MOBILE PLANT FACTORY

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AR3B025 SUSTAINABLE GRADUATION DESIGN

Master Thesis in Building Technology

MOBILE PLANT FACTORY

An Explanatory guide for designing travelling Plant factory with Hybrid lighting system using computational design workflow.

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FOCUS AND RESTRICTIONS

Primary focus on large-scale plant production facility, The building envelops design and adapted strategies for best light access and temperature level. The paper does not focus on other climate control factors such as ventilation and humidity.

ABSTRACT

Plant factory with artificial light PFAL is an advanced facility has been developing through many research based on experimental field work in greenhouses as fully insulated and the airtight production facility. PFAL is one form of "closed plant production system" (CPPS) unit. It is a system where the growing environment optimally controlled and therefore, can provide various type of crops in different climatic conditions at a higher production level. The standard PFAL only use artificial lighting to provide the plant with the light required for photosynthesis needed for growth. The research by design intends to fill the gap between the architecture, agriculture and environmental studies and to reproduce the PFAL in a Hybrid lighting system to benefit from solar light and in combination with an hydroponic farming technique . There are two main parts literature study and the practical section that finally complete with proposed design (Mobile Plant factory) Hybrid system. Plant factory with a successful design required specific requirements of production technique, internal climate boundary conditions, and energy efficient design of the building envelope. The climatology of location has an impact on the selection criteria of production type and skin. This paper is aim to examine the Hybrid system through developing a design example and creating a guide for helping designers in the early design phase.

KEYWORDS Plant factory, greenhouses, horticulture, vertical farming, mobility, Biomimicry, Hybrid lighting system, aquaponic.

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LITERATURE REVIEW

BACKGROUND

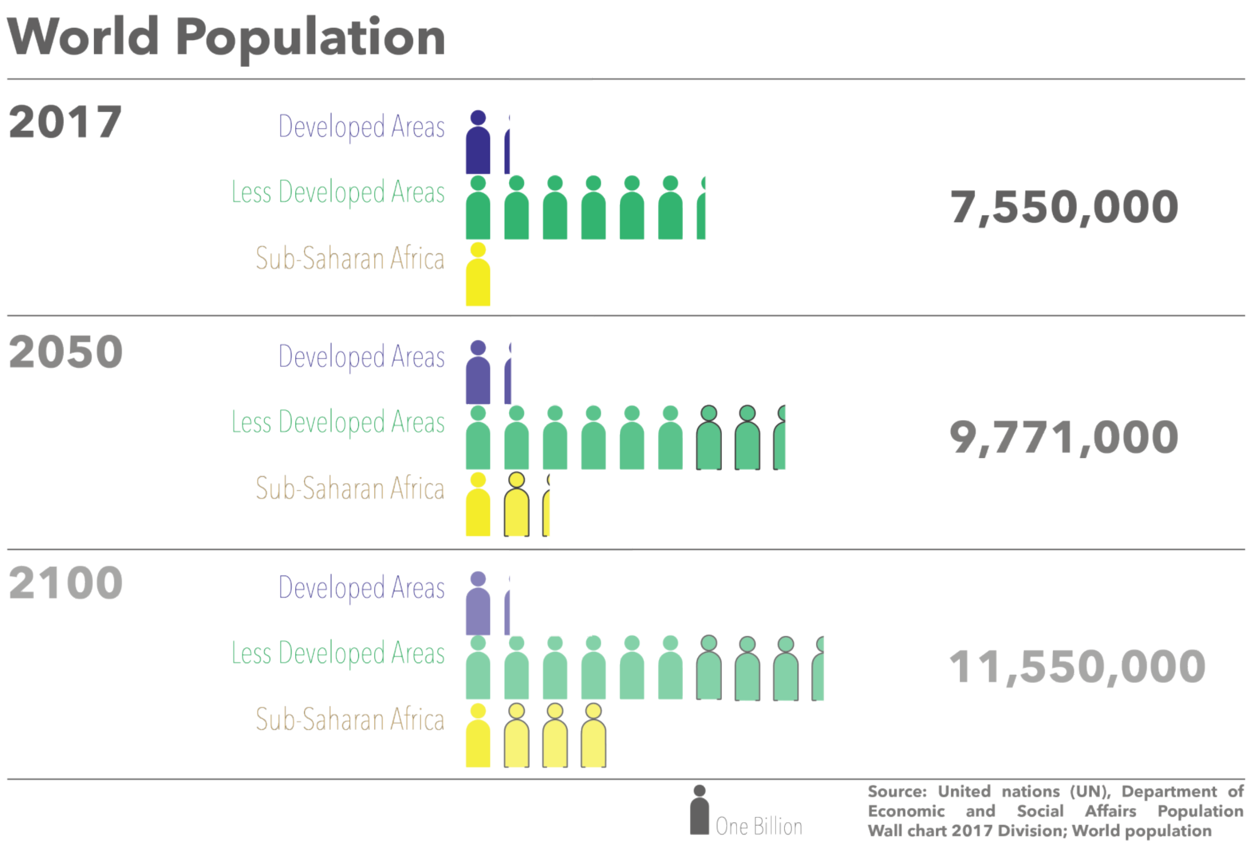

Figure A-1: the forecast of the world population increase in three different areas. Graph by the author.

According to united nation statistics In 2050, the population will Exceed 9.8 Billion, 70 % of them will live in cities, and the increase will reach 11,5 Billion by 2100 **[UN, 2017]**, Making a significant pressure on food and energy resources. In 2015, the Food and Agriculture Organization (FAO) annual report stated that there were approximately 795 million people are unnourished or in hunger around the world – one in nine people, most of them living in developing countries, the changing global economic environment has challenged traditional approaches to addressing hunger. **[FAO, 2015]** It is important to mention that one-quarter of the FAO figure are alone in sub-Saharan Africa as result of a shortage of clean water and drought. 41% of the population in Sub-Saharan living in extreme poverty **[UN.org, 2017]**. Main issues such as scarcity of water, severe climate condition, and instability like wars and conflicts are primary reasons for hunger. Moreover, the conventional farming one-fifth of carbon footprint and wasting 20%.**[Hertwich & Peters 2009]** Figure B-2 page 8.

Fig A-2: Greater Norilsk city It is the world's northernmost city with more than 205,000 inhabitants 2009, source: nordroden.livejournal.com

Inevitably the future of conventional farming has to be changed to adapt new techniques and use innovative technology. Many research is on-going to develop the farming techniques **[Kozai, 2016]**. The plant factory with artificial lighting (PFAL) is one of the recent addition to the farming the term refers to a plant production facility with thermally insulated and nearly airtight warehouse-like structure **[Kozai, 2016]**. However, the plant factories facing a lack of guidance for the industry where most of the time the standard strategies provided by manufacturer adapted without taking in to account the context or all climate responsive design aspects **[Lomon,2017]**.

Figure A-3: displacement people in Yemen. Around seven million people need food aid. CreditTyler Hicks/The New York Times.

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MOBILE PLANT FACTORY

Figure B-1: Close algae farm, Source: National Geographic, The Netherlands

INTRODUCTION

PFAL plant factory with artificial lighting (PFAL)" refers to a plant production facility with a thermally insulated and nearly airtight warehouse-like structure **[Kozai, 2013]** Plant Factory on its terms can be split in tow both meaning whether a multi-layered table greenhouse or Hybrid system using Solar and artificial lighting within the airtight facility. The mobility term derived from the need to create comprehensive guidance cover the difference between climates. The concept behind developing "Transformable plant factory unit'' is it helps the stakeholders of the industry to adapted different strategies based On their geographical location and context. Nevertheless, the design research will cover the climate and the production infill by creating a computational workflow to ensure best output result from both aspects. This study will discuss the potential of using the closed loop urban farming system and mainly will present the variation between an aquaponic system that provides circular loop system for delivering water and nutrients for plants and fish. The research focuses on developing the new construction of combined PFAL, vertical farm on the facade (based on energy evaluation phase) and greenhouse roof that capable of plant production which does not rely on weather or seasons**[Graamans, 2015].**

2.1 PROBLEM STATEMENTS

2.1.1 Main problems

1. Population growth and rapid urbanisation.
2. The high value of production cost in current PFAL and Urban Farming. See figure B-3.
3. Shortage of clean water.
4. The need for direction concerning production technique in extreme cold or warm environment.
5. The need for new farming strategies to tackle food insecurity around the world.FigB-2
6. The lack of design guidance combining the food production and climate responsive design plan in the industry.

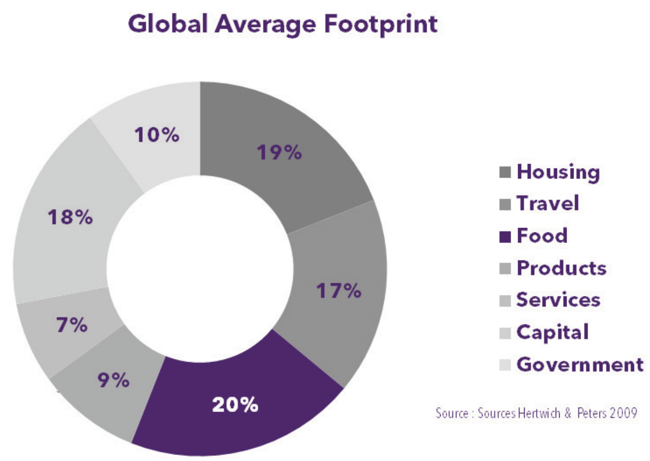


Figure B-2: The environmental impact of current farming practices

2.1.2 Sub-problems

- The need for direction concerning production technique in extreme cold or warm environment alongside local farming issues such as Shortage of clean water.

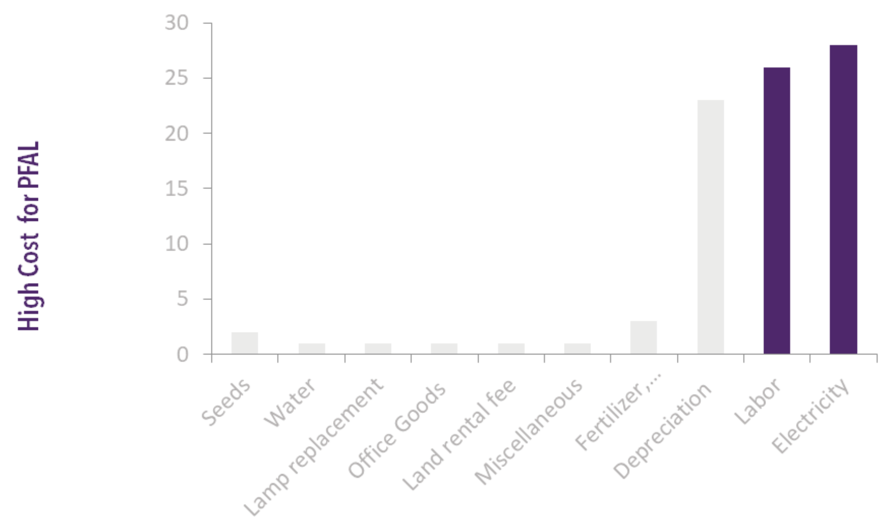


Figure B-3: graph shows the cost breakdown and the highest categories

2.3 OBJECTIVE

2.2.1 General objectives

- Create optimal light and temperature conditions for food production inside plant factory.
- Study the outdoor conditions in Different climate.
- Design climate-responsive, intelligent skin that can intelligently deliver best light and temperature conditions – Hypothesis direction of a solution in biomimicry.

2.2.2 Sub-objectives

- Investigate the applicability for selection of production types in the industry.

This objective will deliver practically a Parametric workflow can provide climate solution of the plant factory (Vertical farming) users Based on the context and location. Also a literature guide for designers and stakeholders in the industry of Urban Farming. The final design of plant factory will be compared to the standard baseline design of the fully closed facility.

The hypotheses about the direction of solutions focused on using algorithm workflow to optimise the building energy and production performance. The study is cross-disciplinary research aims to bring the gap between the different disciplines as shown in fig B-5. This research is methodology led. This approach gives structure to the activities from how literature collected. Implementing this study in a new context will offer new possibilities **[Lucas, 2016].** FigB-4.

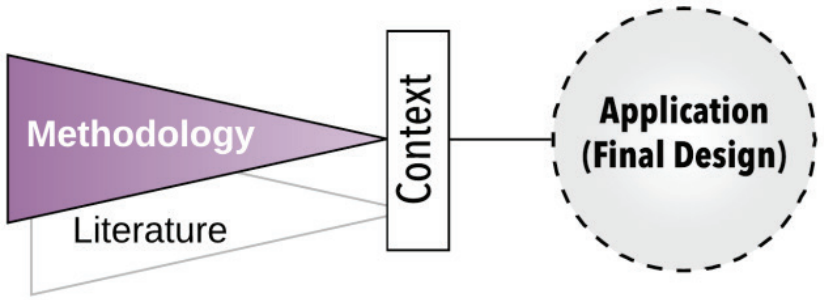


Figure B-4: Research depth and focus, applying the research on different context will lead to different result graph by author

2.4 RESEARCH QUESTIONS

2.4.1 Main Questions

What are the best strategies for designing a mobile plant factory to achieve a high level of production at low energy output based on different external climatic boundary conditions?

2.4.2 Sub Question

To what extent the computational workflow process support the designers to achieve the optimum energy and production output in Plant Factory?

What are the climate design potentials of using a smart skin (Biomimicry) inspired design on designing the facade SKIN of plant factory?

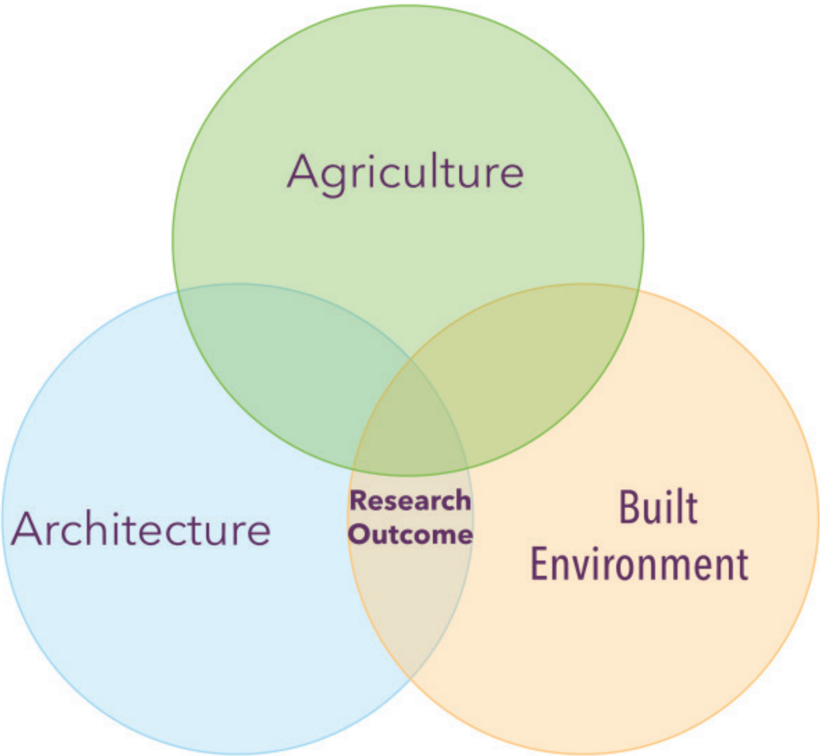


Figure B-4: The area of research output.

2.5 APPROACHES AND METHODOLOGY

2.5.1 Plant factory and greenhouses

The term Hybrid plant factory is combining both type's plant factory with artificial lighting (PFLA) and greenhouse. The PFAL is an indoor, advanced, and intensive form of hydroponic production system where the growing environment optimally controlled. PFAL is one form of "closed plant production system" (CPPS) **[Kozai, 2016]** or in some terms the Greenhouse production, often called Controlled Environment Agriculture (CEA) **[Ponce,2015]**. Where in both greenhouses and plant factory the vertical farming is used to intensify the production. All CPPS unit can be built anywhere and does not affect outside climate or soil fertility wherein PFAL neither solar light nor soil is needed. Additionally, the crops are pesticide-free and have a less bacterial load which is cause for longer shelf life. It is recommended to build the plant factory in or around urban areas to reduce the transport carbon footprint and costs. Thus vertical farming has advantages over using single production layer. Nevertheless, there are some challenges or disadvantages with PFALs that we must address. Foremost among these are the high initial and production costs. The estimation that the cost of constructing the outer structure is as high as the cost of installing the PFAL units inside **[Kozai, 2016]**.

2.5.2 General research framework

The primary research outline consists of 3 main phases. First the study analyse internal and external climatic conditions. Then the phase of developing intelligent skin, and finally achieving the optimal conditions by an elaboration in the building services by adjusting these internal boundary conditions that are not possible through facade phase.

The theoretical part of the research intend to provide a supporting guide for plant factory design.

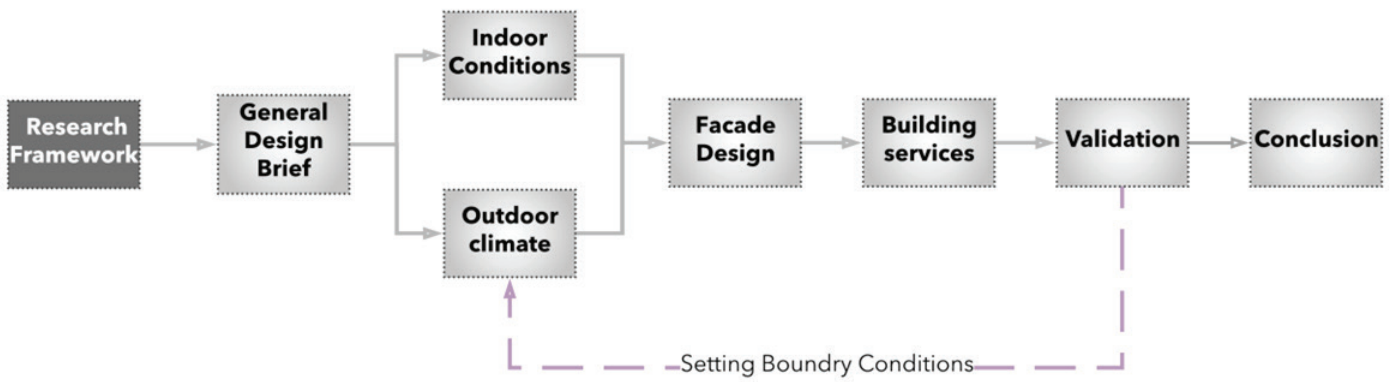


Figure B-5: general research framework.

2.6 RESEARCH FRAMEWORK

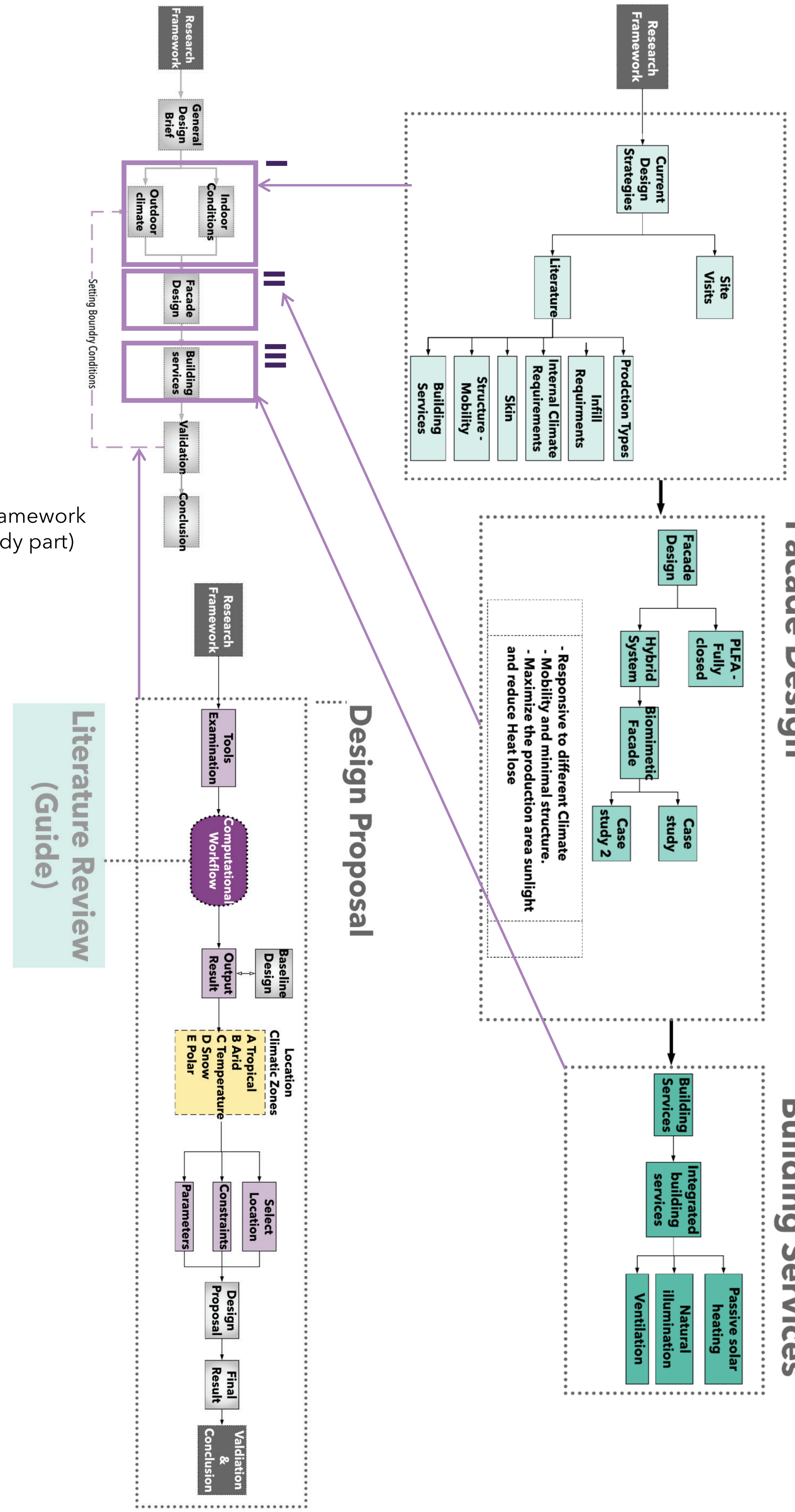


Figure B-6:Research framework diagrams(Literature study part)

Figure C-1: Hybrid farming tests using dripping system, University of Wageningen Bleiswijk research Center Netherlands

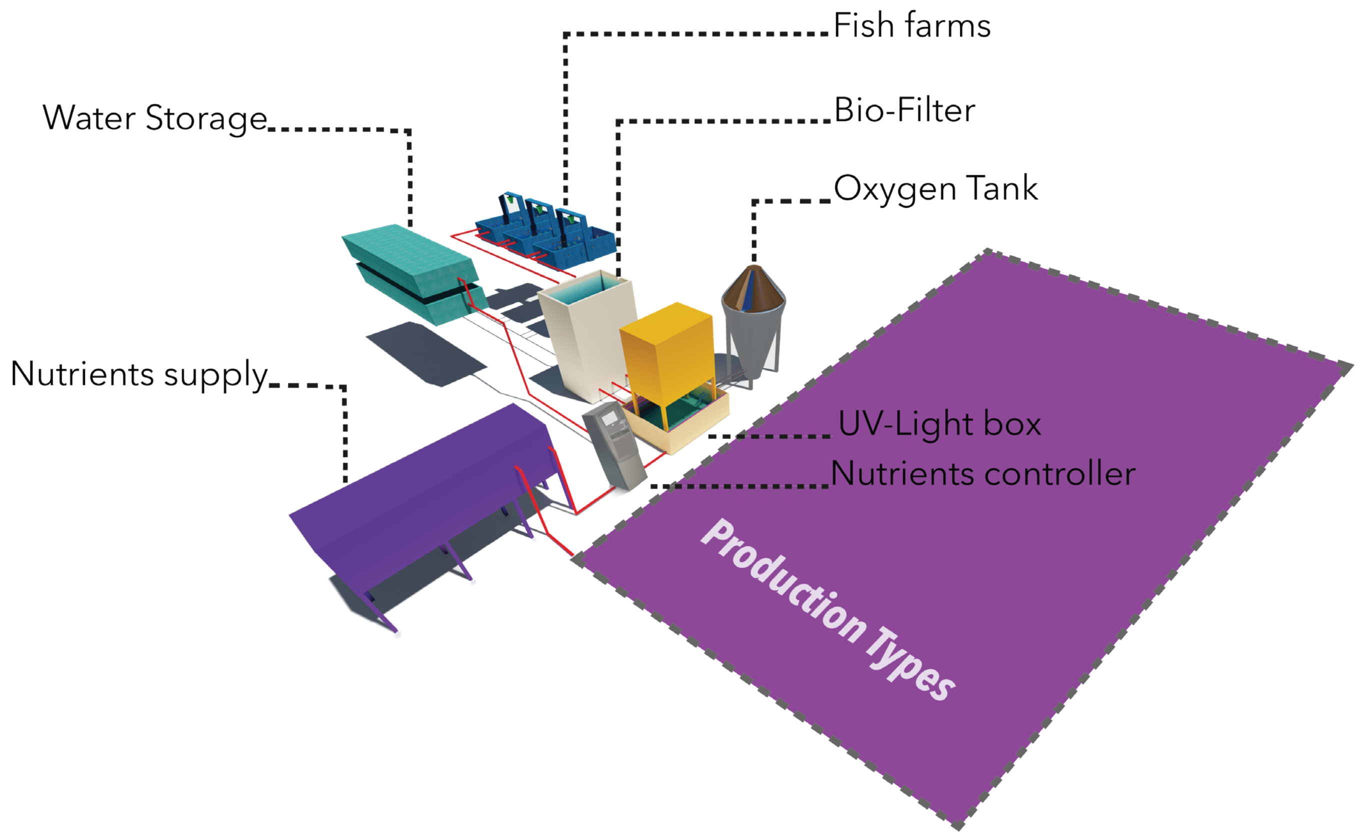
PRODUCTION TYPES

This section aims to provide following key points:

- Understand the existing systems that are being used by urban farmers and industry.
- Define the potential of using each system pros and cons.
- Categorize the selection of the infill (explained in the chosen example).

The research focused on the aquaponic system (combining fish and plant) the fish provides nutrients for the plant where the plant's biomass is providing food for the fish, creating a closed circular system.

Fish production did not differ from typical conventional aquaculture systems with Tilapia and perch **[Graberan, 2008]**. All aquaponics types connected to aggregate (hydroponic) systems. There are three common types are in use for large production scale based on crops type or water management. Today, hydroponics is possibly the most implemented method for crop production in the agricultural industry, where no erosion as in the soil, fewer wastes, no fertilisers needed, no contamination from machinery and its helpful for growing in cities **[Ponce,2015]**.



3.1 PRODUCTION TYPES

Fig C-2: rendering image of typical aquaponics process equipment. Graph by author.

There are different types of farming systems such as closed (by recycling surplus nutrients water solution)and non-closed water system. Hydroponic is ''Soil-less culture'' where plant roots are bathed in circulated mineral nutrient solutions provided in the flowing water with or without the use of an artificial medium, such as sand, gravel, vermiculite, rock wool, peat moss and sawdust to provide mechanical support. **[Ponce,2015]**.

The advantages of using hydroponics are varied, such as stability in growth, healthy crops with fewer diseases, fast and reliable production.

One of the most important factors is the ability to combine this method with fish farming by providing closed loop cycle as the plant benefit from the fish wastes that decomposed into organic fertiliser with the presence of microorganisms, and in return, the fish fed by the crops biomass **[Graber, 2008]**

Aquaponic System Main Parts :

- Bio-Filter, a high vertical tower consists of two type of bacteria heterotrophic and chemotropic to get rid of ammonia in water and create nutrients this bacteria densified by using plastic pieces.
- Water treatment. The bacteria creates a high level of CO_2 in the water this can be removed by heating up the water where the UV light will to get rid of bacteria and protect the plants

in plant factories from the disease. Heating the water used afterwards will reduce oxygen level, so pumping additional oxygen to the water is recommended.

- Nutrients controller (Automated fertilisers) . with an algorithm implemented in a computer program is used to generate the time duration values needed to activate the valves for the addition of liquid fertiliser by the injection unit **[Savvas and Manos, 1999]**. This ISE unit ion-selective membrane was available for most of the essential hydroponic nutrients, including NO3, K+, Ca2+, and Mg2+. Managing stable electrical conductivity EC and controlling PH **[Kozai, 2016]** maintaining stable PH by removing bicarbonate from ground, river and drinking water that allow the plants to absorb the nutrients effectively. Where durable EC can ensure the better growth of the crops and longer shelf-life. **[Priva, 2013]**
- Excessive and drain water recycling and storage.
- Harvesting box for the fish by zapping.
- Excessive and drain water recycling and storage.
- Harvesting box for the fish by zapping.

Several types of hydroponic systems widely used in plant factories. These types discussed on how they work. Choosing the right production for the crops and location is subject to different bases such as availability of water. The plant's size and density, the availability of the movable bed and automation cultivation. Overall the Hydroponic system is the highest production output with a range of 200% to 1000% more than soil growing method depending on infill type. Beside the low cost of operation Of 200% to 1000% more than soil growing method depending on infill type (Tests has been applied on Tomatoes Aubergine and cucumber) **[Graber- graph 14,15 - p153, 2008].** Beside the low cost of operation advantages. Fig C-3 explain the system.

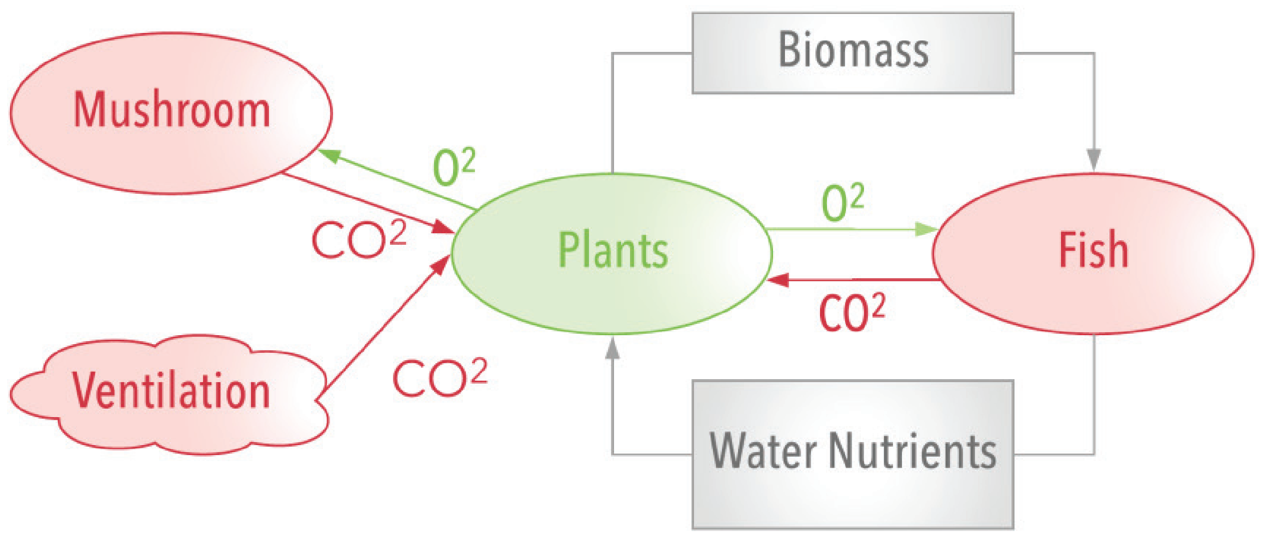


Figure C-3: efficient aquaponic system's closed production cycle; Graph by author.

3.1.1 DWC (Deep Water Culture):

Alternatively, DFT system (Deep flow techniques) this system based on placing the plant in one reservoir where the plant's roots suspended in the water with nutrients. In this method air pump for increasing oxygen level and growing medium required. In some designs the plants placed in separate pots working similarly in Ebb and flow system. There are several types of medium such as burn coconuts or hydroton (expanded clay reusable and PH natural).

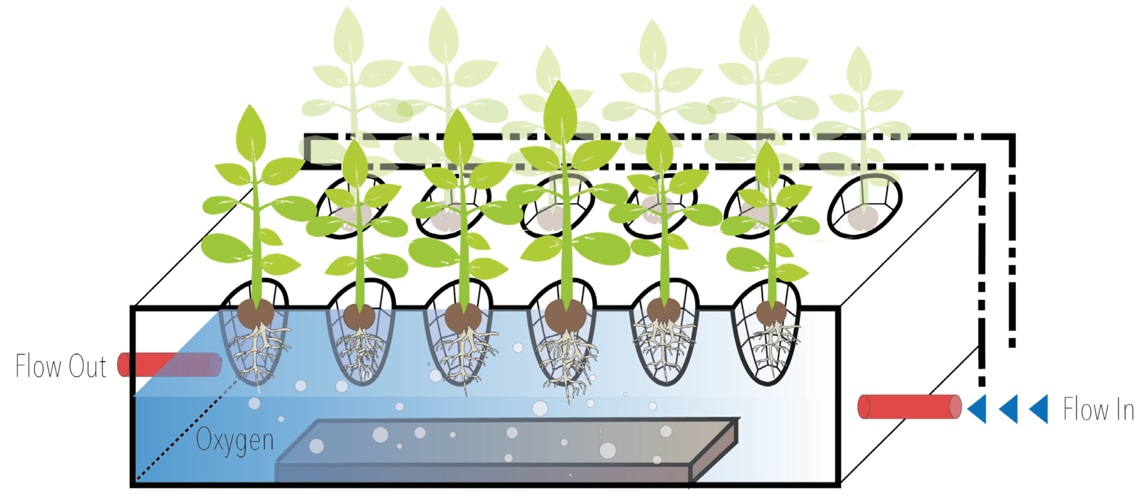


Fig.C-4: Illustration of common DWC system.

3.1.2 NFT (Nutrients film techniques):

A new growing system has been provided to increase the flow in NFT to multilayer. In this system, the plant placed in divided channels creating separated rows.

Fig.C-5: Urban farmers, The Hague. The aquaponic farm has NFT (combined with the dripping system) system each row has different infill. Picture by author.

The system provides a capacity to induce the development of Reliable rooting systems, which result in plants of maximum productive potential and resistance against diseases, alongside its adaptability **[NGS, 2015]**.

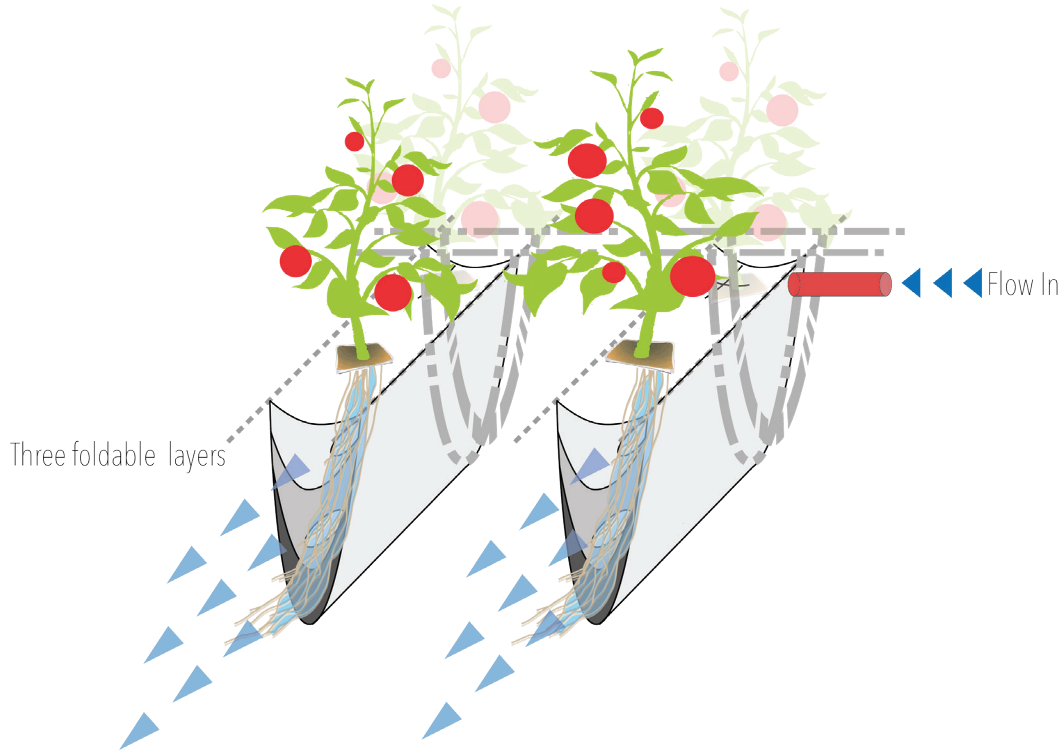


Fig C-6: Illustration of NFT new modified system. Source NGS guide; graph by author

Space is less efficient and less resistant to higher temperature. It is easier to heat nutrients solution, but difficult to maintain a constant temperature as at 37C the oxygen dissolved falls dramatically **[Kao,1991]**. However, it is manageable, and the harvesting can be automated. The plant with long roots and longer than 30 cm, such as cucumber tomatoes and pepper are typically grown in this system. Also, growing leafy vegetables in DFT, and NFT is the best option **[Kozai, 2016].** The economic value should be considered in advance as space will result in less production outcome comparing with DFT.

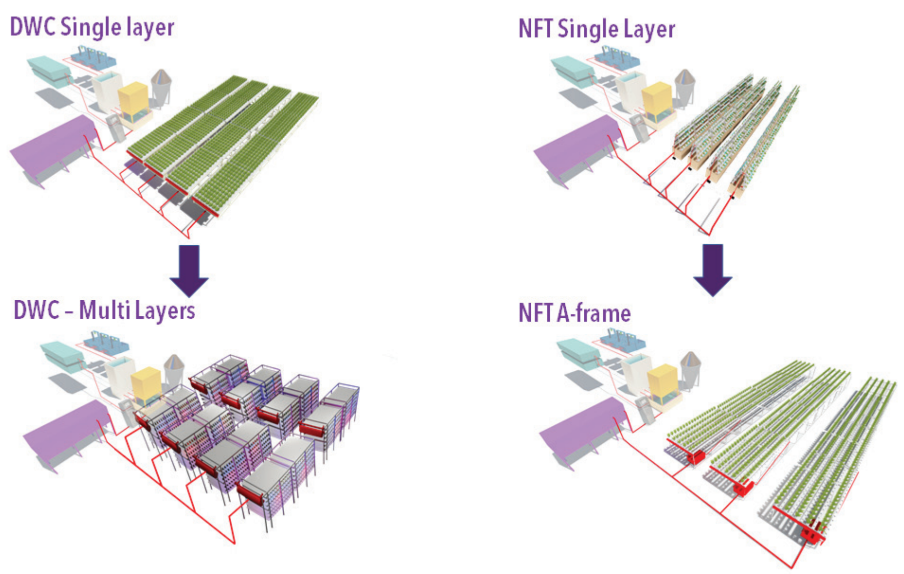


Fig C-7: Illustration of different densification methods. Source NGS guide; graph by author

3.1.3 Aeroponics

The concept behind using aeroponics system is to use less water volume than flowing water system in DFT and NFT; no medium is present only by spraying or misting the water with nutrients continuously on the roots. The production is sufficient, and this type recommended where the farm located in an arid area facing a shortage of water. It needs a stationary bed which decreases use efficiency. The system is not energy efficiency in comparison with other methods.

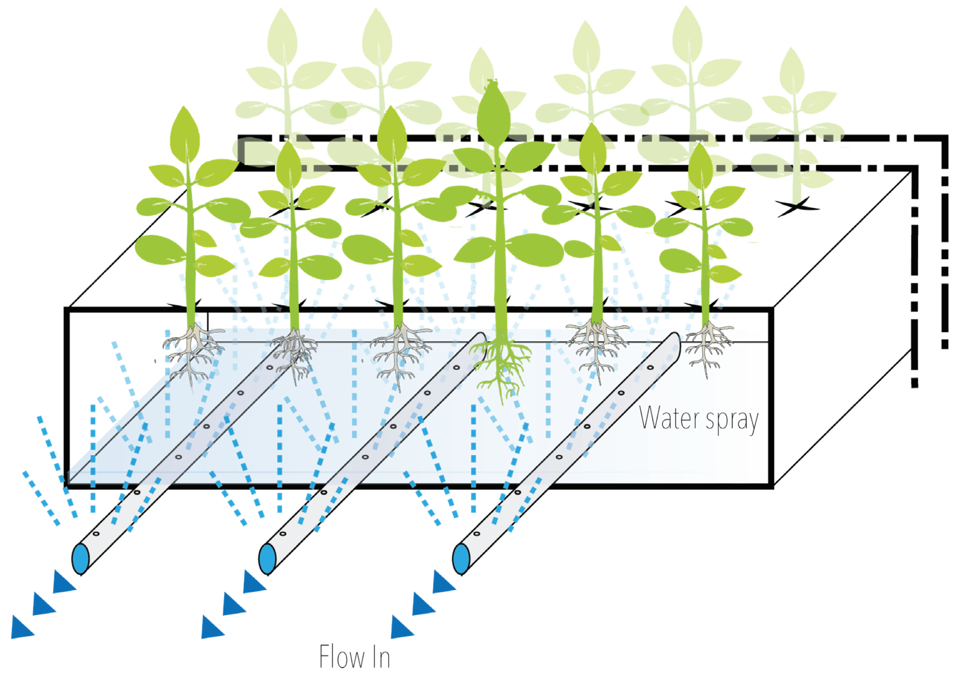


Fig.C-7: Aeroponic system graph by the author.

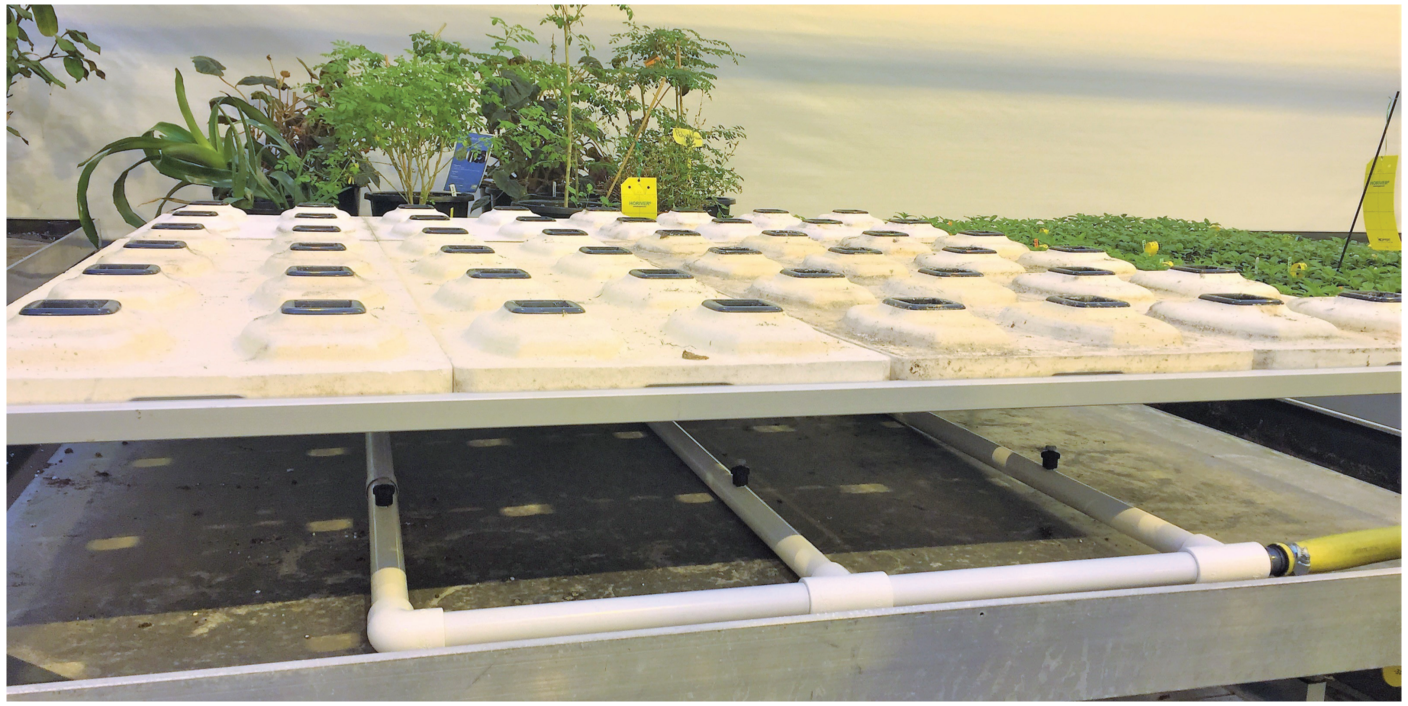


Fig.C8: Aeroponic system tests, University of Wageningen Bleiswijk research Center Netherlands photo by the author.

3.1.4 EBB and Flow (flood and drain)

A closed system consists of a watertight exterior rooting bed, a perforated interior rooting bed containing an inert rooting medium (such as gravel, coarse sand or volcanic rock) **[Graamans, 2015].** There is a pump from the reservoir that holds the nutrients to the plant's upper bed. The nutrient solution is typically supplied only once or twice.

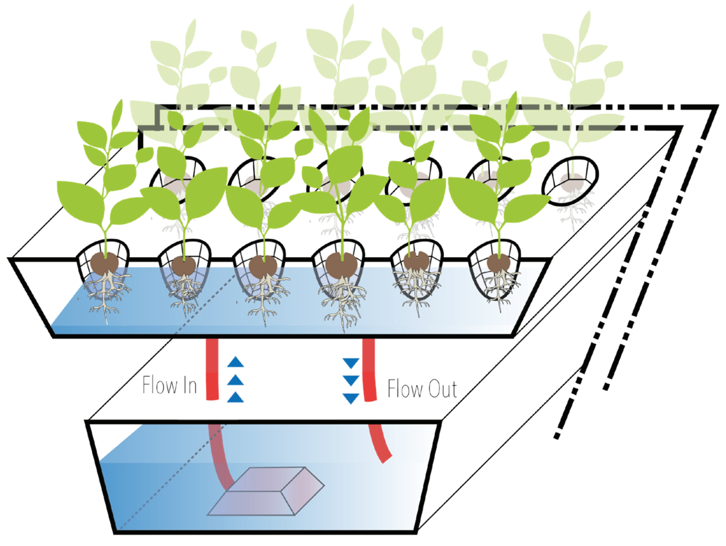


Fig.C-9: Illustration of Ebb and flow system; graph by author

This system is used in small scale. However, a large configuration can be optimised for an automated vertical bed such as shown in fig.

Fig.C-10: Automated cultivation system using 3D-carriers on the vertical transporter with a load capacity of 1550 kg and can be configured a broad diversity of crops. Source Logiqs B.V.; 2017

3.1.5 Semi-Hydroponic System

(Widely used in farming in areas with a shortage of water)

Drip system

Propagation of plants in plant block made of rock wool, rock wool, coconut coir, recycled glass, perlite, sand, and other alternatives. Used as growing medium to regulate plants growth. Drip tubes deliver water and nutrients in precise quantities, substantially increasing the water use efficiency (WUE) of the crop **[Kozai, 2016]**. If there is excessive water, it can be recycled and provided again to the plants

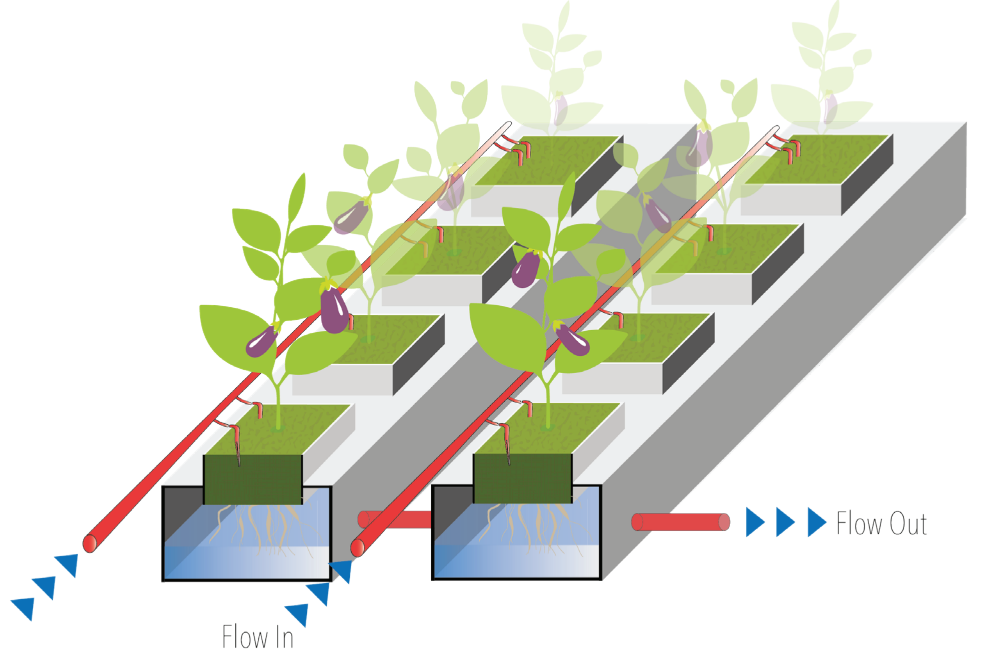


Fig-C11: drip system; graph by author

The medium is allowing the propagation of young plants to benefit from dripping waters minimising the use of speed up the wetting and improve water distribution in roots. These blocks need to be changed annually once or twice. The wasted wool blocks are then recycled, and granulite stone wool used again in making of building bricks and blocks. Hydroponic systems such as EBB and flow (flood and drain) as its distributor in small production size due to difficulty in management in large-scale and have higher risk and unstable PH in closed systems such as NFT, DFT, and ebb-flow systems. It is essential to determine the nutrient solution of optimal composition because prolonged reuse of drainage water may lead to an accumulation of some nutrients.

There are 13 essential elements nutrient solutions are that has the different concentration in the water. In recirculation systems, nutrient solutions that are not absorbed by plants return to the nutrient tank. Therefore, water and nutrient absorption by plants can be easily estimated by measuring the loss of the water **[Kozai, 2016].**

3.2 INTERNAL CLIMATE REQUIREMENTS

General climatic requirements The infill :

- PPFD set at 500 µMol/M2S, minimum 85% integral daylight **[Graamans, 2015]**,However, a 250 µMol/M2S is acceptable as lower threshold.
- Interior temperature 24-31 Celsius, root temperature 24 Celsius.
- CO2 Level 800 - 1200ppm recommended.
- Relative humidity 75-95% higher value is preferred.
- These are the genera conditions and may vary based on the type of infill.

3.3 Infill General Requirements

Mono-crop is recommended as it provides less complexity in the design, consistency in logistics and interior climate **[Kozai, 2016]**.

- Shorter in height, plants suitable for PFALs are that 30 cm or such as leafy greens, transplants, and medicine fast-growing **[Kozai,2016]**. (harvestable20-30 days after transplanting).
- The plant can grow well under low light intensity and at high planting density.
- High-value product if fresh, clean, tasty, nutritious, and pesticide-free.
- The product value can efficiently improve environmental control.
- Providing CO^2 is necessary for speeding the growth, hence mushroom farm is usually used.

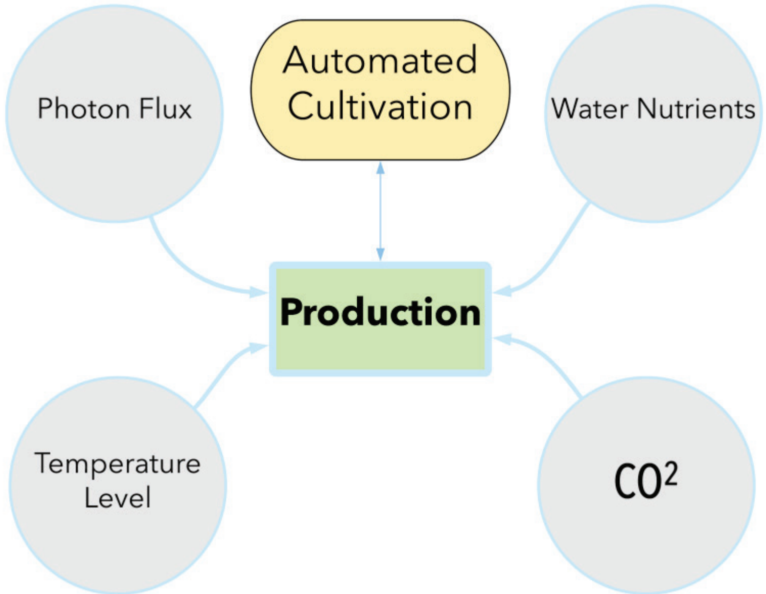


Fig C-12: main factors for fast production in plant factory; graph by the author.

CLIMATOLOGY

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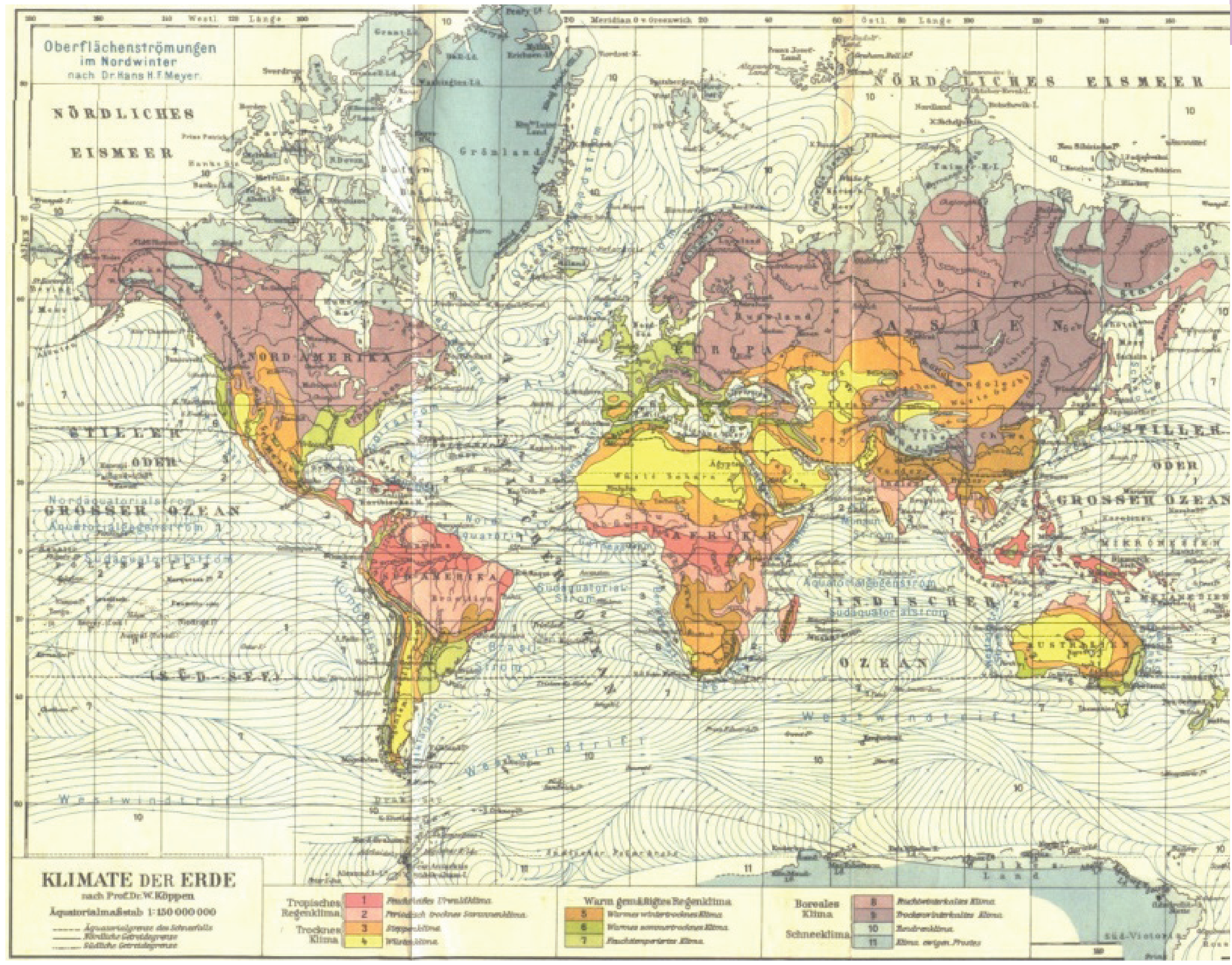


Fig D-1: The original map of the Köppen climate types. The climate types are marked [**Kalvová - Halenka, 2003].**

Outer climate condition is affecting the skin design. There are five main climate regions based on Koeppen's classifications, tropical (A), dry or arid (B), temperate (C), cold (D) and polar (E). As all plant factories are CCPS facility the main factors in this classification is the humidity and light, however, the evaluation of cooling and heating is vary based on seasons temperature, and total outlook of energy study wither it should be PFAL or greenhouse. will cover many dimensions and will generate energy concepts.

4.1 Tropical Rain(A)

The temperature in the coldest months +18, the humidity is high due to large rainfall most of the year. This region divided into three sub-regions based on rainfall level, Heating and insulation are not required, and vents can remain open **[Ponce,2015].**

4.2 Arid Climates (B)

The humidity in this region low, the sub-categories of the arid areas include. The design should consider the strong winds with dust and particles besides the increase in humidity that can reduce the temperature thus climate controller is required.**[Ponce,2015].**

4.3 Temperature rain climates (C)

In the climate zone, the coldest month temperature ranges between -3 to +18. Heating the air inside the greenhouse and insulating and sustaining this heated air is the main consideration **[Ponce,2015].**

4.4 Cold or snow Climate (D)

The warmest months has a mean temperature over +10 C°, and the coldest months should be below -3 C° .**[Kalvová - Halenka, 2003].** this type of environment need solid walls, and strongly constructed, comparatively steep solid roofs to carry snow beside keeping vents closed **[Ponce,2015].**

4.5 Polar snow Climate (E)

The warmest months must be lower than +10 Co **[Kalvová - Halenka, 2003]**. In polar areas, the PFAL with high insulation is the best option regarding reducing heating energy.

It is clear that the closed ventilation system is suites all types where the selection of skin materials need to be stiff to encounter extreme climate conditions and have high insulation values. In some regions introduced the solar light is shining over the year which will lead to increase greenhouses effects that are the primary cause of heat in the greenhouses. This will require reduction of light intensity level or more specifically infrared spectrum. The effect will be discussed in later the chapter 5 and the practical part.

LIGHT PROPERTIES

Figure E-1: Greenhouses in the night, The Netherlands showing The traditional way of using artificial lighting high-pressure Sodium lamps (HPS).Source: National Geographic.

INTRODUCTION

This section provide the necessary knowledge required to evaluate the best internal light condition for hybrid plant factory using solar light beside (light emitting diodes) LED lighting system.

Light energy is an essential source for plant growth. It is composite of an electromagnetic wave. This waves that carry power through photons number by the Einstein famous formula: E= f.H *. There are visible and invisible wavelengths. The smaller the wavelength, the higher the energy.

To create light, there are different arrangements to achieve the desired wavelength or frequency (basically, the colour that you want) **[Duree,2011]**. The most important terms for measuring light in agriculture are active photosynthetic radiation (PAR) that measured by PPF the number of photons per second per square meter of absorbing surface (photon flux) and the PPFD is photon flux density that measures with (Micromole/ square meters X second) The more the plant receive PPF, the faster the growth **[Graamans, 2015]** regulating the PPF per day called daily light integral (DLI).

Solar radiation, 97% is within the 280–2800 nm range. Of this, 43% is visible light, which is useful for plant growth, 4% is ultraviolet, and 53% is infrared, which produces heat **[Kozai,2016].** There is a possibility to manipulate the light by filtering the spectrum using a coloured material or net colour **[Hemming,2007].**

* E is the energy carried by the photon, h is Planck's constant and has a value of 6.626 × 10–34 J·s., f is the frequency of the light.

5.1 WAVELENGTH AND FILTERING

Different light source and colour has different wavelength and effect on the plant and the amount of photon. The response to the light in the plant is a bit different from the human eye that perceives wavelength range between 380-780 nm and in plants 400-700 nm of the solar radiation Fig E-2. The plant looks green to us as they are reflecting this part of the spectrum which expresses why the light used in advance closed facilities in red/pink are turning the plant to black.

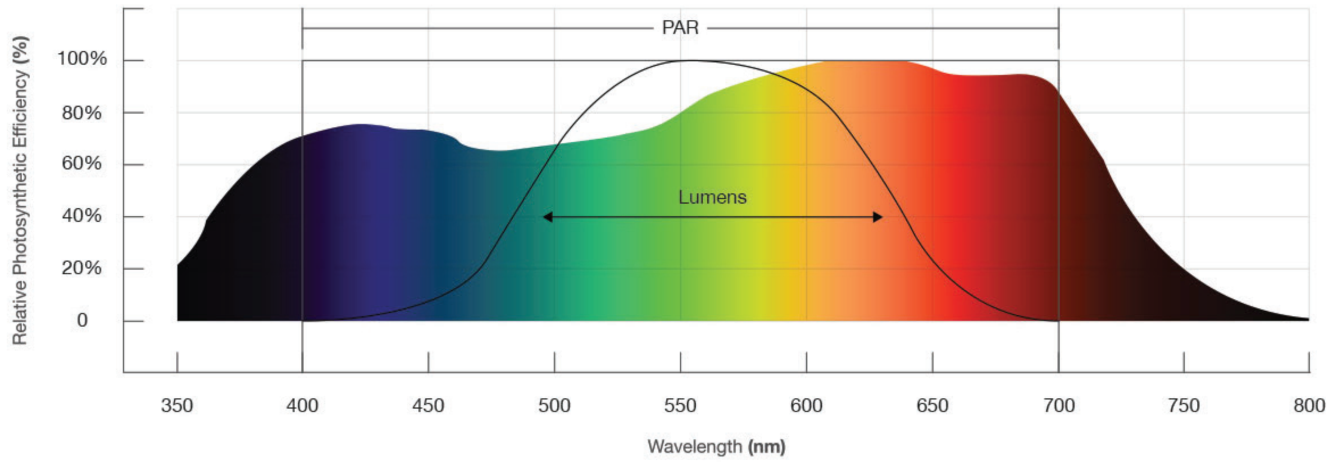


Figure E-2: Light response in the plant, the background colour is the best colour for filtering spectrum; source website: www.fluence .science.

To filter, the certain wavelength required for different growth colours applied on skin material and the colour of LED lights. The selection of best colour based on the type of infill whether its fruits, rose or even vegetables, the colour of the leaf also would influence the selection. For example, applying these colours by LED on rose and tomatoes leaf in laboratory shows that The spectral quantum yield was highest for red light (about 640-680 nm). **[Hemming,2007].** Mixing the colours is also is being used for achieving best photosynthesis in plants that complete the visible range beside the plants colour (non-green colours). This could also describe why is additionally the green colours is also the best for the red rose. The following spectrum importance applied to plant factory according to **[Kozai,2016]:**

Ultraviolet	100 -380 nm	No use
UV-C	100-280 nm	Purifying
UV-B	280-320 nm	Sunburn
UV-A	320-380 nm	No use
Visible light	380-800 nm	Photosynthesis and morphology
Near-infrared	780-2500 + above	Heat
-(Infrared-A)	700-1,400 nm	
-(Infrared-B)	1,400-3,000 nm	

It is important to mention that the sunlight spectrum UV-C is penetrated in low percentage if not filtered the skin materials to the buildings or and the atmosphere. Therefore the claim of benefiting from purifying through sunlight is not reliable.

5.2 LIGHT IN HORTICULTURE

The plant has a different response to light in Horticulture than normal eyes. Thus the light measurement and growth requirements have different rules and conditions aside from the standard rules in daylight study in normal buildings. The scale between light intensity and temperature appeared to have a considerable influence on crop growth. **[Hemming,2007].**Plants tend to optimise light harvesting by solar tracking and enhancing body exposure **[Badarnah, 2016].**

There are two ways of measuring light, the standard method of measuring the PAR transmission for normal incidence (parallel to the normal of the surface- Dutch NEN 2675) FigE-3. Moreover, the hemispherical transmission than perpendicular(developed by University of Wageningen, especially at northern latitudes. Where the diffuse light dominates, up to 80% [**Swinkels,2012**]. There is a wide range of new covering materials with improved thermal insulation, light transmission and diffusing properties have been developed.

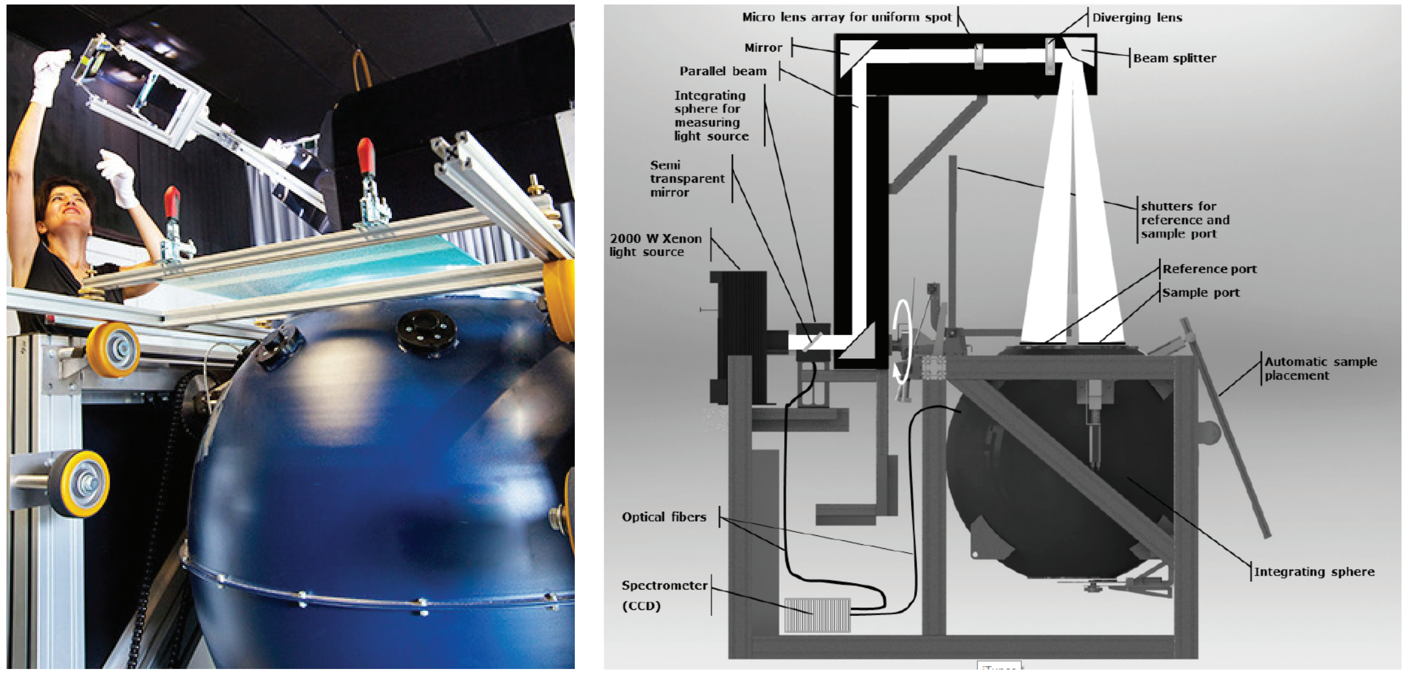


Figure E-3: hemispherical light measurement of the haze, Wageningen Horticulture research center The Netherlands: source University of Wageningen website

For these materials, often with coatings, the relation between the standard and hemispherical transmission is not straightforward which makes the standard way inappropriate[**Swinkels,2012**]. such as the haze of the materials.

A study has investigated the effectiveness of using haze materials in greenhouse comparing, regular cloth, haze glass, standard farm and clear glass. The haze materials show increasing in photosynthesis in plant around 10%. This result in the covering material applied in high-tech greenhouses.

5.3 SHADING AND GEOMETRY

There are several studies conduct on determining the ideal orientation and space dimensions rule of thumbs for having better sunlight access. Observing the orientations and the solar altitude and azimuth angle in the selected context through the year in a different time is essential for any start before the starting the design phase.

Below graphs E-4/5 explaining these rule of thumbs. They are showing that the most extended shadows occur when the sun is low in the sky where the best is to minimise the ground shading. The example of rectangular plane shape can be an explanation of how the design should orient the building block in Fig E-4/5 illustrating the ideal placement of the rectangularly shaped greenhouse.

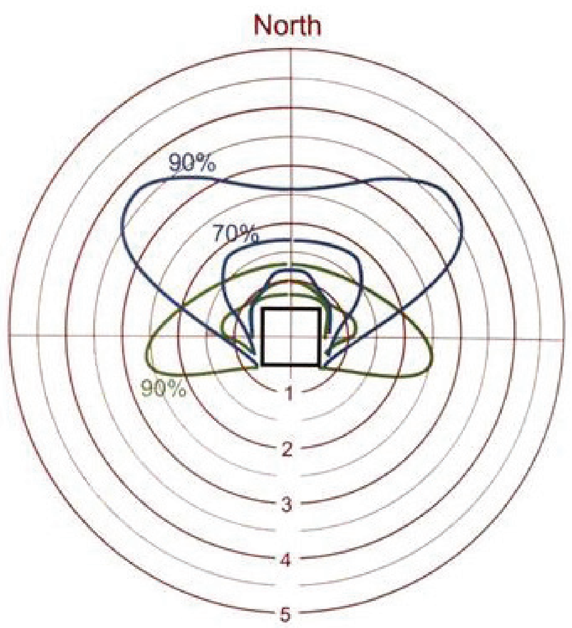
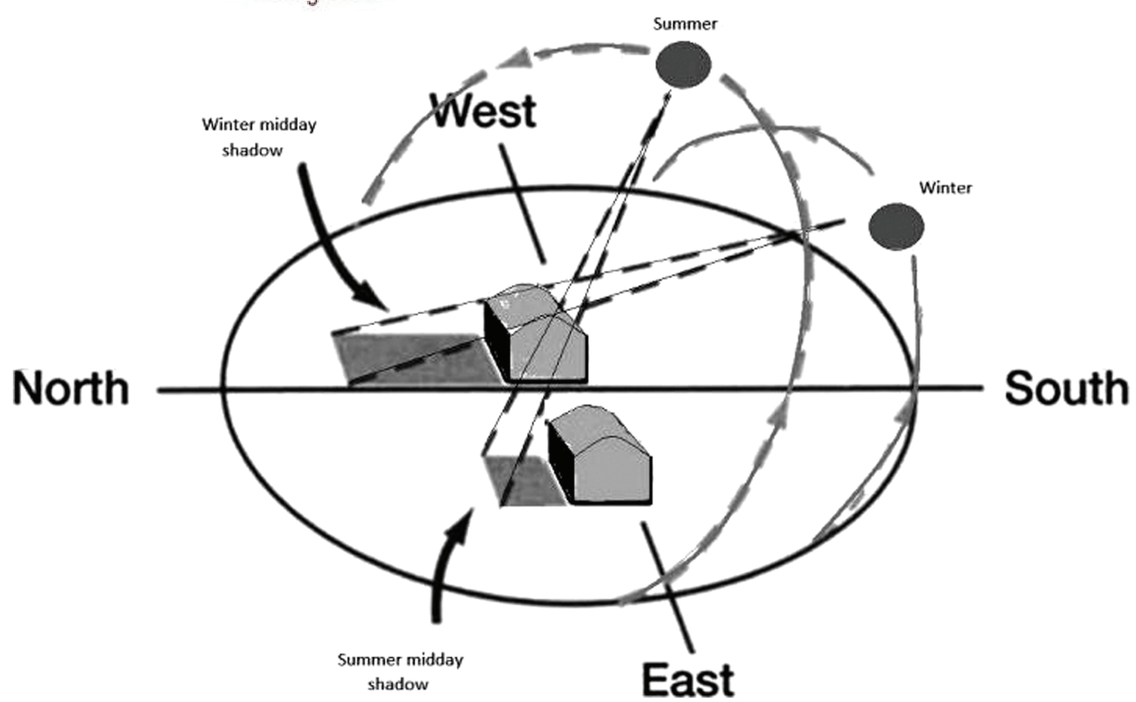


Figure E-4/5 : Shading light on ground plan study in winter-spring autumn (blue), summer (green). Source **[Tregenza,2011]**

E-5: Location for Greenhouse based on Sunlight angle. Source **[Ponce,2015]**



One of the main architectural rules of thumbs in light design can improve the facade and production level dimensions in plant factories to achieve strong daylight from sides of the geometry is to place five times as the height of (floor, production plan level) internal depth to achieve high daylight factor.

The light access of the hybrid plant factory has two factors need to be considered; First is about selecting the geometry. Light access, least Structural and lowest energy footprint are primary factors, Each zone requires different shapes for providing favourable climatic conditions for the growth of plants**[Ponce,2015]**. In the second place, it is essential to consider the production level configurations that adapted the best accessibility for solar light exposure and logistics.

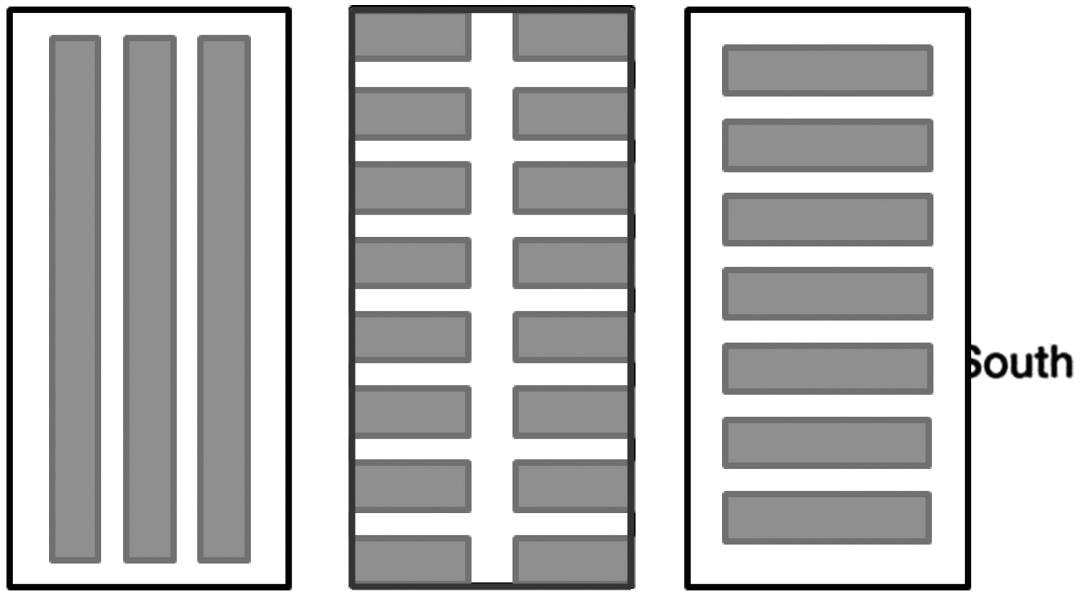


Fig E-5: Different beds and benches in greenhouses **[Ponce,2015]**

6

BIOMIMETIC FACADE

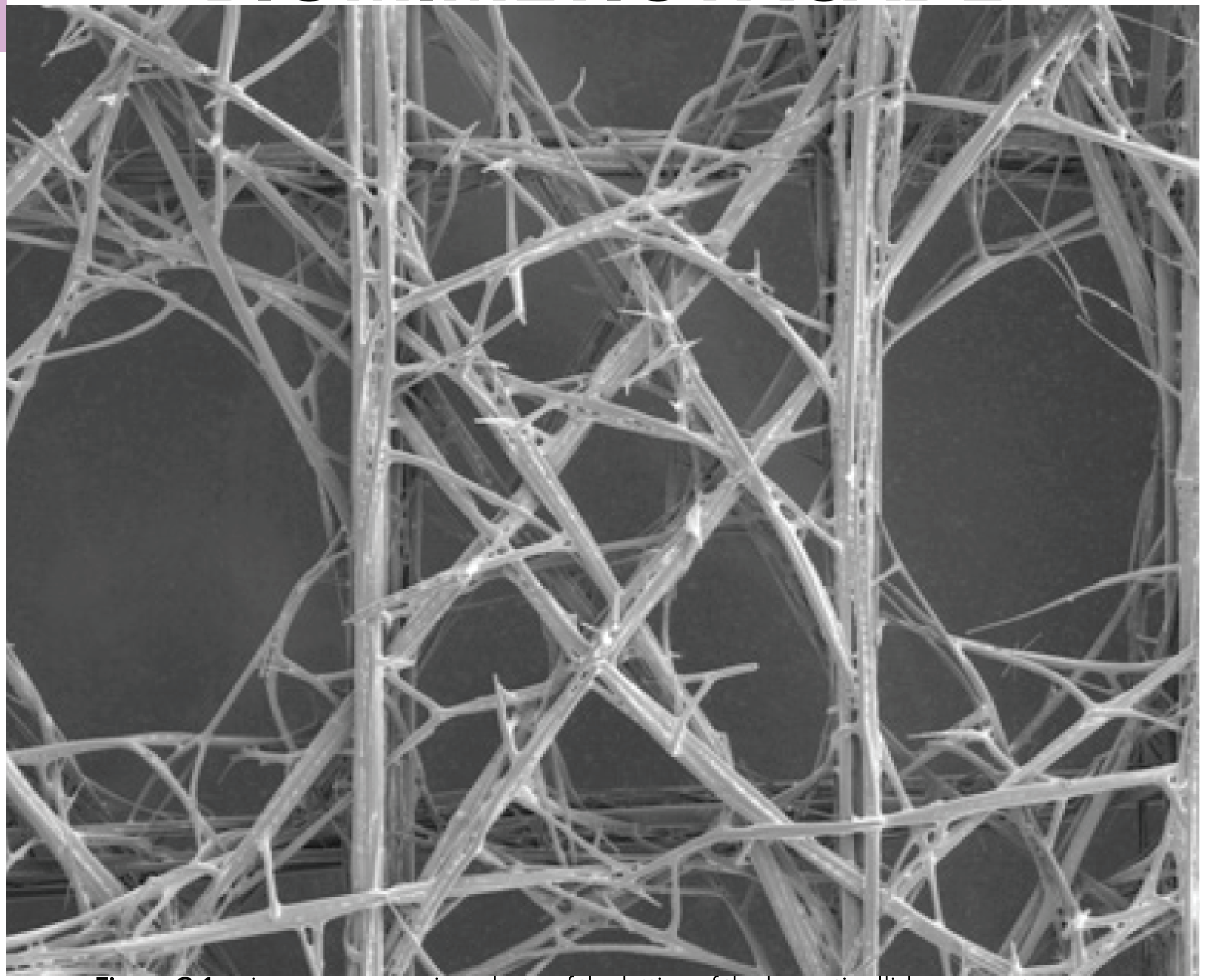


Figure C-1: microscopy scanning photo of the lattice of the hexactinellid sponge structure Euplectella aspergillum. Source **[Weaver,2006]**

INTRODUCTION

The words of Greek origin Bio-mimetics (meaning life-imitates) has inspired many inventors scientists, designers to provide new knowledge that provides ideal solutions by learning from nature perhaps without copying in exact form what it does. This section shows the an example of the selected organism and why that involved in the design for several reasons:

- Nature has shown an ideal example of light management.
- As light consider the source of energy and growth for organisms, it has required different methods to benefit from the light. Light management in nature is very advanced many examples are shows how this management is similar or even surpass to what we are currently using for solar light management in built environment.
- Nature provides a large database of adaptation strategies that can be implemented in design in general, and in the design of building envelopes in particular. **[Badarnah,2017]** .

6.1 RECENT SKIN DESIGN

In conventional greenhouses, the light management through the skin is an essential part of plant growth. Where in Closed facilities such as Plant factories the solar access through the facade could have a potential of reducing artificial light use and in return energy output. In this session, we discussed the general light management in nature and how this could impact on designing intelligent facade inspired by Deep Venus Flower basket or (Euplectella aspergillum) using its glass sponge structure to grow in darkness.

The study of the organism is going through three stages, The current types of the facade in the industry, then the analysis of the organism and later the proposed design inspired by the organism.

There are several techniques to mention. The two options are in discussion as they are presented the latest and the most effective in the field. Both designs are dealing with light differently, and they have an impact on the production significantly. Most modern hydroponic greenhouses for all climates these days feature a standard height of at least 3.05m this provides a better environment for plants and a larger buffer against minor changes in external temperatures **[Ponce, 2015].** In the skin or roof, the volume of air heated in cold climates can be reduced by using thermal screens around the skin.

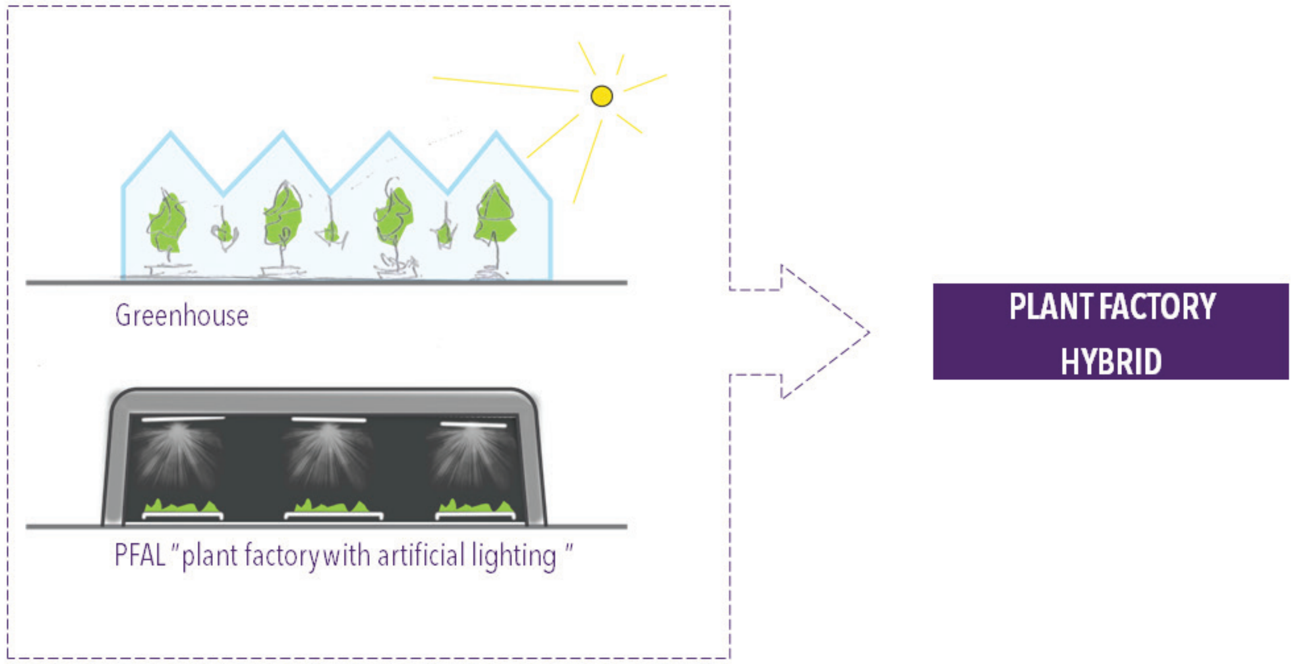


Fig C-2: Fully opaque facade, typical facade for PFAL facility.

Fully Enclosed Facade:

Low amount of solar daylight access during the day could create unbeneficial use of transparent skin. Therefore PFAL is used and insulated wall installed to reduce the energy lose though facade. Using only LED as a source of light.

6.2 GLAZED FACADE USING HAZE GLASS

During periods with high irradiation and in lower latitudes plants often have to be protected against too much light. Screens, temporary coatings or nettings are used to decrease light intensity[**Swinkels,2012**]. Using covering materials which scatter the direct incoming light and make it diffuse to some extent. This is called the haze of the material **[Swinkels,2012]**. At high irradiation levels, diffuse greenhouse coverings result in better light distribution, lower crop temperature, decreased transpiration. Although its decrease the light transmittance by 3-5% its increased photosynthesis and growth, influence micro-climate and increases crop production by 6.5-9.2% **[Hemming et al., 2007].** So the growth rule 1% light = 1% growth not accurate and need to be redefined. The diffuse covering material is not as necessary during the winter months because clouds scatter the sunlight during this period. Diffuse covers are most beneficial in a moderate climate - during spring, summer and autumn when there is more direct sunlight. **[FlowerTECH, 2007]**

Fig C-3. Shows shadows appear which can lead to non-uniformity of the crop and Diffused light that can accelerate production of certain crops source **[Hemming&Reinders, 2007]**

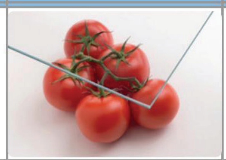
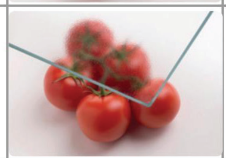
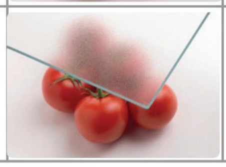
	Glazing Type	Example Albarino® products	Light transmission	Hemispherical (WUR method)	Compare production with using the material in Spring Autumn and Summer	Compare production with using the material in winter
1	Crystal Glass		90.5 - 96.8	90.0	-/0	+
2	Low Haze		91.5 - 96.5	89.0	++ 7% Kg/m2	-/0
3	High Haze		91.5 - 95.5	85.0	++ 9.4% Kg/m2	-/0

Fig C-4. Differences in glass haze level and impact on production, a comparison between the transmittance, hemispherical developed by University of Wageningen and production level output by **[Hemming&Reinders, 2007]** Graph by author

6.3 SKIN REQUIREMENTS

The skin of the facility should consider aspects that integrated into the most high-tech experiments in greenhouses :

- Modularity, most of the "intelligent greenhouse" provides modular design to provide cost-effective skin, easy assembly /disassembly and scalability with faster installation and increase the skin surface if needed.
- The materials are being used or selected is light structure and high resistance to stress and corrosion especially in extreme climate condition.
- The Skin cover can be within a choice of using rigid plastic or foil poly-ethylene "highly recommended", polycarbonate and ETFE also used. Alternatively, glass. See FigC-6
- The envelope of Plant factory is not meant to be used for ventilation as its closed facility, thus allows better environmental control of the facility inside and reduces energy use.
- The geometry should provide best light orientation for the building by place the longer side of the elevation plan into the south direction.

	Material Type	Application	Price	Weight	Refractive Index	UV resistance	Flamibility
1	ETFE		○○○	○	1.4	Good	Self extinguishing
2	Glass		○○	○○○	1.45	Excellent	Non flammable
3	Polyethylene PET		○	○	1.6	Fair	Highly flammable
4	Polycarbonate PC		○○	○○	1.56	Fair	Slow burning

Fig C-6: The properties of materials in greenhouses skin. Graph by author. Information CES Edupack

6.4 BIOMIMETIC INSPIRED FACADE

Biomimicry inspires some solutions giving a variable response to external climate. In this approach, the building envelope can be responsive to the exterior and interior environment conditions by imitating the Physiological (maintain a stable internal condition in a different climate), Morphological (adaptation in form and pattern) and Behavioural adaptation (action) in organisms **[Badarnah, 2017].** The biomimetic design does not copy the nature its rather inspiration from a natural process.

To achieve maximum daylight access minimal structure is required, different types of facade technique can be applied to increase the daylight accessibility to the vertical floor space and reduce energy leakage. There are several technique to mention. Biomimicry inspires some solutions giving a variable response to external climate, solar guide facade, and entirely closed elevation. The two options are in discussion. Light is consist of two primary definitions importantly affect the plant production. The active photosynthetic radiation (PAR) that measured by PPF the number of photons per second per square meter of absorbing surface (photon flux). The PPFD is photon flux The density that measures with (Micromole/square meters X second) The more the

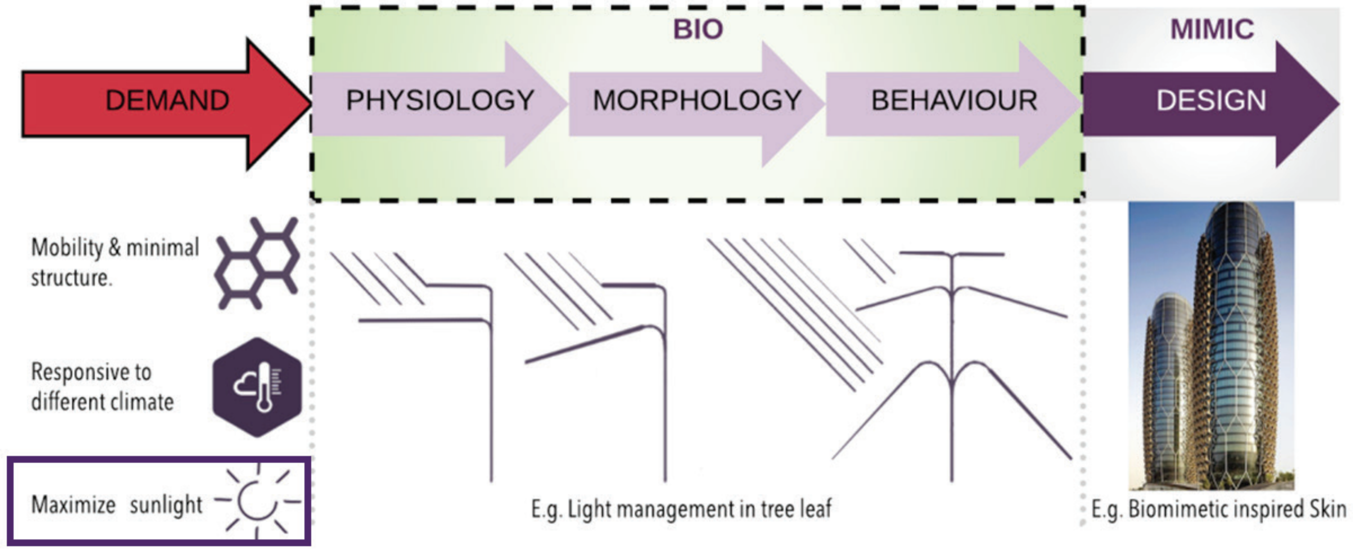


Fig C-6: Biomimicry design process. Graph by the author, e.g. building a picture, Abu Dhabi Al Bahar Tower source: courtesy of Aedas. Graph by Author.

plant receive PPF, the faster the growth **[Graamans, 2015]**. Plants tend to optimise light harvesting by solar tracking and enhancing body exposure **[Badarnah, 2016]**. The impact of using the Bio-mimicry will be highlighted by two examples to investigate how the facade provide a solution by adapting strategies in the nature.

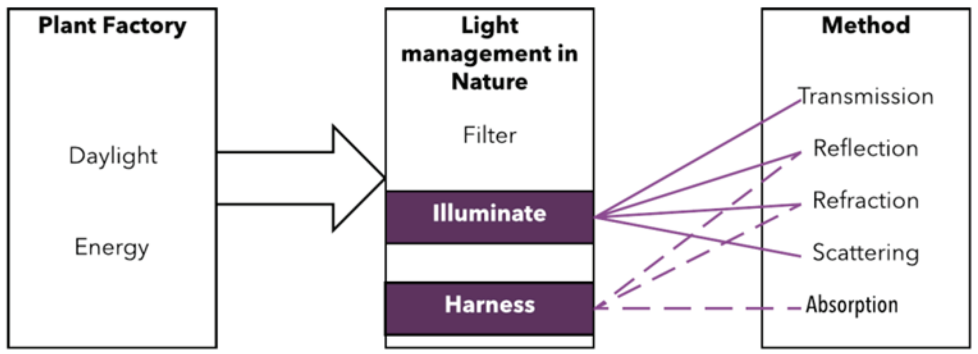


Fig C-6: Light management in nature, and primary focus.

Nature provides ideal examples of the solar light management. Several studies also have been conducted in bending light and reduce energy level of buildings will be discussed in case of studies session. The graph C- shows some biological examples that have similarity with some solutions adopted in building industry such as has materials, selective spectral coating and kinetic facade.

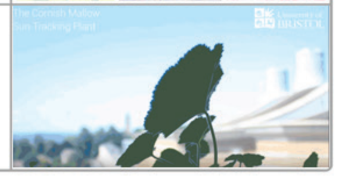
	LIGHT PROPERTIES	NATURE	Feature	Graph
E.g 1	Transmission	Deep Sea Venus flower	Light distribution	
E.g 2	Reflection	Butterfly wing	Reflects certain wavelengths	
E.g .2	Harness	Cornish Mallow	perpendicular to solar radiation	

Fig C-7: Light management examples in some organisms

The following two case studies are highlighted to provide practical evidence and the potential of using a Biomimetic approach in designing skin. Furthermore, it shows the methodology and steps to develop the translation of the biological mode towards final design solution.

6.4.1 FIRST CASE STUDY

''BANANA SLUG INSPIRED SKIN''

Introduction

Research in Southern California Institute for banana slug (Ariolimax columbianus) inspired the design of a greenhouse with an adaptive envelope that adjusts and changes according to weather conditions.

Biological Interpretation

The animal physiological, Behavioral shows that Slugs are most active after rain because of the wet ground, while during dry summer conditions they cover themselves in damp areas under fallen logs or rocks. By using its granules to move. A microscopic view of banana slug mucus granules; these granules are broken open, and mucus is released **[Mazzoleni, 2013].**

Features of the slug were initially investigated and examined relative to the design of the building. Skin's porosity and permeability that allows breathing, the mucus' protection in the slug against both desiccation and predators. The slug's capacity to adapt to changes in humidity and temperature about the encompassing conditions, and the ability to keep stability and connection with its environment. **[Mazzoleni, 2013].**

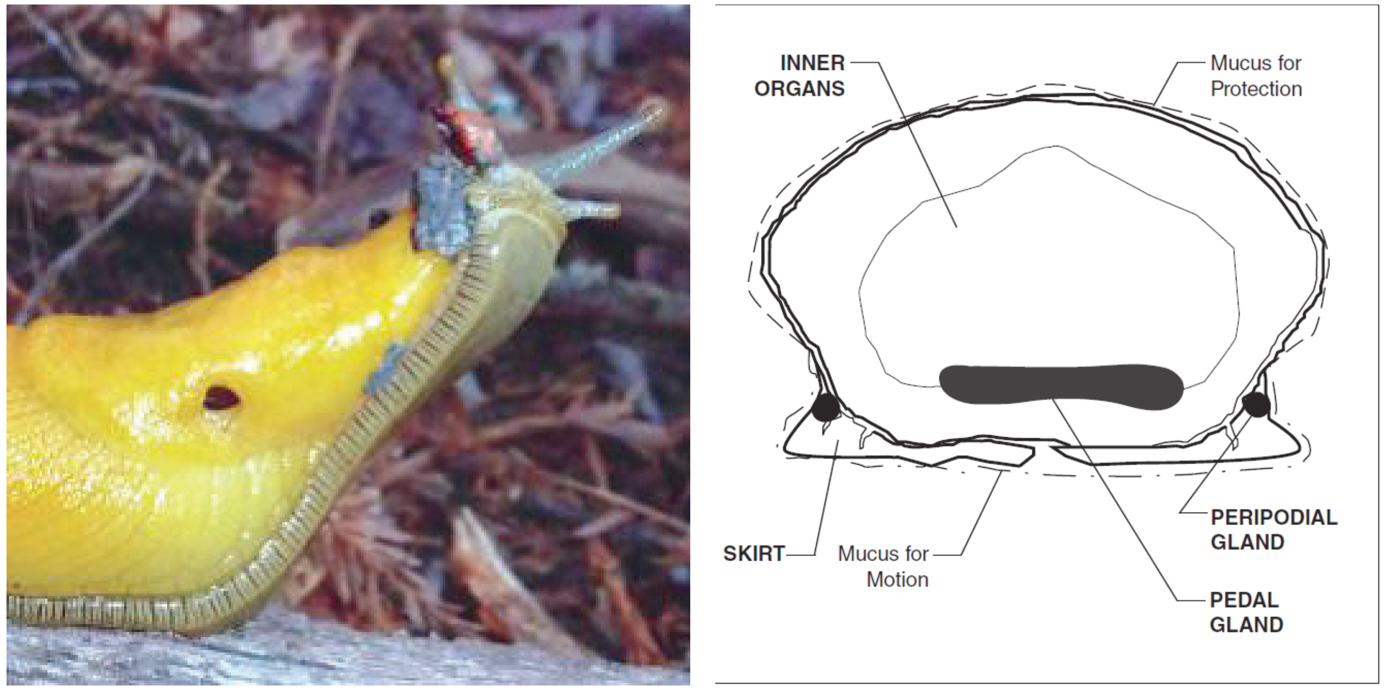


Fig.C-8: The Banana Slugs of skin details and application imitating the movement and behaviour in the organism

In the California forests where the difference between temperature and humidity between winter and summer are significant the banana slug secrete mucus to prevent desiccation. In extreme cold or hot weather, the slug estivates, covering itself under leaf litter and secreting a layer of mucus around its body.

Solution

The need to provide greenhouse with ventilation and humidity alongside solar light is varied depend on different weather cases. The design aims to provide skin has an adaptive cover that changes according to climate statuses. The Skin bend and shifts the internal environment by letting sun, air and rainwater to penetrate inside when wanted, and shielding the crops and providing protection.

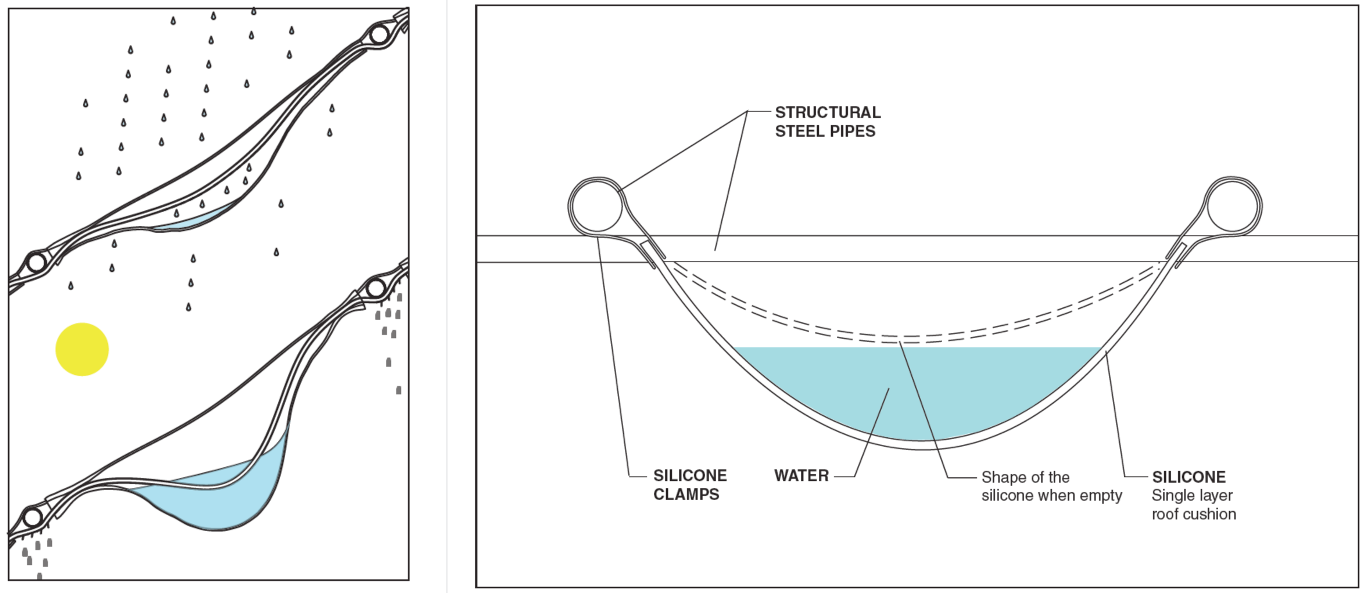


Fig C-9: Details of the roof design showing the silicon layers and dripping process

The irregular elliptical shape of greenhouse cover and foundation adapters the organic uneven forest floor. The above rainwater collection diagram Fig C-9. Built from steel structure holding bladders these are made of one layer of silicon that exposed to outside allowing rainwater to drip straight inside and irrigate the plants through the openings occurred by the edge shrink caused by water fluctuates. When water dry-ups, the walls will close off.

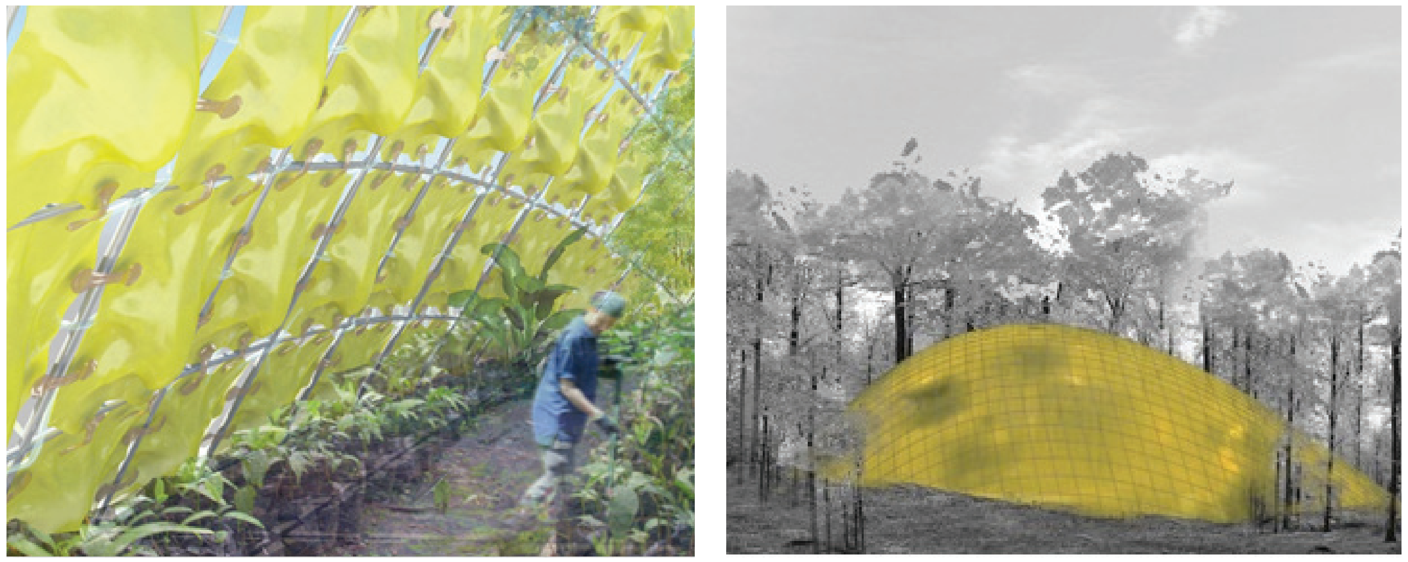


Fig C-10: Details of the roof design showing the silicon layers and dripping process

6.4.2 SECOND CASE STUDY

''REED FROG INSPIRED SKIN''

Introduction

Another Research done by Daphne Fecheyr-Lippens & Pravin Bhiwapurkar on designing building envelops response to the exterior and interior various climate conditions. The primary focus of this example is to reduce the energy demand required for buildings using bio-mimicry principles.

Biological Interpretation

The African reed frog lives in the savannas of western Africa **[Lampert 2001**]. The frog survives at boiling temperature and dry weather while fully exposed to the sun by it is their special aestivation behaviour lowering metabolic rate in high temperature and arid conditions. In the activation season, the frog stored all its nitrogenous waste in the body and converting it to crystals that stored in skin cells as iridophores **[Schmuck, Koblt, Linsenmair 1988].** Causing high refractive index skin becoming light-reflecting cells Their body colour changes from beige or grey to a highly reflective white.

The frog has two other types of specialised cells, chromatophores called xanthophores(yellowish colour) and melanophores (black/brown colour) which contain certain pigments **[Koblt, Linsenmair 1986].** During wet seasons, these latter types of cells shifting to the top of the skin and replace the layer of iridophores.

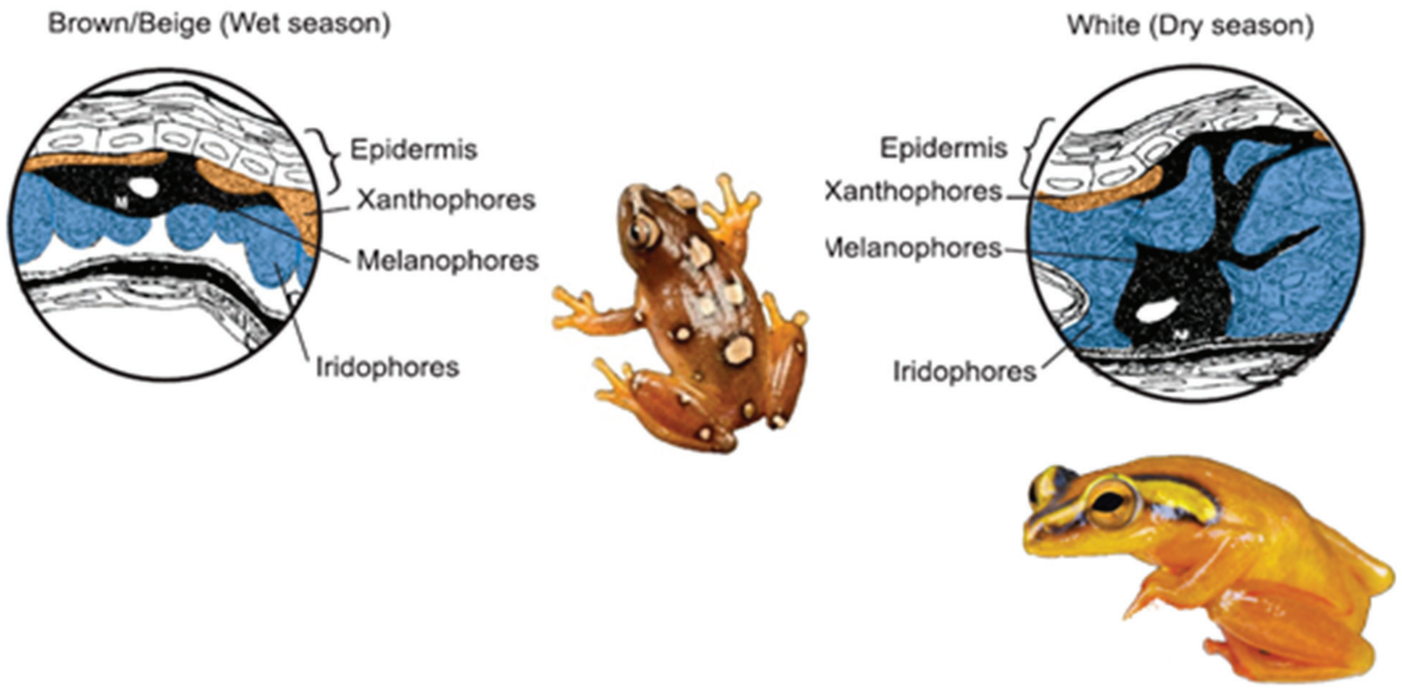


Fig C-11.: Reed Frog changeable skin during different seasons. Source: **[Fecheyr & Pravi,2017]**

Solution

The study analyses the biological domain and understands the principles to translate them into architecture by understanding also the thermal behaviour of building and implement the technology through prototyping and testing strategies.

By Placing integrated hydro-gel with a Bio-PCM layer on high albedo surface inspired by African reed frog that has different skin appearance in winter and summer. The skin hydro-gel chambers dehumidified the air Where the Bio-PCM is used for cooling. This preconditioned air then used for ventilation via an integrated HVAC system. The tests were done on square shaped building 21.3x21.3 with a 30% glazing walls in all four principal elevations as an example of office building case.

The biometric envelop system using mechanical ventilation and natural ventilation saved 13% and 48 % respectively.

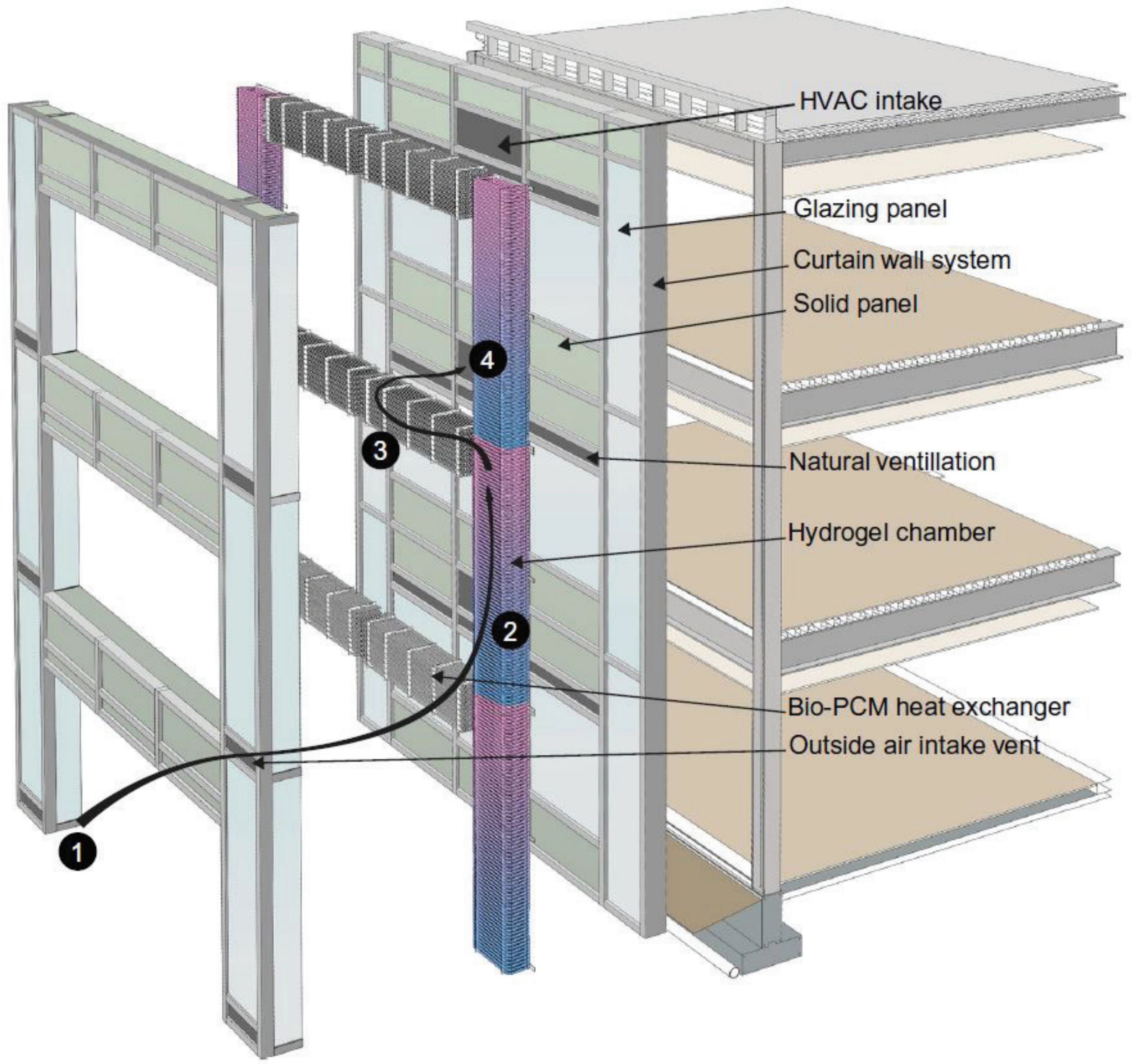


Fig C-12: Bio-mimicry inspired facade; source: [**Fecheyr & Pravi,2017**]

6.5 VENUS FLOWER BASKET ''EUPLECTELLA ASPERGILLUM''

STUDY ANALYSIS OF BIOLOGICAL MODEL

Venus Flower Basket or scientifically '' Euplectella aspergillum'' selected due to its feature relevance and similar to greenhouse design. Especially for its diffusivity effects and transferring various light spectrum in a very similarity of what recent research has been done for haze materials. The light transmission by special fibers in Venus flower is the area of the research. Modern technology cannot yet compete with some of the sophisticated optical systems possessed by biological organisms **[Vikram,2003].** The Venus flower basket is a deep sea sponge of the class Hexactenellida; The hexactinellids are characterised by the unique three-axis (six-rayed) symmetry of their skeletal elements**[Weaver,2016].** Divided into four main structural elements, anchoring apparatus, cap, spiral ridges and tubes horizontally and vertically. This structure has besides its mechanical properties an interesting optical properties of these remarkable skeletal materials. Living up to 5000 meters deep for over 540 million years. Hexactinellid sponges, often named 'glass sponges', sponge with a four and six-pointed skeleton made of silica spicules. This is a minuscule **[van der Brugge].** Also, called basket as its house pair of shrimp.

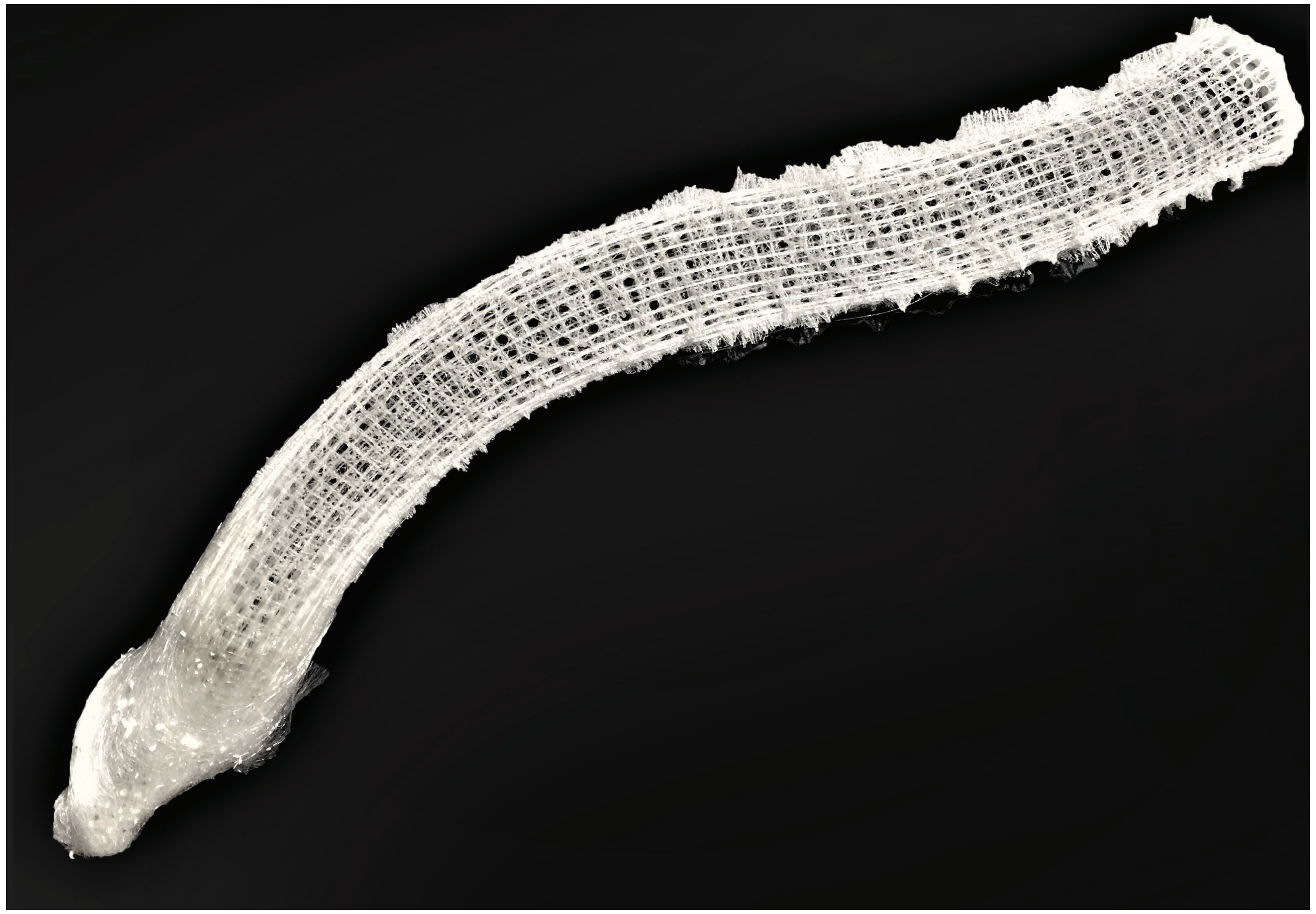


Fig C-13.: Deep sea Venus Flower basket; photo by the author

The spicules of the deep-sea 'glass' sponge Euplectella have remarkable fiber-optical properties, which are surprisingly similar to those of commercial telecommunication fibers **[Vikram,2003]** and superior in terms of fracture resistance **[Weaver,2016]**

From a structural perspective, the silica behaves the same as homogeneous bulk silica **[Weaver,2016]** This design strategy results in the effective division of applied stress onto two independent structure systems (that are not physically fused to one another) The venus flower grid structure has variable sizes. Vertical rays are approximately twice as long as the horizontal ones. The quadratic skeletal lattice formed of two overlapping grid systems one offset regarding the other. The resulting arrangement, shown in Fig.C-14/15

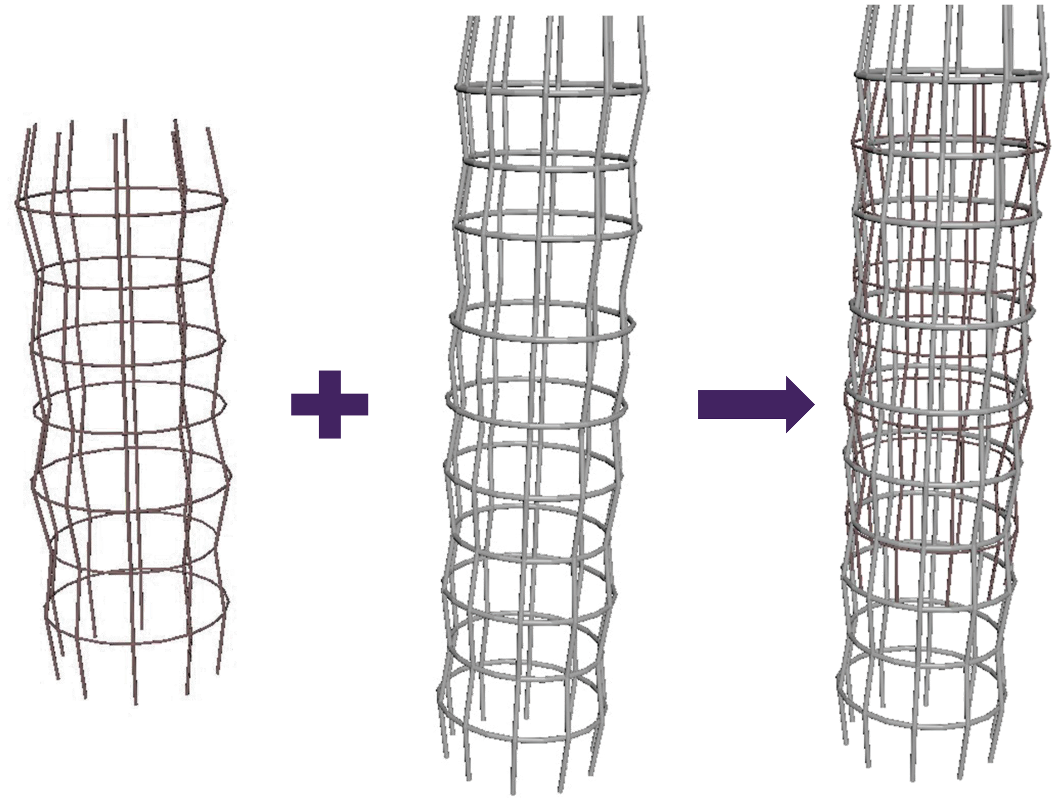


Fig.-C-14/15: 3D drawings of horizontal and vertical structures where two grids retain their capability to move separately from one another (explanation graph no scale), by the author.

Horizontal and diagonal fibrous struts, forming an essential square lattice reinforced with diagonal braces oriented diagonally (at about 45 to the cylinder axis consists of pairs of parallel spicule bundles. Intersecting in a manner that creates a series of alternating open and closed cells) and surrounding the tube in oblique spirals. The incorporation of diagonal bracings is essential for supporting bending, shear, and torsional loads exerted on the skeletal lattice.

Horizontal and diagonal fibrous struts, forming a basic-square lattice. Reinforced with diagonal braces oriented diagonally (at about 45 to the cylinder axis consists of pairs of parallel spicule bundles, intersecting in a manner that creates a series of alternating open and closed cells) and surrounding the tube in oblique spirals, The incorporation of diagonal bracings is essential for supporting bending, shear, and torsional loads exerted on the skeletal lattice. A system that spiral around the skeletal lattice. Additional spicules fill in the gaps between the external design elements.

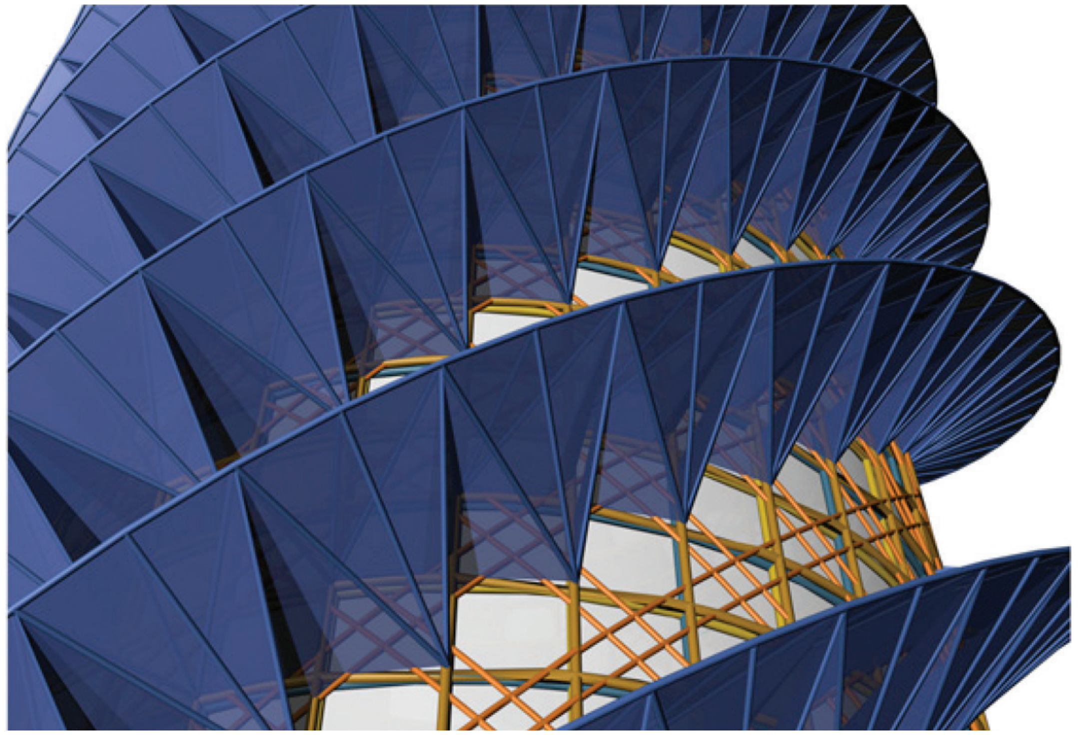


Fig C-16: Three-dimensional structural renderings of the outer pattern details

The refractive-index between the spicule and air has a major role in the optical properties of light was coupled into free-standing the spicules. Enabling them to function as multi-mode fibers as most of the light filling the entire cladding. These natural fibers, therefore, resemble commercial telecommunication fibers, in that they are made of the same material and have comparable dimensions, as well as similar refractive indexes for the high-index core and a low-index cladding. They also function as efficient single-mode, few-mode or multi-mode waveguides, depending on the optical launch conditions **[Vikram,2003]**

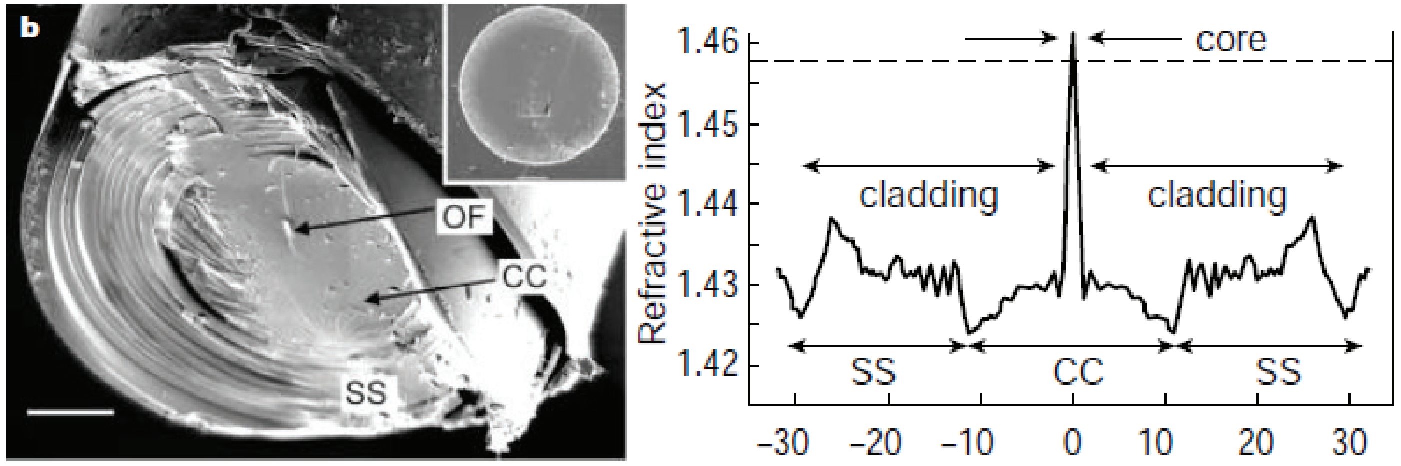


Fig C-17: The difference in refractive index between the core and outer edges. source [Nature,2003]

The optic fibers have this refractive index due to cracks whereas in the spicules due to organic lamination. It has either superior feature as its formation under ambient temperature process unlike the high temperature to create optic fibers that made from fused quartz (approx 1600C). The organic scaffold filament from silica consists of a layer proteinaceous filament square or rectangular cross-section. Organic and inorganic components assemble to form a composite spicule structure. Non-planar cruciform spicules are organised to build a three-dimensional cylindrical arrangement. The walls of the resulting structure are cemented and strengthened by spicule bundles, oriented vertically, horizontally and diagonally concerning the tubular lattice; The entire configuration is cemented by additional silica composite layers **[Weaver,2016]**

While their dimensions are somewhat variable, in general, the vertical rays are approximately twice the length of the horizontal ones. Where the quadrature skeletal lattice is, in reality, composed of two overlapping grid systems: one offset for the other by a distance of half the horizontal ray length. The resulting arrangement, shown in Fig. 4E and F, has openings approximately 2.5 mm wide,2d consistent with the experimentally measured values. Retain their ability to move independently of one another; this design strategy results in the practical division of applied stress onto two independent strut systems (that are not physically fused to one another). Higher magnification analyses reveal the all of the vertical components of the grid are positioned on the outside of the lattice and all of the horizontal elements on the inside, as seen in the three-dimensional structural rendering (Fig. 4G**) [Weaver,2016]**

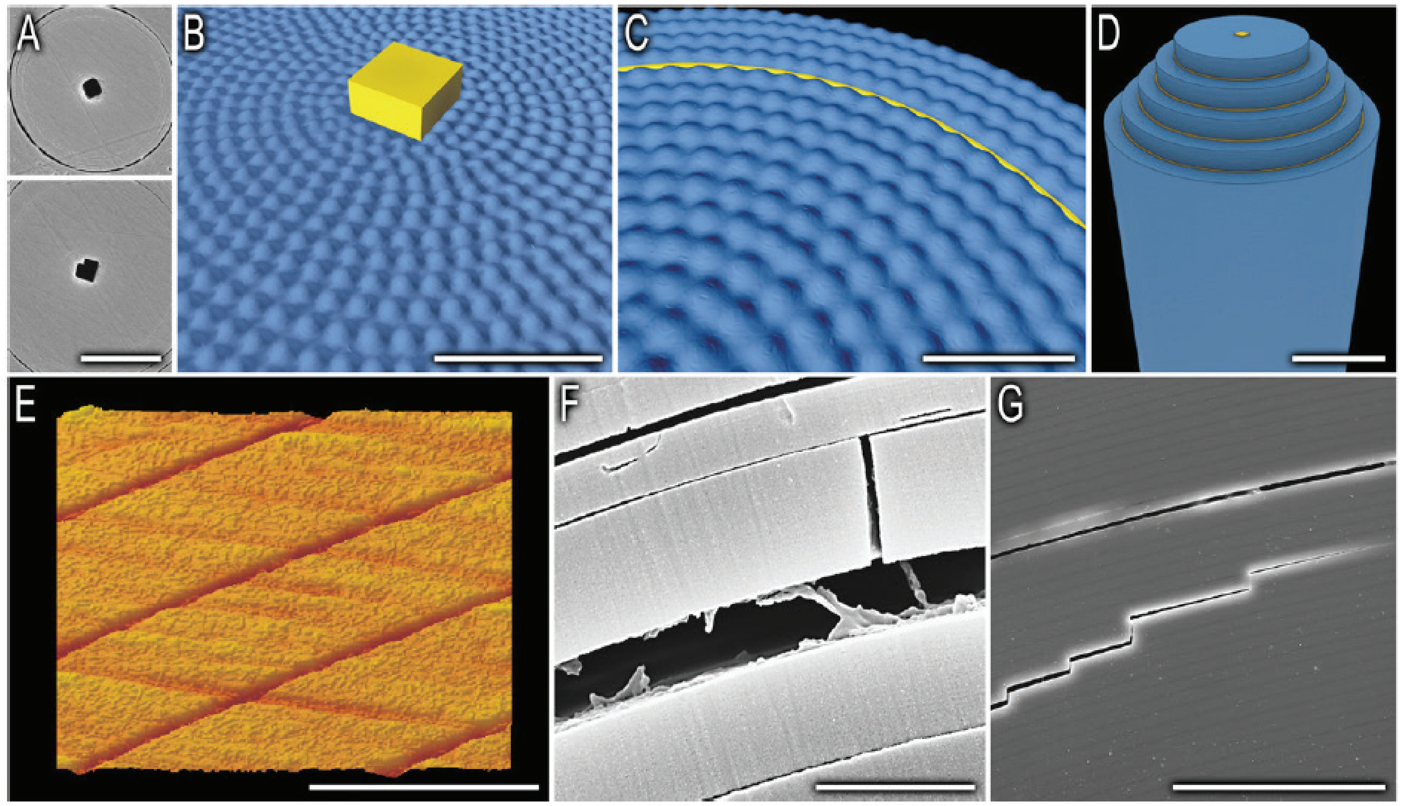


Fig.C-19: Microscopic scan of the spicule section shows the lamination layers and the centre core. Source: **[Weaver,2016]**

The ability to move independently in the elements result in toughness as the rigid design would increase internal stresses underloaded. The number of transverse circular spicular struts ranges from sixty to eighty in a full-grown specimen **[Schulze, 1887]**. While the number of vertically oriented struts remains relatively constant along the length of the skeletal lattice,these ridges gradually increase in height towards the upper end of the skeletal tube. In some specimens they hardly attain a maximum dimension of 2 or 3 mm, while in other cases they extend10 mm or more **[Schulze, 1887]**. The ridges are supported by a series of steeply set beams which unite at an acute angle corresponding to the sharp-edge of the ridges. By constructing oblique, helical ridges running in opposite directions, the sponge can resist both failure modes (ovalisation'' deformation of the cross-section from the original circular shape.'' And torsion). The bidirectional ridges occupy a position on every other diagonal set of paired spicular struts **[Weaver,2016]**

At the apex of the skeletal lattice, the open cylinder is covered with an irregular network-like structure that constitutes the terminal sieve plate. In addition to the ability to protect the sponge interior, the development of a rigid capping structure has important mechanical consequences as well. By preventing a lateral collapse of the top of the skeletal lattice, strength and stiffness are significantly increased. The spicules of Euplectella, beyond structural anchorage support, could also provide a highly effective fibre-optical network, which may be useful in distributing light in its deep-sea environment **[Weaver,2016]**

BIOLUMINESCENCE

Fig D-1: dinoflagellates glow light on the sea in Vaadhoo Island in the Maldives. Photography by Doug Perrine.

INTRODUCTION

There are many animals and plants can emit light. However, they are unrelated and diverse organisms which make these biological phenomena is striking for the scientist. Porifera (sponges) Hexactinellida (glass sponges) where the Venus Flower basket classified is one of these organisms that rely on light.

In this part, the research is focusing on the dinoflagellates that are producing the lights in the sea, as this kind of algae area and has the potential of growing in a Hydroponic farm that proposed in the design. This part will provide:

- General information about Bioilumscesnce in some creatures and its properties.
- The order of magnitude for the dinoflagellates.
- The proposed design based on the translation from the biological model.

7.1 DINOFLAGELLATES

Bioluminescence (Greek words means ''Bio'' life and Latin words lumen ''light'') is the effect of a chemical response occurs in particular living organisms, in which enzymes (luciferase) catalyse the release of energy as visible light. It is also Happens in many various bions such as bacteria, fungi, jellies, squids, worms, shrimp, insects, and fish. Mostly in the marine environment only around 30% of the marine species are glowing. Dinoflagellates are essential as symbiont, notably for providing photosynthesis and carbon fixation in animals. The primary functions of light in this organisms as result of defense, offence, communication, and dispersal **[Woodland,2016]** .

As in Dinoflagellates light is Flagellated flash when disturbed by fish Dinoflagellates are stimulated to emit light when predators (such as crustaceans) are feeding, which can startle and divert the predator, resulting in reduced predation. The response time to stimulation (milliseconds) is indeed fast enough to have this effect. **[Woodland,2016]**

The Dinoflagellate are predominately marine, with relatively few freshwater species can be seen from a distance as homogeneous and devoid of large spots of light. There are many types of Dinoflagellate such as Ceratium, Pyrodinium, Hematotalasia ''found in red colour and called The blood of the Sea'', Gomyaulaux '' brownish yellow''. **[Harvey,1952].**

Fig 2-D: The dinoflagellate fusiformis photographed using a microscope (magnified).
Source: bioglow.eu

In many cases, dinoflagellates form coloured patches on the sea, red, brown, or yellow patches associated with brilliant luminescence at night **[Harvey,1952].**

7.2 THE ORDER OF MAGNITUDE

The bioluminescence does not come from or depend on light absorbed by the organism. It derives from an enzymatically catalysed chemiluminescence, that is, a reaction in which the energy released is transformed into light energy. **[Woodland,2016]**

Attempts were made in (1924) to determine the brightness of the light, using an optical pyrometer of the type in which an incandescent filament is superimposed upon the glowing surface. The brightness measured at that time the readings range between 0.116 millilambert Lambert for dinoflagellates to 0.033 millilamberts ''9 candle/square meter'' depends on the type of Dinoflagellate **[Harvey,1952].**

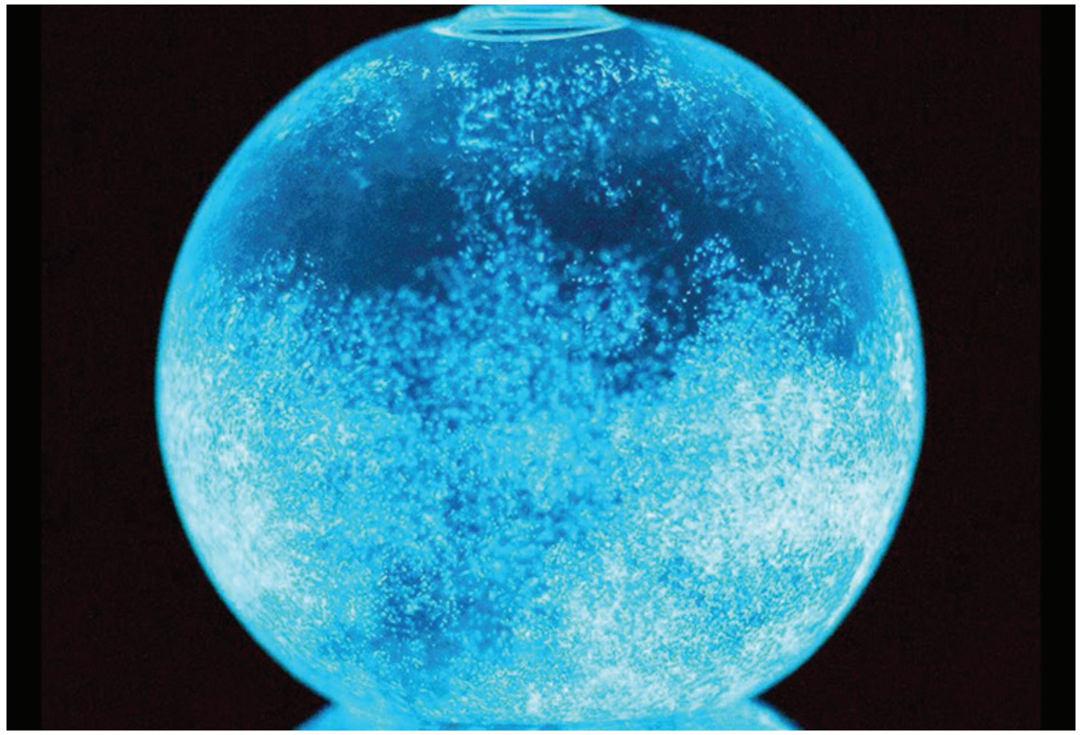


Fig 3-D: dinoflagellate sample type name 'Pyrocystis fusiformis'' with blue fluorescent light. Picture from biopop startup website.

The glow-in-the-dark algae live in 24-17 Celsius degree and emit light only after sunset (even they are in the dark room) as the large has the internal biological clock, keeping them able to track the time of the day.

The energy provided in the algae is coming from the nutrients and indirect sunlight as plants the algae use photosynthesis (not highly depended on intense light). Growing by cells division every 7 - 10 days. However, they can survive for several months if they kept in clean and closed containers and proper living temperature (opened very slight for Co2 and O2 exchange).

After shaking for extended time continually the light will diminish, so they need some time to recharge. Cover the time; the algae will last more extended time with growth and increase in light intensity. Some Algae cultures have faster growth rate than other types such as lunula; others might be larger in cell size 1mm like fusiformis mixing cells from various cultures can also be possible.

7.3 PROPOSED DESIGN

(TRANSLATION OF BIOLOGICAL EXAMPLE)

The Concept is derived from the light transmittance in the selected organism "Venus flower basket" In the low part of the structure where the sponge is anchored. There are Dinoflagellate organisms lives on that part light created by a minor fluctuates of the optic fibers threads and transferred through the spicules body of Euplectella sponge where the lattice spread the light through the fabrication. See fig 4D

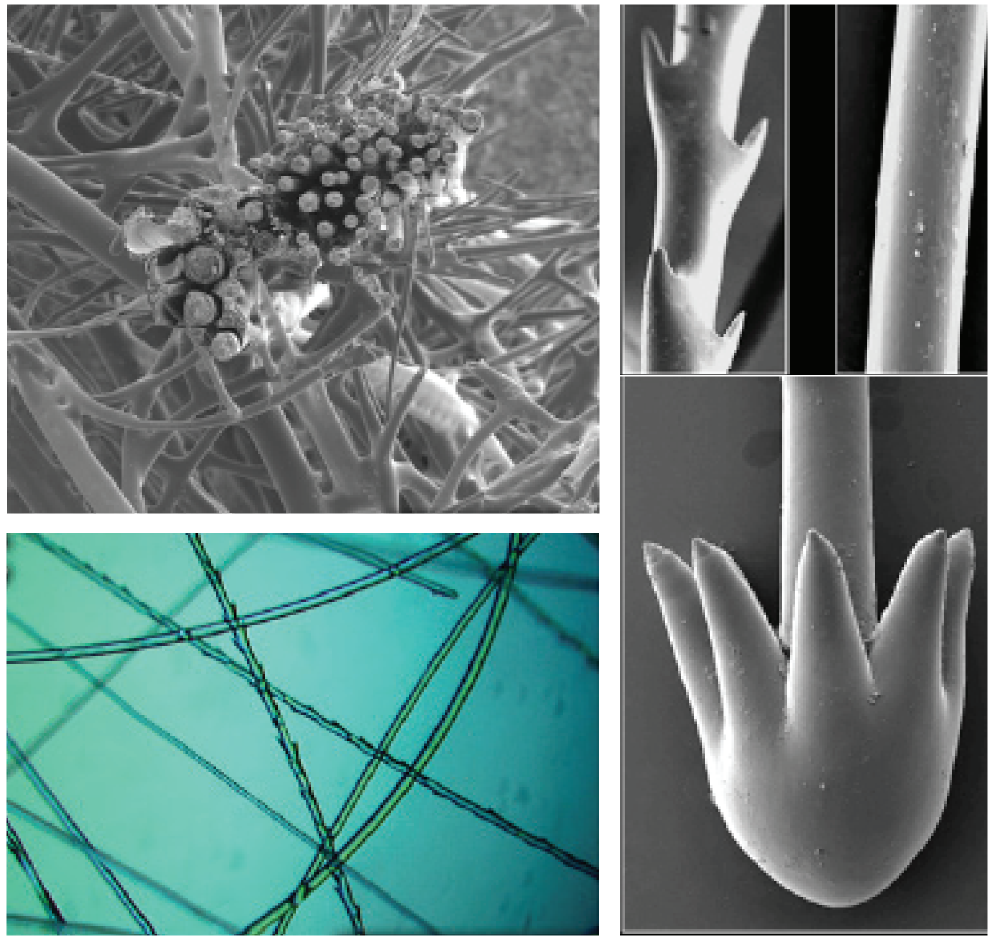


Fig 4-D: micrograph picture of individual spicules and the anchors were the Bioluminosity light produced and transferred to the rest of sponge spicules skeleton. Source:[Weaver, 2006]

The solar light and Bioluminosity the source of growth for the sponge, the morphology helps the organism to achieve best light management. The design is shown in Graph 5-D, and 6-D is for placing the Dinoflagellate medium into silver coated to a pot to catch maximum photons and transfer the light through cable. The continuous movement in the medium and replacing the medium is to keep its continuity. The light is unique and has an incredibly bright fluorescent colour that makes it different from standard LED lights. As an initial idea, this light will be used to light the pathways for the visitors and skin in late time. More visualisation will be illustrated in the final design chapter 10.

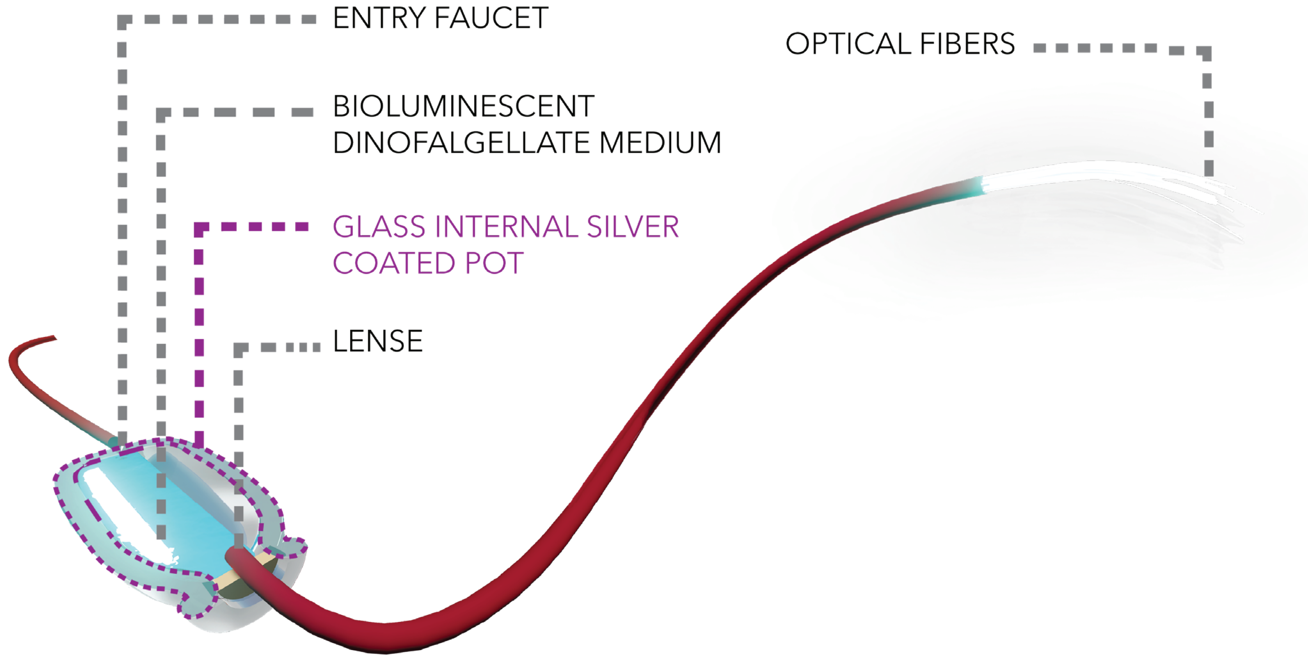


Fig 4-D: 3D section for the proposed design inspired by Venus flower basket. Graph by the author

Since the plant factory in an urban context and although the literature has not covered the light intensity and if its reliable. The conceptual design is to provide inspiration for visitors of a potential search for a new source of light in nature.

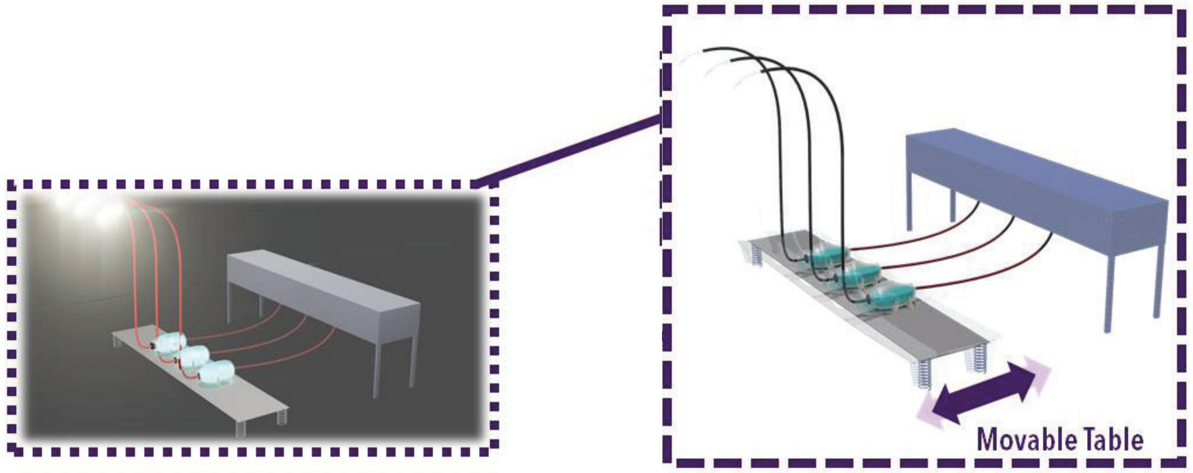


Fig 4-D: proposed continual light production by injecting the medium into movable table design inspired by Venus flower basket. Graph by the author

COMPUTATIONAL IN FARMING

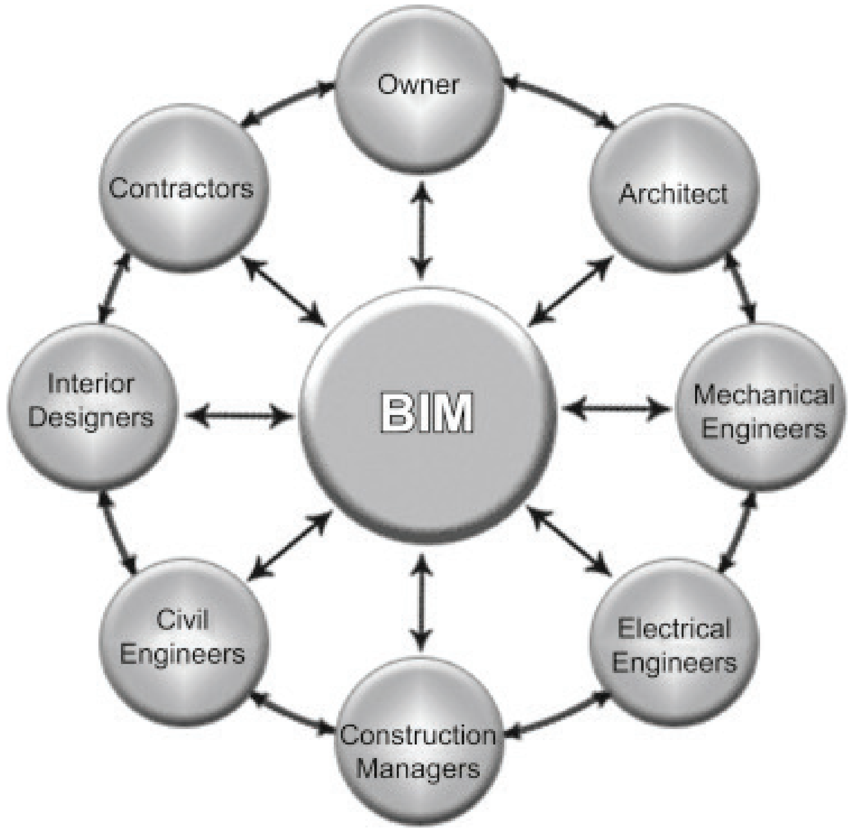


Fig Z1: The relationship of BIM to the different stakeholders explain the BIM as the most feasible and reliable option in the building construction industry Source: **[Kubba,2017].**

INTRODUCTION

The computational part is essential for exploring v different design alternatives where in ''traditional process the lack of diverging steps and designers typically explore very small numbers based on architectural concept [**Turrin , von Buelow , Stouffs, 2011**]. This part aim to provide general information about BIM as approach for designing Plant factory. BIM is not CAD as CAD is a replacement for pen and paper, a documentation tool, and the files are primary data consists of elements that are lines, arcs, and circles—and sometimes surfaces and solids, which are purely graphical representations of building components The relationship of BIM to the different stakeholders explain the BIM as the most feasible and reliable option in the building construction industry **[Kubba,2017]**. Limited research and information are available for designers and planners to design such buildings. The research aims to bridges the gap between agriculture and architecture by proposing a Building information modeling as a reliable tool that has used in architecture and construction since its start in use 1960s **[Khan, Aziz and Ahmed, 2018]**. This section is provide an insight to the computational process in farming industry. This part will provide:

- General definitions , computational work-flow in farming from literature and site visits.
- Current computational process in farming and the applications of Building information modeling.
- Field study of using AI in Farming.

8.1 DEFINITIONS

Energy modeling in this paper is presenting mainly the creation of three-dimensional building computer models to analyse and investigate different assumptions. The results may include the system feasibility, CO2 emissions, financial costs, natural resource use, and energy efficiency of the system under investigation. Energy models are designed to assist the system operations, engineering and early design decisions.

EUI - energy user intensity, expresses energy use as a capacity of the building's mass by identifying energy use per square meter per year. By dividing the total energy of the building consumes within a single year on total gross floor area.

BIM is a methodology, comprised of processes to generate and manage the information of building or group of buildings **[Peckienė and Ustinovicius, 2017]** BIM was started earlier 1960s, which marked 3D information-rich model from 2D drawings **[Kubba,2017].** Many architectural and construction firms have been using these tools for improvement in productivity and cost-savings throughout all stages of architectural, engineering and construction industry **[Singh, 2017].** Consequently, BIM is ideal for designing and managing agricultural buildings as well; and in this research, the focus is on BIM tools and objects' attributes that it contains.

The modern greenhouses, have a variety of a simple structure with a complex controlled environment, delivering suitable environmental conditions for plants throughout the year. An example of a software controlling model for fruit ''cucumber model'which is done by Wageningen University to achieve the best profit and crop quality in Fig Z-3.

On the other hand, BIM technology enable managing the building information. Moreover, create a platform for virtual models that represent what is going to be constructed so the designers can get a better understanding of the environment and test the model proposals by analysing, extract and examine information. Some tests such as using BIAIM Building Horticulture plug-in for planing and space management inside greenhouse **[Khan, Aziz and Ahmed, 2018].**

per-formative emerged as design approach in which building performance broadly understood, becomes guiding criteria. [**Turrin , von Buelow , Stouffs, 2011**].

Current computational Work-flow in Farming:

The parametric models used for simulating greenhouse environment are based on practical research of plant growth models such as Van Henten Lettuce Model or Heuvelink, Bakker Cucumber model. Through the writer visits to the research center in WUR the research team has explained that the fully closed environment tested model are the best to provide accurate information and results. The Figure Z2 shows the current work-flow based on author collected information from filed visits and literature study.

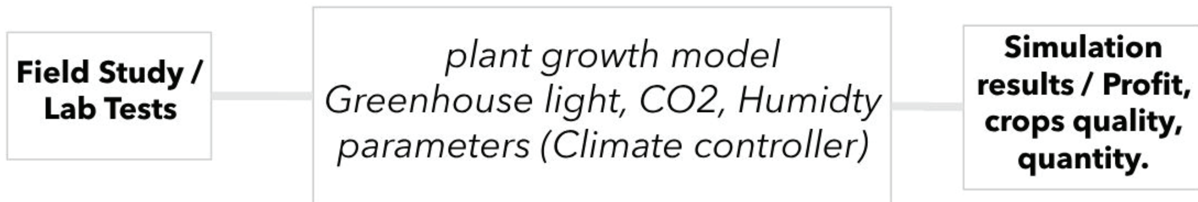


Fig Z2: Current plant production work flow, graph by author.

The plant growth model has the possibility to adjust internal light, CO2, Humidity and temperature that influenced by adjusting skin and shading elements of standard greenhouse design rather than the geometrical shape. Experienced growers manage quite well to perform this complex task. However, it is likely that with the aid of Artificial Intelligence, this complex task can even be performed better. And once Artificial Intelligence shows to be capable of doing the job, progress will be made in the production of greenhouse products in a sustainable way **[De Zwart, Righini,2018].**

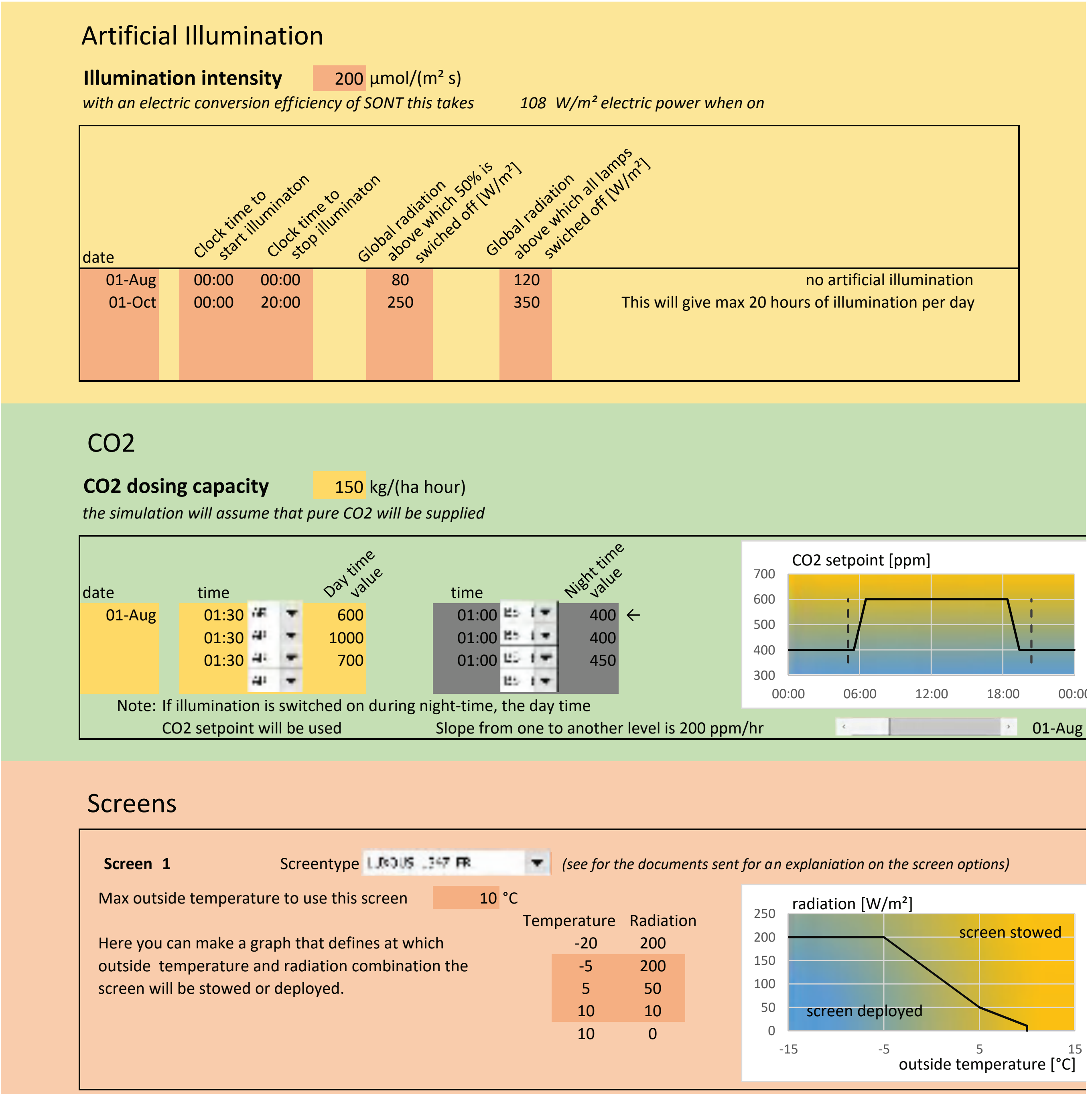
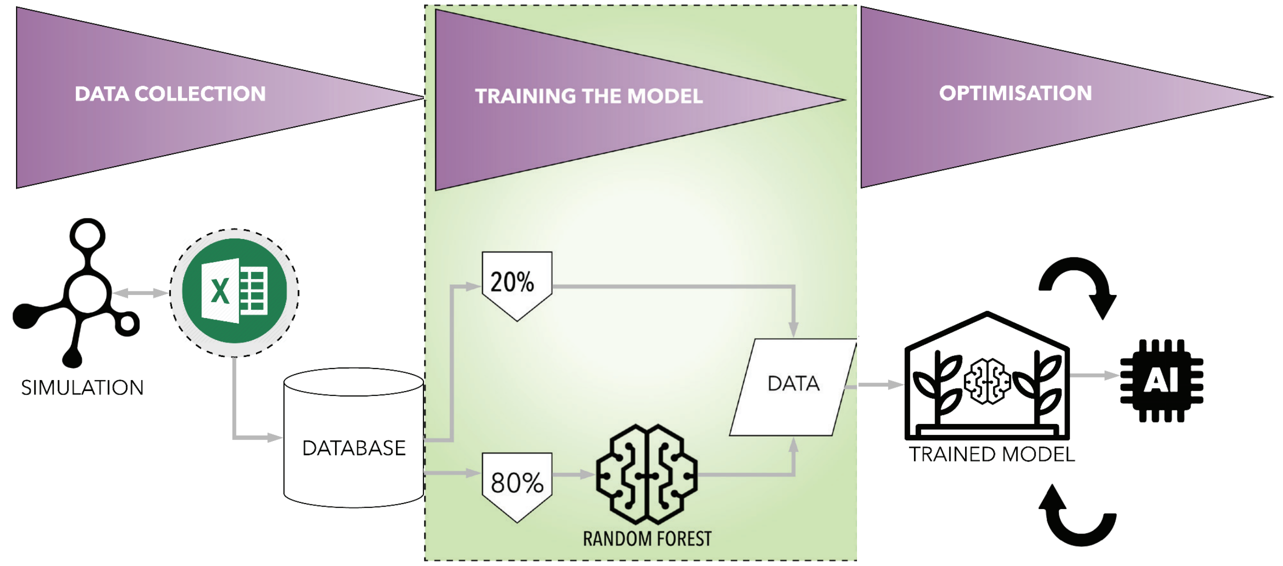


Fig Z3: Shows screen capture of the excel input for a cucumber production model source: WUR.

Fig Z3 is an example of the plant model used in typical greenhouses. The model may consist of several parameters that affecting the profit and quality of crops such as Global Solar Radiation, relative humidity, PAR light from artificial light, CO2 level, total opening of vents.



-Prepare xls files.

-Send the files to simulation software automatically.

-Gather the results automatically & process them.

-combine all results into one dataset.

-Split the dataset into training & data validation 80%-20% Random Forest.

-Feed the dataset to different ML optimises

-Determine the best one.

Using the trained model, prediction can be made on simulation input.

Use genetic optimisation to find the best setting

Fig Z4: Artificial intelligent work-flow (machine learning to deliver best input of climate controller for cucumber greenhouse model adjusting the daylight, screen movement, ventilation and CO2 injection). Concept : Veronika Heidegger Arup. Graph by Author.

PRACTICAL STUDY

MATERIALITY AND DESIGN

Fig E-1: Eden project Cornwall Source: Grimshaw Architects, UK

INTRODUCTION

This section is intended to show the translation of biological model " venus flower basket" into a practical design proposal to validate the approach on the second phase the transaction based on the literature study of materials and light properties on the previous section that is covered extensively in previous chapters. These parts are discussing the ETFE as an approach to being used in the smart skin for Hybrid plant factory as follows:

- Provide an overview of the selected materials "ETFE" and the history of use in greenhouses, and farming.
- Design new solution based on the need to provide responsive climate's skin that is suitable for plant internal climate conditions for fast and stable growth.
- Conduct light spectral analyses to validate the design proposal for producing best photosynthetic approach.

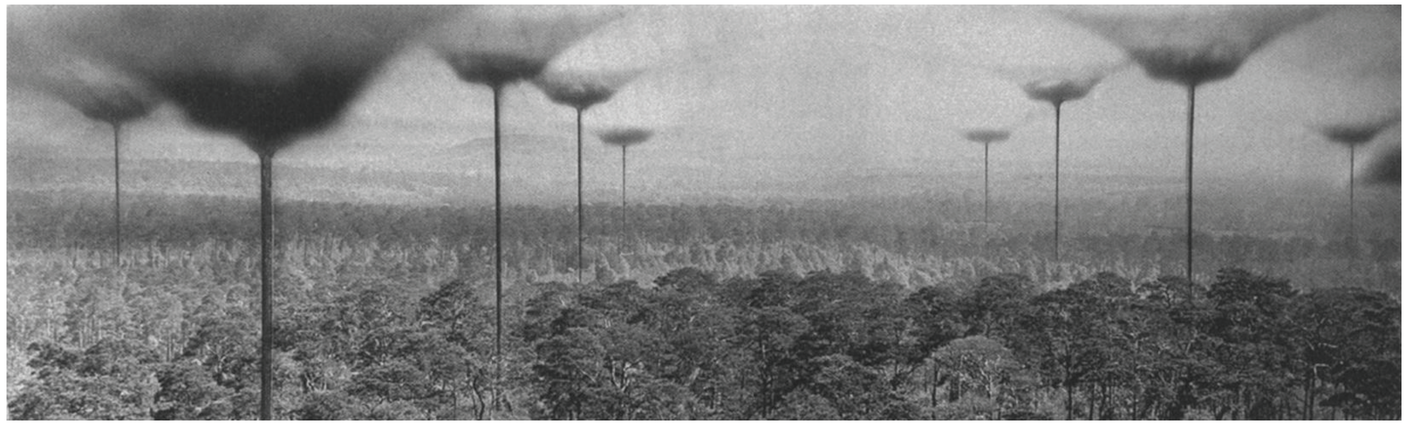
9.1 HISTORY AND APPLICATION

ETFE (ethylene-tetra-fluorine-ethylene) is lightweight materials and highly transmittance foil for a solar light. Since the introduction of the market in 1970, ETFE is one of the most chemically resistant materials in the world **[Cremers, Marx, 2016]**

One of the first projects was to be covered with ETFE cushion (air supported envelop – enclosing 150,000 squares meters) in design was the Degrees North, an enclosed City-in-the-Arctic scheme in 1980. The selection was due to its toughness and extraordinary elastic range up to 400 % strain to failure. The outer and inner foils are white tinted to about 50 % translucency **[LeCuyer,2008]**

Pneumatics structure, Air filled material, used as a building material. It is a recent phenomenon in architecture from Buckminster Fuller's 1929 Dymaxion House proposal incorporated pneumatically stressed structural components and Manhattan bubble envisioned an urban scale climatic envelop Figure D-2, to Frei Otto's 1965 study for an air-supported greenhouse enveloped nature on a vast scale Fig D-3.

Fig E-2/3: Manhattan bubble envisioned, Buckminster Fuller's. On below the air-supported greenhouse enveloped nature by Frei Otto's. Source:**[LeCuyer,2008]**



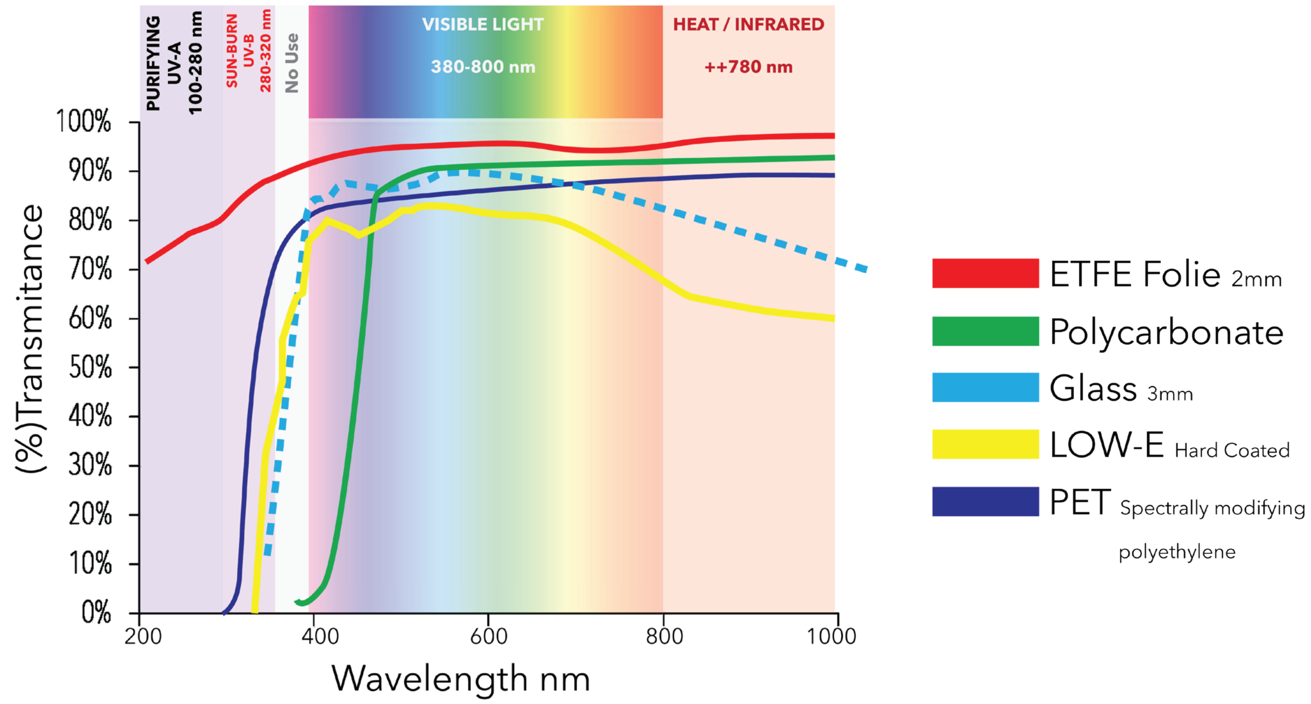
ETFE films were pioneered by Vector Foiltec, who was sailmaker in Bremen **[LeCuyer,2008]**. The first applications were for plant houses at Burgers' Zoo in Arnhem in the Netherlands the name of project "The Overkapping dessert Burgers Zoo" by ABT Adviesbureau voor Bouwtechniekin 1982. FigD-4 Another successful project that contained tropical Biome "Eden Project's build in Cornwall in The UK.Fig D-1

Fig E-4/5: Burgers' Zoo in Arnhem in the Netherland. Source ABT

The Projects the ETFE has involved in are mostly are tropical plants gardens, due to the latter fact that the material transmittance properties for infra-red are high.

9.2 THE MATERIAL PROPERTIES

The material itself is an excellent heat insulator. In cold weather, even with the same U-value, the thermal comfort level of ETFE cushions, with their warm inner surface typically close to the ambient interior temperature, is much better than glass. With U-values ranging from approximately 2.94 Wm-'K for a two-layer cushion to 1.18 Wm-'K for a five layer assembly **[LeCuyer,2008]**. The lack of air infiltration through a cushioned envelope increases the U-value by approximately 0.35 Wm-'K. The material is highly resisted to UV radiation and acid. The ETFE is better than glass, PET, Polycarbonate concerning light and solar transition, however, ETFE is 1.5-3 percent diffuse two which makes objects viewed through the foils look slightly milky **[LeCuyer,2008]**. See Figure D-2.



Sorce: glass, PC, ETFE **[LeCuyer,2008]** - PET **[Abd El-Al,2008]**

Fig E-5: The optical properties of the most common materials in greenhouses skin
Graph by author. Information sources in the footer.

ETFE's ability to take extremely high short-term loading, combined with its fluid damping mechanism and a high tolerance for deflection, make it well suited for earthquake and severe weather applications **[LeCuyer,2008].**

However, Standard ETFE foils have a very high solar transmission. This can result in severe problems with overheating. Without suitable sun protection, the risk of heating in summer is quite high. The solar infra-red rays (50% of the energy of the solar light spectrum) is the foil absorbs the main reason for heating up the building, and the internal spaces remain cold for the longest time **[Cremers, Hannes, 2016].** Implementing ETFE cushions in building design is a complicated task due to the unusual transmission characteristics of the material. Since currently available commercial software tools are not developed to take into account the long-wave transmittance through the ETFE panels, in practice ETFE foils are usually modeled as glazing units. Depending on the building use, the building design, the site, and geographical location of the building, this simplification may impact on the accuracy of the simulated building performance **[Poirazis, Kragh, Hogg,2009].**

The foil can be treated with different options for solar control. fritting, the surface of the foil is one of the options by covering the surface with a different patterns to reduce solar gain and retaining translucency. Different percentage of coverage and density of the ink result in a various energy transmission level through the skin. **[Wilson,2013]** the printing of ETFE- foils is a complicated process due to the specific surface properties **[Poirazis, Kragh, Hogg,2009]**

Another option is by using a multilayer film surface with that has high visible light transmission while blocking infrared heat by reflection.

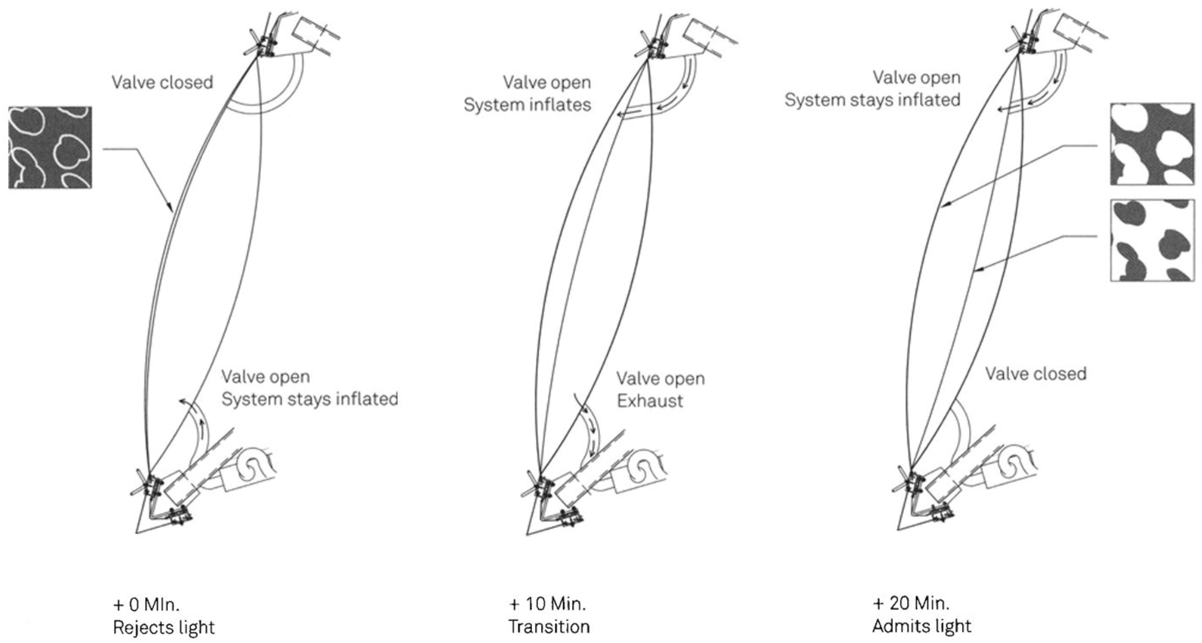


Fig E-6 Variable position of middle layer ETFE, Source **[LeCuyer,2008]**.

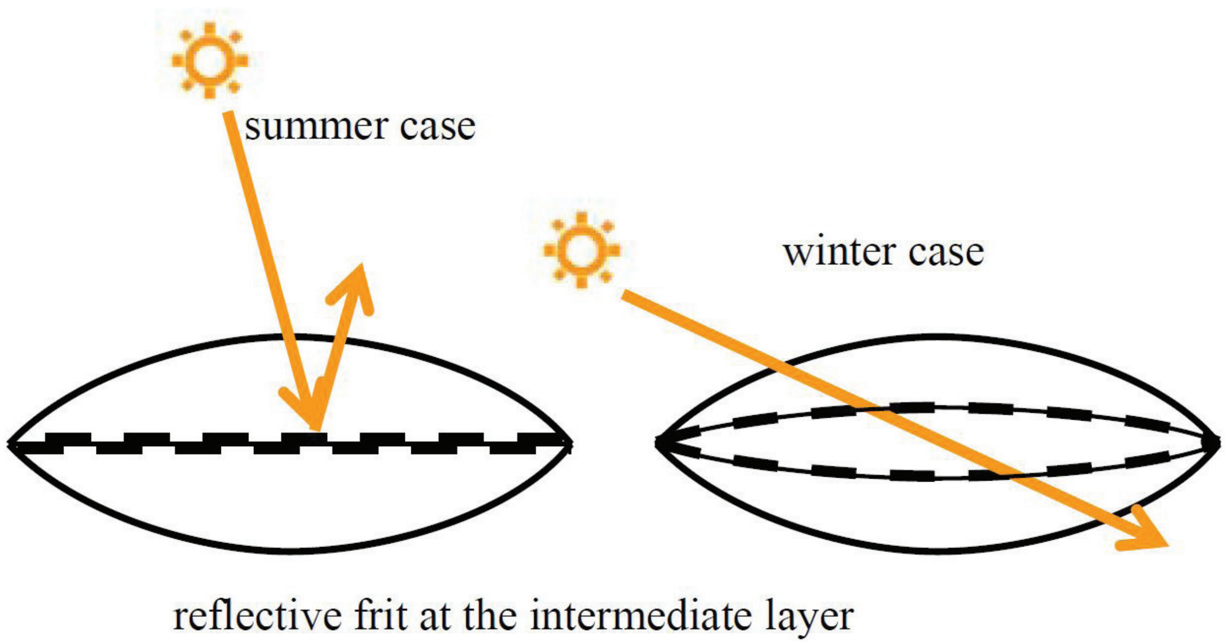


Fig E-7 Movable middle layer by air to filter out the light **[Poirazis, Kragh, Hogg,2009]**

TRANSLATION OF BIOLOGICAL MODEL

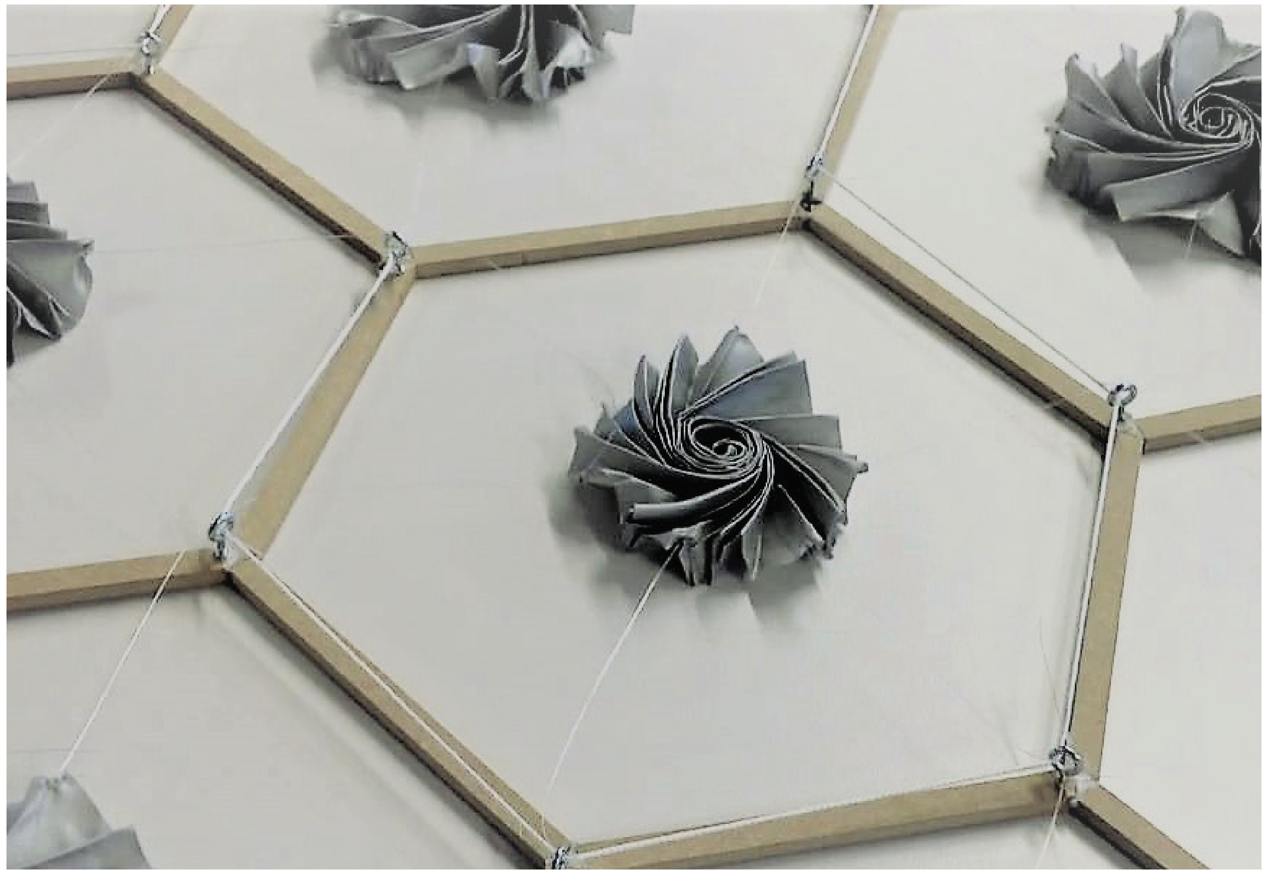


Fig F-1 Movable shading facade initial concept prototype from Bukylab Course in 2011 **[Bukylab. Blog TU Delft]**.

INTRODUCTION

This section is to highlight the inspiration of the Biological Model and the influence into the skin design. There are three main parts:

- Biomimetic Skin Design and the selection of materials based on Literature study that described earlier in section 5 & 7.
- The computational study including, solar analysis of the geometry envelop selection based on production area and solar hourly analysis of the skin, then building part of the parametric energy model, and finally the interactive shading spectral film that reacts to real-time solar analysis in the model.
- The third part is about the evaluation of final proposed Hybrid plant factory design in comparison with the PFAL, considering the proposal are entirely insulated, using LED light and has closed facade.

10.1 THE SKIN DESIGN

Based on literature study the selection of the materials have to consider the solar light's spectral properties access the facade to ensure the best plant photosynthesis. The facade also should have high insulation value by air cavity, increase the number of ETFE layers. The biomimicry helps to establish the skin concept through the three-phase studies as shown in Fig F-2

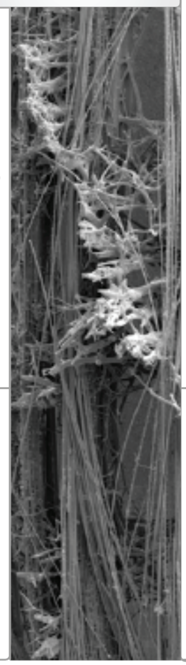
Deep Sea Venus flower	Area Of Study	Physiology (Structure)	Morphology (Pattern and Design)	Behaviour (Process)
E.g 1 	Light Management Transmission	-The walls of the organism structure are cemented and strengthened by spicule bundles, oriented vertically, horizontally and diagonally concerning the cylindrical lattice. - The Fibres function as structural parts as well Divided into four main structural elements, anchoring apparatus, cap, spiral ridges and tubes horizontally and vertically where the last two skeletal parts are separated in form. That maintains the glass sponge stiffness.	- The top open skeletal lattice cylinder covered with an irregular network-like structure that constitutes the terminal sieve plate. Protect the sponge interior, and provide rigid capping structure has a mechanical role. By preventing lateral collapse. - beyond structural anchorage support, could also provide a highly effective fibre-optical network, which may be useful in distributing light in its deep-sea environment.	- Refractive indices for the high-index core and a low-index cladding. They also function as efficient single-mode, few-mode or multi-mode waveguides, depending on the optical launch conditions, the optic fibres have this friction index due to cracks whereas in the spicules due to organic lamination. - The transmittance occurs by very thin natural silica spicules - similar to human-made optic fibres alongside thin lamination layer of the proteinaceous filament. The optical fibres have this friction index due to cracks whereas in the spicules due to organic lamination. It has either superior feature as its formation under ambient temperature process.
Result	Translation in Skin Design	The Skin Material made of pneumatic ETFE cushions that are lightweight and can highly stiff to the outer dead and live loads. The shading is reacting independently inside the cushions in separate installation expand with the increase of air volume that based on solar analysis	- The Geometrical form that based on best oriention to capture solar light as well as well as using highly resistence materilas for harsh wether condtions (selection of ETFE).	- The Use of Optic fibres to transfer the light of the Dinoallge to the production source indirectly. -selecting the materials based on spectral wavelength and diffusivity '' haze materials effects.'' - implement internal selective spectral shading elements that manipulate the light to deliver the best light spectrum combination for production level.

Fig F-2: The interpretation of biological model in the design. graph by author

The proposed design "Smart Facade."

The selected materials (ETFE) has the best spectral properties which ' can provide the plants with best photosynthesis response's range to boost its growth alongside with the high insulation value of the materials compared with standard glazing.

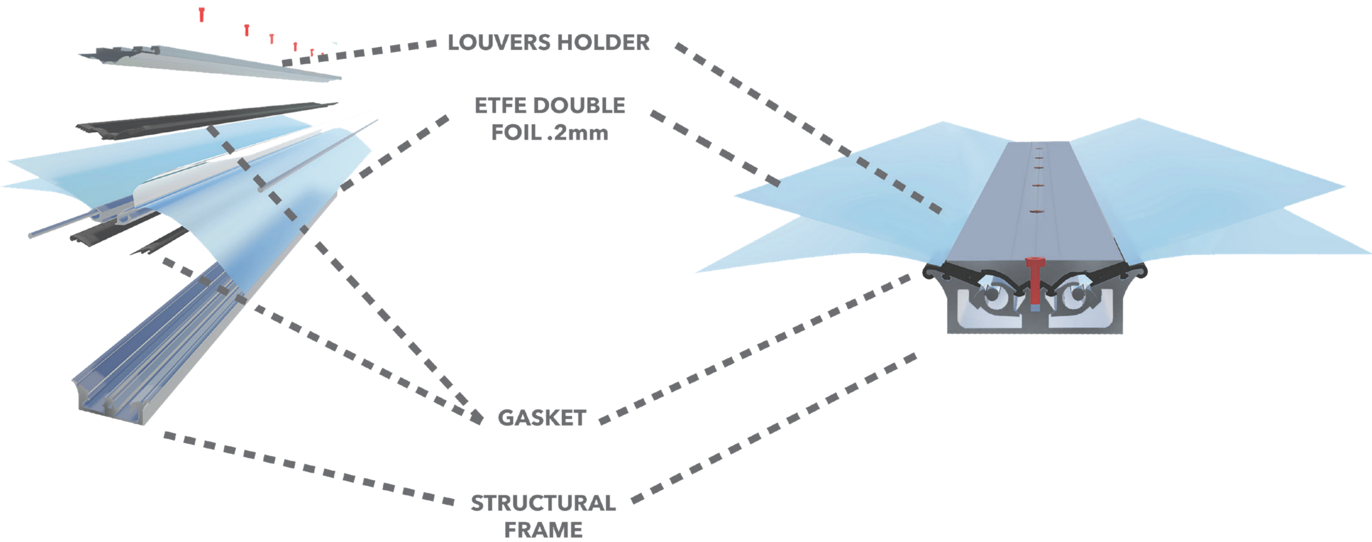


Fig F-3: ETFE cushion frame design details. graph by author

The ETFE used with a low thickness ranging between .02 -.04 mm making the facade structure lightweight. Astonishingly the Film layers have a high stiffness capacity toward externally applied loads. Fig-3 shows the ETFE cushion frame details.

Despite the high transmittance value of visible light. A significant amount of infra-red spectrum penetrates ETFE that can increase the heat during the summer time which increases the greenhouse effects inside the Plant factory. However, the facility can benefit from this feature in the winter season when the less solar light hit its skin. To reduce the high infra-red light value an independent circular shape memory layer cloth embedded in the design works in line with analysis read provided from energy model. By filling the air, a connected helix joint to middle layer will pull and rotated this internal layer, and it will shrink. The design will provide the possibility of using the skin in different climatic conditions and different seasons when the temperature level exceeds the required value for plant growth through the greenhouse heating phenomena.

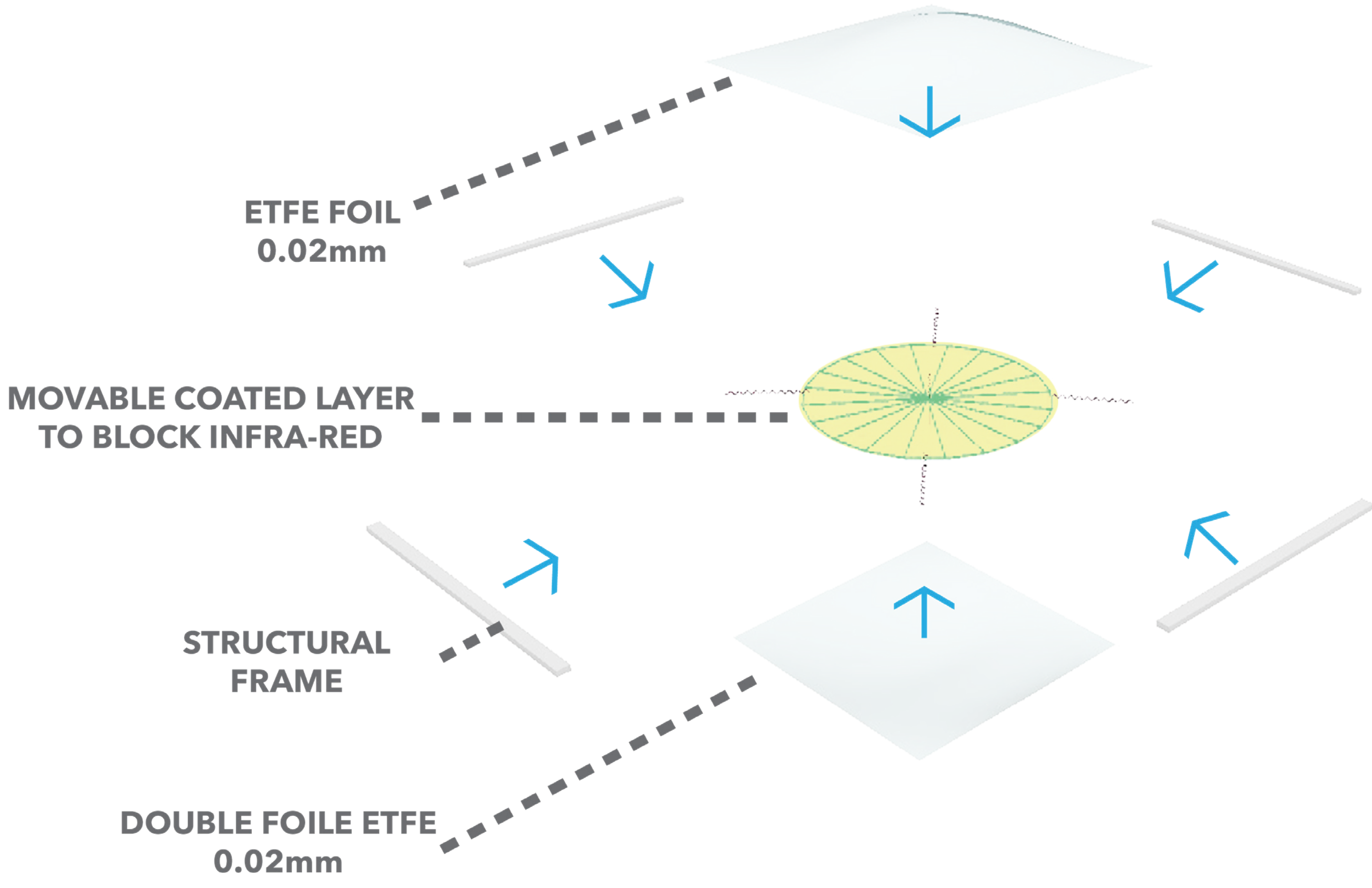


Fig F-4: ETFE cushion Details frame design details. Graph by author

The middle layer illustrate the translation of the Biomimetic model as different spectrum can be translated through the optic fibres due to different refractive index occurs in the spicules and the natural cracks. The skeleton itself is made from a divider network, and similarly, the design has placed different materials that have different spectral properties. The ETFE as mentioned can be fitted or coated and can be placed in pneumatic structure ranging from 2 and up to 4 layers.

Multiple layers will produce different solar transmittance values g-value in comparison with glass as shown in the following schedule Source **[Salz, 2006]**:

Thickness		**U-value (W/m2K)**	**g-value**
6mm	monolithic glass	5.9	0.95
6-12-6	Double Glazing Unit	2.8	0.83
6-12-6	High-Performances Double Glazing Unit	2.0	0.35
2 Layer	ETFE Cushion	2.9	0.71
3 Layer	ETFE Cushion	1.9	0.71
4 Layer	ETFE Cushion	1.4	0.71

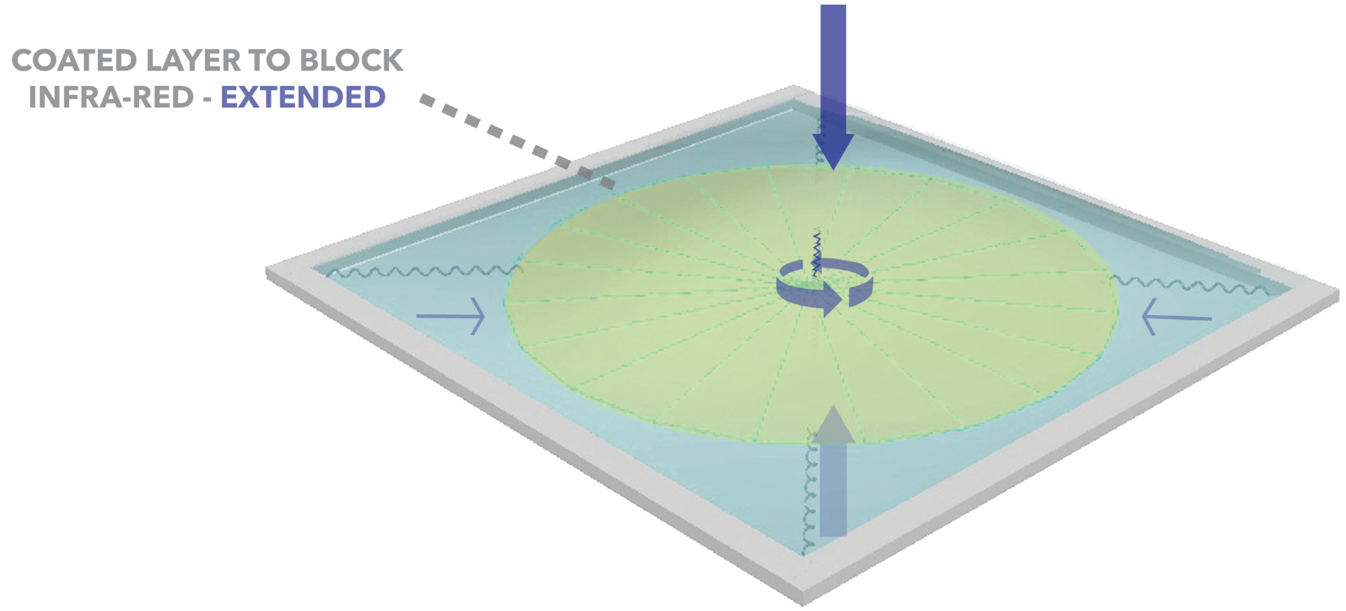


Fig F-5: Proposed ETFE cushion with a selective spectral layer to filter the infra-red in the standard situation. Extended and open the filter layer. Graph by author

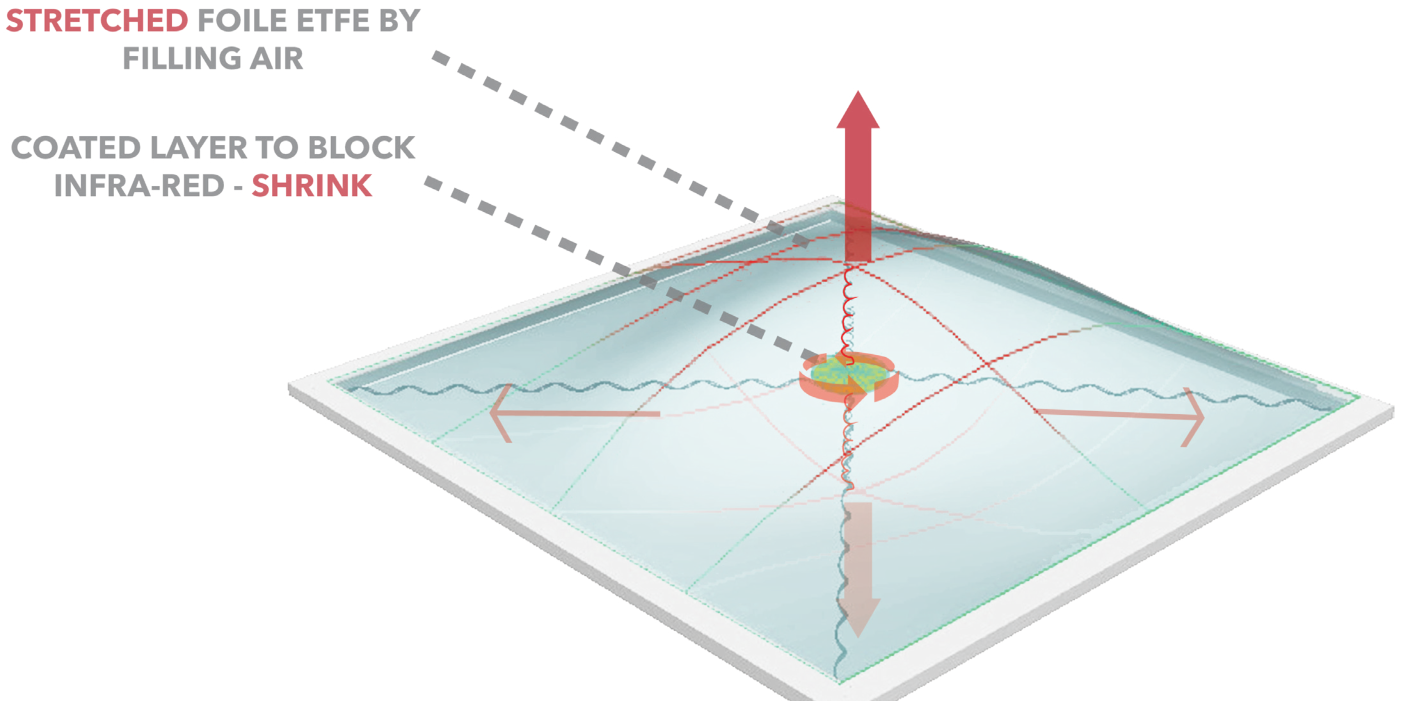


Fig F-6: Proposed ETFE cushion with a selective spectral layer to filter the infra-red. Middle Shrink and closed by filling the panel. Graph by author

10.2 SELECTIVE SPECTRAL SHADING

Different materials have various spectral properties changed by its refractive index value and reflection, absorption and transmittance properties. There are come materials proof its effectiveness in filtering the light to produce idea spectral properties for plant growth. ETFE infra-red absorbing (solar IR) layer are the selected in proposed design due to its high absorbing value for near (IR-A) and medium- (IR-B) infrared range infrared A- B range that causes heating as shown in the graph. 9-F.

Solar infra-red beams which are to considerably account (50% of the energy of the solar spectrum) **[Cremers,2016]** for heating up the greenhouses are absorbed by the film which allows for better light spectral control to adjust internal climate temperature inside the plant factory.

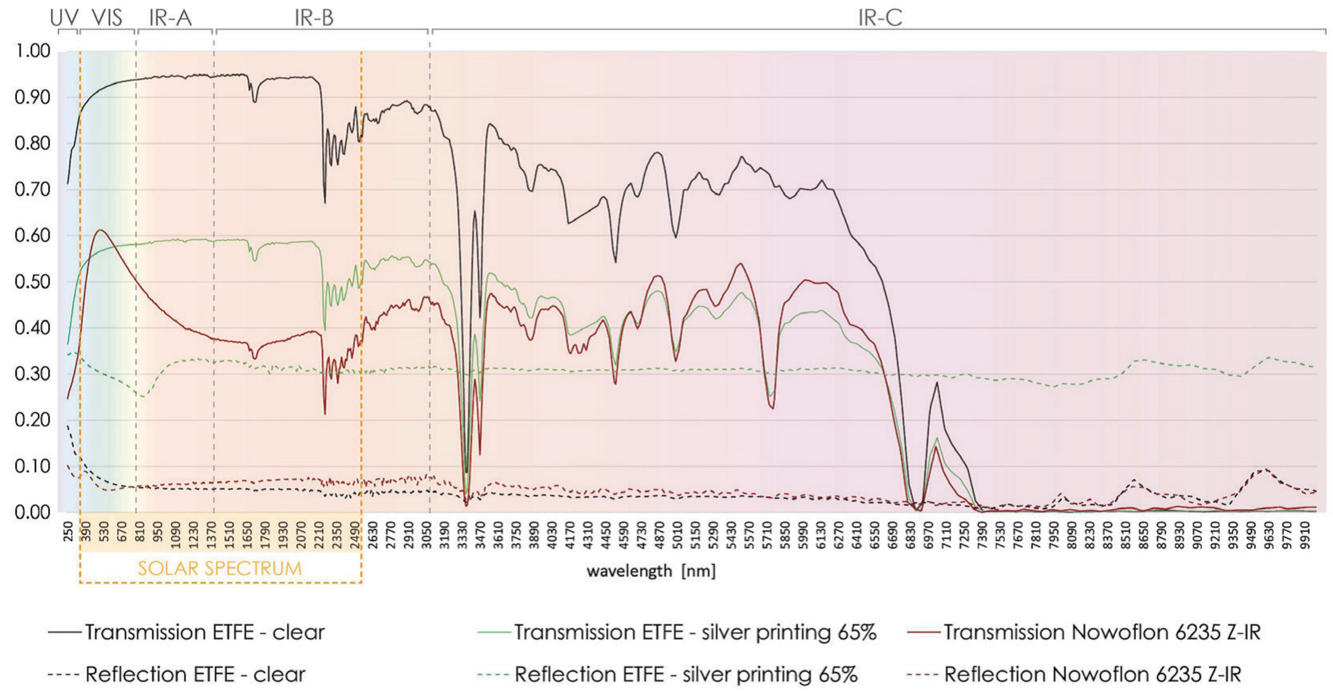


Fig F-7: Light transmittance properties differences between Infrared absorption, clear, and silver coated ETFE film Sorce**[Cremers,2016].**

To explain the design concept of the ETFE cushion the Fig 8-F. Simplify the transmittance theory. The proposed design will benefit from the use of these layers by adjusting the size of the ideal layer and therefore manipulating the spectral needed for heating or plant photosynthesis as illustrated in Fig F-8.

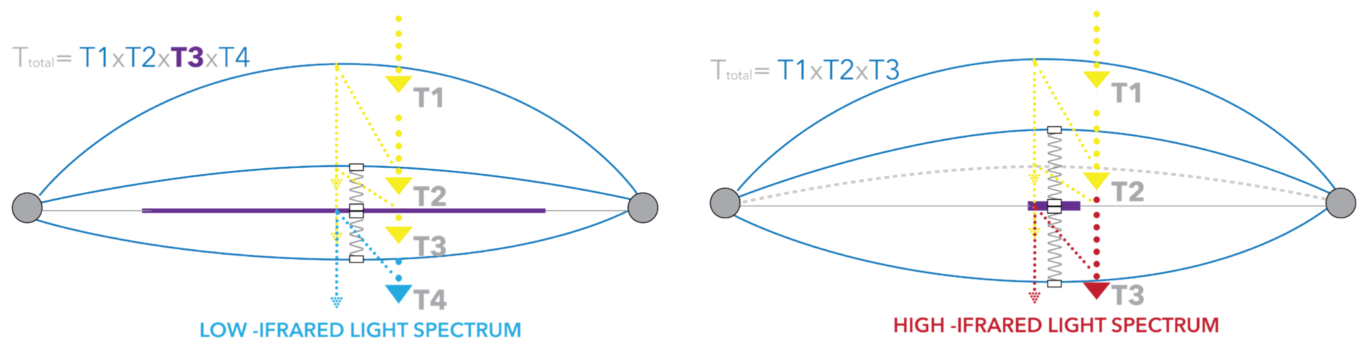


Fig F-8: Simplified drawings of the proposed panel with basic light transmittance theory showing the differences between Infrared absorption (middle layer extended) on the left, and the standard case for triple ETFE foil (middle layer shrink)

PROJECT DESIGN

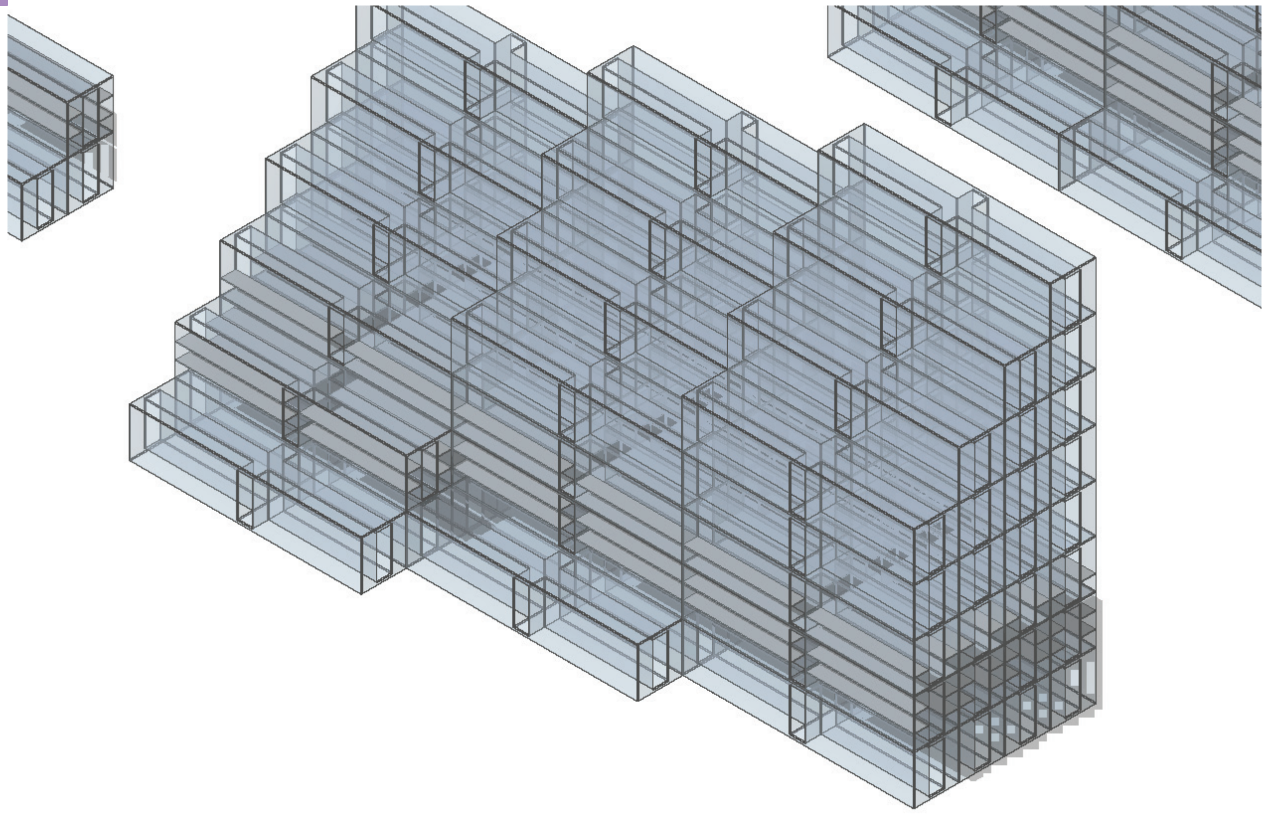


Fig J-1: First analytical models to study the daylight access to the containers floor plan (By author)

INTRODUCTION

The final process to validate the literature is applying computational workflow through four phases. This part will describe these steps and use them in two different context. This part explain the following design stages:

- The selected location and type of infill. With a highlight of weather and context.
- Explain the main design phases to build the energy model, and computational workflow applied to achieve the best option.
- Analysis of the Containers configurations and estimated production Area.
- Study the daylight access level on production level by analysing the widest point to nominate the best selection.
- Offsetting the geometry outline to build the skin and analyse solar hourly analysis on the skin.
- Optimise the selected designs skin options, orientation and ventilation and calculate energy use intensity EUI based on geographical location.

11.1 LOCATION AND CONTEXTS

10.1.1 Amsterdam Metropolitan Area, The Netherlands.

The first location to apply the design is in Almere that located on the northeastern side of the city. The Urban context alongside the easy access to the city with Amsterdam within a short time is main reasons to select Almere for the project. Secondly, Amsterdam combines a relatively strong economic growth, both nationally and at a global scale, with a relatively compact and planned urban and regional structure **[Federico, Willem, 2015]**. New towns like Almere founded due to the trend was reinforced by the city's extensive social housing program and the massive construction in suburban areas since the beginning of large-scale suburbanization in the early 1960s **[Federico, Willem, 2015].**

In Almere there are several projects has been planned to establish greenhouses and urban farms such as Regenvillages in Oosterwold District. See Fig 2- for the selected area.

Fig J-2: project location in The Netherlands, Almere near Cirkelbos park, Source Google earth graph by the author

There are around 430 thousand homes in Amsterdam **[Wassink,2018]**. The city planning for 2040 going of enormous challenge for shifting to the sustainable energy system and become fossil free city **[Van den Dobbelsteen, Cityzien,2018]** The project is line up with this transition and will aim to provide substantial local food resources to the area that can reduce the carbon footprint caused by the current supply chain. A large part, sometimes up to 50%, of air pollution in Amsterdam caused by motorised traffic **[van der Giessen, Linden,2016]**. One of the main reasons for increasing air-polluting particles and CO_2 emissions in Amsterdam is the vehicles and car delivery the graph J3 shows the nitrogen dioxide (NO_2) Level in the city, the concentrations do not meet European standards for nitrogen dioxide emissions in all areas. Note that delivery vans and freight (LGVs) cover relatively few miles, yet contribute substantially to NO_2 emissions **[van der Giessen, Linden,2016].**

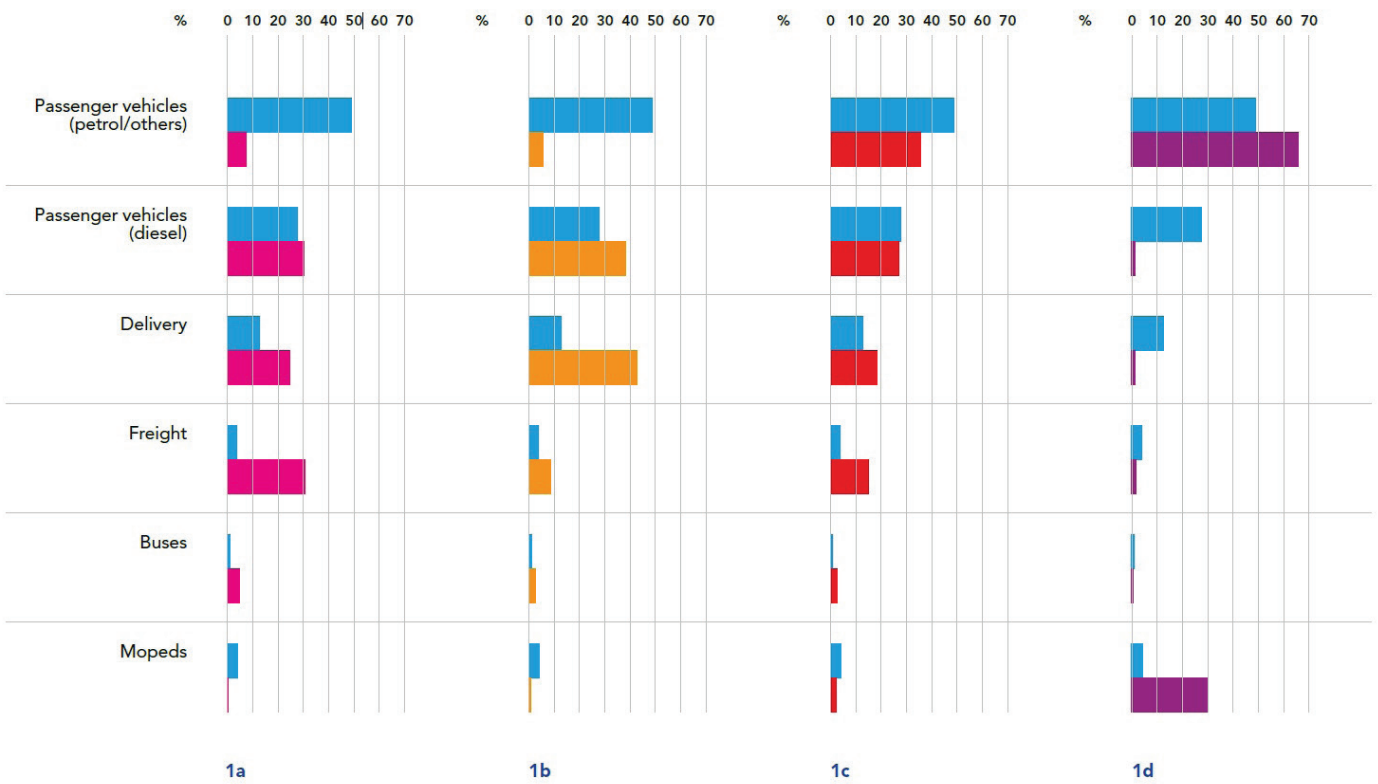


Fig J-3: Air pollution levels and factors, **1a** shows concentrations of (NO2 level), **1b** particulate matter (PM10), **1c** (EC-elemental carbon), **1d** hydrocarbons (HC)- Highly hazards, traffic contributes up to 50% of soot emissions. Source **[van der Giessen ,Linden,2016]** and TNO

10.1.2 Damascus, Syria.

Damascus Founded in the 3rd Millennium B.C and was a major cultural and trade centre, by its geographical area at the crossings of the East and the West, between Africa and Asia. The old city of Damascus considered to be among the oldest continually inhabited cities in the world. Damascus was inhabited as early as 8,000 to 10,000 BC. The city exhibits outstanding evidence of the civilisations which created it - Hellenistic, Roman, Byzantine and Islamic. Despite Islam's prevailing influence, traces of earlier cultures particularly the Roman and Byzantine continue to be seen in the city. Thus the city today is based on a Roman plan and maintains the aspect and the orientation of the Greek capital, in that all its streets are oriented north-south or east-west and is a crucial example of urban planning **[WHS UNESCO,2017]**

All areas in Syria and the capital city has been living intense international conflict and civil war with a complicated situation considered one of the hottest issues in the modern history. From losing safety, security and internal migration in the city that face extraordinary challenges never experienced in its long history. However, significant effect on the people's life and traffic during the day and significant changes occurred after the war came over in 2011.

The selection of the location inside the old city has two reasons. First, the transport of large vehicles inside the old city is difficult and has a negative impact on the ancient monuments due to its Narrow roads.

The city used to have more green and agricultural areas in the past. The city historical sites are listed are listed endanger since the conflict has started, and the long continuous inhabitation is threatened like never before in its history. The second concept is driven by the latter fact, to provide an architectural idea of producing a continual reservoir of living in the city.Fig4 Highlight the site of the projects inside the city.

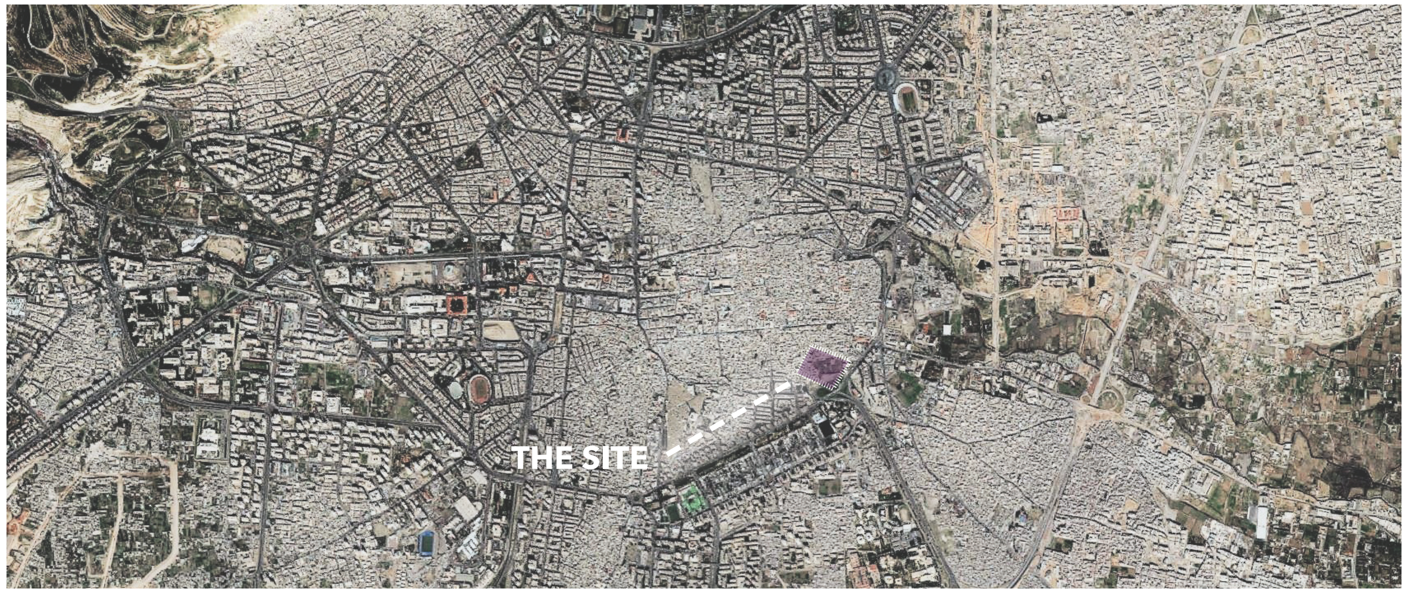


Fig J-4: Project location in Syria, Damascus near Bab Sharqi (The gate of The Sun) , Source Google earth graph by the author

10.1.3 Type of Infill.

The infill proposed for the energy model parameters is lettuce due to the available information to compare with other models. The criteria of selection are based on three factors. Lettuce has economic value in both proposed locations. Secondly, its contribution to the local diet mainly in Syria due to the high malnutrition level among Syrian children as the crop provides a high value of foliate acid. Finally, there are several studies used lettuce model such as Van Henten model that is an excellent base for other energy simulations and can give a precise evaluation of the paper's validation part.

11.2 COMPUTATIONAL WORKFLOW

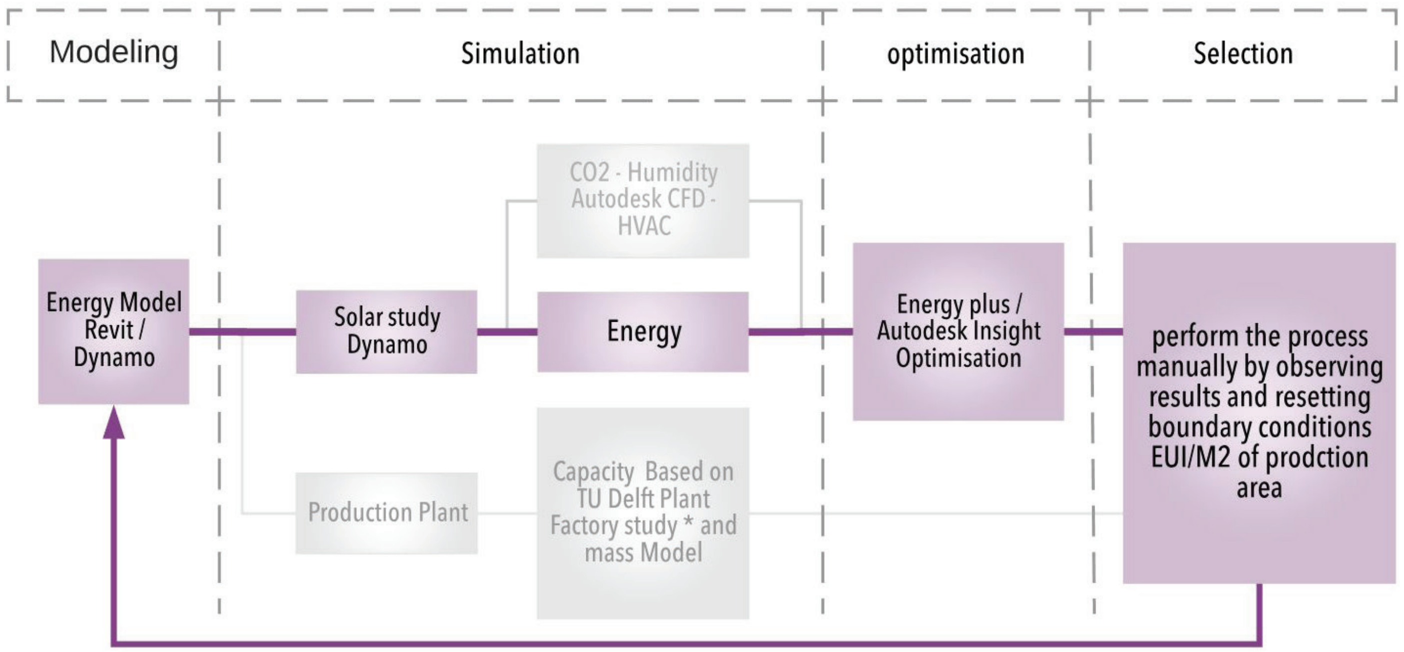


Fig J-5: The research Computational , Graph by the author

Often building codes and construction guidelines use a prescriptive approach—the opposite of a performance-based **[Peters, 2018]** the research design is based on the results output from the simulations and energy optimisation which influence in return the key indicator factors. A computational workflow for Plant factory with hybrid system starts from following aspects in the research:

- Design a Per-formative structure (performance oriented structure) based on context and climate location.
- Evaluate different designs (containers configuration) based on daylight access, solar hourly analysis and EUI energy use intensity.
- Select the best option based on energy use level. The EUI (Energy use intensity) influenced by the temperature change that increases the cooling or heating.
- The key performance indicators (KPI) based on energy KWH/m2 for the production gross area (not dry area).

As mentioned in the literature part current PFAL Comparing with greenhouse, has an initial cost of about 15 times more than a greenhouse, but the production is also 15 times more and can reach 100 times more than an open field. The Labour cost is too high; handling operation is conduct manually where greenhouses nowadays start to be more or less automated **[Kozai, 2015].** The energy bill for PFAL is still high and proofing the possibility to benefit from greenhouse effects and solar light can be validated through the computational analysis.

11.2.1 Tools and Methodology

The research used various software and computational tools to select the geometry and validate the final design these tools are:

- Dynamo 1.3 for creating energy model (containers configuration).
- Revit Architecture 2018. Also used for energy model.
- Autodesk Insight 360. (Daylight analysis simulation and EUI value)
- Energy plus for cooling and heating loads.

The BIM has been used in industry for a more than two decades. There are many advantages of using BIM mentioned in literature part. One of the most important feature is to have a real-time evaluation of the energy model, quantifying the materials and plant production. BIM lifesaver for complicated projects because of its ability to correct errors early in the design pahse and accurately schedule construction materials properties **[Kubba,2017]**. On the other hand, the limitation was found in modifying some parameters related to the materials properties especially spectral transmittance of the ETFE. The result is approximate and can give an insight of what the energy cost will be in Hybrid plant factory.

10.2.2 The Making of Energy Models.

To create different configurations Fig J-12-13, and analyise the options by generating parametric model in Dynamo and build the energy model in short time from the standard containers. The resarch used Dynamo script consists of four stages. First is defining the container instance point (insert point origin) in Dynamo, and then published the configurations in point grid to replace the family on the network. Later the surfaces and vertex extracted. These surfaces refined to host the ETFE panels and analyse the cushion on the skin surface. The process in Dynamo described in the following table J-11. The basic containers built from family mass model shown in Fig 6,7,8,9-J.

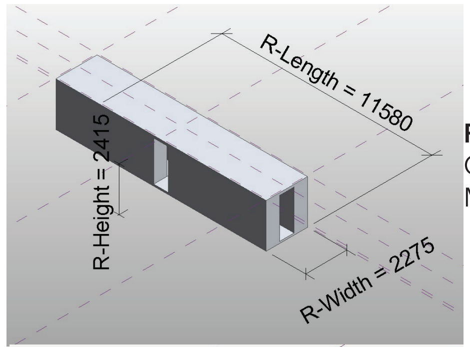


Fig 6-J: 40 " Containers Mass Model

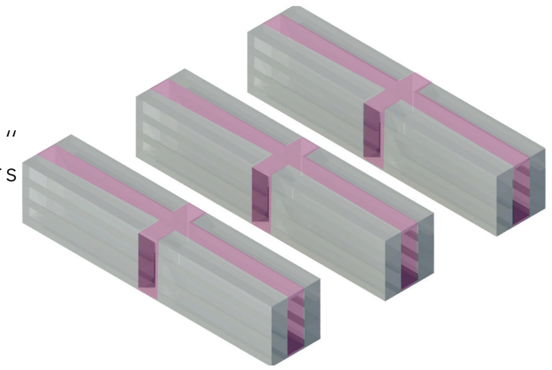


Fig 8-J: Hallways paths enable connecting the model (purple)

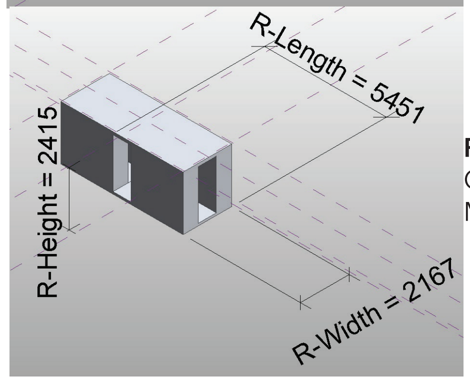


Fig 7-J: 20 " Containers Mass Model

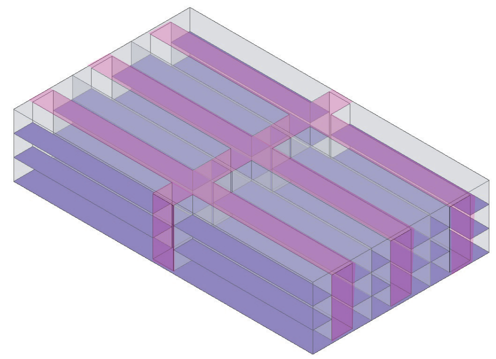
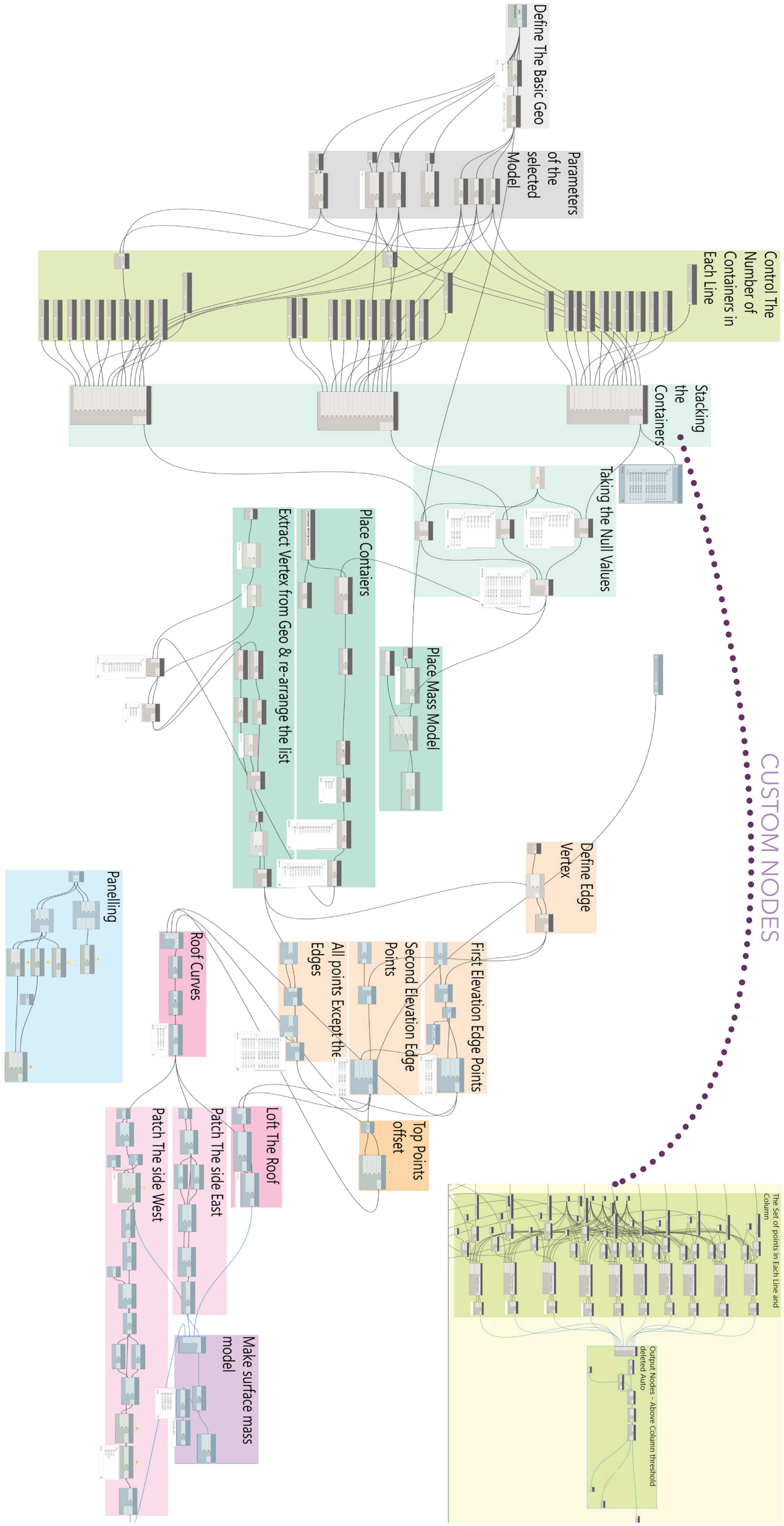
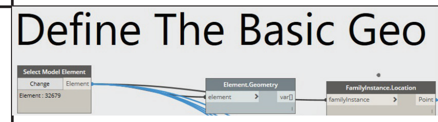
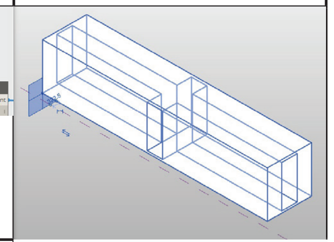
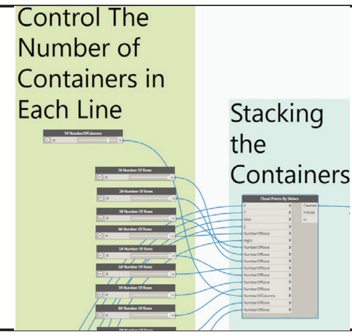
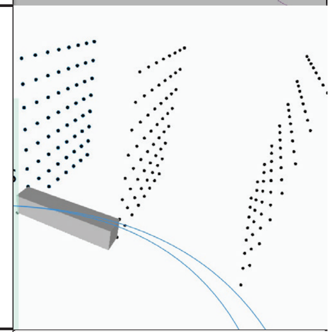
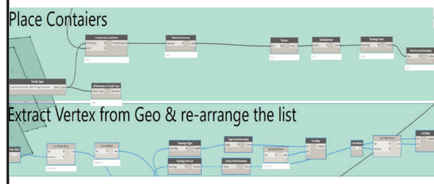
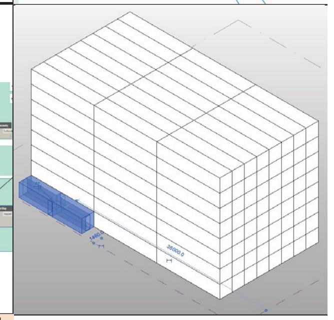
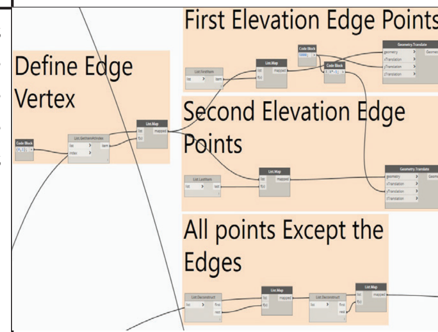
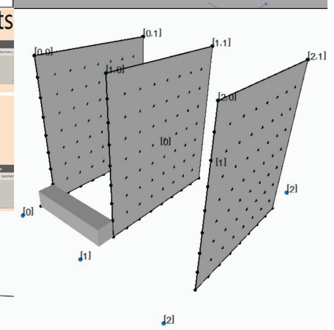
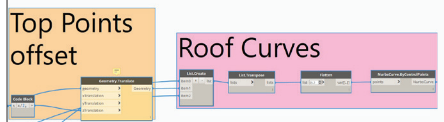
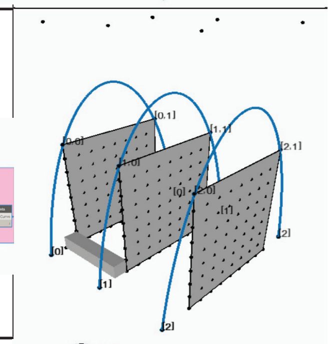
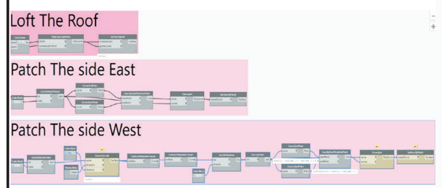
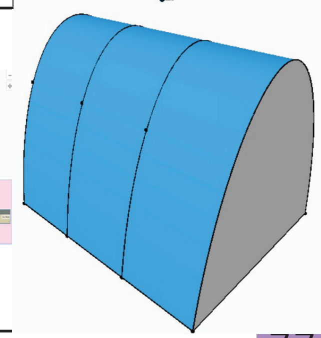
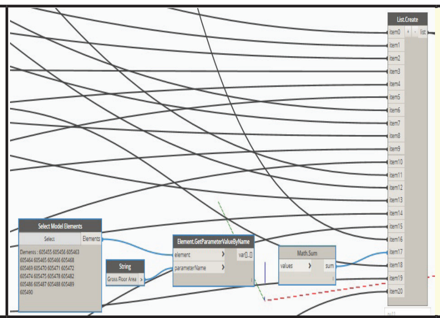
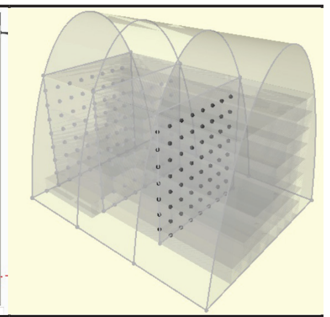
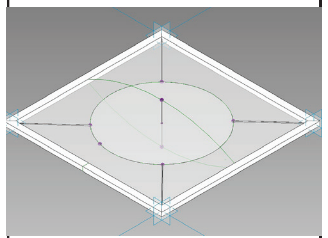


Fig 9-J : Production floor areas after join the units, each three production levels at height 805 mm for each.

Fig 10-J: Energy Model Script in Dynamo for generating the different configurations of 3 line stacking in maximum height of 8 containers.



NO	Process	Description-Steps	Script Graph	Model Graph
1	Define basic geometry	Create the standard size containers and define the instance point of the family (Highlighted in blue).		
2	Create set of points in grid network	Create custom node in Dynamo to define the maximum hight (8 containers) and number and stacked containers in each column		
3	Place the mass model family on the point network	-Define the family type. -Get family parameters (geometry vertexes) the basic geometry in blue.		
4	Extract the configurations side faces.	Combine the containers geometry on the same line and extract the surface topology of the geometries and vertexes (Shown in points label)		
5	Offset the outer Vertex on Z axis (edge vertex on X direction) to draw the main surface curves	- The edge points are always lay in certain location in the list (sorted previously) - The middle parts are vary depend on the configuration by using a code block series equation will select all other values.		
6	Create the cover surface of the configuration	By lofting the curves and patching the sides the final surface are set to translated in to mass surface in order to adapt the panel family model of the ETFE cushion.		

7	Calculate the gross production level area using dynamo	As the Dynamo integrated in Revit environment calculating the floor plan of the parameters are possible through string node in Dynamo.		
8	Panalising surface the surface through Dynamo/ Revit.	- First the surface has been Panalising surface in Dynamo in order to check the UV direction are generated properly and later inside Revit through the mass model.	-Create custom family panel for ETFE cushion, in order to place the panels on the panalised surface. In Fig N-1 -Define the middle layer material "PET" and ETFE cushion properties.	

The final result of the skin surface is produced by eliminating internal vertexes and using the outer points or closest to the surface; this has been done for the final selected model of the daylight analysis as shown in Solar Insolation graphs from J-11&14.

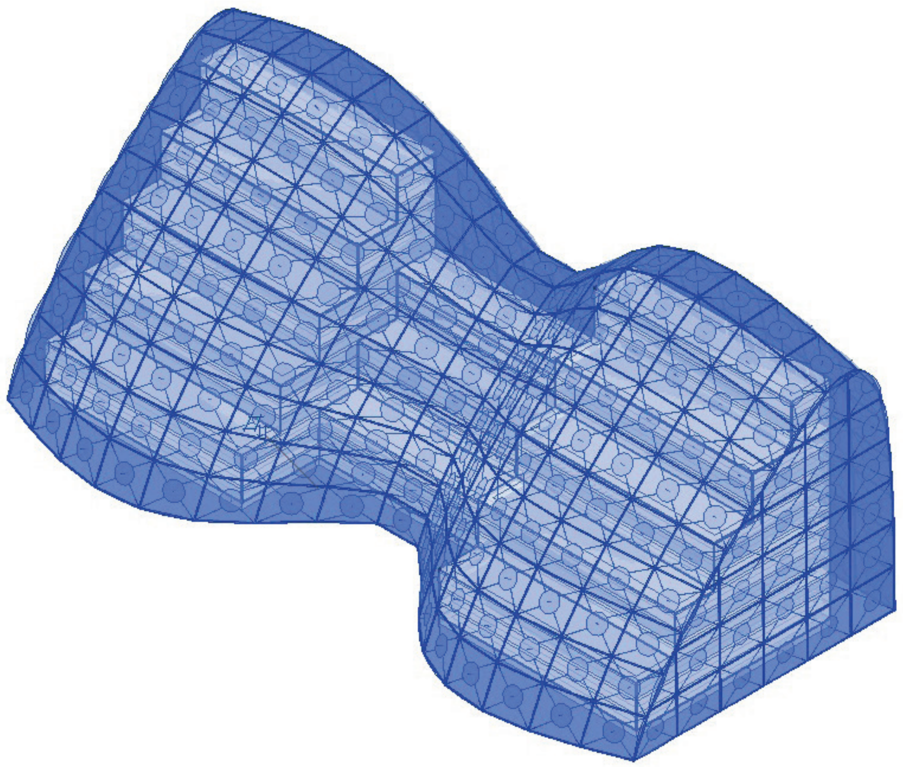


Fig 11-J: Panlised surface with proposed ETFE cushion family.

11.2.3 Configurations

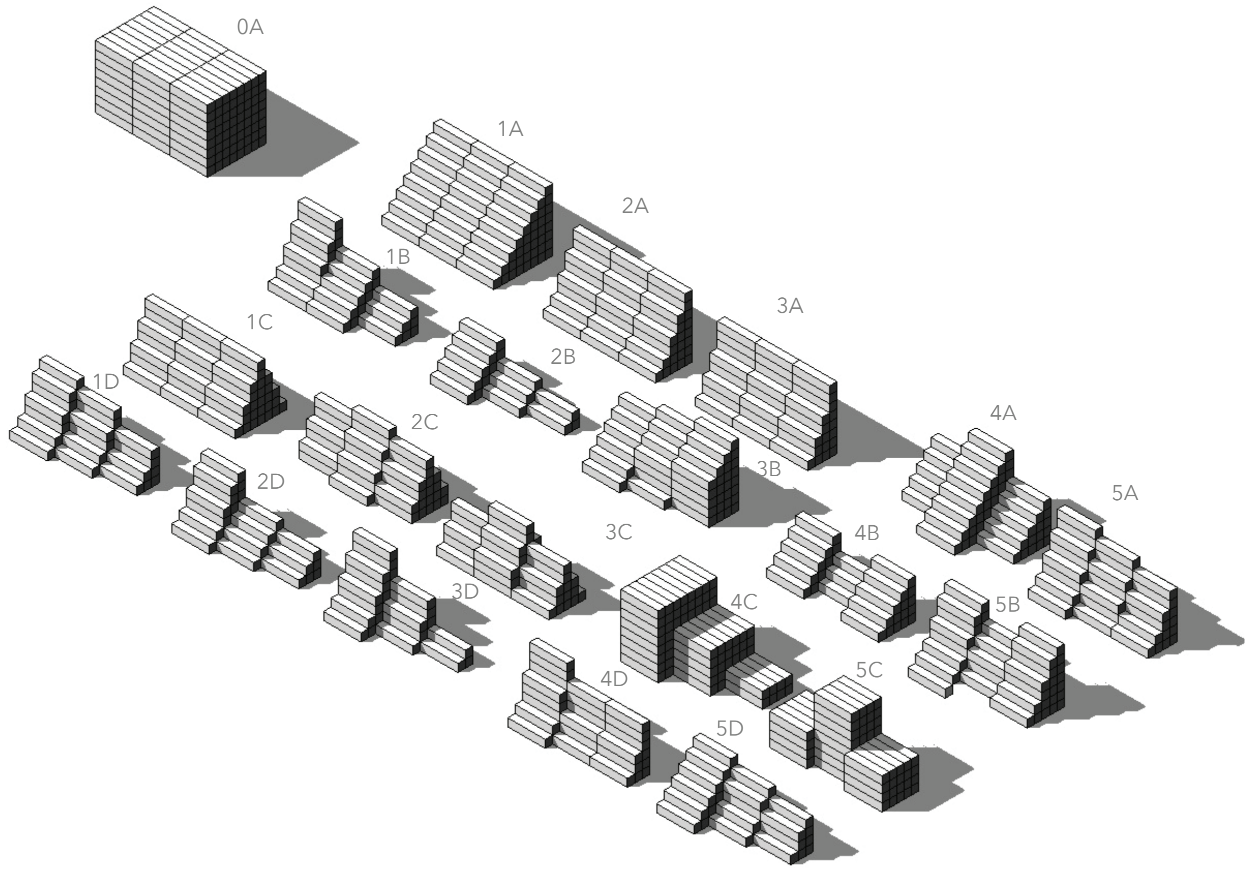


Fig 12-J: Different container configurations model for Mobile Plant factory design (phase one)

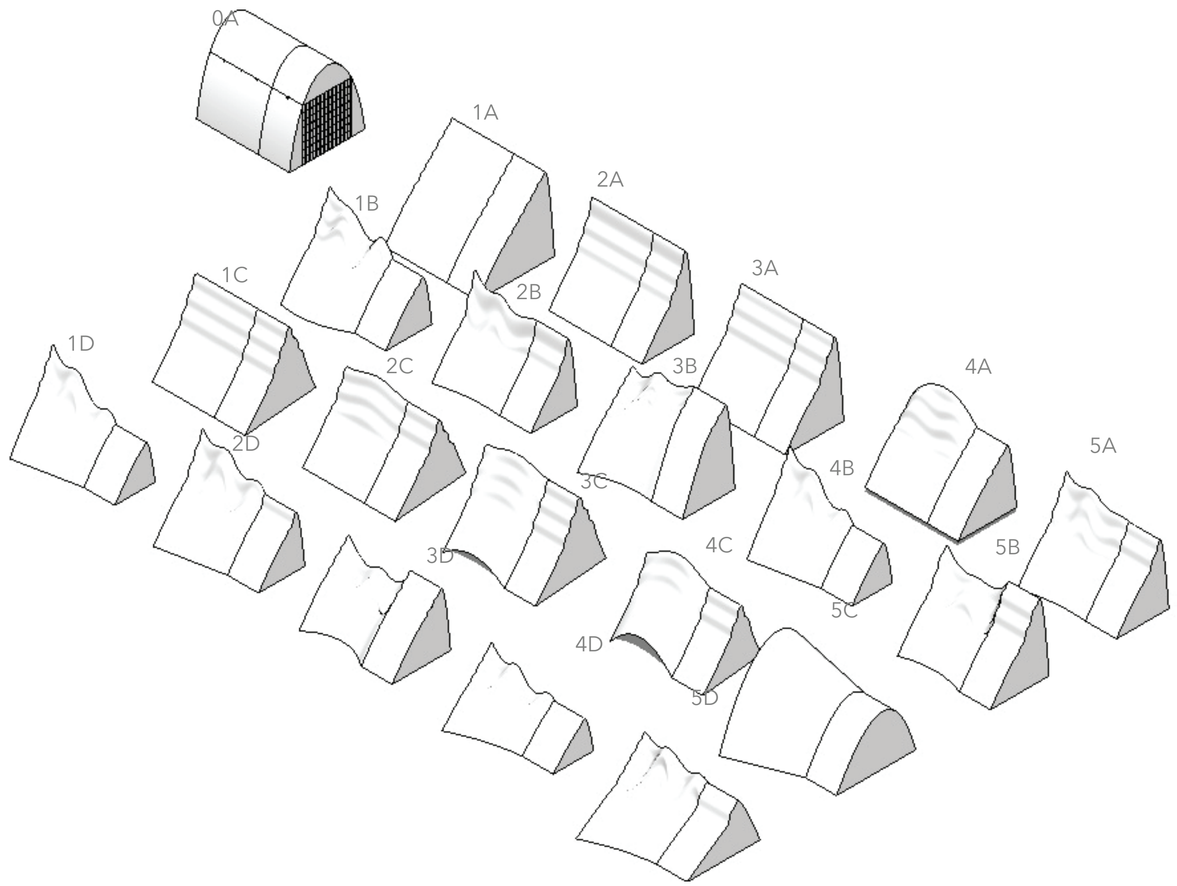
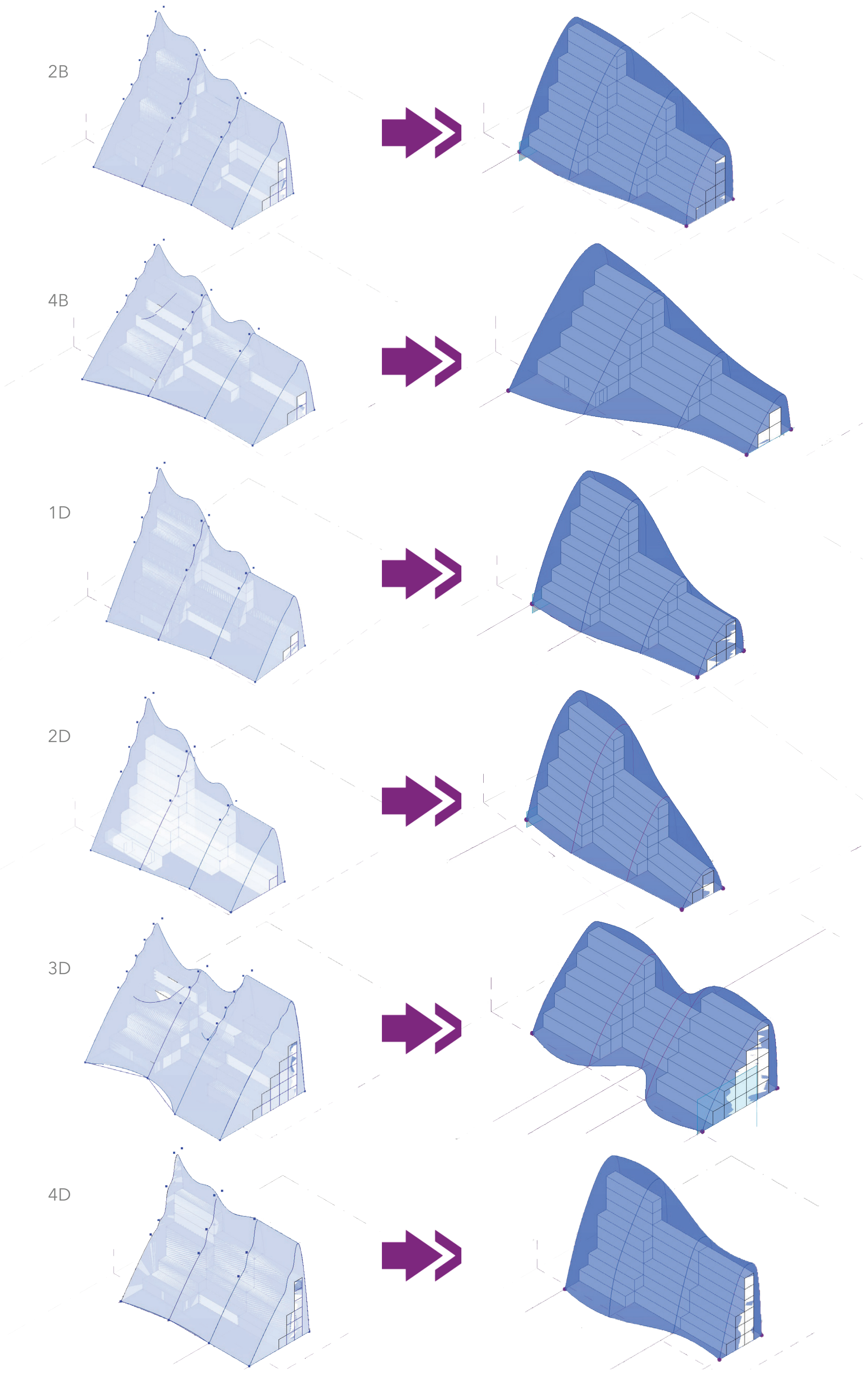


Fig 13-J: Surface offset for the configurations geometry generated by the Dynamo script.

Fig 14-J: Refine the surfaces of the selected models. (Selected geometries in Table 19/20)



11.2.3 DAYLIGHT ANALYSIS FIRST SELECTION PHASE

Firstly, the simulation conduct on the 20 different configurations that has best passing rate above the minimum threshold (300 Lux) of solar daylight access to the production level. The simulation was done in the top of the base containers in configurations at the height of 3320 mm on the production level. The proposed configurations shown in table 12/13-J.

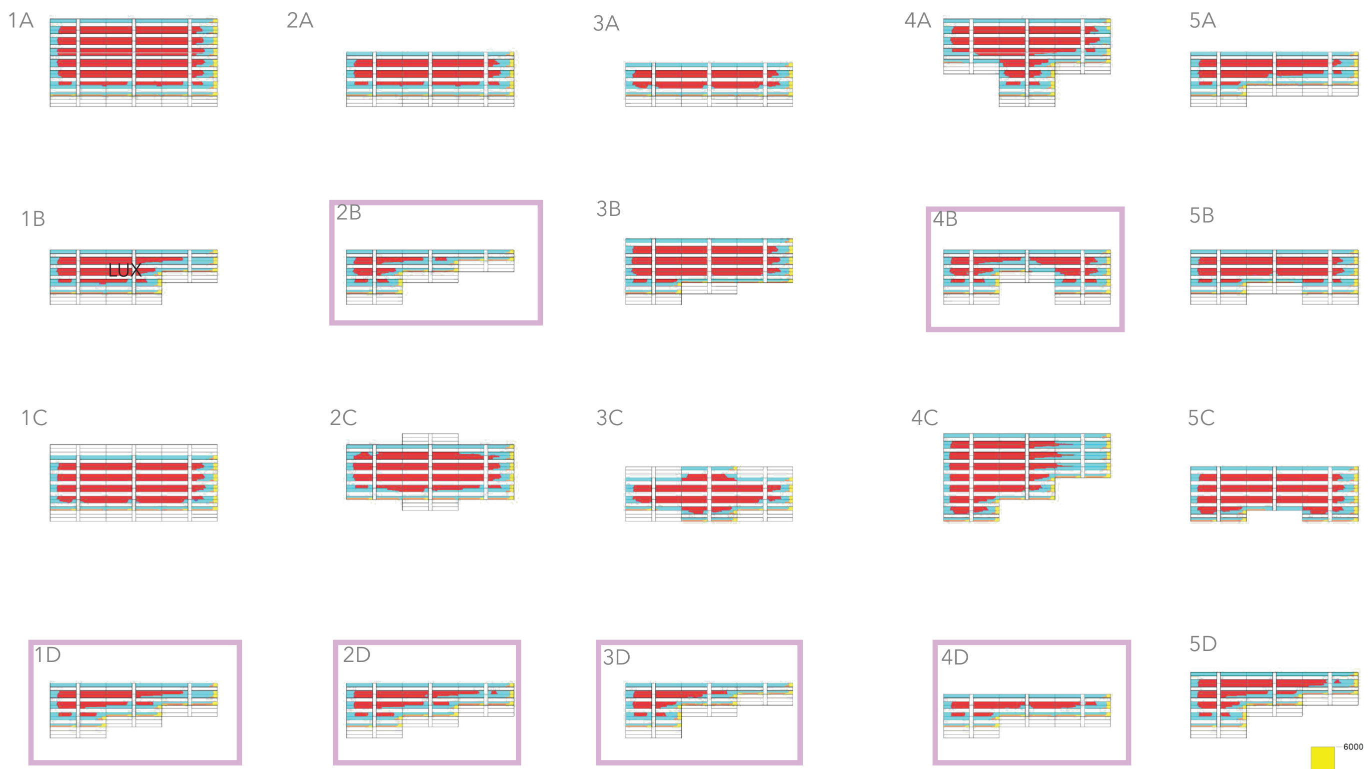
The analysis shows the best configurations in both locations Amsterdam and Damascus. However, the simulations were applied annually on both locations. The analysis sorted and the result was classified by two ranking based on light grid output.

Good: 30-50 % or more of the internal space has 300 Lux or above the minimum threshold and a Low percentage of the surfaces (grid) has luminosity value below 104 Lux of the scale.
Fair: Dark areas below(100lux) are covering the largest percentage of the area in the production plan.

By applying the measuring tool set on these four dates and observe the best results. The result of the luminance analysis shows that Model 2B,4B, 1D, 2D. 3D, 4D has the best daylight access in As shown in Fig a/b16 J and the results in table 17-J.

Model NO	First Line	Second Line	Third Line	Production Area M2
0	{8,8,8,8,8,8,8,8}	{8,8,8,8,8,8,8,8}	{8,8,8,8,8,8,8,8}	11163
1A	{8,7,6,5,4,3,2,1}	{8,7,6,5,4,3,2,1}	{8,7,6,5,4,3,2,1}	6279
2A	{8,5,3,1}	{8,5,3,1}	{8,5,3,1}	3663
3A	{8,6,4,2,1}	{8,6,4,2,1}	{8,6,4,2,1}	2965
4A	{5,4,3,2,1}	{5,4,3,2,1}	{5,4,3,2,1}	3837
5A	{8,6,4,2,1}	{7,5,3,1}	{6,4,2,1}	2907
1B	{8,6,4,2,1}	{5,4,3,2,1}	{3,2,1}	2442
2B	{5,4,3,2,1}	{3,2,1}	{2,1}	1395
3B	{6,5,4,3,2,1}	{7,6,5,4}	{8,7,6,5}	4070
4B	{5,4,3,2,1}	{3,2,1}	{5,4,3,2,1}	2093
5B	{7,6,4,2,1}	{5,4,3,1}	{7,6,4,2,1}	3081
1C	{1,3,5,7,5,3,1}	{1,3,5,7,5,3,1}	{1,3,5,7,5,3,1}	2442
2C	{2,4,6,4,2}	{1,3,5,7,5,3,1}	{2,4,6,4,2}	1394
3C	{1,3,5,7,5,3,1}	{2,4,6,8,6,4,2}	{1,3,5,7,5,3,1}	2849
4C	{1,3,5,3,1}	{3,5,7,5,3}	{1,3,5,3,1}	5930
5C	{8,8,8,8,8,8,8,8}	{4,4,4,4,4,4}	{2,2,2,2}	4186
1D	{8,6,4,2,1}	{6,4,2,1}	{4,2,1}	4360
2D	{8,6,4,2,1}	{4,3,2,1}	{3,2,1}	3546
3D	{8,6,4,2,1}	{5,3,1}	{2,1}	2849
4D	{8,5,2,1}	{6,3,1}	{6,3,1}	5930
5D	{6,5,4,3,2,1}	{5,4,2,1}	{4,3,1}	4186

Table 15-J:
Different configurations of 3 line stacking model no linked to FigJ-5 Model No. The table below J-12 Shows the light simulation result in 4 shifting season's set points of the year.



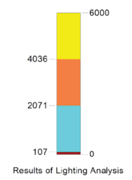
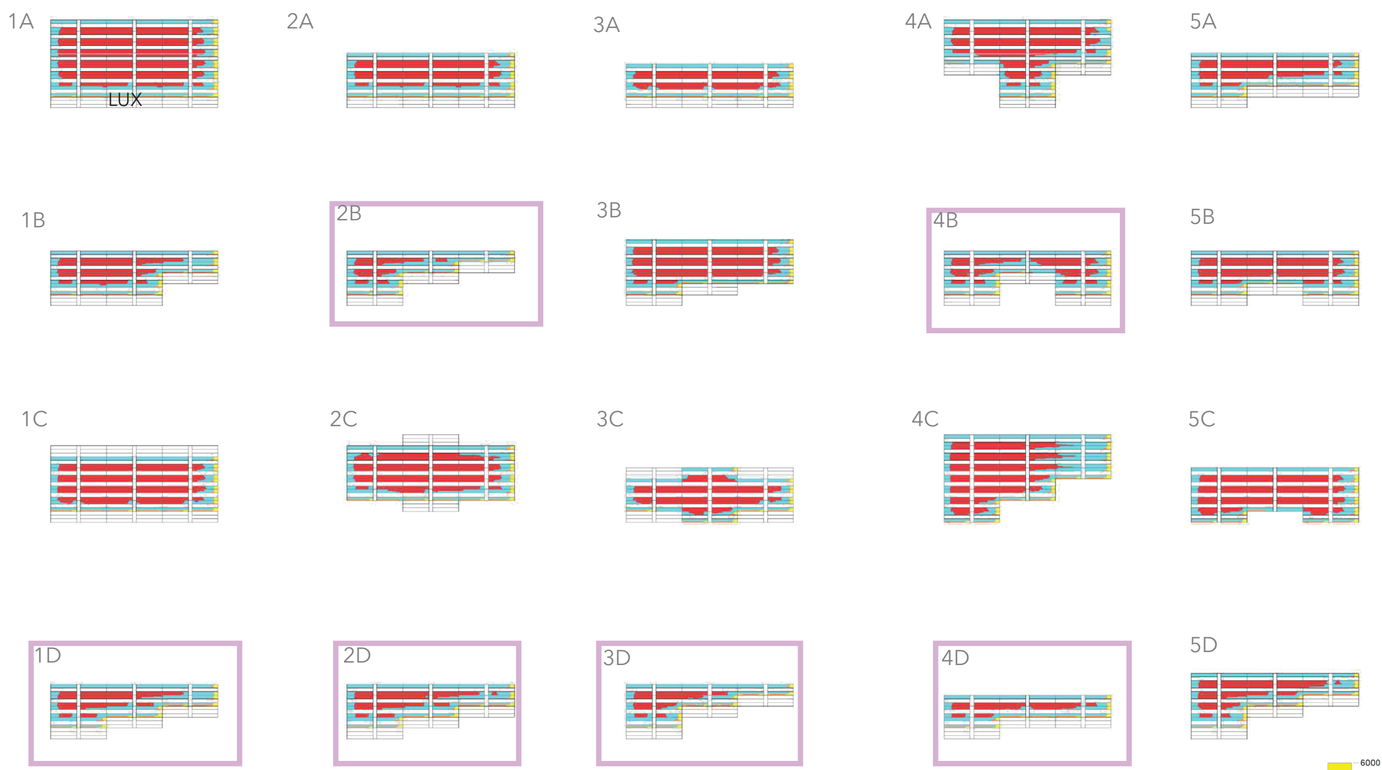


Fig a16-J : Light analysis Yearly Average Amsterdam



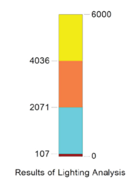


Fig b16-J : Light analysis Yearly Average Damascus

Model NO	Light Analysis Summer Solstice 21 June Amsterdam	Light Analysis Summer Solstice 21 June Damascus
0	Fair	Fair
1A	Fair	Fair
2A	Fair	Fair
3A	Fair	Fair
4A	Fair	Fair
5A	Fair	Fair
1B	Fair	Fair
2B	Good	Good
3B	Fair	Fair
4B	Good	Good
5B	Fair	Fair
1C	Fair	Fair
2C	Fair	Fair
3C	Fair	Fair
4C	Fair	Fair
5C	Fair	Fair
1D	Good	Good
2D	Good	Good
3D	Good	Good
4D	Good	Good
5D	Fair	Fair

Table 17-J:
Shows the light simulation result in average around the year Solstice and Equinox shifting season's set points of the year.

11.2.5 SOLAR HOURLY ANALYSES

The solar study indicates the number of hours that the surface receives the solar light. Its measure the normal incidence Direct radiation from the sun (direct beam radiation = Ib) which is always measured perpendicular to the sun's rays and Diffuse radiation that is both scattered by the clouds and atmosphere (diffuse sky radiation = Id) front of the surface (Ir) **[Autodesk sustainability workshop website,2018]** annually in both locations. This simulation will help to evaluate the model geometry in phase one, And wither cold or warm climate will influence the energy use for cooling and heating. Fig 18-J & 19-J shows the average solar heat gain annually on first phase's selected model and the values in table 20-J.

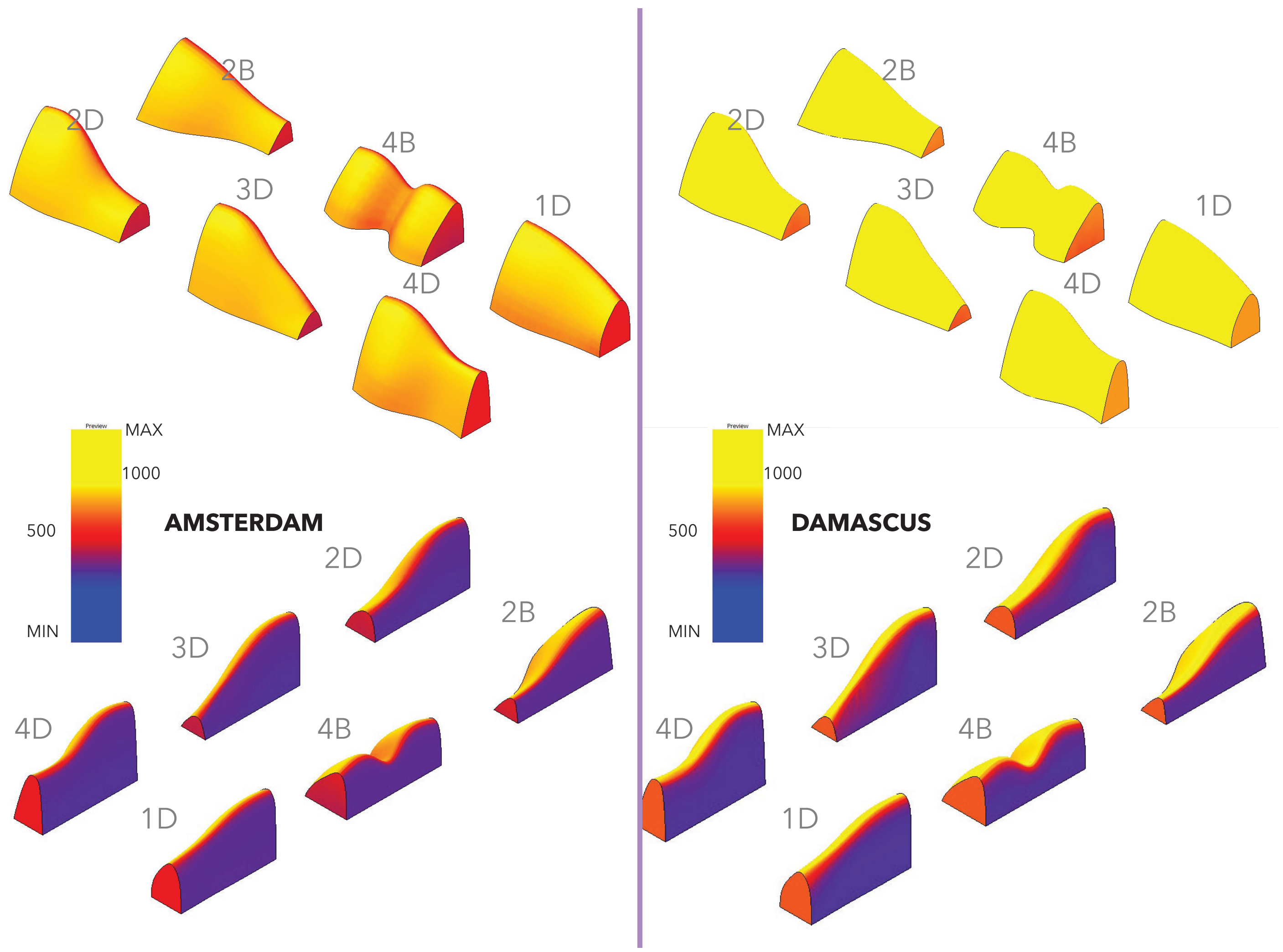


Fig 19-J: Annual average solar hourly analysis SHA for Amsterdam and Damascus (first phase).

Model NO	Offset surface Area M2	AMS Average Annual Solar Insolation Analysis KWH/m2. day.year	AMS Peak Annual Solar Insolation Analysis KWH/m2. day.year	AMS Cumulative Annual Solar Insolation Analysis KWH/m2. day.year	DAM Average Annual Solar Insolation Analysis KWH/m2. day.year	DAM Peak Annual Solar Insolation Analysis KWH/m2. day.year	DAM Cumulative Annual Solar Insolation Analysis KWH/m2. day.year
2B	1,304	0.16	0.61	755	0.28	0.68	1,304
4B	1,476	0.14	0.53	658	0.27	0.67	1,242
1D	1,816	0.16	0.56	735	0.24	0.56	1,816
2D	1,575	0.15	0.53	696	0.26	0.59	1,185
3D	1,290	0.14	0.49	640	0.23	0.56	1,102
4D	1,952	0.14	0.49	652	0.23	0.56	1,090

Fig 20-J: Annual average, peak and cumulative, solar hourly analysis SHA for both locations.

The study shows the south elevations have higher solar heat flow values through the facade than north part of the models around the year (chapter 5 greenhouse orientation). The values in Amsterdam have less solar gain than in Damascus site as shown in the Table 21.

Model NO	AMS Average Annual Solar Isolation Analysis KWH	AMS Cumulative Annual Solar Isolation Analysis KWH	AMS Cumulative Annual Solar Isolation Analysis KWH	DAM Average Annual Solar Isolation Analysis KWH	DAM Peak Annual Solar Isolation Analysis KWH	DAM Cumulative Annual Solar Isolation Analysis KWH
2B	209	795	984520	365	887	1700416
4B	207	782	971208	399	989	1833192
1D	291	1017	1334760	436	1017	3297856
2D	236	835	1096200	410	929	1866375
3D	181	632	825600	297	722	1421580
4D	273	956	1272704	449	1093	2127680

Fig 21-J: Total sum of the average, peak and cumulative, SHA values based on surface area from table 20-J page 77.

The bar graphs present the average SHA values differences between models in phase one. The EUI values in later section hours shows that the 4B (red color) has lowest EUI value in both locations. in Amsterdam where in Damascus the numbers are fall between 350-450 KWH.

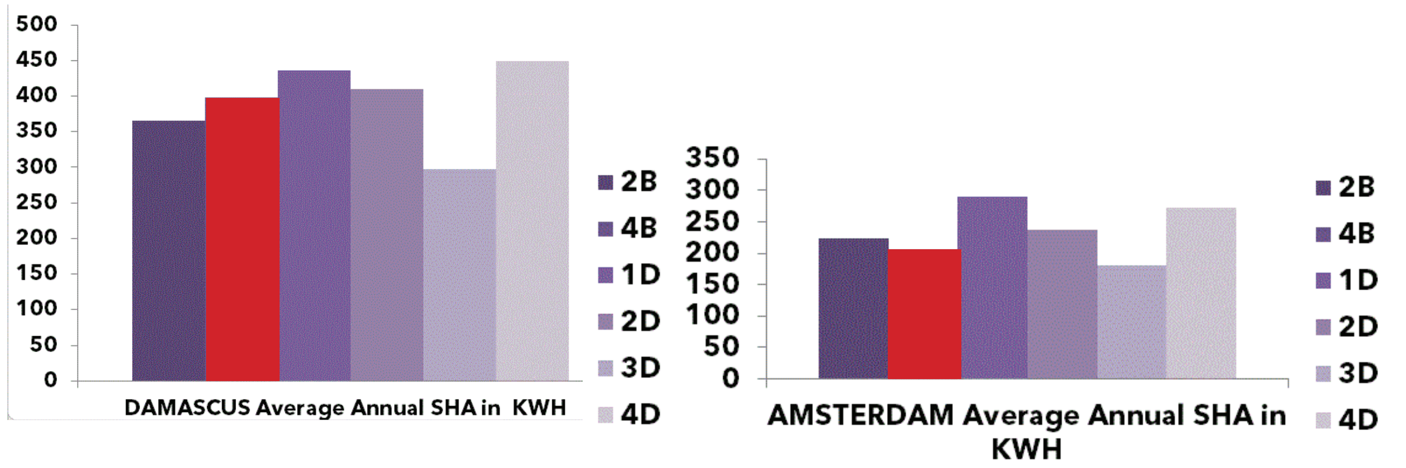


Fig 22-J: Annual average solar hourly analysis values (phase one) in Amsterdam and Damascus showing the best configuration with lowest EUI in red (refer to section 10.2.6).

11.2.6 DAYLIGHT ANALYSIS SECOND PHASE

Based on first daylight and later EUI simulation in phase one in 10.2.6, results shows several boundaries should be taken into account to improve the design and selection:
- The design should be more compact and spaces are connected between the three lines as it shows less energy use level (refer to the section 10.2.8 energy use)
- Configurations should be in gradual decrease from below to the top at (South facade) refer to light chapter 5 for greenhouse orientation).
-Best Height 5-6
-Maximum Base depth is 4 - 5 containers.
-Maximum height is 6 containers.
-Differences between two line need to be minimum of 2 to make change in the final skin shape.

The simulation conduct annually with threshold set on minimum of 300 Lux. The simulation shows the passing rate on different times of the year These different dates are for northern hemisphere Summer solstice on June 21st, Winter solstice on 22nd December, Spring and Autumn equinox on 22 September and 20th of March respectively in overcast sky condition in table 26-J

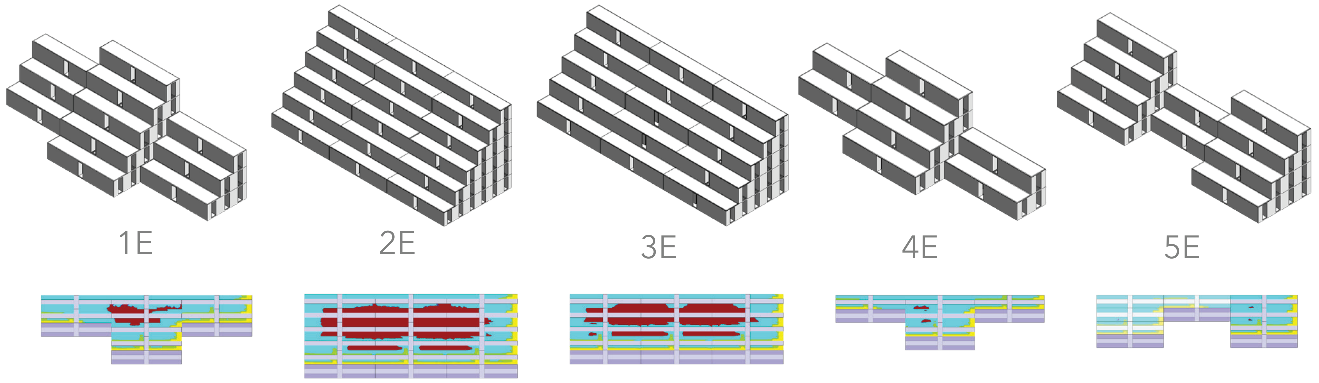


Fig 24-J: Daylight study for the second configurations based on the set boundaries

Model NO	First Line	Second Line	Third Line
0E	{5,4,3,2,1}	{3,2,1}	{5,4,3,2,1}
1E	{3,2,1}	{5,4,3,2,1}	{3,2,1}
2E	{6,5,4,3,2,1}	{6,5,4,3,2,1}	{6,5,4,3,2,1}
3E	{5,4,3,2,1}	{5,4,3,2,1}	{5,4,3,2,1}
4E	{1,2}	{4,3,2,1}	{1,2}
5E	{4,3,2,1}	{1,2}	{4,3,2,1}

Fig 25/26J: Phase 2 configurations. 26-J shows the Daylight study for the second configurations solar light pass the minimum threshold set of 300 Lux

Model NO	Light Analysis Summer & winter above 300 Lux, passing rate	Light Analysis Equinox Above 300 Lux, passing rate
0E	49%	37%
1E	42%	33%
2E	48%	40%
3E	24%	20%
4E	49%	41%
5E	52%	37%

11.2.7 SOLAR HOURLY ANALYSES SECOND PHASE

The second phase of solar light study is aim to provide clear differences between the selected model (second phase) in terms of solar gain annually. The results shows that 4E and 1E has the lowest total solar heat average heat flow while 2 and 3 E (similar geometry difference in scale) has the highest. The best options with lowest EUI

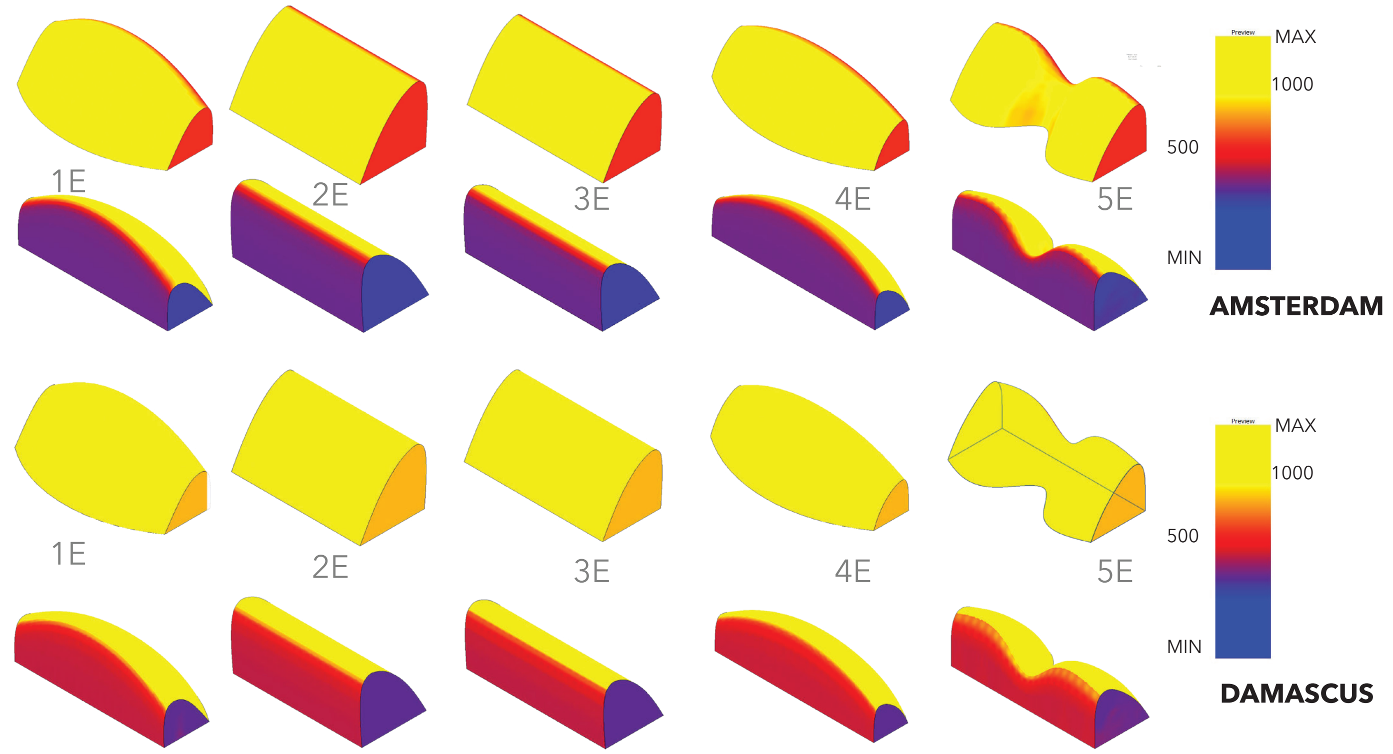
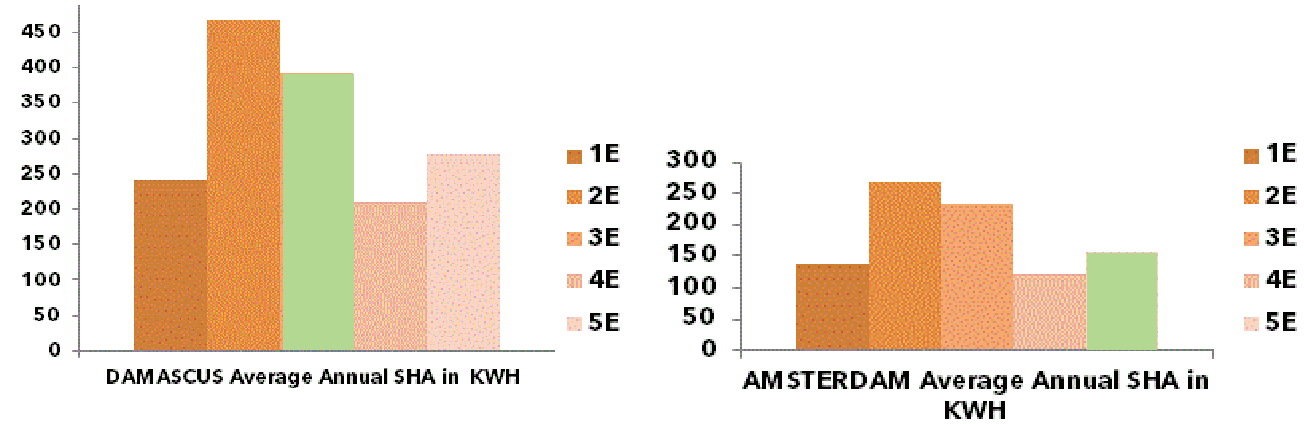


Fig 27J: 3D simulation of the surfaces Average solar heat gain annually for phase 2 configurations.



Type	AMSTERDAM Average Annual SHA in KWH	AMS Peak Annual SHA in KWH	AMS Cumulative Annual Solar Isolation Analysis KWH	DAMASCUS Average Annual SHA in KWH	DAM Peak Annual Solar Isolation Analysis KWH	DAM Cumulative Annual Solar Isolation Analysis KWH
0E	207	782	971208	399	989	1833192
1E	138	501	601344	242	544	1086912
2E	269	970	1149440	467	1042	2135444
3E	232	798	945400	392	870	1777700
4E	121	434	524208	209	466	922992
5E	157	605	788920	278	702	1253560

Fig 28J: Average solar heat gain annually for phase 2 configurations.

11.2.8 ENERGY OPTIMISATION

Energy models required a range of inputs need to be defined for the optmisation in Autodesk insight is similar workflow to Rhino/grasshopper as shown in Fig 29-J, including local weather files and geographical location data. This called typical meteorological year (TMY) files which are designed to represent current or future realities. TMY files typically used as data for programs, such as Energy Plus, are collections of average weather data, including temperature and humidity readings, averaged of over 15 to 30 years of data based on selected weather station locations (typically airports) **[Peters,2018]**. Six selected models after simulation of daylight access, an initial energy user intensity has been calculated using the same energy model by Autodesk Insight 360. The energy model has been simplified, and all essential values set for both contexts in Amsterdam and Damascus and simulated in Energy plus.

General Definitions

The software has limited parameters as the interface intend to be used for occupants. The greenhouses and PFAL have different criteria than any other buildings. Energy model and materials parameters. These definitions are :

- Area per Person (People/ sq. M.) – the change in definition will be ''number of sq.M f gross area of plants'' per unit area within the space.
- People sensible heat gain per person (W/person) – the change in definition will be the internal sensible gain for sq.M gross area of plants.
- People latent heat gain per person (W/person) – the change in definition will be the internal latent gain for sq.M gross production area of plants.
- Lighting Load Density (W/sq. M.) – gain for lighting
- Power Load Density (W/sq. ft.) – internal sensible gain for miscellaneous equipment
- Plenum Lighting Contribution
- Occupancy Schedule - times at which the heating/cooling set point will be held
- Lighting Schedule - shows times when lighting gain occurs
- Power Schedule - shows times when equipment gain occurs
- Opening time
- Closing time
- Unoccupied Cooling Set Point

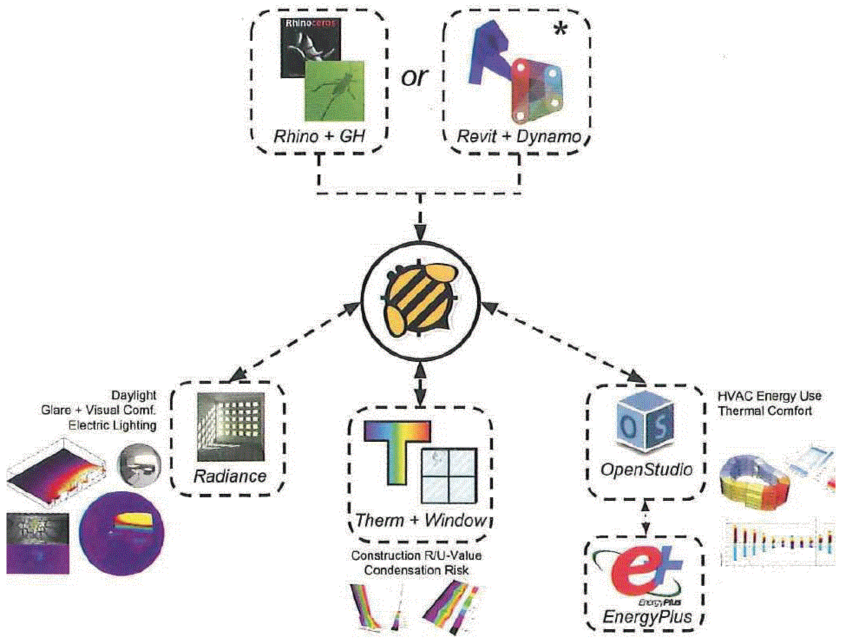


Fig29-J: Dynamo connection has been partially released the Energy Plus is ongoing development to match the features of Grasshopper. Source **[Peters,2018].**

11.2.9 SIMULATION PARAMETERS

The default temperature set on 24 Celsius and light 600 PPFD is applied in the study. The parameters set for the materials covering energy models as following:
- ETFE three layers with thickness of 200µm
U value 2.1 W/(m2.K) - Solar heat gain .65 - Visual transmittance .65 . Fig26/27-J show the material thermal properties in Revit model.

	☑ Transmits Light
Behavior	Isotropic
Thermal Conductivity	0.2400 W/(m·K)
Specific Heat	1.5000 J/(g·°C)
Density	1,300.00 kg/m³
Emissivity	0.01
Permeability	0.0000 ng/(Pa·s·m²)
Porosity	0.01
Reflectivity	0.05
Electrical Resistivity	1.00E+10 Ω·m

Fig 30-J: ETFE Thermal properties setup in Revit materials panel.

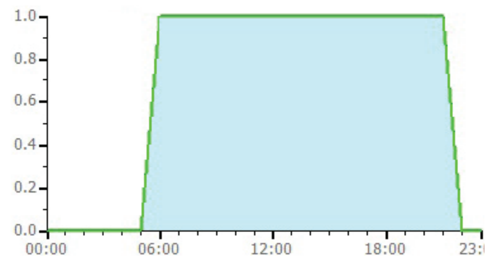
	☐ Transmits Light
Behavior	Isotropic
Thermal Conductivity	138.0000 W/(m·K)
Specific Heat	0.8800 J/(g·°C)
Density	2,680.00 kg/m³
Emissivity	0.20
Permeability	0.0000 ng/(Pa·s·m²)
Porosity	0.01
Reflectivity	0.00
Electrical Resistivity	0.0000 Ω·m

Fig31-J: Frame settings Thermal setup properties in Revit materials panel.

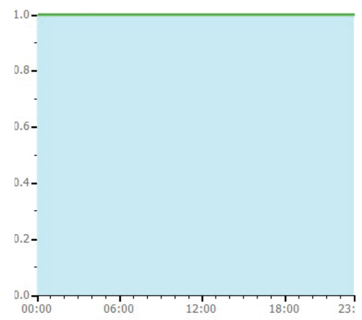
The energy analysis main parameters for the model were set in similar to the paper ''Plant factory versus greenhouse '' by **[Graamans, Baeza, Van den Dobbelsteen, 2018]** as a reference for later comparison to the final design. Plant factory is closed production unit system; therefore, mechanical ventilation is required, the proposed HVAC system for the simulation is 4-pipe fan coil system, chiller. The proposed Theses parameters in table 32/ and graphs33/34J.

Graphs 32/33/34-J: from left to right, energy model analytical parameters, light operating schedule, building power schedule.

Energy Analysis	
Area per Person	1.000 m²
Sensible Heat Gain per person	110.00 W
Latent Heat Gain per person	143.30 W
Lighting Load Density	231.00 W/m²
Power Load Density	16.15 W/m²
Plenum Lighting Contribution	20.0000%
Occupancy Schedule	On - 24 Hours
Lighting Schedule	On - 6 AM to 10 PM
Power Schedule	On - 24 Hours
Opening Time	06:00
Closing Time	22:00
Unoccupied Cooling Set Point	31.00 °C

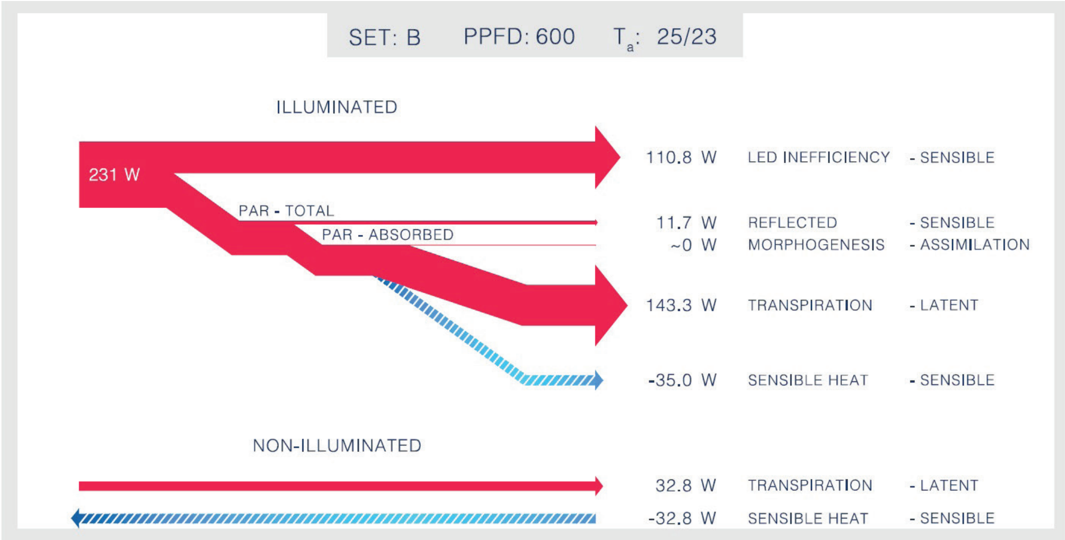


Time	Factor	Time	Factor
00:00	0.00%	12:00	100.00%
01:00	0.00%	13:00	100.00%
02:00	0.00%	14:00	100.00%
03:00	0.00%	15:00	100.00%
04:00	0.00%	16:00	100.00%
05:00	0.00%	17:00	100.00%
06:00	100.00%	18:00	100.00%
07:00	100.00%	19:00	100.00%
08:00	100.00%	20:00	100.00%
09:00	100.00%	21:00	100.00%



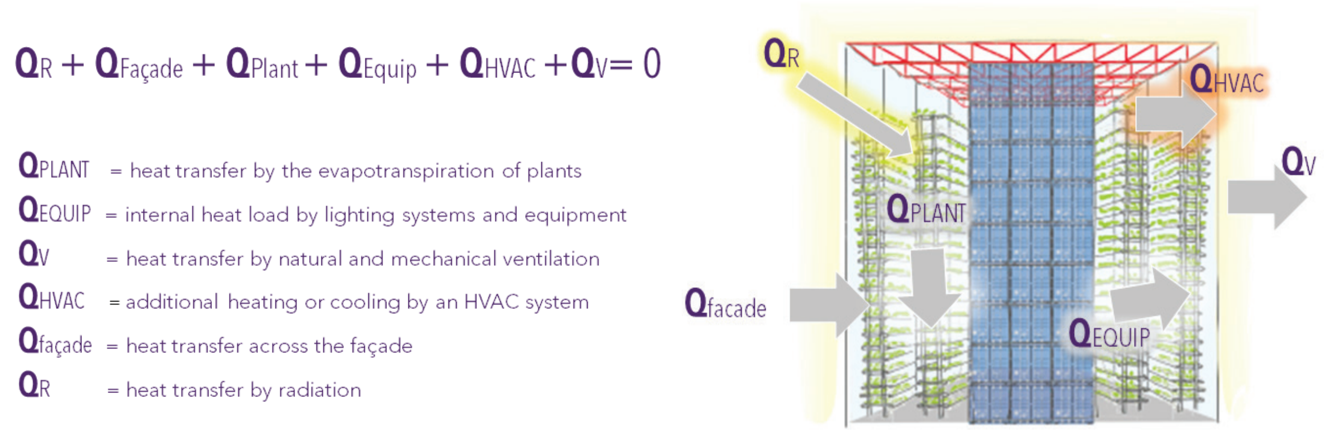
Time	Factor	Time	Factor
00:00	100.00%	12:00	100.00%
01:00	100.00%	13:00	100.00%
02:00	100.00%	14:00	100.00%
03:00	100.00%	15:00	100.00%
04:00	100.00%	16:00	100.00%
05:00	100.00%	17:00	100.00%
06:00	100.00%	18:00	100.00%
07:00	100.00%	19:00	100.00%
08:00	100.00%	20:00	100.00%
09:00	100.00%	21:00	100.00%
10:00	100.00%	22:00	100.00%
11:00	100.00%	23:00	100.00%

For the parameters people Sensible Heat Gain (W/person) and People Latent Heat Gain (W/person) the change is to consider W/sq.M of gross production area plant. The figures are based on **[Graamans, Van den Dobbelsteen, Meinenb, Stanghellinib, 2017]** shown in graph **35-J.**



Graphs 35: Energy flux for 600 PPFD at 23/25 temperature level. Source **[Graamans, , Van den Dobbelsteen, Meinenb, Stanghellinib, 2017]**

The optimisation performed for the 6 models in each context first at the first phase then on the four "E" series models for the second phase. First location set in Almere-Haven, Flevoland Amsterdam Metropolitan Area in the Netherlands. The second locations set in city of Damascus, Syria. The sum of EUI are in graph 38-39-J for Amsterdam page 92 and 40-41-J page 93 in comparison with paper "Plant Factory versus greenhouses" and all the result details can be seen in appendix(A). The Total energy heat flows based on the factors in Fig 36-J.



Graphs 36-J:Heat flows in hybrid plant factory.

11.2.10 DISCUSSION

The evaluation of the best configuration have two daylight study phase. In the first phase the best EUI result were the 4 "B" for both locations due to slight similarity in climate. Additionally the design has more compact shape. To evaluate the results of the analysis. The chart 38-39-J present the total EUI . with comparison with fully closed plant factory and greenhouse From the simulations, the graphs show that the cooling energy is very high in both locations. This cause by the solar heat gained through the facade. This might be influenced by the high transmittance value set to the glass to match ETFE so possible decrease for the figure in case of considering the design proposed for the middle layer light filter.

The mechanical ventilation is accounted for almost 80-70 %. An example of optimising the parameters to achieve lower energy load can be seen for the case in Amsterdam by implementing these optional strategies on 4B-Model such as closing all northern walls fig 34-J.

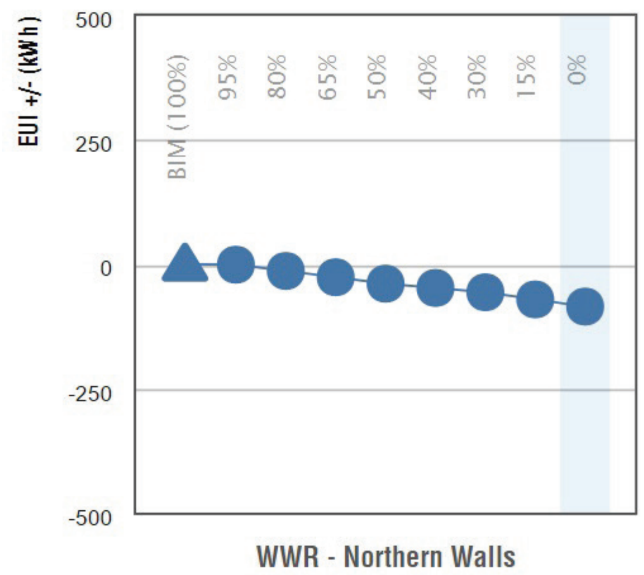


Fig 35-J: Shows the window wall ratio WWR reduction and impact on the final EUI. (Triangular shape symbol the existing model). closing the north facade reduce the energy loss.

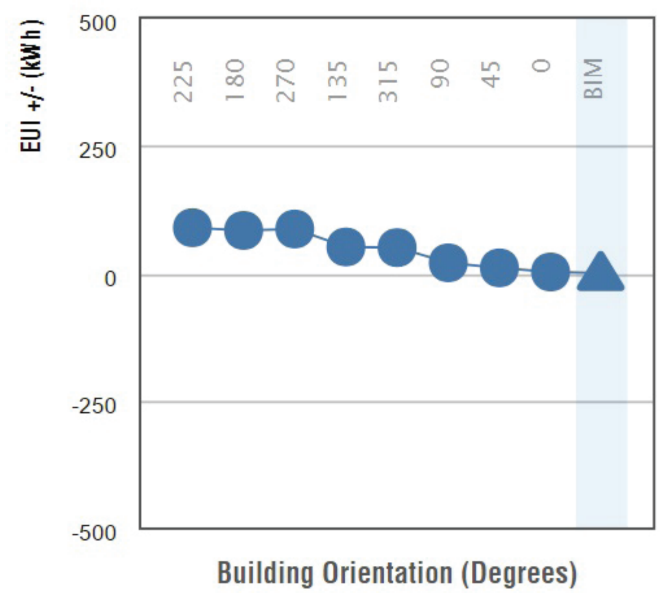
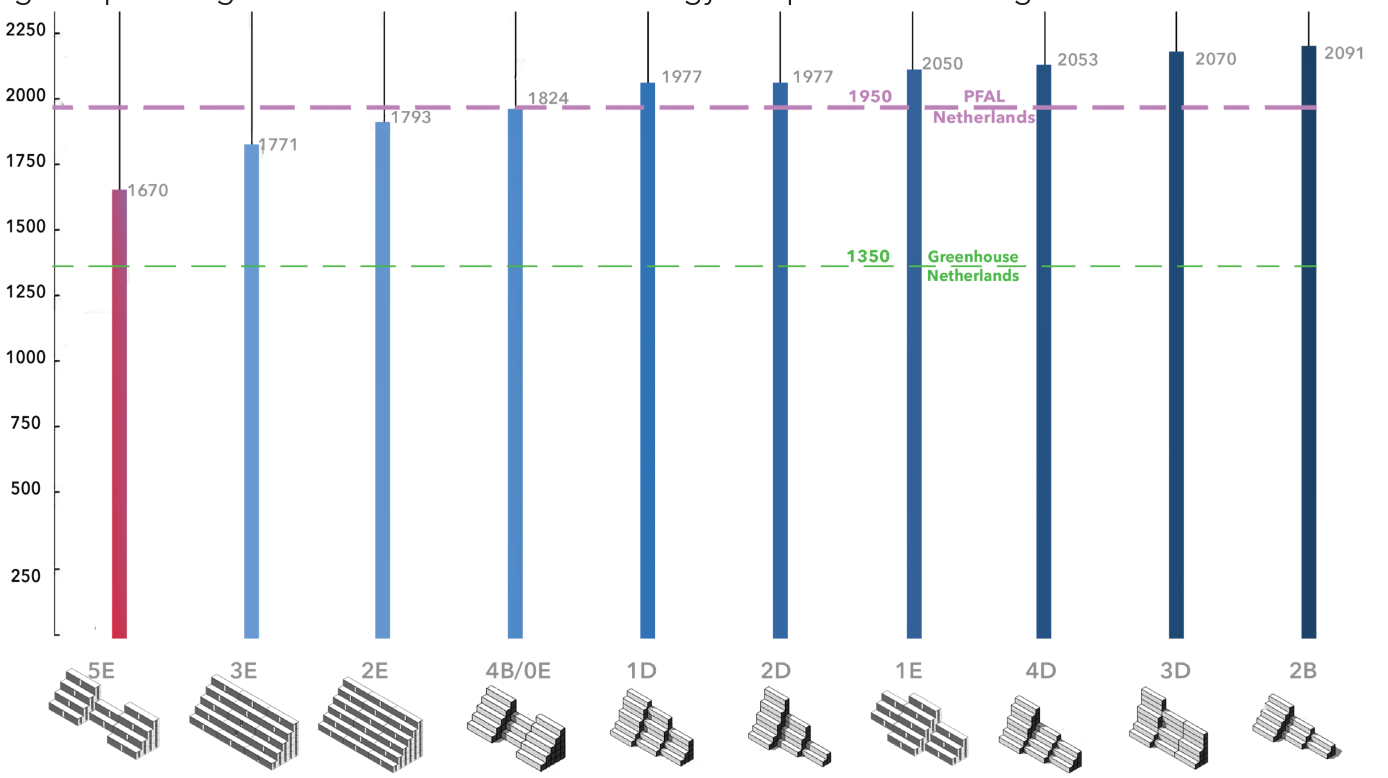


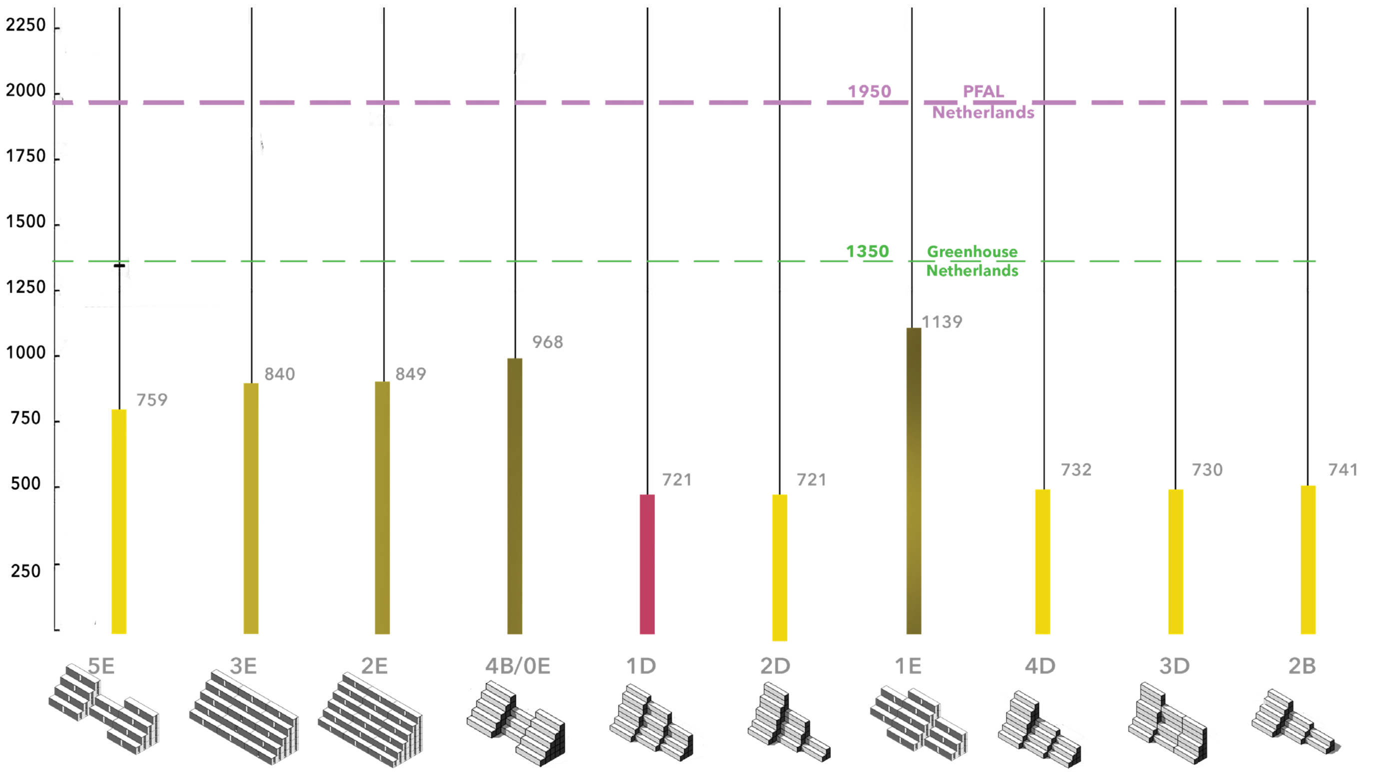
Fig 35.1-J:Building orientation, the current (triangular shape)is the is beat option. BIM has "South orientation"

11.2.11 ENERGY USE INTENSITY EUI

Based on the parameters set the output values were different in each context. This initially study aim to create baseline of comparison between various model. Remarkably in the both locations the same model 4B configuration has the lowest total energy use intensity (EUI). HVAC has the highest parentages accounted for increase energy footprint in the design.



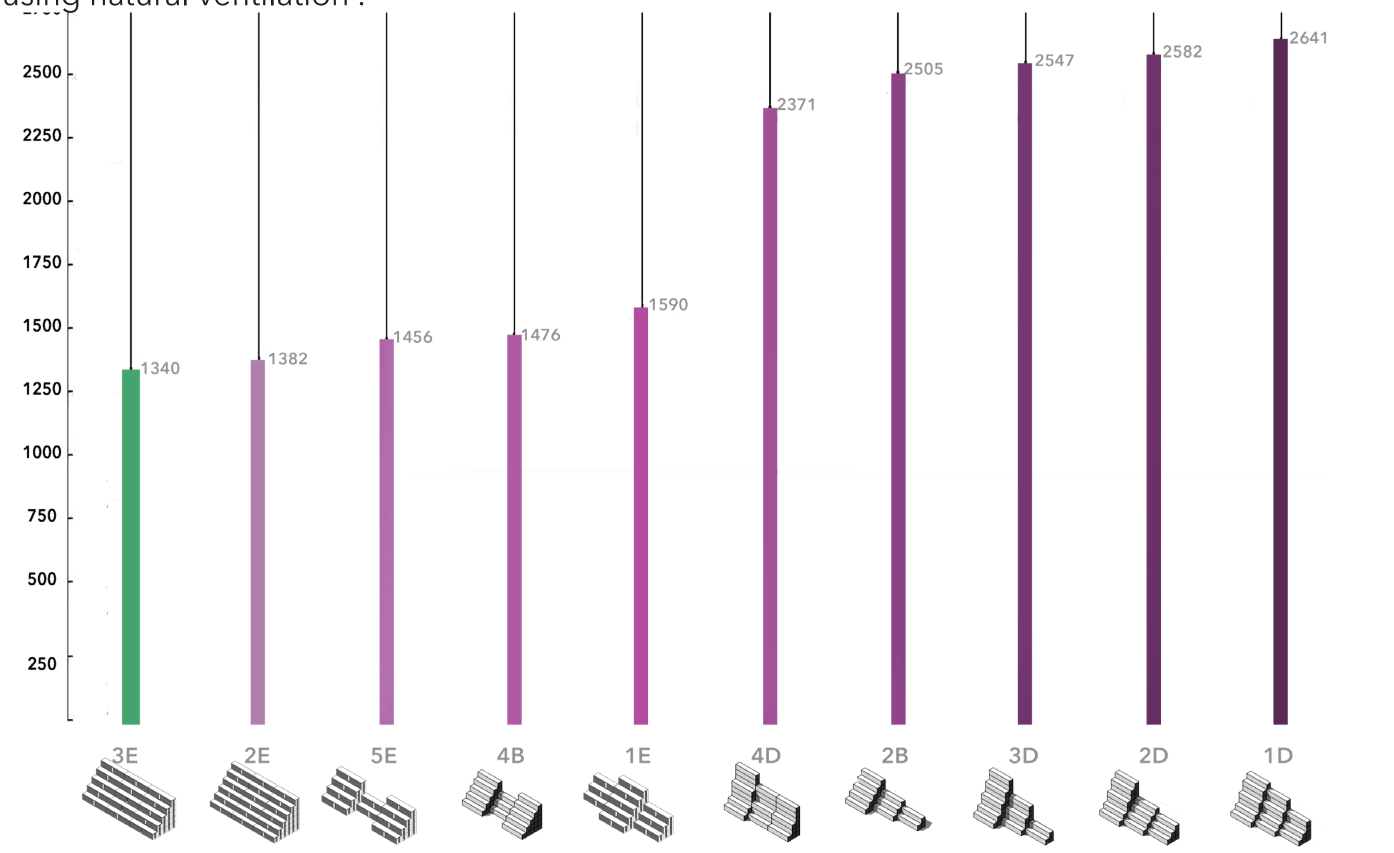
Graphs 38: EUI output produced by Autodesk 360 insight for the selected configuration in Amsterdam site. The colored dashed lines are the total energy load values per cultivation sq meter from paper **[Graamans, Baeza, Van den Dobbelsteen, 2018]**



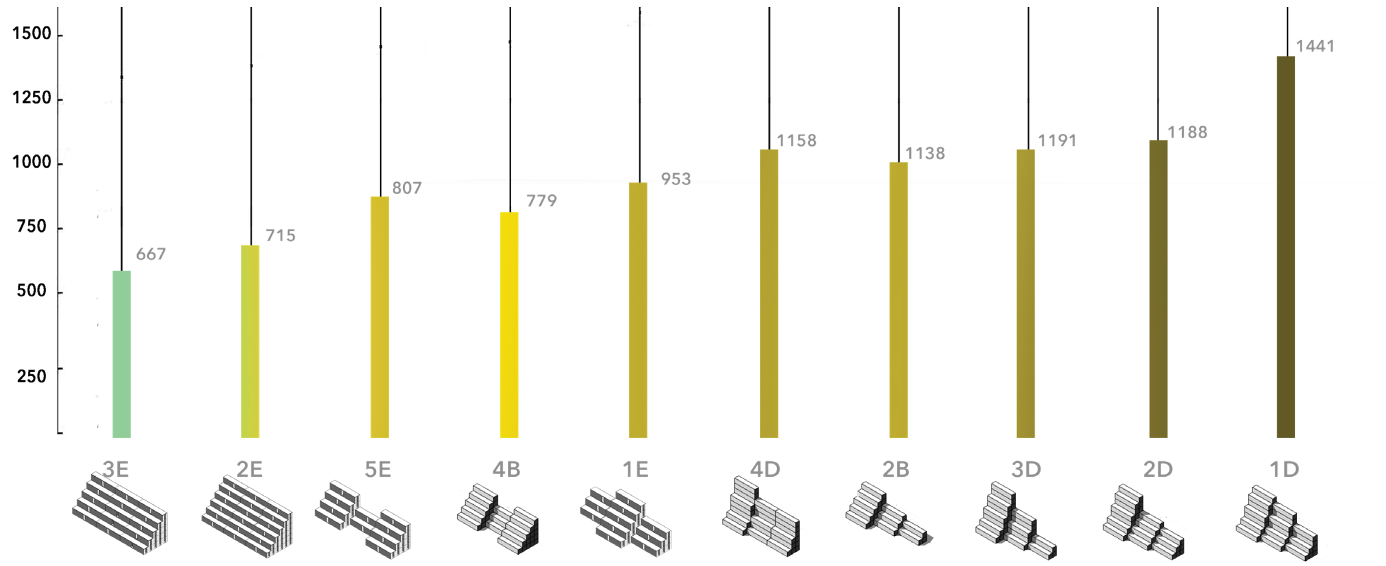
Graphs 39: EUI output for the selected configuration in Amsterdam site. The EUI is lower due to the use of natural ventilation

The EUI in Amsterdam drop up to 45% when the Plant Factory has changed from air tight (mechanical ventilation) to natural ventilation. The configuration 2D has the best result after this change. However, other solutions can applied to deal with the excessive heat produced by LED lights and solar gain discussed in heating and colling section. The following graphs 40-41-J shows the best configuration in Damascus location.

The numbers shows that 3 E has Lower EUI and remain the same after the improvement by using natural ventilation .



Graphs 40: EUI output for the selected configuration in Damascus site.

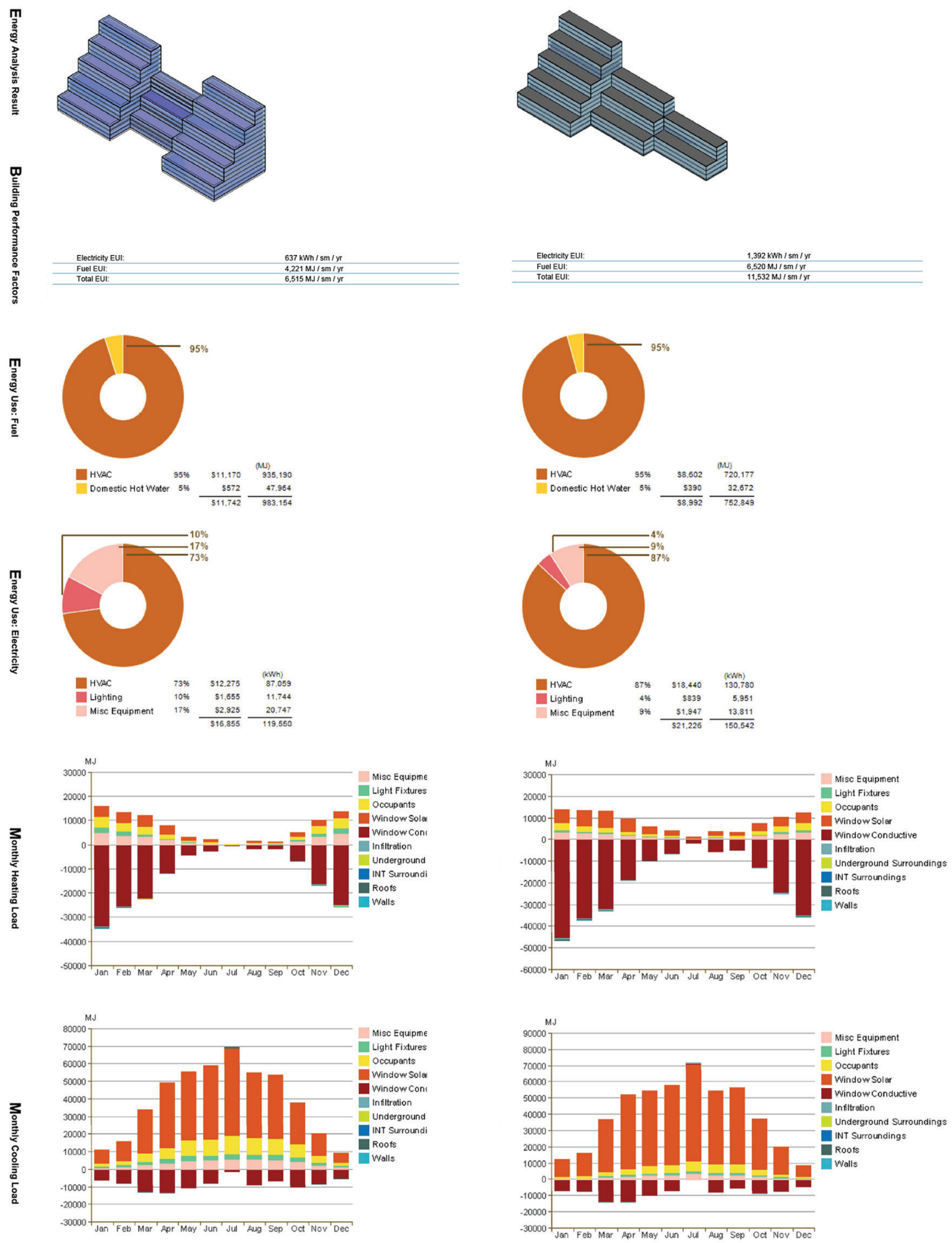


Graphs 41: EUI output for the selected configuration in Damscus site. The EUI is lower due to the use of natural ventilation .

11.3 COMPARISON

The graphs from results and compare in green-building studio explain the EUI numbers and what are the major influence. For example in Amsterdam detailed figures the LED light has higher value in 2B. Also window ''skin'' has higher leakage in model 2B than 4B as shown in the monthly heating load. The heating loads below the zero are the energy being lost, so more heat needs to

4B Amsterdam 2B



be added to compensate this loss. For the cooling chart 33-J, the value below the zero represents the same for energy loss because of cooling. However, above the null value refer to the extra heat should be removed to compensate the energy demand for maintaining the internal temperature set inside Which is 31 Celsius for the unoccupied area and 24 Celsius for Production level. From the simulations, the graphs show that the cooling energy is very high in both locations. This cause by the solar heat gained through the facade. This might be influenced by the high transmittance value set to the glass to match ETFE

The Heating and Cooling system

Heating in Dutch greenhouses is based on hot water filled heating pipes. The main heating circuit Typically pipe-rail system consists of steel pipes. The system in the BIM model is based on similar system using coal/boiler **[De Zwart, Righini,2018].**

For the natural ventilation the models has shown significant drop in EUI by using natural

Fig 43-J:Energy simulation for the lowest EUI options 4B-E0 and the highest 2B. Source **[De Zwart, Righini,2018]**

ventilation. Fig **00** shows the common and standard ventilation to remove excessive heat in Dutch greenhouses use natural ventilation by opening vents at one or two sides of the Greenhouse. The ventilation surface is about 10% of the covering surface. **[De Zwart, Righini,2018]**

On the other hand, there are more efficient systems such as PTAC (package terminal air conditioning) that attached to the skin face the elaboration on Amsterdam context shown in Fig-44 . And more renewable using ATES (Aquifer Thermal Energy Storage) benefit from energy storage in the underground depending on geological, hydro-geological and other site conditions **[Andersson, 2007].**

VISUALIZATION

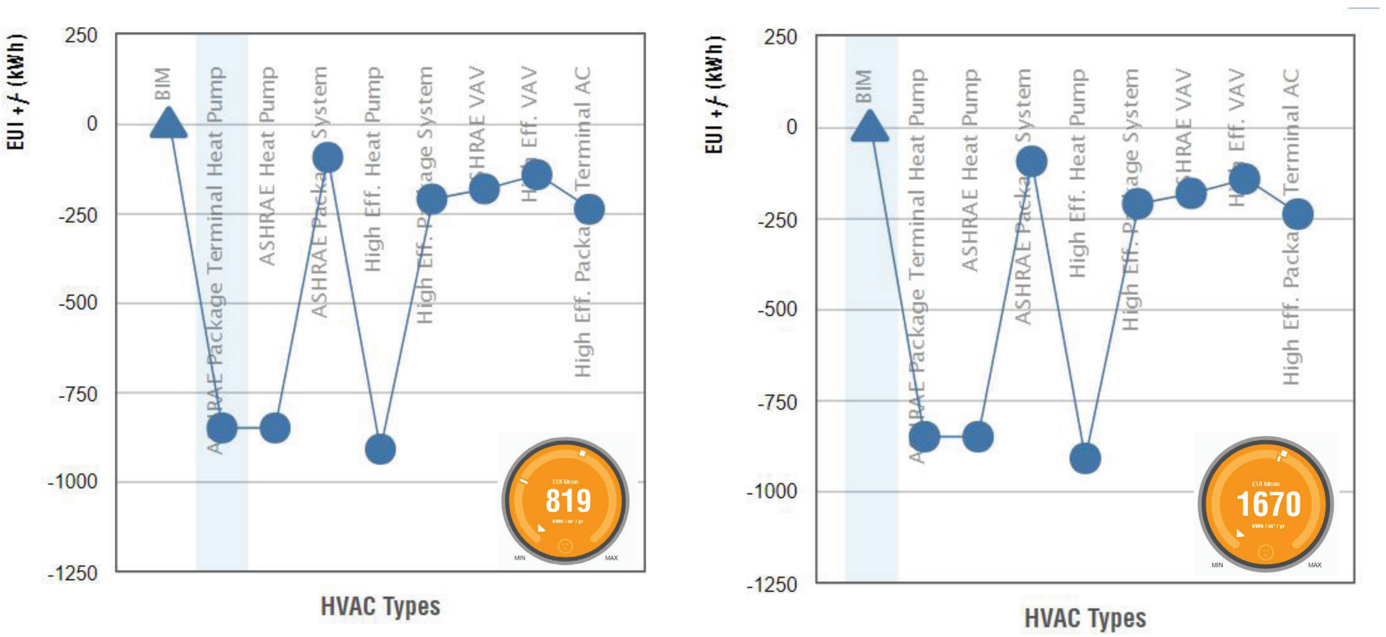


Fig 43-J:optmization of PTHP or PTAC and compare EUI with air tight Plant factory "BIM" Triangle symbol.

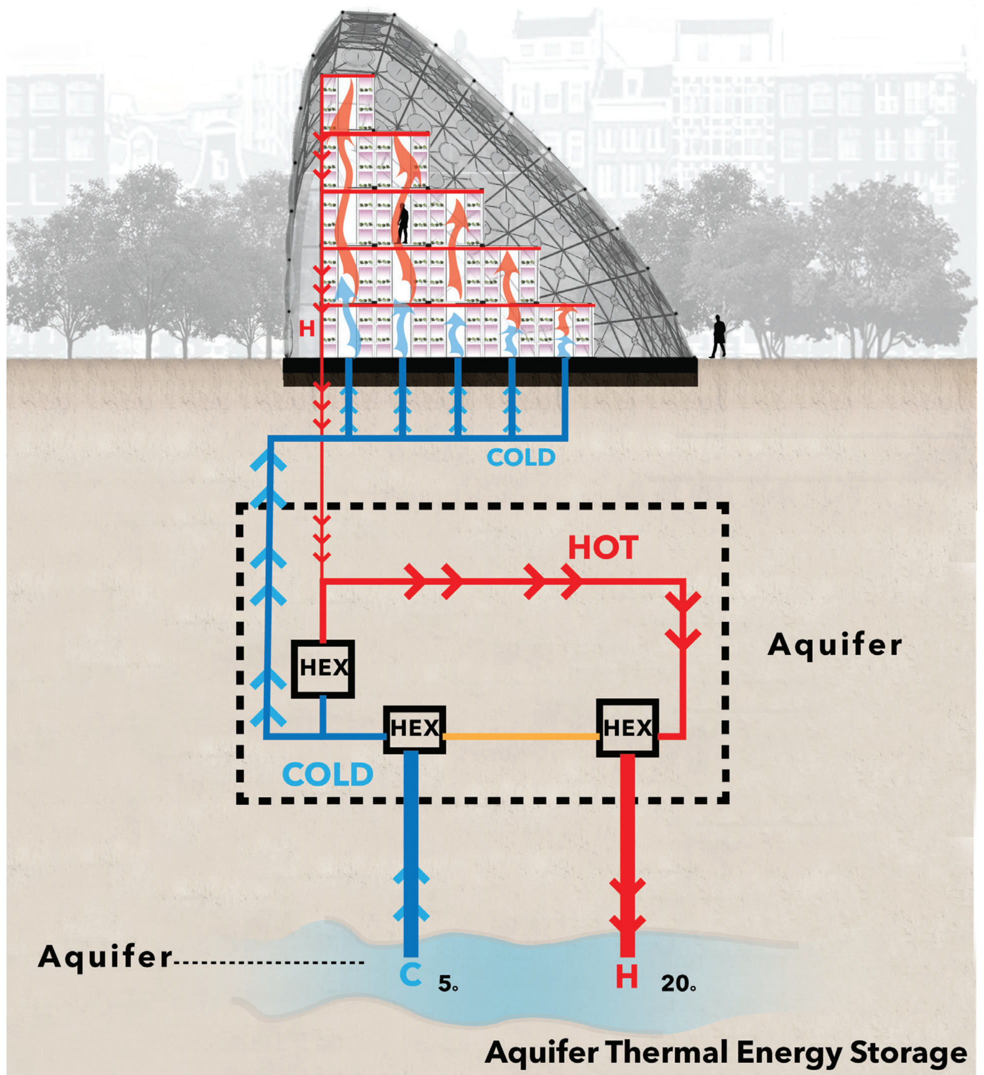
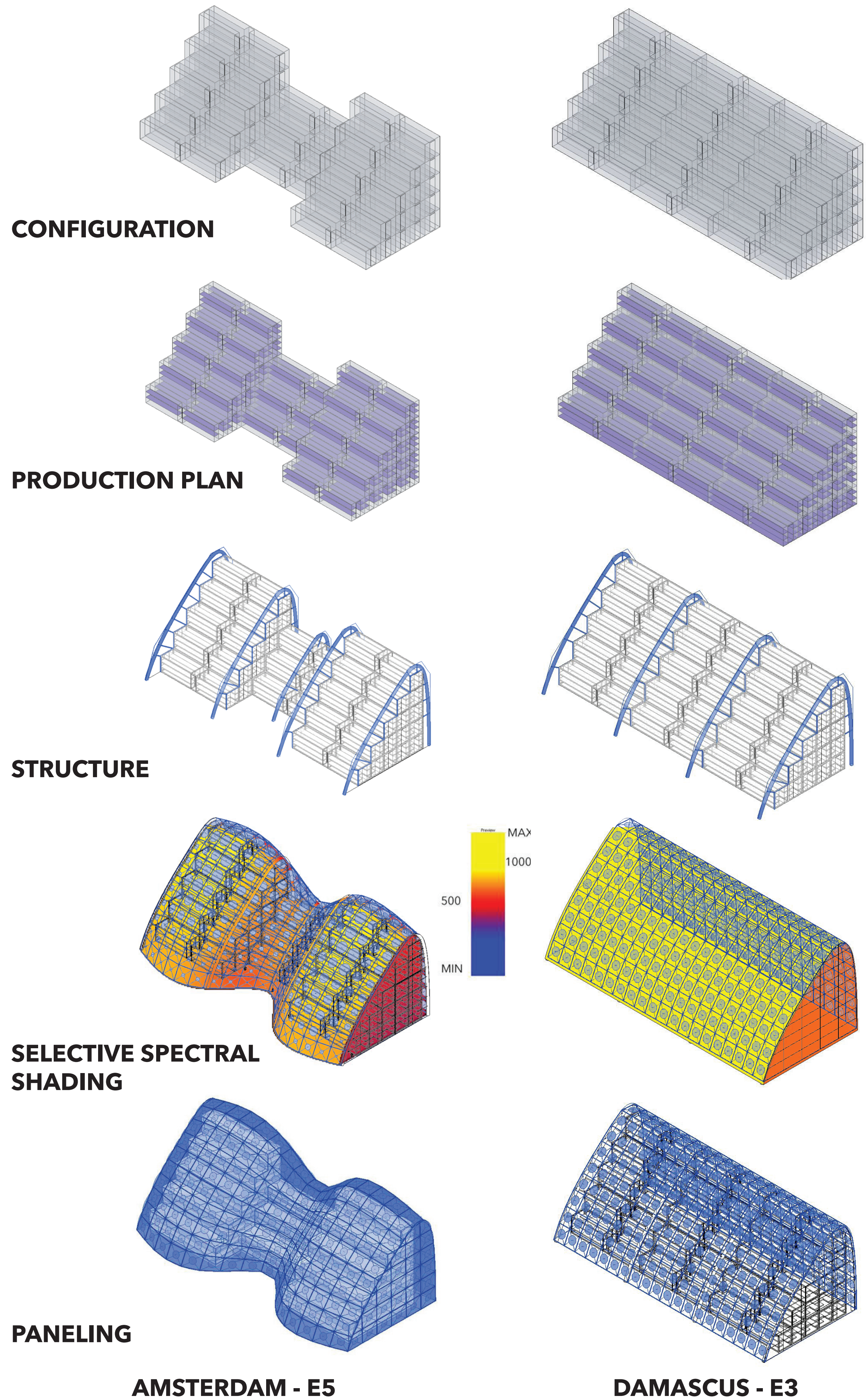
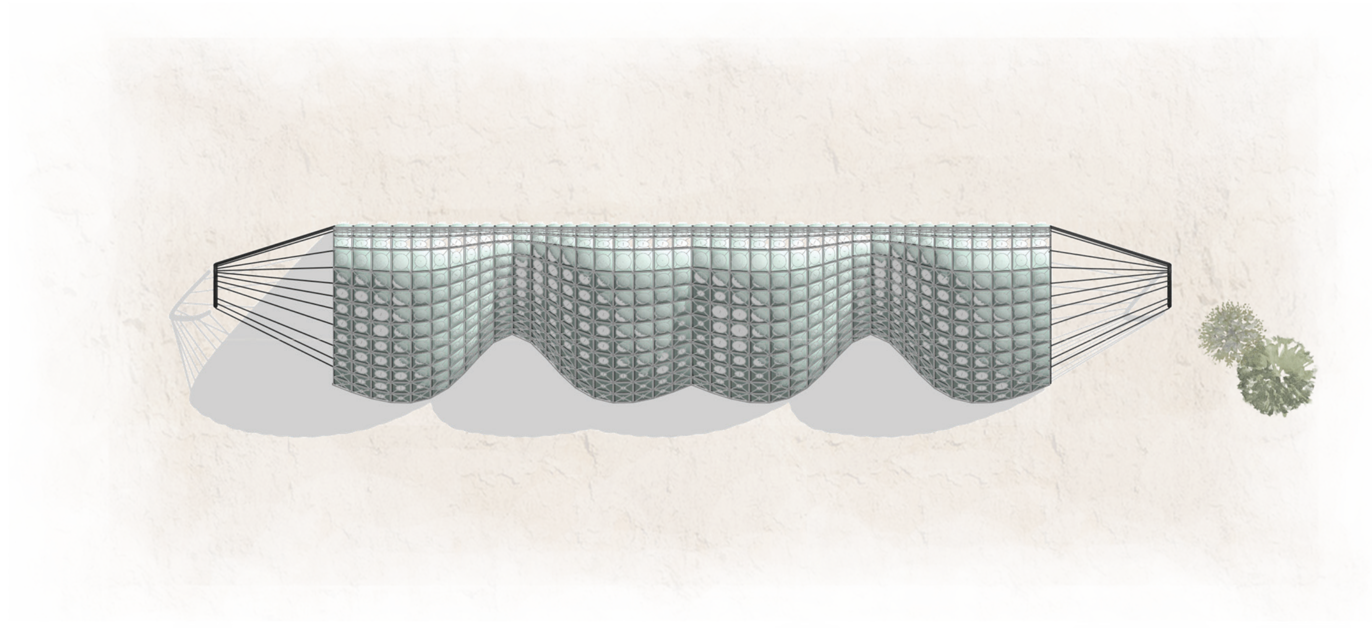
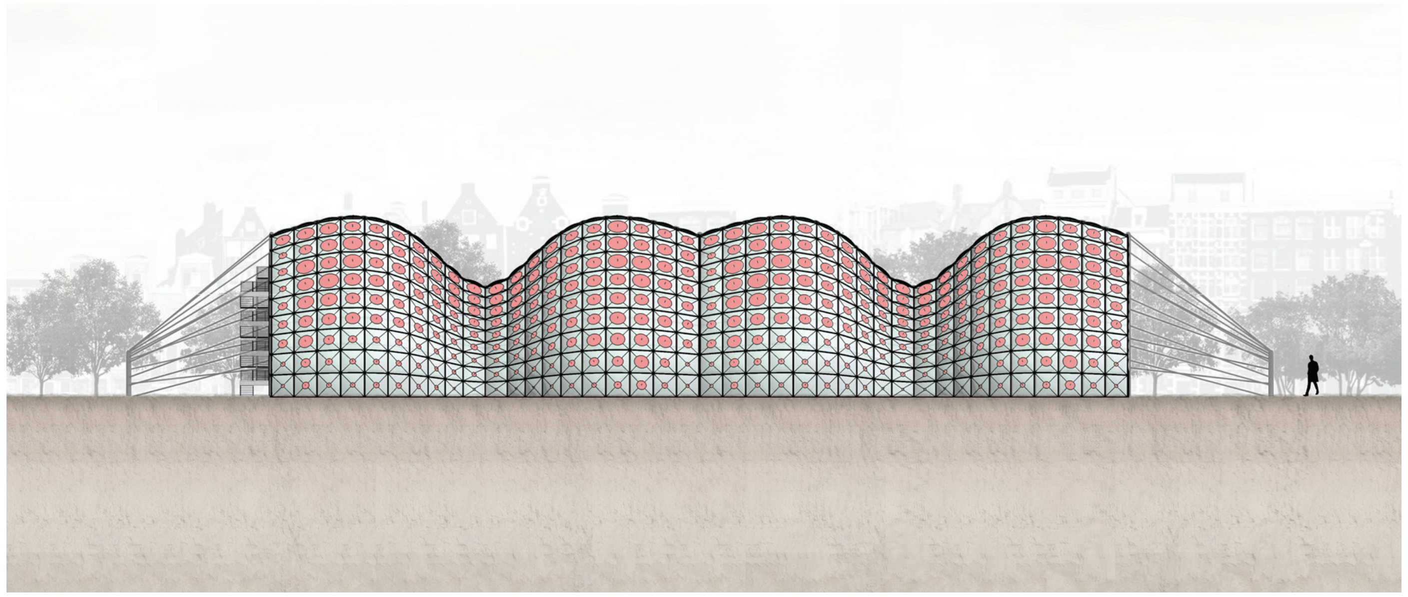


Fig J-5: E5 option in Amsterdam location showing ATES in winter, concept drawing: Prof Andy van den Dobbelsteen Graph by the author

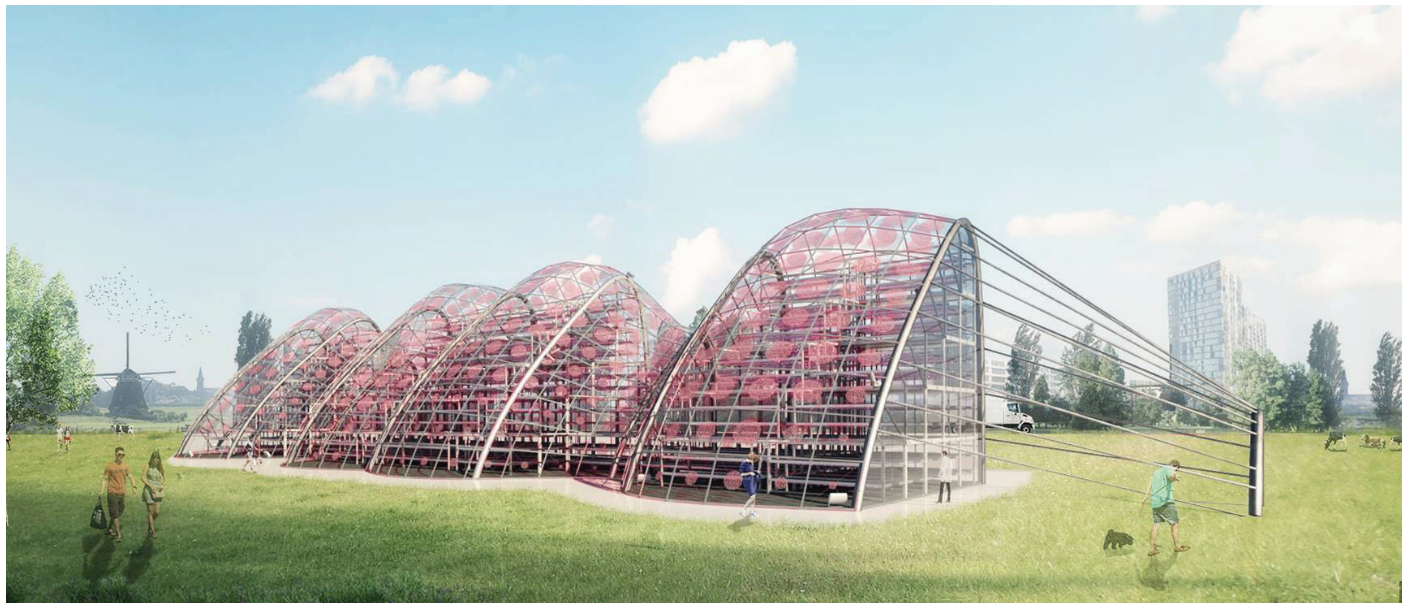


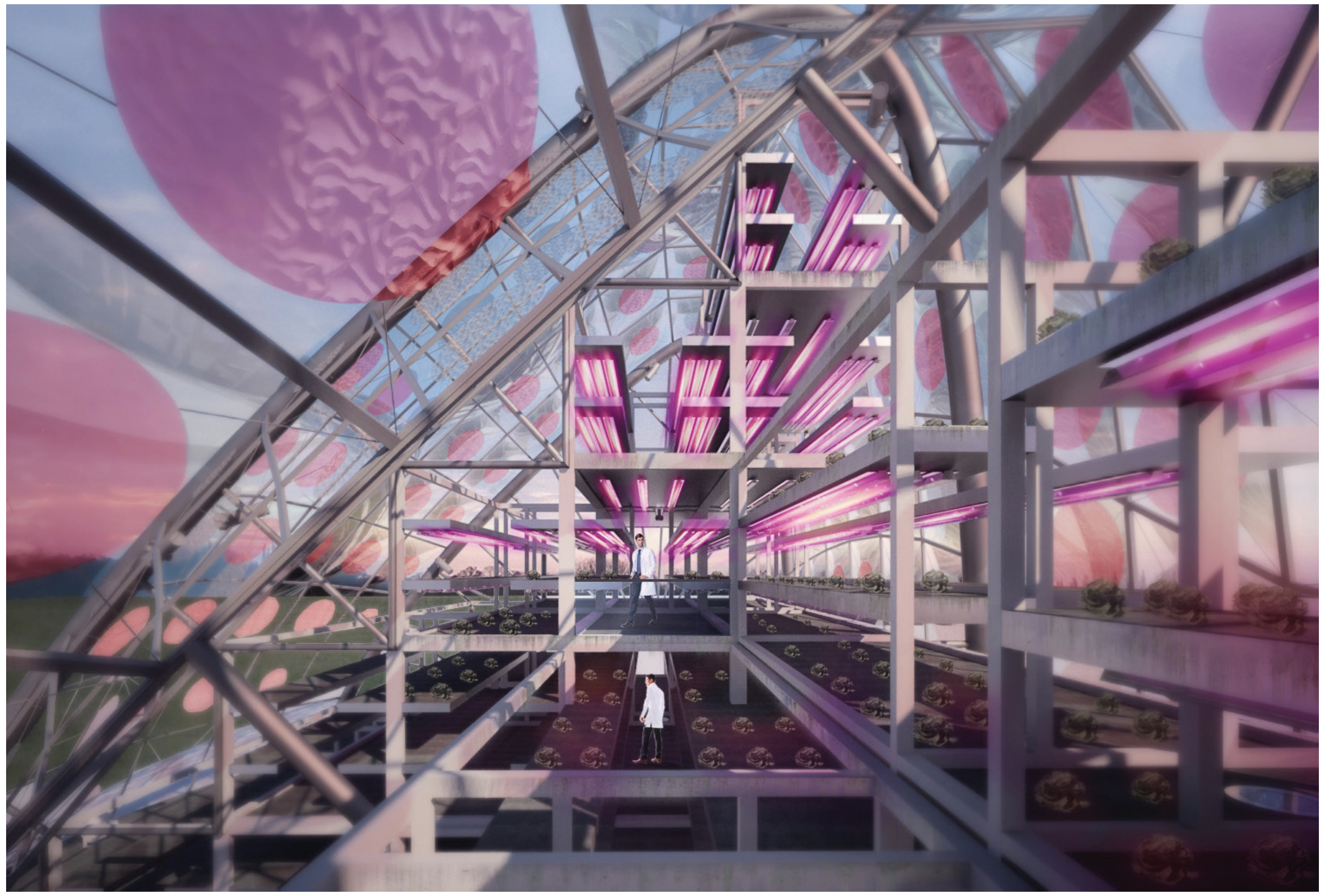
AMSTERDAM HYBRID PLANT FACTORY - SITE PLAN/ ELEVATION



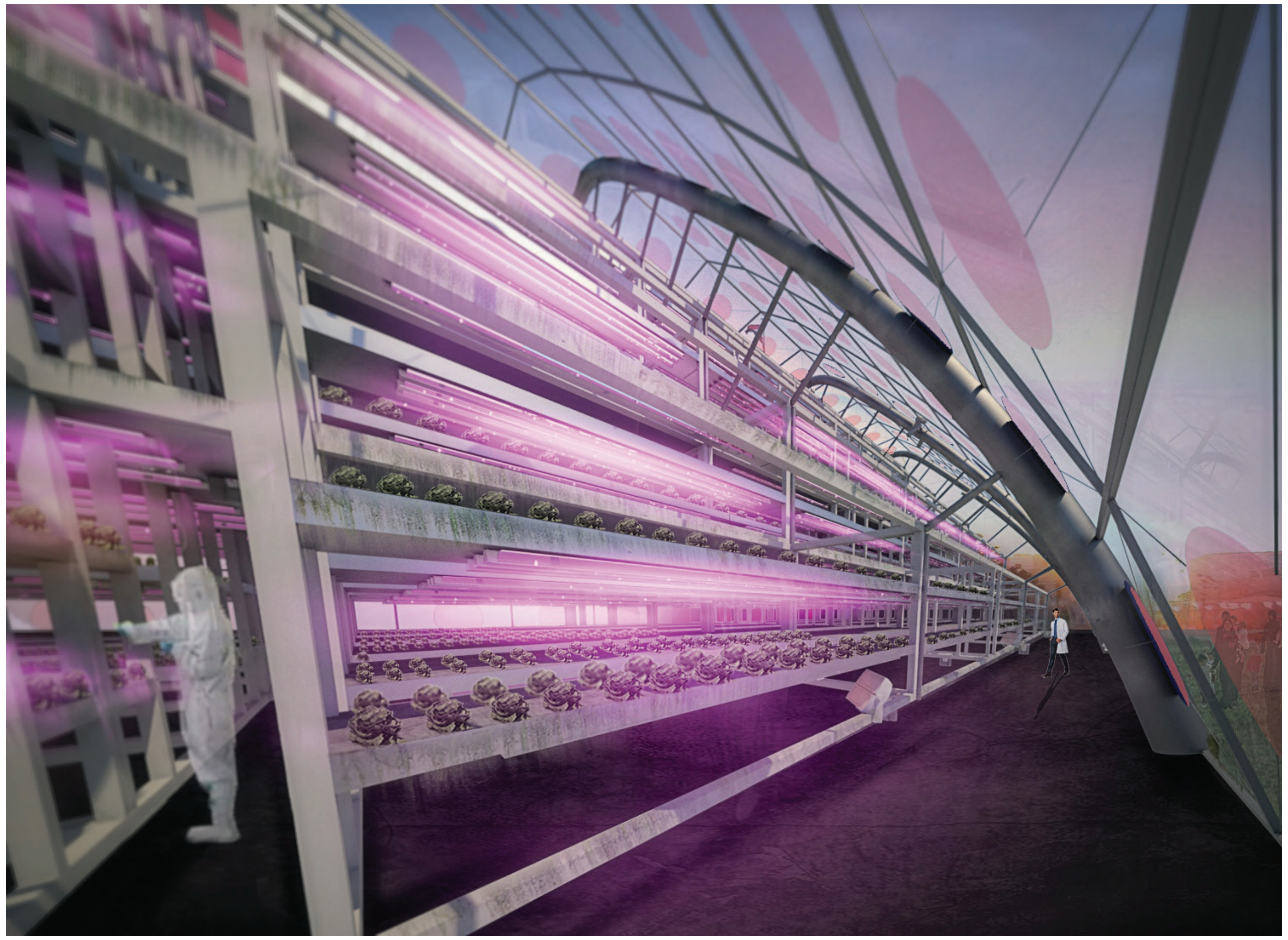


AMSTERDAM HYBRID PLANT FACTORY - 3D





DAMASCUS HYBRID PLANT FACTORY - 3D



LIMITATION

The study is providing design strategies through literature part and validate these information through proposed design. However, in some parts of literature, there were limitation in time for for laboratory tests such as the material spectral properties and Bioilumencse light intensity.

For the computational phase. The software packages implemented in the study are in development when the study made and still has lack of clear impact on some parameters change. Although the analysis performed several times to ensure accuracy the building dimension still has some limitation such as the analysis of curved surfaces and small building dimensions. Besides the limitation in modifying some parameters like negative values for latent and sensible heating or cooling.

Final points to be mentioned about the Lighting Analysis for Revit (LAR) which includes visible components of solar radiation, direct, diffuse, and reflected indexes and therefore spectral information about building exterior and interior surfaces are taken into account. Nonetheless, the ETFE Spectral properties cannot be adjusted, and only some parameters changed to match the case as U-value, G value, reflectivity and light transmittance. The selection based on a simplified model but the comparison still needs more accuracy to get a precise insight into differences between PFAL and greenhouse by performing detailed optimisation covering all possible climate and skin scenario.

CONCLUSION

The literature study provide valuable information about the light in details . understanding the light and the previous discussed parameters such as temperature and CO2 level can change the way standard greenhouses designed the phrase "every light percentages transmittance through the facade is increasing the growth" would not be applicable any more. The temperature stability level, spectral properties and its distribution on the cultivated area are critical factors for designing plant factory. These strategies are crucial and provide a good starting point for the designers.

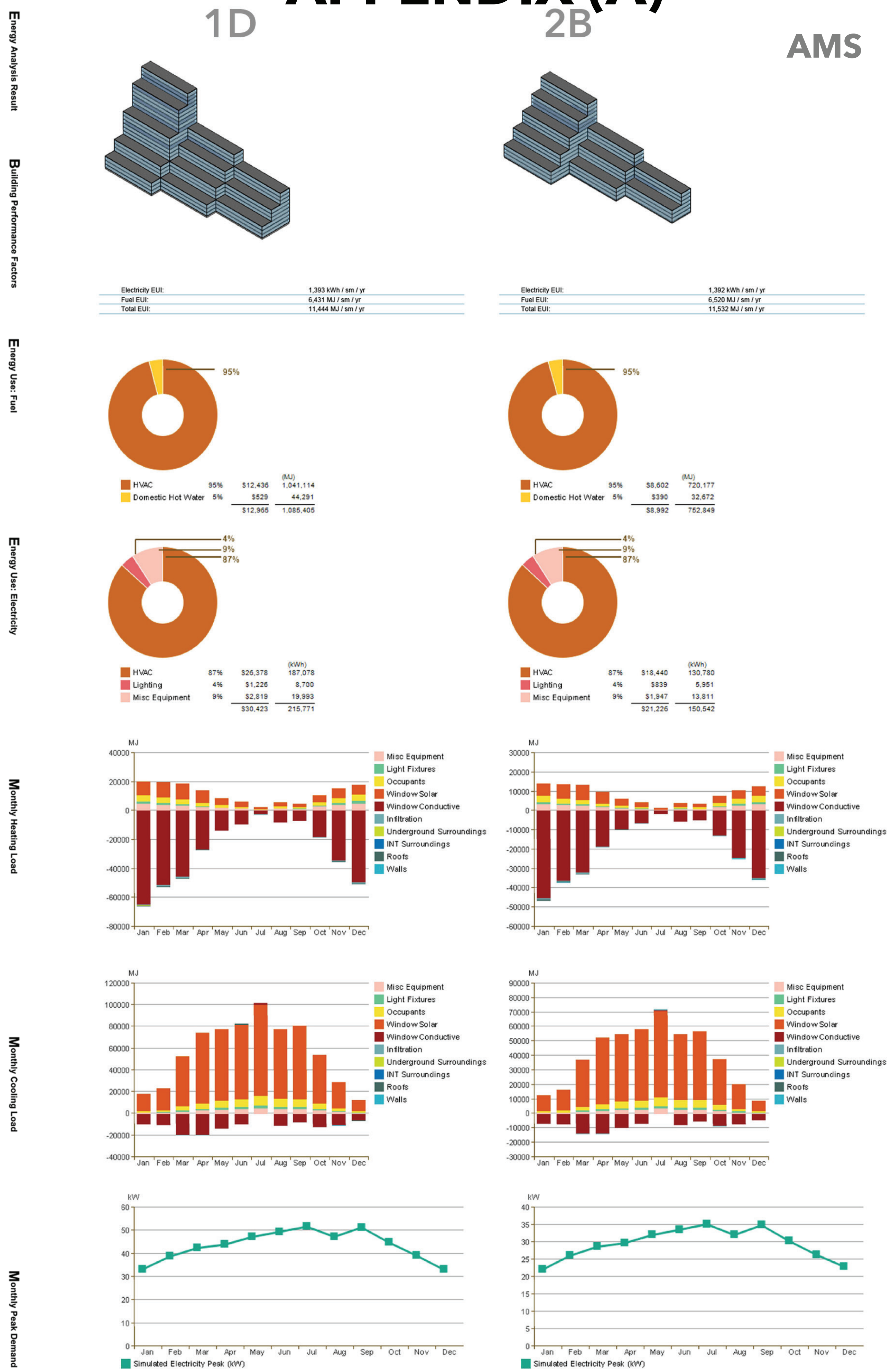
A successful design for a Plant factory with a hybrid lighting system required specific requirements of production technique, internal climate control and energy efficiency design. The desgin has an envelope can compete with greenhouse and PFAL to provide lower EUI and better light and temperature condition. The climatology of location has an impact on the selection criteria of production type and skin. Where the design strategies, light and temperature study is applicable for all contexts. The analysis explains the process through developing a design example and creating a base guide for helping designers in the early design phase. The final figures of energy load show potential of combining both natural and artificial light. This evaluation through computational workflow has simplified the selection process and decision making for better optimal light and temperature level.

The envelope is the most active part of the design proposal. The mobility required adaptive skin that function in different climatic conditions and achieve a balance between best energy performance and production capacity. The adaptive envelopes help achieve the

best light and internal temperature This can be seen in the energy output that has limited variation in diverse locations. A hybrid facility can offer lower EUI than PFAL and greenhouse (based on design). The

Biomimetic inspired a new approach to enhance the light management in the skin. The selective spectral "shading" materials alongside haze effect. These proposed strategies are executed to answer the main questions that the paper proposes to discuss and solve.

APPENDIX (A)

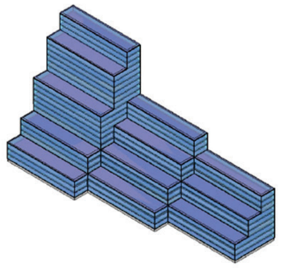


AMS

Energy Analysis Result

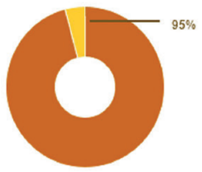
2D

Building Performance Factors



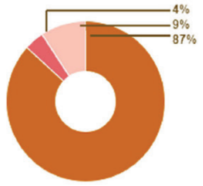
Electricity EUI:	1,393 kWh / sm / yr
Fuel EUI:	6,431 MJ / sm / yr
Total EUI:	11,444 MJ / sm / yr

Energy Use: Fuel



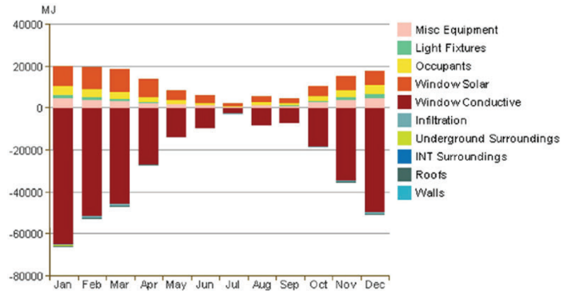
			(MJ)
HVAC	95%	$12,436	1,041,114
Domestic Hot Water	5%	$529	44,291
		$12,965	1,085,405

Energy Use: Electricity

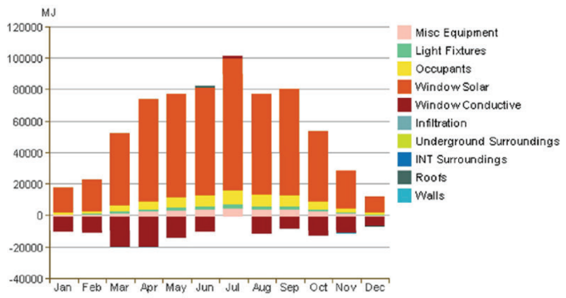


			(kWh)
HVAC	87%	$26,378	187,078
Lighting	4%	$1,226	8,700
Misc Equipment	9%	$2,819	19,993
		$30,423	215,771

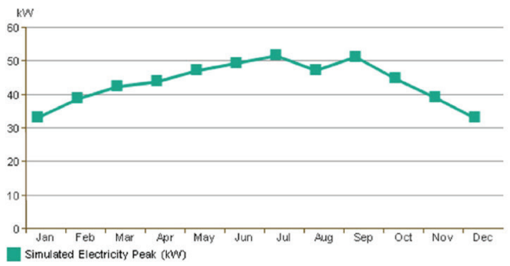
Monthly Heating Load



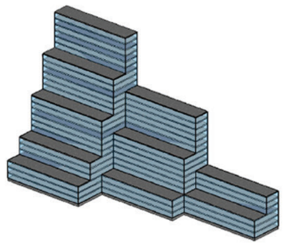
Monthly Cooling Load



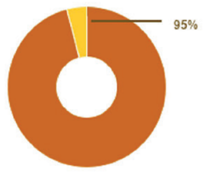
Monthly Peak Demand



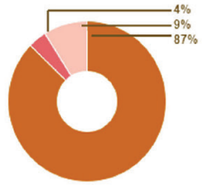
3D



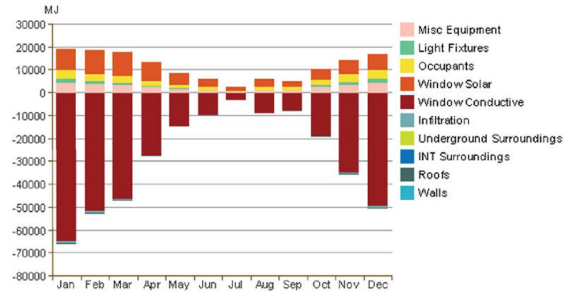
Electricity EUI:	1,488 kWh / sm / yr
Fuel EUI:	6,735 MJ / sm / yr
Total EUI:	12,090 MJ / sm / yr

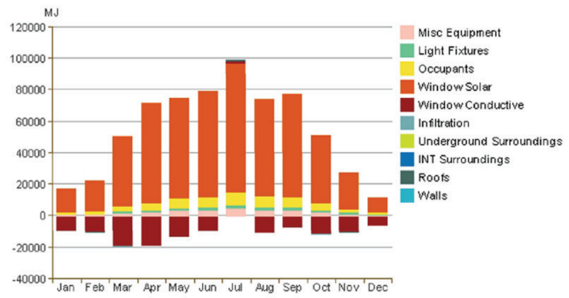


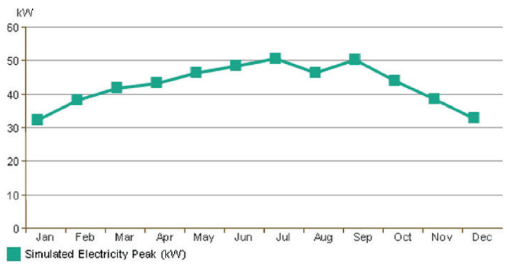
			(MJ)
HVAC	95%	$11,853	992,356
Domestic Hot Water	5%	$500	41,934
		$12,353	1,034,290



			(kWh)
HVAC	87%	$25,731	182,490
Lighting	4%	$1,116	7,915
Misc Equipment	9%	$2,641	18,736
		$29,488	209,141







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