building while closing the greenhouse roof ventilation.

A greenhouse is a sun collector. A greenhouse in Bergen will collect twice the amount of heat necessary for optimal plant growth. The problem is that the heat is collected during the day and the summer and used during the night and winter. Water containing buffer systems have been developed to reuse the solar energy.

Recently, a new environmental control system was developed by the company GreenCap Solutions AS in cooperation with NIBIO. The system consists of a heat pump, an energy conserver ('harvesting' the solar energy) and a CO_2 unit (that takes CO_2 from the outside air and concentrates this three times before it is added to the greenhouse air to 'feed' the plants), and is connected to an internal ventilation system in the greenhouse. Using this system, roof ventilation can be closed and CO_2 emissions from greenhouse production can even become negative. According to unpublished, preliminary results from estimations of yields with the new GreenCap system, the yearly tomato yields per 1000 m^2 is 120.000-150.000 kg[4].

5.4 Marketing and business models

As we have seen, there are higher construction costs for a rooftop greenhouse, and these should in some way be compensated for if the greenhouse is to be able to make profits. One possibility is to attract public funding, or possibilities to take loans from sources with a social profile and a lower interest rate. But the marketing activities of the greenhouse company are also highly important, and can be a source of income that a rural greenhouse on the ground may not have access to.

According to numbers from Opplysningskontoret for frukt og grønt, the average consumption of fresh tomatoes per person in Norway was approximately 7 kg in 2018, of which 2/3 is imported. The population of the Bergen Municipality is 282 000, which means that the yearly consumption of fresh tomatoes in the city is approximately 2000 tons. Note that this is for all types of tomatoes. For cucumbers the estimated consumption in Bergen is 1400 tons per year. The consumption of vegetables in Norway is far lower than the level recommended by health authorities, and with an increased focus on sustainability and health, there could be an increased demand in the future.

Table 5-4 shows the estimated yearly yields per m^2 of tomatoes from greenhouse production. If we assume that the greenhouse with the profit from yields maximising business model is 3000 m^2 and produces 120 000 kg per 1000 m^2, it will generate 360 000 kg of tomatoes per year, which is 18% of the estimated entire consumption of tomatoes in Bergen. With an average producer price for tomatoes of 18 NOK/kg, the total income will be 6,5 million NOK if the entire produce is sold at this price, and the gross margin will be approximately 2,4 million, which is to cover for instance labour costs. Due to economies of scale (from technical equipment and other fixed costs), net profit per square meter will probably be higher for a greenhouse of 3000 m^2 compared to a 1000 m^2 greenhouse. Furthermore, if the tomatoes from the greenhouse at Bontelabo are branded as something special, short travelled, fresher and more environmentally friendly than ordinary tomatoes, they can generate a higher price paid by the Bergen citizens, and thereby a higher net profit.

5.4.1 Profit from yields maximising business model

A challenge arising with the profit from yields maximising model is that it produces a substantial amount of vegetables that it will be necessary to sell, and it may be challenging to do so with a direct sales model, selling directly to restaurants or to consumers from a sales outlet at the greenhouse. Selling to the supermarkets in the city of Bergen is an alternative, but this must be done through one of the main sales channels for fruits and vegetables. In Norway there are two producer organisations who collaborate with wholesalers: Norgrønt/Coop and Gartnerhallen/BAMA AS (the largest one), who supply to most of the supermarket chains in the country. Supermarkets that are part of a chain cannot purchase what they want from who they want, and their fresh, Norwegian fruits and vegetables are usually purchased from one of the two main producer organisations in the country. To supply the main supermarkets it is therefore necessary to be a member of these producer organisations. For a newly established greenhouse it can be challenging to enter this market, as it is already saturated with supplies from existing producer organisation members, who get the priority before newcomers. One way of making your way into the market could be to argue that you have a product which is different, such as a new or different tomato variety, as well as a sustainable, urban agriculture image, which could make consumers eat more tomatoes than before. Since 2/3 of the Norwegian tomatoes are imported, it is also possible to replace some of these imports.

In the maintream sales channels the produce usually goes through an established chain of warehousing and transport, to facilitate the logistics. In the case of Bergen, the main warehouse is

[4] Preliminary results by Michel Verheul, Project BioFresh, NIBIO

situated in Arna, some 20 km from Bontelabo. The scenario could then be that the tomatoes from the rooftop greenhouse will be trucked first to Arna, and from there to the supermarkets in Bergen. However, to some extent this makes sense, as the Bergen municipality stretches into less densely populated areas, and the majority of the food purchases are made outside of the city centre. It is also possible that the rooftop greenhouse could make its own direct deliveries to supermarkets and restaurants in the city centre, as done by some strawberry producers (with payment still going through the producer organisation).

Even if the tomatoes go through the mainstream sales channels, it should still be possible to differentiate them from other tomatoes by labelling them in a particular way for the Bergen consumers to recognise, as done by Gotham Greens and the basil plants produced by ECF in Berlin. Their packages contain short information about the way the product is produced (e.g. “sustainable farming”, “urban agriculture”), and this can generate extra willingness to pay among certain consumers, allowing for a higher price to be charged. If one assumes that the consumer segment with a higher willingness to pay is rather small, it speaks for having more than just one type of product, for instance both tomatoes and cucumbers, to create a variety for these consumers. But this could increase the production costs compared to having just one type of product.

An alternative to marketing through the main sales channels in Bergen is to create a scheme for subscription to food boxes, using the Lufa Farms model. This increases the price received by the greenhouse producer as several levels of the supply chain (wholesaler and supermarket) are eliminated. In order to create interesting food boxes, the greenhouse should not specialise on just one product, and, following the Lufa Farms model, it will be beneficial to collaborate with local farmers in the area providing other types of products. This requires building up logistics for deliveries. It could be a challenge to create a large enough market for food boxes, which is only interesting for a segment of consumers, and Bergen has a much smaller population that Montreal and its surroundings. Outside of Bergen the municipalities are far less densely populated, and the next cities of a certain size are nearly 3 hours’ drive away.

5.4.2 Architect designed greenhouse with multifunctional business model

If the greenhouse uses a multifunctional business model, it will focus on not only profits from yields, but also other income sources such as food serving in a restaurant, guided tours and education, and organisation of events. For the Bontelabo case study the architects in the project group (TAG arkitekter) have designed a special greenhouse suited to the Bontelabo building, to make it more aesthetically pleasing than an ordinary, commercial greenhouse (see appendix 1). The greenhouse will be connected with a restaurant with both an indoor area inside the building, and an outdoor area on the roof next to the greenhouse. The greenhouse will shelter this outdoor sitting area from the northern winds coming from the sea, and its shape is lower at the sea front, to make sure the wind blows above the restaurant guests. This type of greenhouse could produce a variety of products to cater for the restaurant as well as to urban consumers purchasing directly, and guided tours inside the greenhouse will be an important source of income. On the area outside of the greenhouse the architects also envisioned food producing beds for herbs, bushes and other plants that are better produced outside, and which can also be used in the restaurant.

The architect designed greenhouse will have a higher square meter price than a standard size greenhouse, because it is more difficult to use standard, off the shelf building material. But a project like this, which generates more values to the society, including aesthetic ones, might more easily receive funding from authorities or benevolent actors. It might also be easier to get exemptions for building regulations from the public authorities.

With a lower amount of yields it is easier to sell with a direct sales model from a sales outlet near the greenhouse or by deliveries to restaurants or specialty stores in the area, and thereby receive a higher price per kilo by cutting levels in the supply chain. With a multifunctional business model which involves more visitors to the greenhouse, and if it also involves an aesthetically pleasing, eye catching greenhouse building, it should also be easier to advertise the greenhouse and its products to the citizens of Bergen, and thereby generate a higher willingness to pay for the products. With its closeness to the city and plans for attracting consumers to the area with shops, galleries and cafes, the Bontelabo building has the potential to be suitable for such a business model. With a multifunctional business model, it is more likely economically worthwhile to have more than just one type of product, in order to offer a variety to restaurant visitors and consumers purchasing directly. A higher sales price for the products can defend the extra costs that this diversification of production implies.

6 Summary and conclusion

The advantages of making a rooftop greenhouse in an urban area are many, and can be summarised as:

- Closeness to consumers (less financial and environmental costs related to transport and storage, and fresher products)
- Saving land for agriculture, green space or other types of housing
- Saving energy by using excess heat from building below
- Education and social interaction

In addition, greenhouse cultivation in itself has some advantages compared to other types of cultivation, such as less use of chemical pesticides.

But the road to the construction and running of a rooftop greenhouse can be bumpy. The first challenge is to find the right type of building and get the permission from public authorities to build. But the main challenge is the higher construction costs when building on a rooftop instead of on the ground. These costs will be particularly high if the building below needs to be strengthened, and if there is to be an integration with it for heat and air exchange. But even without this, building on a rooftop will normally require the use of cranes and more costly procedures for attachment to the foundation, and a stronger building than a greenhouse on the ground because of higher wind loads. The construction costs will be even higher if the rooftop greenhouse is architect designed for higher aesthetic values.

But although a rooftop greenhouse has higher investment costs, it also has some possibilities for extra incomes, which a rural, on the ground greenhouse may not have. Firstly, the environmental and other societal benefits of an urban rooftop greenhouse make it easier to attract funding from public authorities and benevolent actors, with opportunities for getting loans with lower interest rates. Secondly, a rooftop greenhouse can become a well-known brand in a city, associated with environmental and societal benefits. This, in addition to the freshness of short travelled products, can create an extra willingness to pay among consumers. Thirdly, for an urban rooftop greenhouse it is easier to use direct sales models, such as having a sales outlet, or a food box scheme, which means that a larger share of the consumer price goes to the greenhouse company. And fourthly, an urban rooftop greenhouse can create other sources of income than just selling the products, such as guided tours. Such activities can also add to the social value of the greenhouse and contribute to the building of a brand.

The higher construction costs seem to be the most plausible explanation to why there are not more rooftop greenhouses in the world today. Because of this it seems to be the case that such greenhouses will usually only be built when you have very dedicated entrepreneurs, or support from public authorities or other benevolent actors, or a combination of the two. Whether or not we will see an increase in rooftop greenhouses in the future, will to a large extent depend on the support they will get, from financial sources as well as from consumers. With climate change and more extreme weather events, food security becomes a more predominant theme, and more cities will perhaps want to be less dependent on food transported from far away. Reducing greenhouse gas emissions is another theme gaining importance, and with new technology greenhouse vegetables, which previously have had a high carbon footprints, is becoming low emission food and should therefore be expected to gain popularity. These factors point in the direction that we will see more rooftop greenhouses in the future, including, perhaps, in Bergen.

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TAG Arkitekter Bergen
Nøstegaten 44
5011 Bergen

post@tagarkitekter.no
tagarkitekter.no

GREENHOUSE ON THE ROOFTOP IN BERGEN

DATO: 14.10.2019
DRAFT PROJECT
A3

Org.no: NO 894 607 262 MVA
Bank: 1503.35.55455

CONTENT

Arkitekter

CURRENT SITUATION

LOCATION. The project area is located on the rooftop of the 2-store office building at the Bontelabo street and currently, it is used for parking. From the rooftop, there is a rare unobstructed and wide-angle view of the sea and the view to the Bergenhus fortress is opening from the South. The plot has direct access to the sea from the North, where is also located the pier for cruise ships.

TRANSPORT AND ACCESS. The location of the plot is quite central; it has a short walk distance from Bryggen. The Bontelabo bus stop is located directly in front of the building in the south. The part of the embankment in the north of the site is reserved for parking.

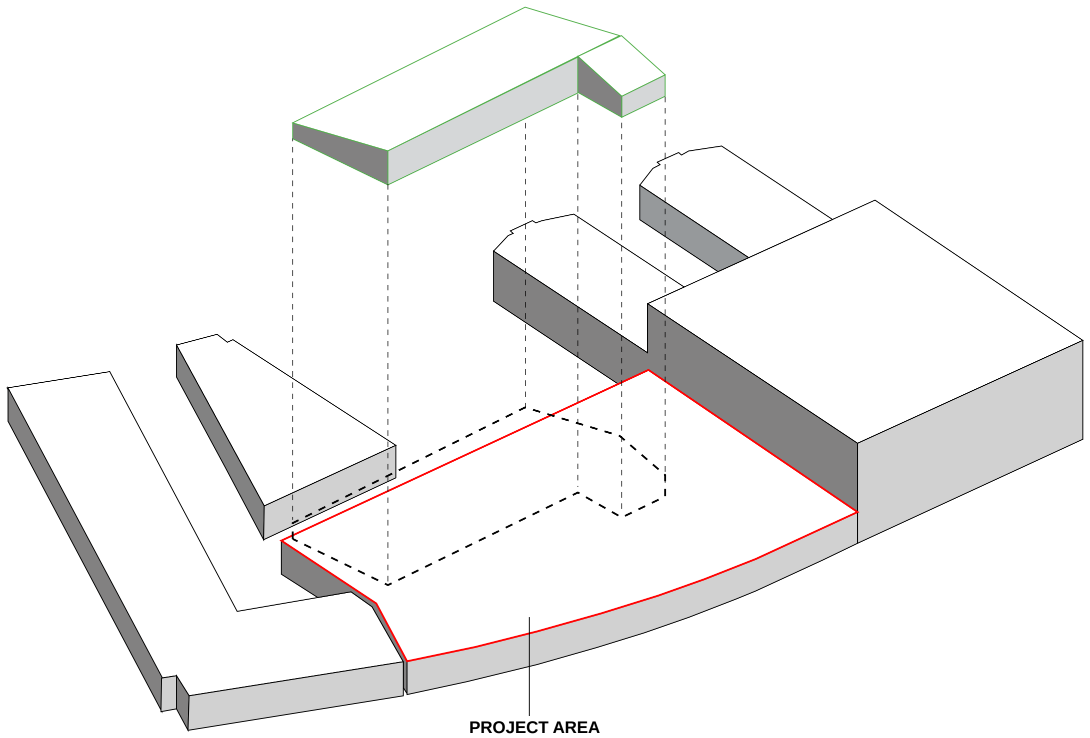
CONSEPT

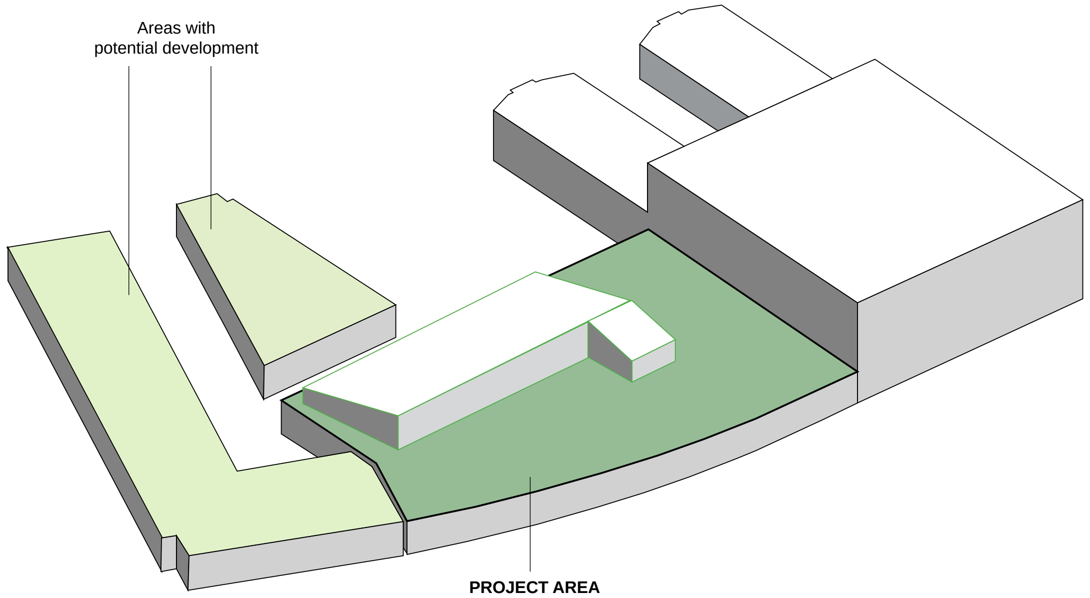
INTRO
The idea is to utilize the rooftop for cultivation inside and outside the greenhouse. A combination of the private business – greenhouse itself (together with trade in the form of a restaurant, café, outlets or sales stalls) and public offerings creates a social meeting place with the focus on urban cultivation. Here, people will be able to come to buy products, eat a meal, learn about growing in the city, and have the opportunity to grow themselves.

ACCESSIBILITY
Bontelabo is a heavily trafficked street with both private and public transport as well as pedestrians and cyclists. It is therefore obvious to think that a public and opened access to the roof would be beneficial. That access can be accomplished in the form of stairs or even exterior elevator so that people with physical disabilities will have unhindered access. It is also advantageous to separate visitors entrance from delivering transport to and from the greenhouse and outlets.
Such access to delivery transport will be organised through a parking house.

MATERIALS
The main material for the greenhouse is glass or polycarbonate. The structural part might be done from steel or aluminium to make a whole construction lighter. The wooden construction parts can be considered as well.

POTENTIAL DEVELOPMENT
With the increasing interest and limits of the capacity, the concept can be extended over another 2 rooftops on the same level (see illustration).





TAGs

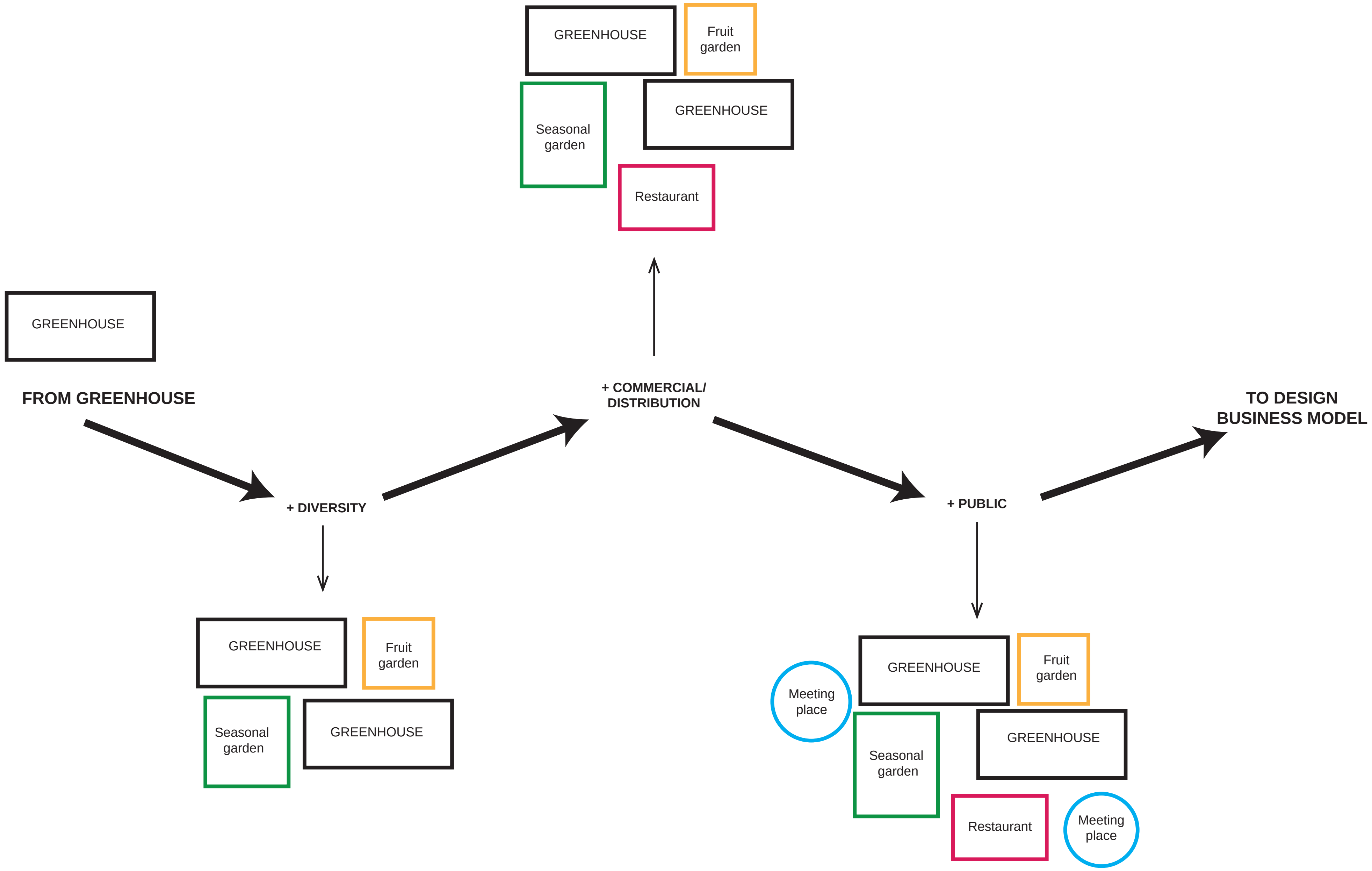
PRIVATE + PUBLIC

In this project, we combined private and public sectors.

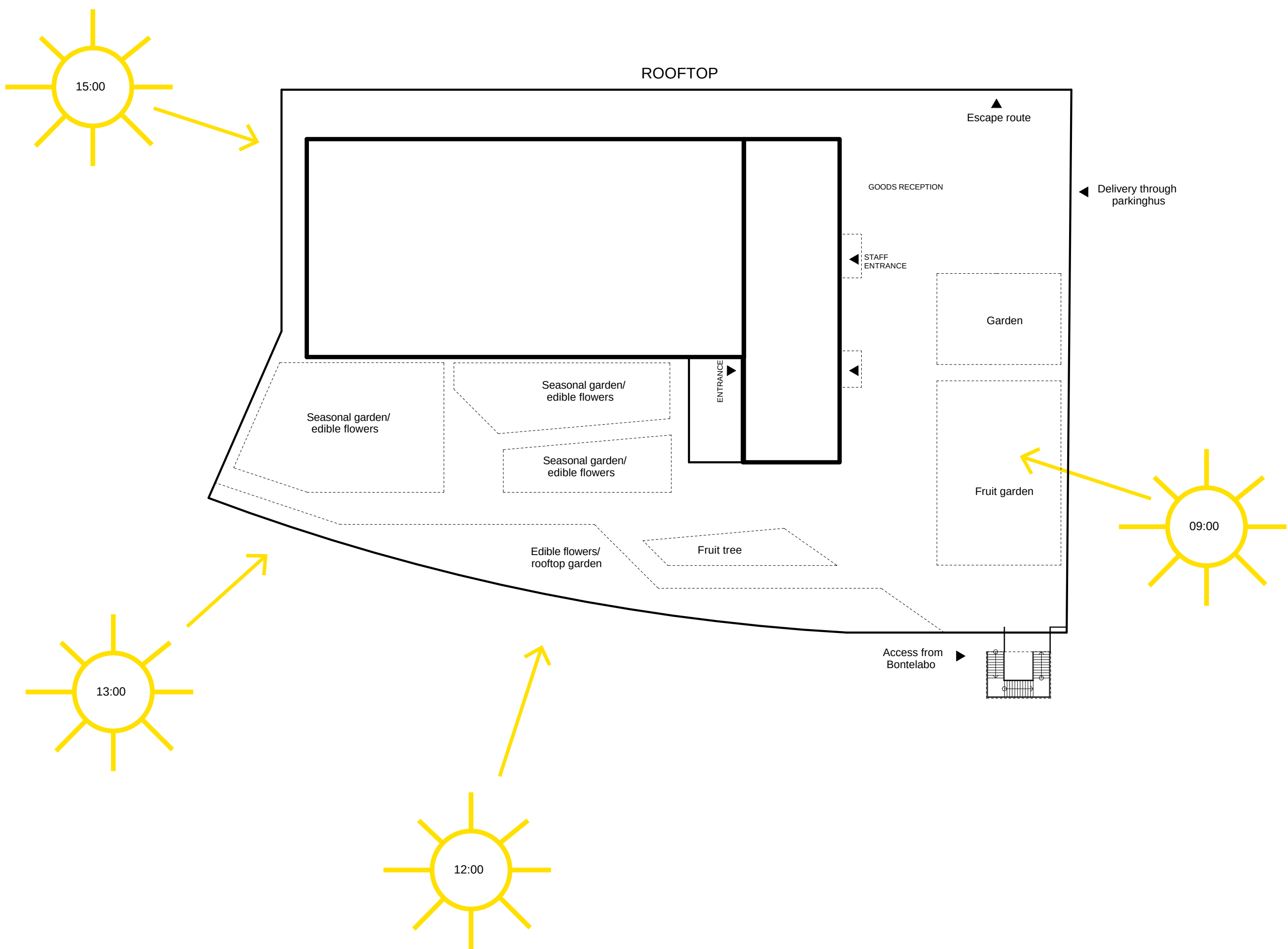
Visitors will be offered a product from sales stalls, cafes and restaurants run by private individuals. Seasonal cultivation gardens both inside and outside will cover the needs for local production.

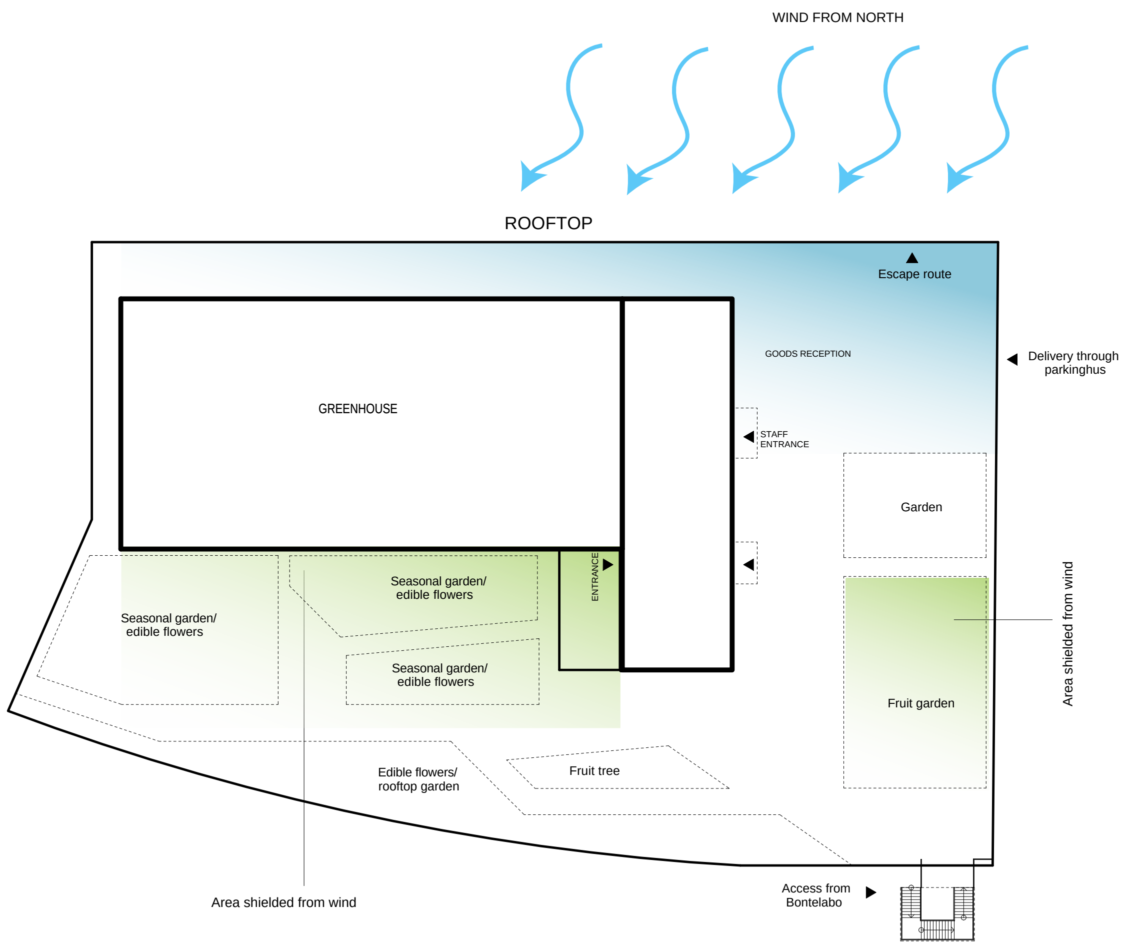
Creating an outdoor garden on the roof is important for establishing meeting places for visitors, places where you can spend time together in nature and harvest the fruits. A gray parking deck is turned into a green garden with beautiful views, lifted from the traffic.

The choice of utilizing this unused rooftop in the city center provides both good access for visitors coming from the seaside direction and as an end stop after a walk through the city center over Bryggen.



TAGs





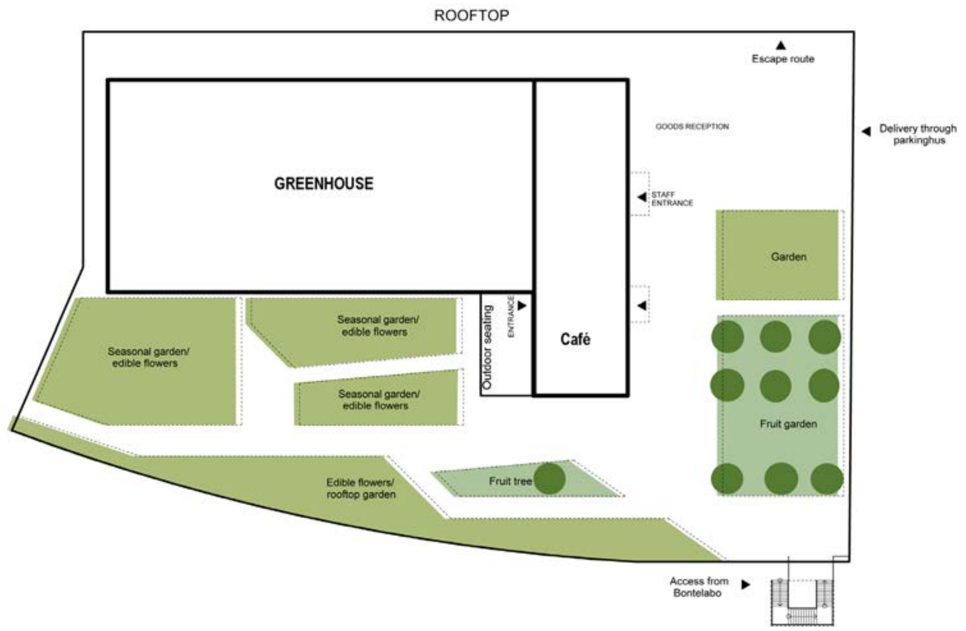
SUN CONDITION

The roof surface naturally is very sunny. Large parts of the outdoor areas of the project are located in the south-west and so fully utilize the sun hours. Lifted from the traffic and the shade, the rooftop greenhouse will offer a warm and quiet place to be.

WIND CONDITION

Most of the wind comes naturally from the sea in the north. By placing the volumes to the north, it protects the outside areas in the south, creating good zones in the shelter. This makes it possible to add seasonal cultivation gardens here.

TAGs



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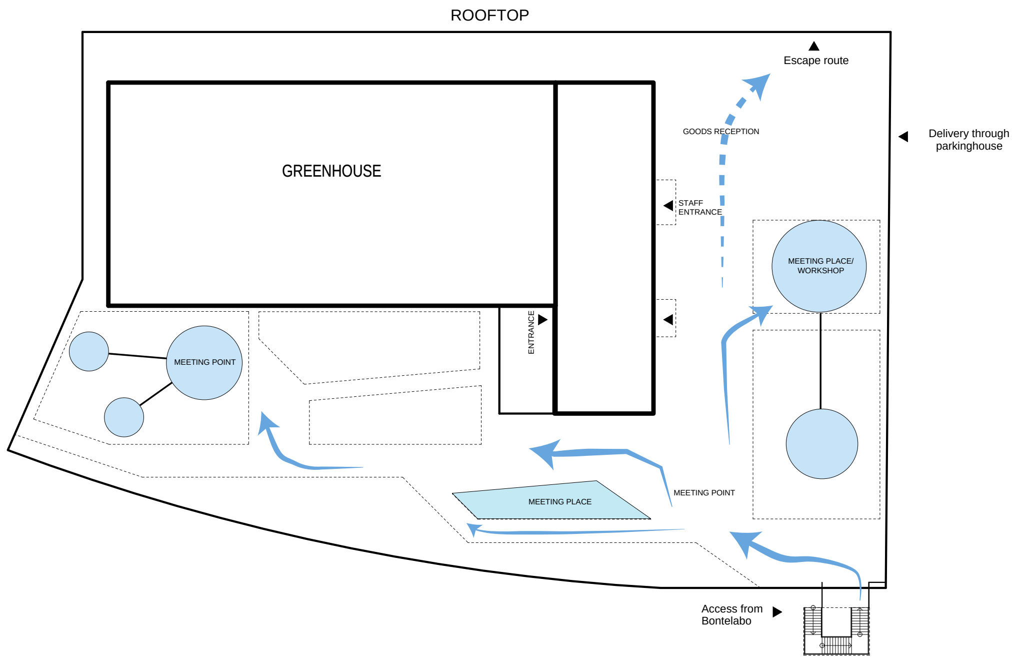

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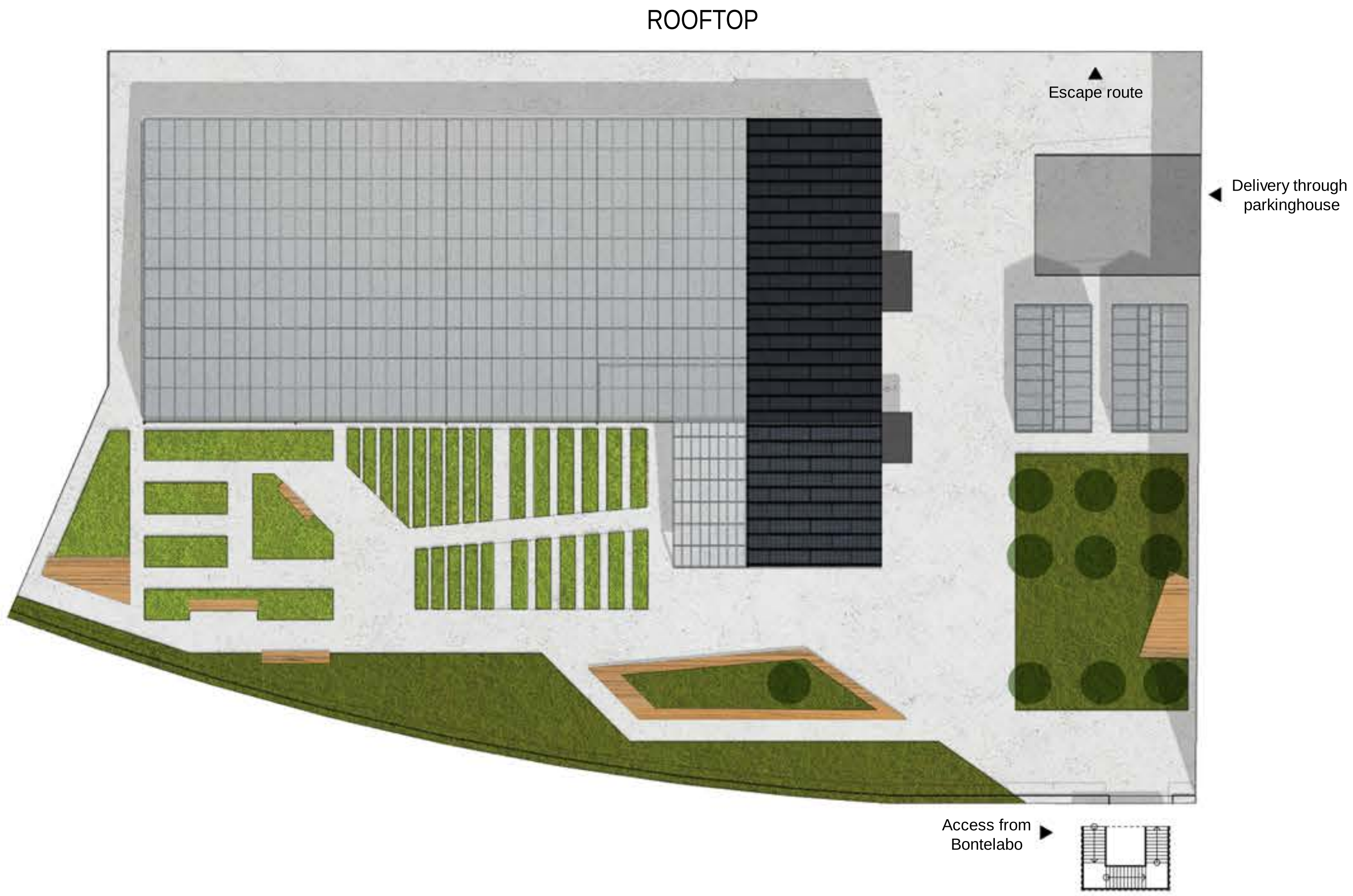
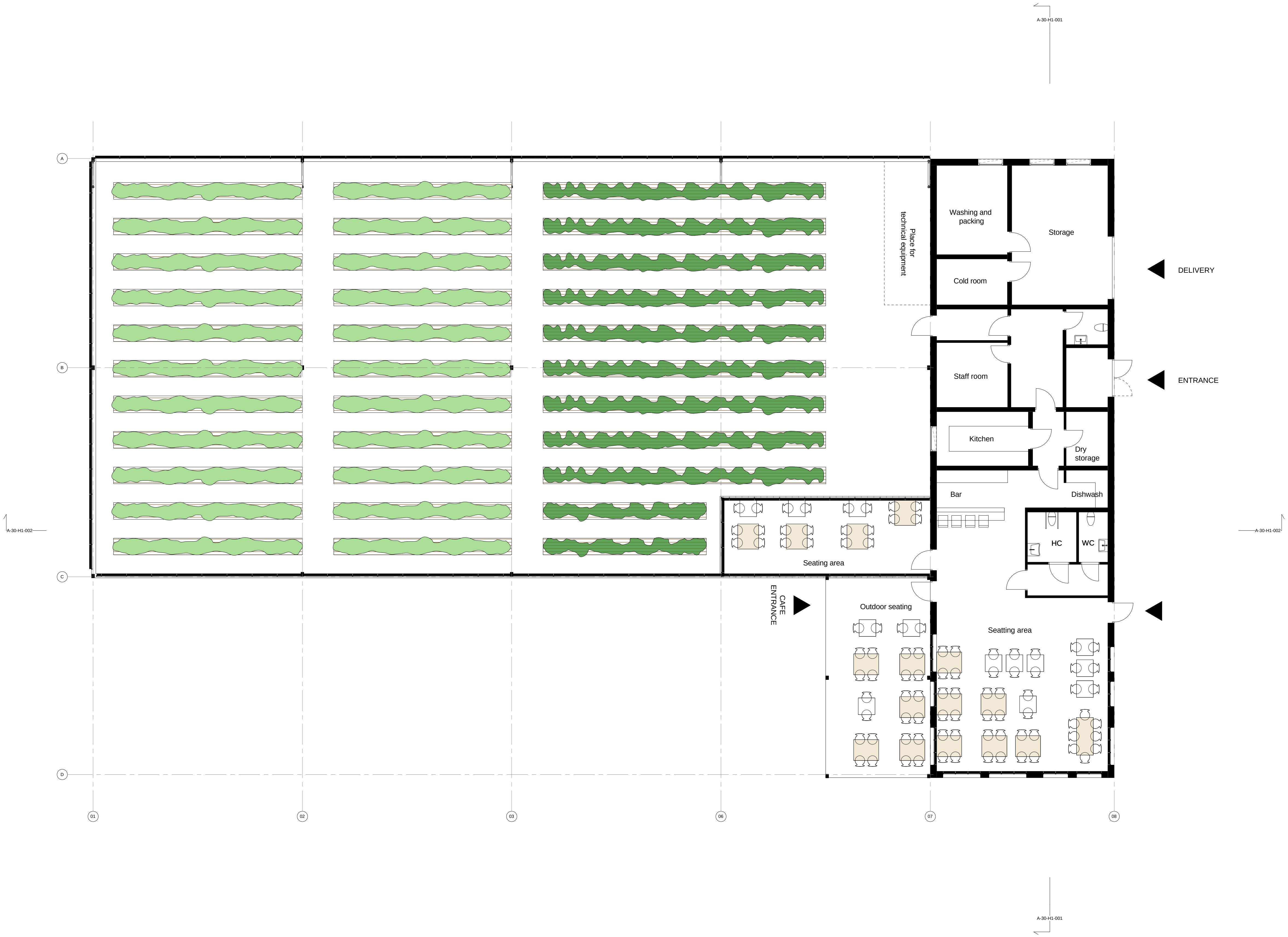
SONER

The outdoor area consists of a variety of different cultivation zones. The main characterization for the zone is vegetation where it is also available places/pockets for visitors staying. Such places will be organized as outdoor seating and workshop areas, where one can have the opportunity to learn about urban cultivation.



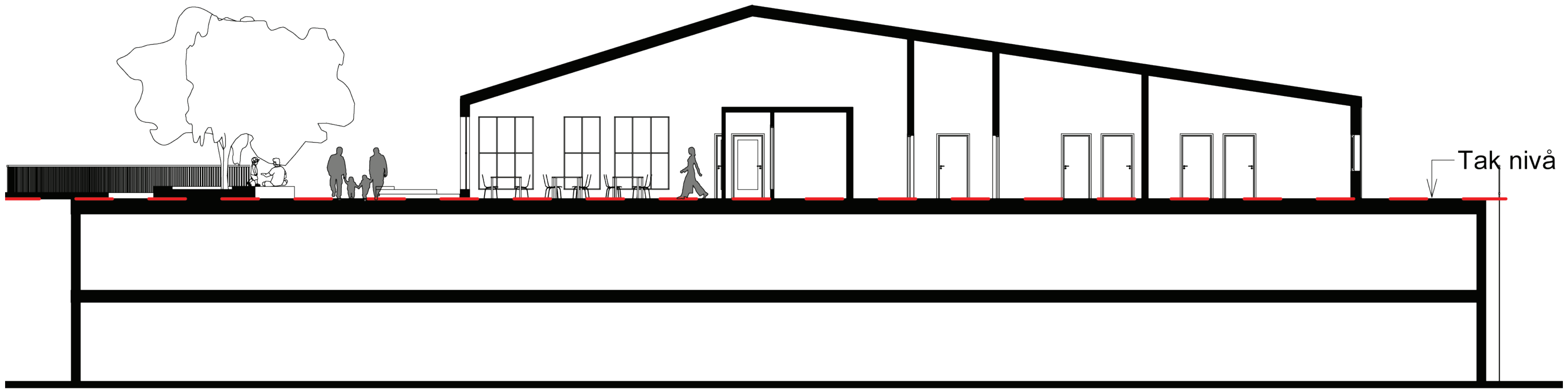
PLAN



Washing and packing
Storage
Cold room
Place for technical equipment
DELIVERY
Staff room
ENTRANCE
Kitchen
Dry storage
Bar
Dishwash
HC
WC
Seating area
CAFE ENTRANCE
Outdoor seating
Seatting area

SNITT

CROSS SECTION



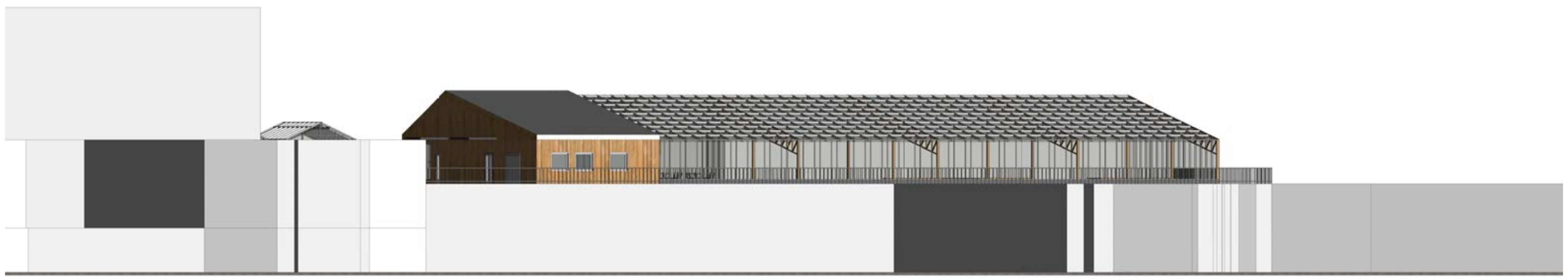
LONGITUDINAL SECTION

TRG Arkitekter

FACADES

SOUTH FACADE

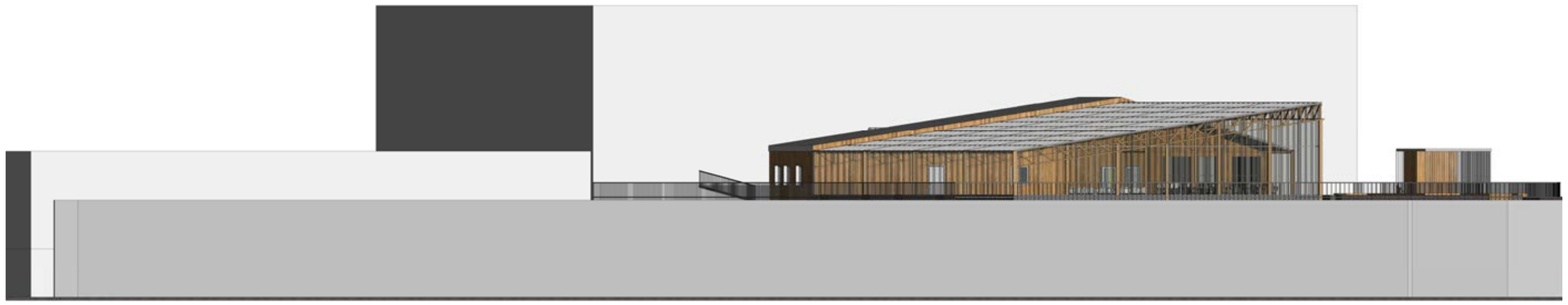
NORTH FACADE



FACADES

EAST FACADE

WEST FACADE



Arkitekter


ILLUST
RATION


ILLUST
RATION

DETAILS

ROOF GARDEN

The roof park comes up when the season for the growing plants outside is over. People will still enjoy the greenery even though the trees no longer bear fruit.

SHADING

By using shading systems for the greenhouse and expose other parts to the sun, a variety of growths can be allowed to a greater extent.

Furthermore, it is also possible in the evening to prevent annoying light on neighbors if warm and LED lights are used.

COMBINED MEETING POINTS

A variety of meeting places is created, in the forms of benches among the garden areas, small workshops in their own transparent greenhouse-like buildings, and the outdoor serving place for the restaurant.

Everyone can enjoy their staying on the roof and lie on the grass!

CULTIVATION

An innovative approach for cultivation plants can increase capacity and provide aesthetically interesting and vertical gardens.

NIBIO
NORSK INSTITUTT FOR BIOØKONOMI

Norsk institutt for bioøkonomi (NIBIO) ble opprettet 1. juli 2015 som en fusjon av Bioforsk, Norsk institutt for landbruksøkonomisk forskning (NILF) og Norsk institutt for skog og landskap.

Bioøkonomi baserer seg på utnyttelse og forvaltning av biologiske ressurser fra jord og hav, fremfor en fossil økonomi som er basert på kull, olje og gass. NIBIO skal være nasjonalt ledende for utvikling av kunnskap om bioøkonomi.

Gjennom forskning og kunnskapsproduksjon skal instituttet bidra til matsikkerhet, bærekraftig ressursforvaltning, innovasjon og verdiskaping innenfor verdikjedene for mat, skog og andre biobaserte næringer. Instituttet skal levere forskning, forvaltningsstøtte og kunnskap til anvendelse i nasjonal beredskap, forvaltning, næringsliv og samfunnet for øvrig.

NIBIO er eid av Landbruks- og matdepartementet som et forvaltningsorgan med særskilte fullmakter og eget styre. Hovedkontoret er på Ås. Instituttet har flere regionale enheter og et avdelingskontor i Oslo.

Forsidefoto: TAG arkitekter

nibio.no