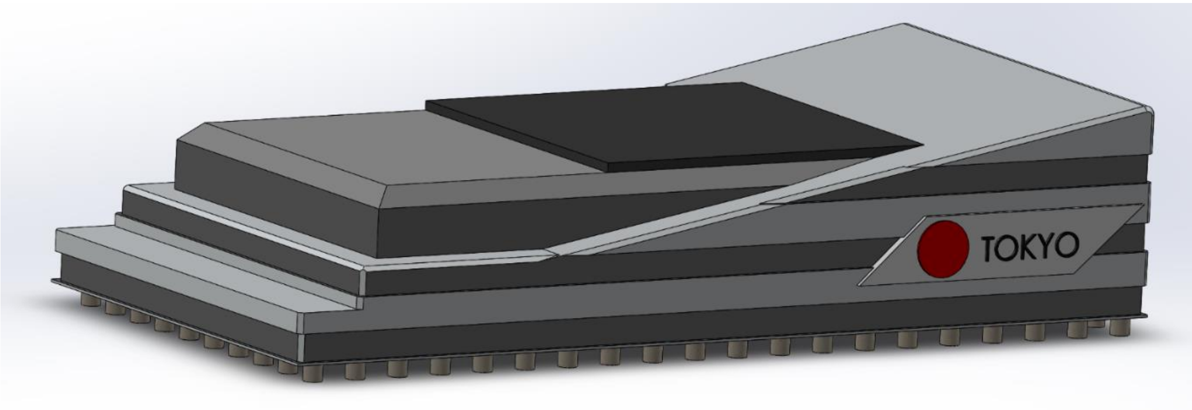
School of Engineering
Integrated Design Project 2 Concept Design 2019/20
Group: 1

ゼロハンガー

(translation- zero hunger)



13/12/2019

Authors

Sam Cook 1884198

Anas Najeeb 1924281

Emma Howard 1896525

Jonathan Sill 1895031

Lucy Grimes 1903437

Rongsen Wang 2092201

Word count:21018

STATEMENT OF CONTRIBUTION

Name	Student ID	Contribution in their own words	Contribution level agreed with group with respect to the group average. (high/normal/low/none)
Sam Cook	1884198	As group co-ordinator I often assigned different work/tasks to individuals within the group, taking a leadership role. I was also responsible for the farming section of the project and the design work that goes with it. On top of this I had input into the floorplans and aeroponic bed CAD renderings for the final design. Finally, I formatted most of the final document ready for submission.	high
Anas Najeeb	1924281	I was responsible for lighting in the project. I made sure that I have produced my best quality work through thorough research, hard work and by communicating with my group mates. I have also actively taken part in the exercises given by the module leader.	normal
Emma Howard	1896525	I was in charge of energy systems. I communicated with all other systems, especially lighting and water- as decisions had to be made regarding sourcing and distributing energy. I did individual research to get a wide knowledge of energy flows in farming. I actively took part in individual research to ensure I have a wide knowledge evolving around energy flows In farming systems. I also contributed to lab sheets each week and made sure that I completed work assigned to me on time and of a good quality	normal
Jonathan Sill	1895031	I worked on structure, involving concept designs and CAD and also incorporating other sections. Also wrote up research journals and completed multiple design tasks. Responsible for CAD and some document formatting.	high
Lucy Grimes	1903437	Responsible for Environmental and operation control section. Also contributed to research by reporting on journals affecting our project. Completed TRIZ table and LCA. Also contributed to the weekly labs. I also heavily contributed to the script, PowerPoint and recording of the video.	normal
Rongsen Wang	2092201	I’m responsible for water. I arranged the transportation and discharge of indoor water expressed by CAD and optimized the whole system to reduce the waste. During the session, I do some reading and exercises to help task completed and try my best to my work as assignment split.	normal

EXECUTIVE SUMMARY (VIDEO)

Structure:

The initial designs aimed to be functional and aesthetically pleasing, whilst maintaining the cultural essence of Tokyo. The final design was made in Solidworks.

Each material was chosen to be as sustainable as possible, with all the metals being widely recycled and corrosion resistant. The roofing material is galvanised steel, cladding of the building is aluminium – it is ideal for the outdoors and can withstand extreme weather. The main infrastructure is structural lightweight concrete. This can be reinforced with steel bars and made very strong.

The building will be on top of an existing university complex. This is to save space in an already crowded urban environment.

Many external features are included to withstand extreme weather and the earthquake-prone environment.

Farming:

There will be no livestock due to the practicalities of farming and moving towards a more sustainable way of life – with less meat consumption. The crops chosen are radish, cabbage, and broccoli. These are amongst the top consumed foods in our target demographic.

Each crop has specific requirements in terms of pH, lighting, water and more. This can be accommodated for through our systems.

Using aeroponics is the preferred system out of all the hydroponic options.

Energy:

The main energy use will be for lighting, HVAC, aeroponic systems and to pump water.

The energy sources will all be renewable and will consist of solar, tidal and hydroelectric systems.

Water:

As mentioned, aeroponics will be used. Water loss can be reduced by dehumidifying the air. Water use efficiency increases with leaf area index and number of air exchanges.

Lighting:

LED lighting which is more efficient and has a longer life span will be used. Specifically, the Philips' Green Power LED top lighting.

Hours of daylight can be tailored for the requirements of each crop.

The Philips' Grow Wise control system allows farmers to form custom wavelength LED recipes for crops to provide the exact lighting requirements based on plant characteristics, compactness and branch development. This means that unnecessary wavelengths are not used and energy can be saved.

Environmental and Operational Control:

There are 4 main areas to the HVAC subsystem which are essentially handling the incoming, circulating and outgoing air. These provide for the plants in terms of humidity, temperature, and air flow.

Waste is a circular system where it is either reused or recycled – none goes to landfill. Plant-based waste can be traded to make other products.

For labour, 1 person will work on a floor, apart from at harvest when there will be 5. There will also be 2 cleaning and 2 maintenance staff.

Automation will be used for the nutrient delivery system, temperature and HVAC and the automated moveable roof.

TEAM PROFILE

Results of the Belbin personality profile test

Sam Cook	Emma Howard	Lucy Grimes	Anas Najeeb	Rongsen Wang	Jonathan Sill
Implementer (13) Co-ordinator (12) Team Worker (12)	Implementer (12) Team Worker (12)	Implementer (16) Shaper (12)	Implementer (12) Specialist (11)	Implementer (23) Resource Investigator (14)	Implementer (10) Co-ordinator (10) Specialist (10)

Impact of the profiling on your group work.

Above is a table showing the main results from the team Belbin tests (full results for each individual can be found in the appendices.) One key notice from this is that everybody in the team is an implementer, which means that we should be good at finding a practical solution based on our ideas. As Sam had a high score for co-ordinator, we chose him to be the group co-ordinator, this should mean the group is organised and stays on task. Another note is that Rongsen had a high score for resource investigation, so we shall use his club journal reports as examples.

An example of social intelligence used

On the whole our group seemed to work very well together. The only slight issues encountered were punctuality related. When group members were occasionally late for meetings, rather than lead to an argument we adopted the principles of Albrecht and Goleman. As our group were able to read the situation, and as we had built a general rapport, rather than leading to an argument we had a clear and professional discussion about punctuality. Group members were able to explain their reasoning for lateness, and we clearly communicated rules to be followed regarding punctuality (for instance informing the group if you knew you would be late.)

An example of Enterprise Design Thinking used

Feedback Grid

Things that worked	Things to change
• The objective tree is now the correct layout • The requirements table seems in detail and on focus • The beginning our design brainstorms are appropriate • Worked well to schedule, we are not struggling to catch up on anything major • We are working well as a group, there are no arguments occurring and people are completing work assigned to them. • We have worked well from previous feedback (i.e. the changing of the objective tree.)	• Need to find some sort of way to identify traceability from the objective tree and functional analysis to the requirements table. • Some of the designs are too vague and need refining • Need to develop an overall concept design for the farm • Specifically need to finish some design activities (i.e. LCA and causal diagram)
Questions we still have	**New ideas to try**
• Are our design sheets in the correct format? • We are still slightly confused over the final format of design submissions • The template tells us to summarise the design rationale in just 100 words but this seems far too short • Are our designs too complex or in not enough detail? We are currently unsure.	• Use a colour coding system to demonstrate the traceability between objective tree to the requirements table • Use Solidworks to develop an overall 3-D model with general dimensions of the farm • Try block diagrams and schematics to convey ideas regarding each section (i.e. lighting etc) • Keep hand sketches to a minimum unless they are depicting concepts • Need to try and combine all design ideas/sheets into the main document

The figure above is evidence of use of another IBM Enterprise Design Thinking Activity. We decided the most appropriate activity to complete would be the feedback grid, as we can use it after meetings with our academic mentor. This is the feedback grid from our third meeting with our mentor, and we created it to focus on what had gone well so far, but also more importantly to focus on what we needed to do to complete our designs. This meant that we were organised and that everyone in the team knew what needed to be done to achieve our goals.

PROJECT PLAN

Gantt Chart

Stage	Start	End
PLANNING		
Project Plan/Role Assignment	1	2
Belbin & Personality Profiles	2	2
Gantt Chart	3	3
RESEARCH		
General Research Reading	2	3
Area Specific Research Readi	3	4
Journal Report Meeting	4	4
Objective Tree	4	5
Functional Analysis	5	5
Requirements Specification	5	6
SUSTAINABILITY		
Progression of the UN SDG	4	5
Life Cycle Analysis	5	5
DESIGN		
Brainstorming/Initial Concepts	6	7
Morphological Chart	7	8
TRIZ Contradiction Matrix	8	8
H.A.Z.O.P	8	8
BUSINESS CASE		
Calculate costs	8	9
Budget plan	9	10
Final design	10	11
DEPLOYMENT		
Hire Architects	8	9
Hire contractors/workers	9	11
Procure energy and water sup	10	11
Contact material suppliers	10	12
Build structure	13	60
Build rooms and inner structu	50	64
Hire staff	64	64
Train staff	64	69
Run the farm	69	End

Due to the fact that our Gantt chart spans a 70-week period- from the first week of IDP to the running of the farm) it cannot be fit onto one page. This is the first page with all IDP activities up to building the farm. The next part of the Gantt chart depicts the length of time to build and begin operations of the farm. Close ups can be found in the appendices.

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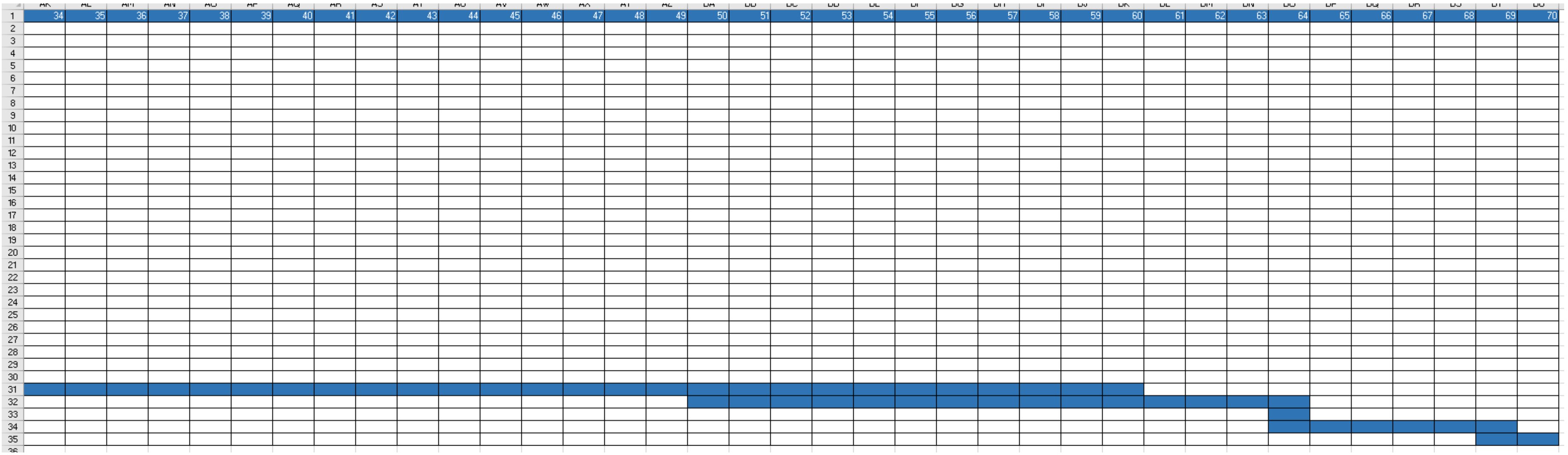

34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70

RESEARCH

Structure

By reading into the structure of already implemented forms of future farming, as well as the theoretical understanding of the urban topology and the garden city, it helped to develop my concept for the structure, as well as how to implement key parts. Furthermore, it also gave me a fundamental insight into features and ideas that I hadn't even considered, which greatly improved the safety, aesthetics and functionality of the structure - as well as helping to inform the other sections of the project.

1. Beacham, A., Vickers, L. and Monaghan, J. (2019). Vertical farming: a summary of approaches to growing skywards. *The Journal of Horticultural Science and Biotechnology*, 94(3), pp.277-283.
2. Abel, C. (2010). The Vertical Garden City: Towards a New Urban Topology. *CTBUH Journal, 2010 Issue II*, [online] (II). Available at: https://global.ctbuh.org/resources/papers/download/390-the-vertical-garden-city-towards-a-new-urban-topology.pdf.
3. Kozai, T., Niu, G. and Takagaki, M. (2016). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*. 1st ed. Amsterdam: Elsevier, pp.Chapters 13-15.
4. Brassley, P. and Soffe, R. (2016). *Agriculture*. 1st ed. Oxford University Press.

Energy

After reading the plant factory report, it gave me ideas that I should consider to make a vertical farm feasible. We have decided to use small dense plants (under 30cm), we have incorporated the use of dehumidifiers to maintain a stable environment with a condenser to recycle water. We will use fans to provide forced convection at a rate of 0.01-0.02 m/s to promote air exchanges. From the skyscraper sustainability report I have now researched the solar radiation in Tokyo as we have decided to place solar panels along the side of the building which was proposed as a result of reading this report.

Kozai, T., Niu, G. and Takagaki, M. (2016). *Plant factory*.
Al-Chalabi, M. (2015). *Vertical farming*.

Lighting

After reading LEDs for photons, physiology and food, it gave me the idea to choose LEDs over other lights such as HPS and showed how plants interacted with different settings of LEDs as LEDs are completely flexible in terms of light intensity, colour, wavelengths and light distribution providing me with the idea to use a control system. Reading plant factory gave me an insight into how control-systems and sensors work and how the played a vital role in enhancing the growth of plants in a Vertical Farm.

1. Kozai, T., Niu, G. & Takagaki, M., 2016. Plant factory: an indoor vertical farming system for efficient quality food production. Amsterdam: Academic Press is an imprint of Elsevie.
2. Pattison, P. M., Tsao, J. Y., Brainard, G. C. & Bugbee, B., 2018. LEDs for photons, physiology and food in Nature. 563(7732), pp. 493-500.
3. Song, X. P., Tan, H. T. & Tan, P. Y., 2018. Assessment of light adequacy for vertical farming in a tropical city in Urban Forestry & Urban Greening. Volume 29, pp. 49-57.

Water

After reading some references, we decided to use hydroponic system with nutrient film technique, which is practical for nurturing plants especially in plant factories with artificial lighting commercially and widely. Besides, according to the experimental results of water use efficiency, closed plant production system instead of the greenhouse, increasing leaf area index and a high level of airtightness are some efficient ways to reduce the loss of water in systems.

1.Kozai, T., Niu, G. and Takagaki, M. (2016). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*. 1st ed. Amsterdam: Elsevier, pp.Chapters 19-21.

2.A. Chaudhry and V. Mishra (2017).“A Comparative Analysis of Vertical Agriculture Systems in Residential Apartments”, Amity University Dubai

3.Kheir Al-Kodmany (2018), “The Vertical Farm: A Review of Developments and Implications for the Vertical City”, University of Illinois at Chicago, Chicago, IL 60607, USA

Environmental and Operational Control

After reading the articles, decisions were made for the Environmental and Operational Control section of the work – from broad, key points to specific details. For instance, an HVAC and other subsystems room were deemed appropriate for the job in hand which controls CO 2 concentration, temperature, airflow speed, humidity, light and more. This is to be at least semi-autonomous for simplicity in operation. There was considerable information on waste recycling and reuse. The project should not have any waste go to landfill but will instead use the suggested sustainable methods. Finally, the workforce size was established to fit the conditions and location of our farm.

40_principles_of_TRIZ_method_960dpi.jpg, 2019, Canvas, University of Birmingham

TRIZ 40 Design Principles, 2019, adapted from slides by Darryl Mann, Canvas, University of Birmingham

HVAC sub-system diagram, 2019, <http://apps.who.int/medicinedocs/en/d/Js14065e/4.html>

HAVES, P., SALSBURY, T.I., and WRIGHT, J.A., 1996. Condition monitoring in HVAC subsystems using first principles models. ASHRAE Transactions, 102 (1), pp.519-527

Farming

From reading the assigned articles it was clear what the specific needs were for each plant (for instance the pH levels/nutrient levels/temperature required.) As well as this the articles have helped inform us on what farming systems are available for use (different hydroponic systems). On top of this the articles have helped inform a decision upon which crops it is that will be grown as part of the vertical farm.

Reddy, J. (2019). *Growing Hydroponic Cabbage, Planting, Care, Harvesting | Gardening Tips*. [online] Gardening Tips. Available at: https://gardeningtips.in/growing-hydroponic-cabbage-planting-care-harvesting [Accessed 14 Oct. 2019].

NoSoilSolutions. (2019). *How To Grow Hydroponic Broccoli - NoSoilSolutions*. [online] Available at: https://www.nosoilsolutions.com/how-to-grow-hydroponic-broccoli/ [Accessed 15 Oct. 2019].

Luv2garden.com. (2019). *Hydroponic Radishes - Proven Techniques to grow High Quality Radishes Quickly*. [online] Available at: https://luv2garden.com/hydroponic_radishes.html [Accessed 15 Oct. 2019].

Simply Hydroponics LLC (2019). *Simply Hydroponics – Replace bulb*. [online] Available at: https://www.simplyhydro.com/system/ [Accessed 16 Oct. 2019].

Baessler, L. (2019). *Radish Plant Fertilizer: Tips On Fertilizing Radish Plants*. [online] Gardening Know How. Available at: https://www.gardeningknowhow.com/edible/vegetables/radish/fertilizing-radish-plants.htm [Accessed 16 Oct. 2019].

1.Kozai, T., Niu, G. and Takagaki, M. (2016). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*. 1st ed. Amsterdam: Elsevier, pp.Chapters 16-18.

Brassley, P. and Soffe, R. (2016). Agriculture: A Very Short Introduction. pp.1-116.

(this is 528 words plus references)

BUSINESS CASE

PEST Analysis

Political factors:

- **Local area zoning rules,** as a result of these, the size and shape of the building and namely its cardinal dimensions will be restricted, this is in part so that it suits the theme of the modern Tokyo area, but also so that it stays within safety limits, as well as to prevent the structure from becoming an eyesore. In addition is also restricts which areas we can build our vertical farm, as we can't build in residential areas, as well as parks and landmarks etc.
- **Taxation and grants,** because the nature of our building is to be sustainable and solve food problems within the greater Tokyo area, it is possible that the project cold receive a government grant to help us achieve realisation, or even reduced taxation on the produce to help in recouping our costs quickly. This would help on the financial side of the project and allow us to use the money saved by injecting it back into the project to further increase efficiency or quality, or to reduce the initial funding needed.
- **Employment legislation,** this would cover the rights of the workers and ensure that all their interactions with the employer and facilities is professional. This is a two way street, and useful as it ensures that the workers are happy and receiving everything that they need, and will therefore be more productive. Furthermore, by showing that the company follows the employment legislation it will be easier to get workers to join and stay, which also reduces the amount of training needed for new/replacement workers – thereby cutting costs and losses of productivity/efficiency.

Economic factors:

- **Investment**, with investment from other companies with similar goals or even individuals who support what the project is hoping to achieve, the vertical farm is much more likely to succeed, not just through construction, but also the extra research and development that the money could help to secure. Furthermore, it could also help to procure higher quality materials or even technology than what was originally proposed.
- **Gross National Product (GNP),** if the project is successful it will contribute massively to Japan's GNP, particularly once the vertical farm concept has been adopted more widely, and other similar or even repeated structures start appearing across the country.
- **Energy cost,** a big factor that comes into play with the vertical farm concept – due to the sheer amount of energy required to power the hydroponics system, HVAC system, lighting, and water system – is the cost of energy. Within Japan, thanks to the large system of hydroelectric power plants across the coasts, the energy production per year

is fairly high considering the size of the country. This then means that the cost of electricity in Japan is much lower compared to other countries, and as a result is an appropriate place to have such an electricity hungry structure.

Social/cultural factors

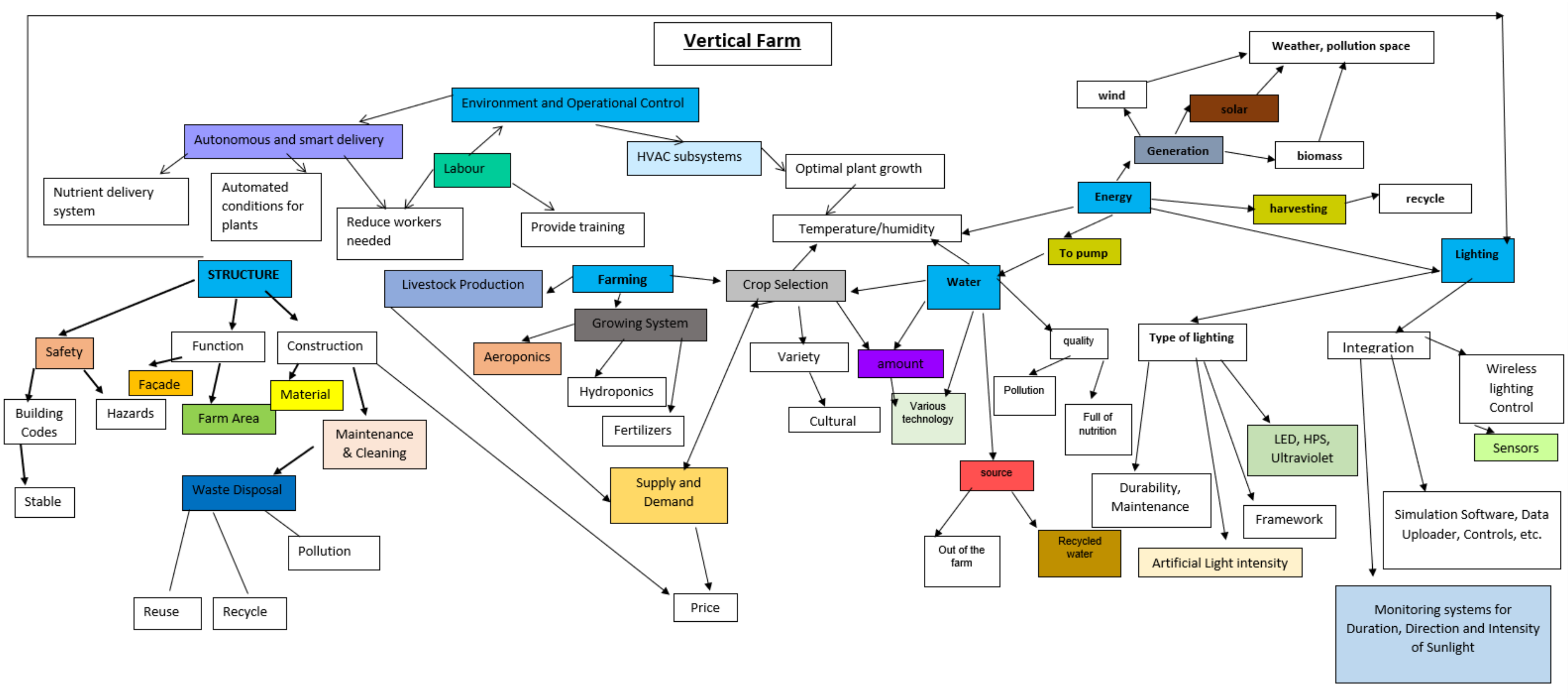
- **Lifestyle,** when coming up with a concept design it is important to keep in mind the lifestyle that the average consumer lives, and with that what sort of product they would purchase. This goes on to influence not only the type of crops that are grown within the vertical farm but also how they are grown. Furthermore, it needs to be in line with
- **Consumerism,** the consumer ultimately controls the success of the Vertical Farm project, because even if the food is grown in the farm and ready for sale, if the local market doesn't want to purchase the produce, then the farm won't be able to make any money and continue to run. As a result of this, its important that the project does whatever it can to ensure that the products are as appealing as possible to the consumers – whether it be with low prices, high nutrition, or other factors.
- **Demographics,** by studying the demographics of the local area and the customers its possible to take away an understanding of what different groups want from their diets and which of the produce is most popular to their group.

Technical factors

- **Research and development,** depending upon the research conducted by those leading the fields of hydroponics and agriculture, its possible that new inventions and discoveries could uncover even more efficient and ingenious ways to produce crops. This means that the canvas of the project is constantly changing, and so to remain productive and relevant in the face of these discoveries it is important that the vertical farm periodically upgrades its equipment and technology, and when big enough changes occur, could even lead to larger scale changes within the structure and the other sub-systems.
- **Speed of technology change,** the speed of this technological change will also affect the lifestyle of the building and its incorporated systems. This has a two-sided effect, in that it will mean that significant, or rather, over investment in one particular method or technology could prove ineffective in the future – particularly if the technology does not provide the room to improve or adapt easily, as this could result in an expensive change in technology. On the other side, if the speed of this change is very rapid, it will mean that the equipment used is constantly evolving, and therefore improving the overall function of the vertical farm.
- **Product lifecycle,** similarly to the last few points, there will also become a point in which the vertical farm is no longer able to facilitate further advances in technology and innovation without significant structural change – and thereby the products lifecycle comes into question. It goes in hand with this then that the vertical farm should be built and specialised, but should also leave room to be able to adapt to whatever the future may have – and in that sense leave a certain level of flexibility in the deliverance of all the key components required to grow the crops.

DESIGN ACTIVITIES

OBJECTIVE TREE



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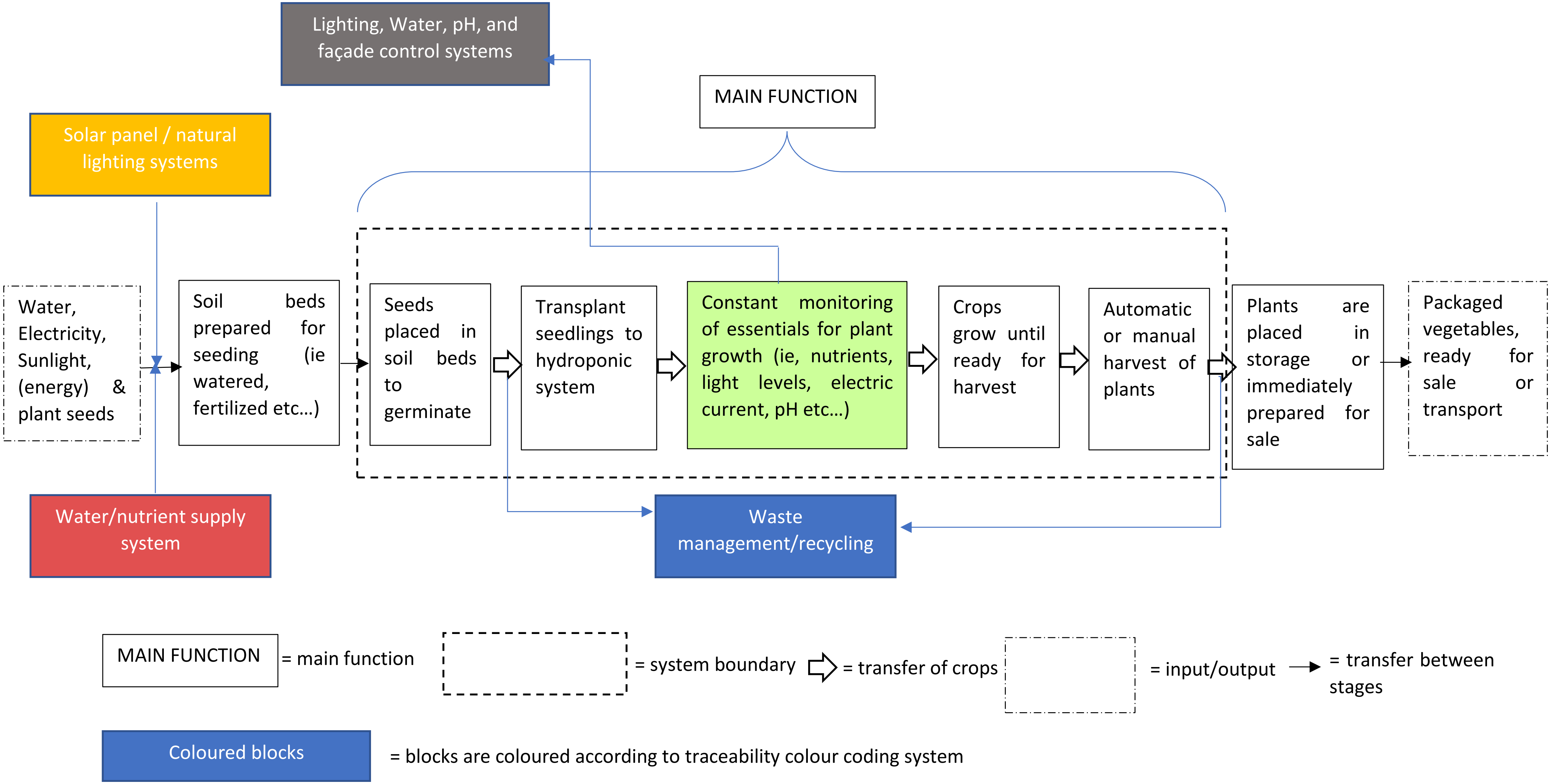
Functional Analysis



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Requirements Specification and Adequacy Assessment

System	Requirement number	Description	Requirement Type	Rationale	Traceability to objective tree/ functional analysis.
1. Structure	1.1	To supply 1500 people in the Greater Tokyo Area with supplementary food each month (enough to help meet daily calorie intake of 2000-2500)	Customer	If the VF farm can supply 2000 people with enough food for a month, it will have fulfilled its primary purpose of providing sustainable food to a local area, with reduced carbon footprint	Farm area
	1.2	Total Farm Area of 7-10 ha	Technical	This farm area will provide sufficient space to effectively cultivate the crops for volume and quality – and is a good measure of the available crop density of the facility.	Farm area
	1.3	Between 2-5 floors	Functional	Having these floors will give a clear distinction between each section and they can be given separate functions, as well as different conditions to maintain, and therefore can grow different crops, and even change the crop type, to better suit the demand within Tokyo	Farm area
	1.4	Uses aluminium, steel, concrete and wood as construction materials	Functional	These materials are most common in buildings, as they have suitable properties that make them desirable for different sections of the structure. In addition this means that they are strong and stable, and their properties and behaviour is well known, as well as being readily available in Tokyo, particularly steel.	Material

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	1.5	4 Floors of semi-traditional crop farming and 1 floor of hydroponics	Functional	This clear distinction will allow for each floor to be specialised as previously mentioned, and for the hydroponics to aid with the nutrient delivery system to fertilise the crops	Farm area
	1.6	Façade light transmission and thermal rate to be used to aid optimal conditions for the plants, but not as the sole source	Functional	As light and thermal transmission from the façade is not a particularly reliable or consistent method, it should only be used in addition to the HVAC system if at all, and should be more focused on keeping the internal conditions in - as this will increase the efficiency of the system and maintain optimal conditions for the crops to grow	Facade
	1.7	% waste energy used in construction	Technical	Whilst it is almost impossible to predict the energy used in construction, it is possible to try and minimise energy waste as much as possible throughout the construction process. As such, in order to maximise the efficiency of the process, energy waste should be kept below 60% - this is achievable through careful coordination and planning of construction actions, as well as conscious monitoring of energy by the workers and supervisors.	Waste Disposal
	1.8	Maintenance/cleaning should be done regularly and have workers dedicated to these jobs	Quality	This ensures that the vertical farm runs smoothly and has as little down time as possible – as this would affect the rate at which	Maintenance & Cleaning

				the crops grow as well as dictating their maximum density. Furthermore, this will also ensure that the working environment is pleasant and safe for the labourers – and provide specialised jobs for locals	
	1.9	Built upon an existing structure to save space within the dense urban area		Due to the extremely dense urban environment of Tokyo, building upon an existing structure is the most land efficient method of having a farm close to the centre of the greater area – as well as allowing our vertical farm to have access to the already existing infrastructure of the building, such as energy and water supply, as well as having a solid foundation	Farm area
	1.10	Building footprint with dimensions of 50x100 m		This is in keeping with the already existing structure and prevents the vertical farm from taking over the skyline and appearing out of place. Furthermore, it will also give plenty of space per floor to lay out the crops and walkways effectively without it feeling cramped or claustrophobic	Farm area
	1.11	Structure built with natural disasters in mind		In order for the building to last a long time and produce as much crops as possible, it has to be suited to the environment in Tokyo – which unfortunately is prone to natural disasters. However, by introducing systems such as shockwave	Safety

				absorbers or flood fail-safes the effects of these disasters can be mitigated or even stopped entirely. The main disasters to prepare for would be heavy rains, typhoons, and earthquakes.	
2. Farming	2.1	The type of crop grown in our farm will be cruciferous vegetables- cabbage, radish, broccoli.	Functional/ customer	These are crops that are high in demand in Japanese diets and are also healthy food options. They also grow in similar conditions making environment in the farm easier to control.	Crop Selection
	2.2	Growing conditions will need to be monitored to the specific needs of each crop. For instance, the pH ranges for the three different crops are 6.5-7,6-7 and 3.5-6.5 in the order mentioned above. (Other consideration will be E.C, temperature, daylight hours and water/nutrient supply.)	Technical/ quality	These are the conditions that lead to optimum growth for these types of vegetables.	Growing System
	2.3	There will be no livestock production as part of our farm.	Functional/customer	This is in part due to the modern advancement towards veganism. Also the farm is being built above an existing building causing a logistical issue. It would also mean the employment of battery farming which is unethical.	Livestock Production
	2.4	The farming system will be an aeroponic system.	Technical	This is one of the more advanced growing systems currently being adopted in the development of vertical farms. It is a system that will allow us to carefully monitor pH etc… It can also be scaled up to an industrial scale.	Aeroponics
	2.5	The farm will need to feed 2000 people in the local area	Customer/Functional	This is the amount of people we have been	Supply and Demand

		around the farm- for instance a large part of this will be the university population and surrounding area.		briefed to attempt to feed, and is around the maximum amount of people our one farm could cater for.	
3. Lighting	3.1	Artificial light type (LED or HPS)	Functional	Knowing the right type of light can help in enhancing the growth of crops, as well as to minimise the use of energy and to maintain the heat produced by it.	LED, HPS, Ultraviolet
	3.2	To Measure and monitor direction and concentration of Daylight and solar gain	Technical	The lights used will only be switched on when there is a lack of sunlight. Knowing the time of exposure and intensity also helps in saving energy.	Monitoring systems for Duration, Direction and Intensity of Sunlight
	3.3	Artificial Light Intensity 4000-2000 lx	Functional	Having the appropriate intensity of artificial light can increase the rate of growth of the crops.	Artificial Light intensity
	3.4	Heating of the plants will need to be monitored so that they are kept in an ideal temperature range. This being 18-21 for cabbage, 12-18 for broccoli and 10-20 for radishes (degrees celcius.)		These are the ideal temperatures to provide optimum growth for the plants. This also ensures crops grow at a consistent rate allowing a schedule for harvest.	Sensors
4. Water	4.1	The total amount of water needed for vertical farms and the nutrients they carry, i.e. the quality of the water	Statistical type	Most usual method used in vertical farming is Hydroponics in which mineral and nutrient solutions in water are used to grow plants. It depends on huge amount of water to Rear plants.	Amount
	4.2	The source of water supply and the cost of the whole water supply project	Statistical type	Japan is a coastal country, how to extract available water resources from the sea and its cost is a big problem.	Source
	4.3	How to solve the problem of water waste and reuse in the whole process	Technology type	According to statistics, water waste in agriculture is still serious every year	Recycled water

	4.4	Different crops and geographical locations need different irrigation methods	Technology type	The technologies applied in vertical farming are Hydroponics, Aeroponics and Aquaponics, which are suitable for different types of farming systems.	Various technology
5. Energy	5.1	To generate enough renewable energy to power the whole farm.	Functional	We want to be able to run a farm which can have enough power to use technical equipment such as fans, conveyor belts and ventilators. We also want to help combat climate so we want to use renewable energy sources.	Generation
	5.2	To use solar panels along the south facing side of the building.	Technical	We want to rely on renewable energy and solar radiation will be the main source.	solar
	5.3	To have 18 hours of lighting a day	Quality	To enable the plants to grow to the best quality we need to generate enough artificial light for 18 hours.	Monitoring systems for Duration, Direction and Intensity of Sunlight
	5.4	To have energy for technical equipment	Technical	The farm will require the use of moving plants, fans, ventilators and pumps.	To pump & harvesting
6. Environment and Operation Control	6.1	Labour – reduce workers needed due to only 2.3% unemployment but provide training to those who are employed. 1 crop worker per floor – apart from at harvest where this increases to 5. 2 cleaners and 2 maintenance personnel for the building.	Functional	There is high employment and therefore not many people to employ. Automated technology should be used to reduce the number of people who need to be employed. However, those who are employed will need to be able to operate the farm and will require training to do so.	Labour
	6.2	Install a nutrient delivery system and means for	Technical	The hydroponic system will deliver everything the plants need in order	Autonomous and smart delivery

		automated conditions for plant growth		to grow. There should also be automated controls to ensure the correct growth conditions are maintained.	
	6.3	Install HVAC subsystems for optimal temperature and humidity to produce 60% more yield at optimal	Technical	This will bring air in, condition it to the correct specifications for gas quantities, temperature and humidity levels and then distribute that air. The air should travel between 0.5 and 1m/s for optimal circulation. Reconditioning and recirculating will occur. There will be gasses released from the process, but these should not be polluting.	HVAC subsystems
	6.4	90% of waste must be reused or recycled to construction products or other means. This should be done with harmful pollution as close to harmful pollution as possible.	Functional	The project should be as sustainable as possible. Any plant waste should be sold on for use in different products and building materials which as sustainable. Then as much as possible should be recycled. The farm should not use anything that produces waste that has to be sent to landfill.	Recycled water

We have used a simple colour coding system to demonstrate the traceability between our different design activities. Coloured blocks from the objective tree show the links from the tree nodes, to the functional analysis, and then to the different requirements in the requirements table.

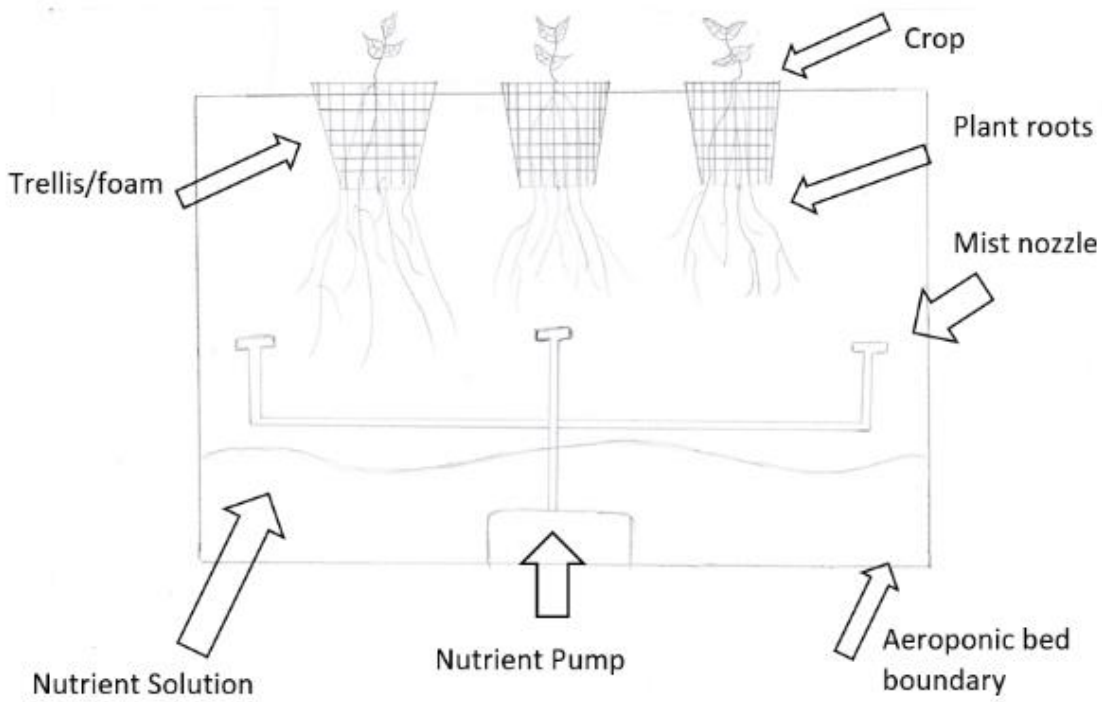
DESIGN IDEAS

Brainstorming – initial concepts

We have split our initial concepts into the different sections.

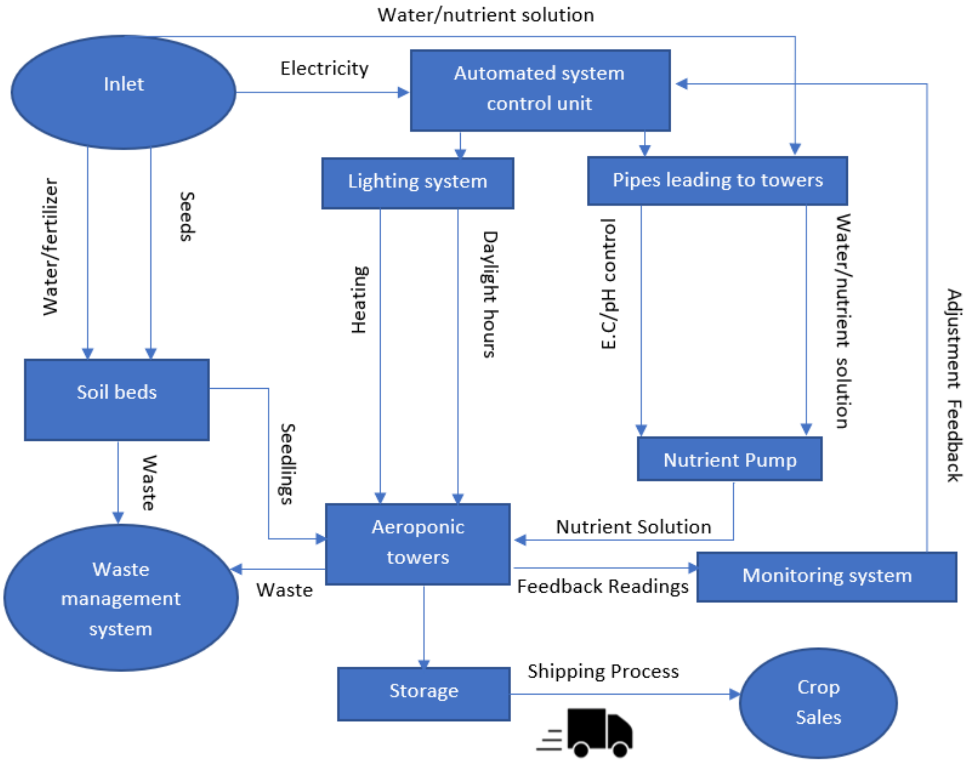
Farming

The initial ideas developed for farming are based on the requirements table and also the functional analysis (as the farming system is the main function of the farm.) In the figure below is a very basic initial sketch of how an aeroponic system works, and this should enable us to develop an isometric model of the beds later.



This works by supplying a nutrient solution to a pump below the suspended crops in the trellis or foam. This solution is then pumped as a mist to the roots of the crops to supply them with the nutrients required in the quantities required. Each of the crops being grown can be supplied with 10-10-10 (nitrogen, phosphorous and potassium) ratio of nutrients, so to be efficient and save money on wholesale this is the mix that will be used. There will be slight differences in the uses of this system for the different crops to be grown. Firstly, the spacing between the seedlings will be different for cabbage, broccoli and radish- 45cm, 35cm, and 10cm respectively. Secondly radishes can be suspended in close-cell foam, whilst the heavier broccoli and cabbage would need to be held in a supportive trellis.

As well as this, the figure below is an initial block diagram, demonstrating how the growing system will work:


Water/nutrient solution
Inlet
Electricity
Automated system control unit
Lighting system
Pipes leading to towers
Water/fertilizer
Seeds
Heating
Daylight hours
E.C/pH control
Water/nutrient solution
Adjustment Feedback
Soil beds
Seedlings
Waste
Nutrient Pump
Aeroponic towers
Nutrient Solution
Waste management system
Waste
Feedback Readings
Monitoring system
Storage
Shipping Process
Crop Sales

Energy

Main energy flows in the system:

- Main outputs will be energy for lighting, technical equipment and energy to pump water throughout the building.
- Our main energy source will come from solar panels which will be located along the south-facing side of the building.

Technical equipment required:

- Belt conveyors to transport plants around the farm.
- Fans to promote gas exchange and helps transfer heat to maintain a constant temperature between shelves.
- Air ventilation to maintain levels of oxygen and carbon dioxide to optimise plant growth and to remove any exhaust/waste gases.
- Dehumidifiers to remove maintain a balanced climate and to collect condensation which can be recycled.
- Hydroponic/aeroponic systems will involve pumps for drip systems and nutrient dilution.

Solar radiation data for Tokyo in 2018:

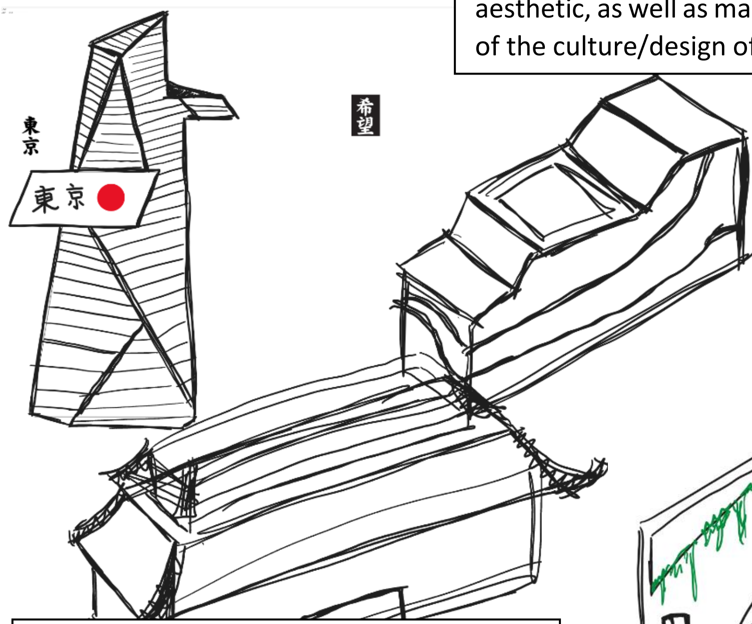
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2018	3.4	6.4	12.1	16.2	17.0	14.6	18.0	15.1	15.6	9.3	4.4	2.6	11.2

Structure

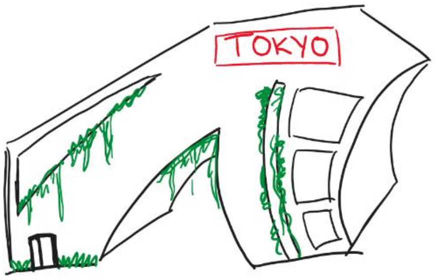
Initial sketches

I attempted to create a structure that would be both functional and aesthetic, as well as maintaining some of the culture/design of Tokyo.

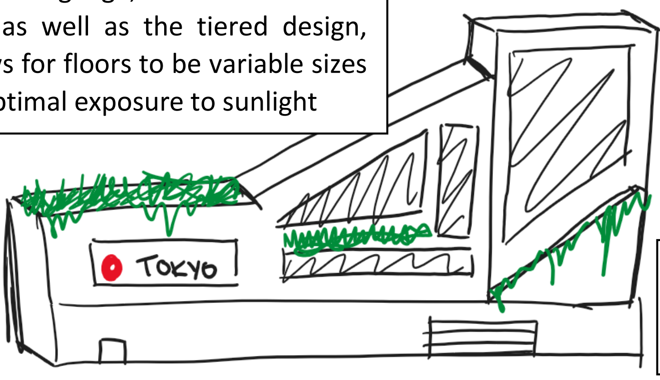
My designs slowly leant towards a more angular design which took some key parts of each design and combined them.

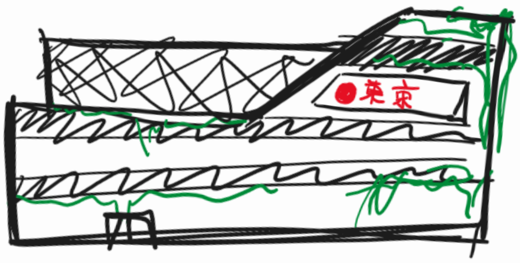


I also chose to keep a tiered design, as it allows the floors to have lots of exposure to sunlight, and the movable roof also enables it to be variable, whilst still maintaining the functionality of the design.

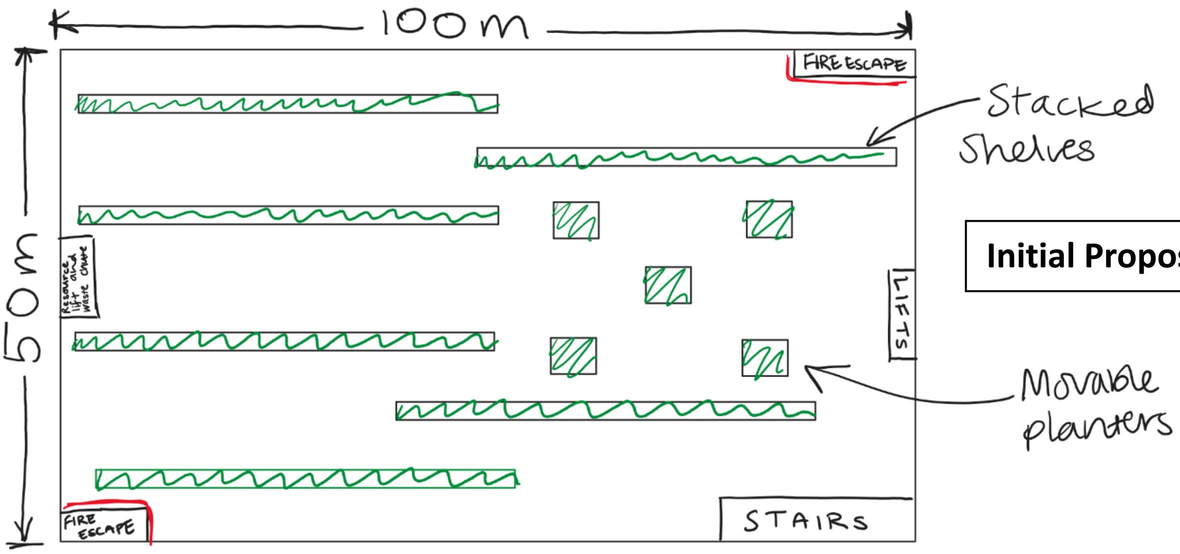


From my first three designs above, I chose to keep the signage, as I felt it was important, as well as the tiered design, which allows for floors to be variable sizes and have optimal exposure to sunlight





Eventually I settled on the final design below, as it can be seen fully built in Solidworks.



Initial Proposed Floor plan

Water

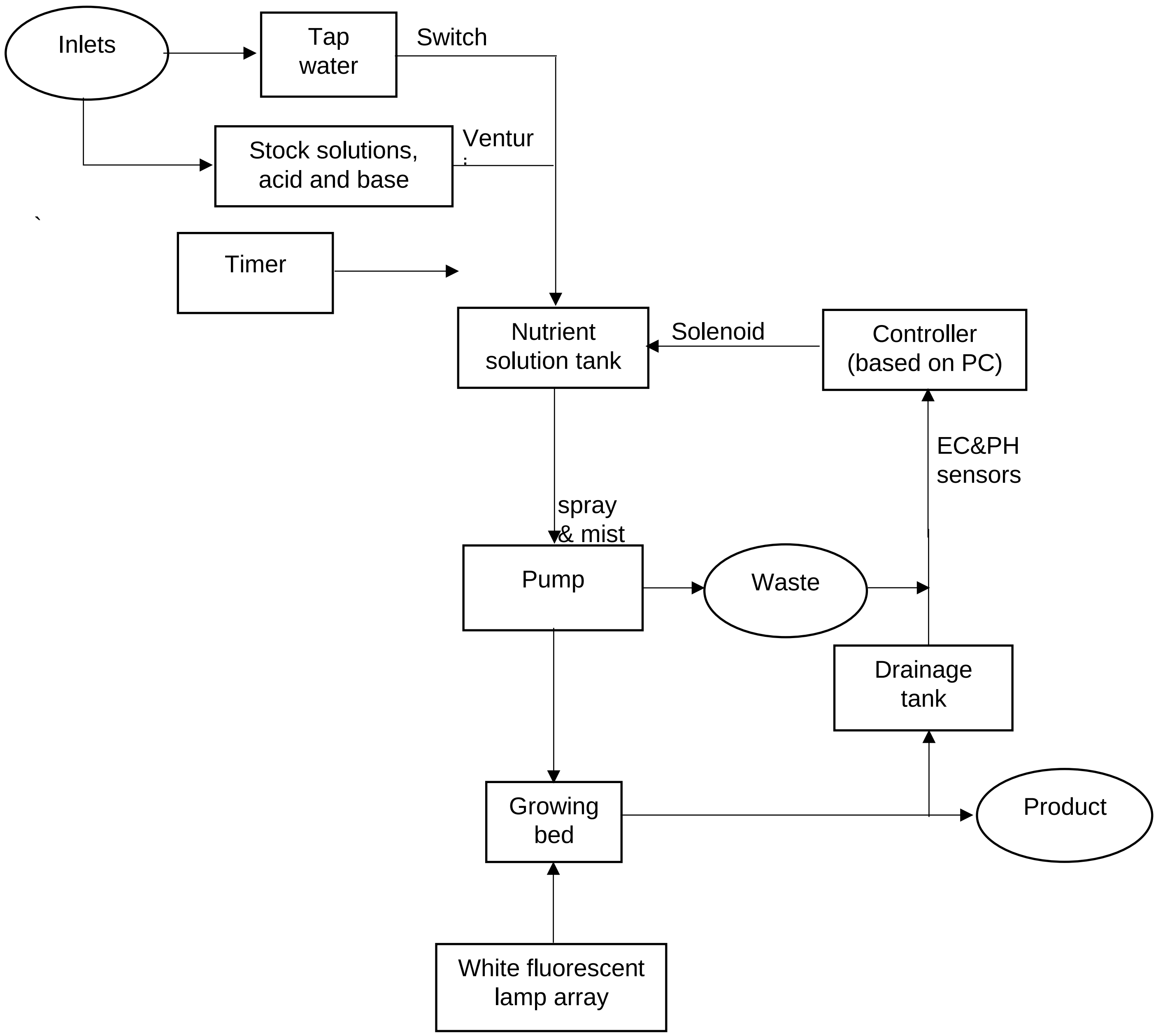
Aeroponics system

In most vertical farming, hydroponic systems are practical for nurturing plants especially in plant factories with artificial lighting. However, in our vertical farming, we use Aeroponics system which is a technological leap forward from traditional hydroponics.

Features

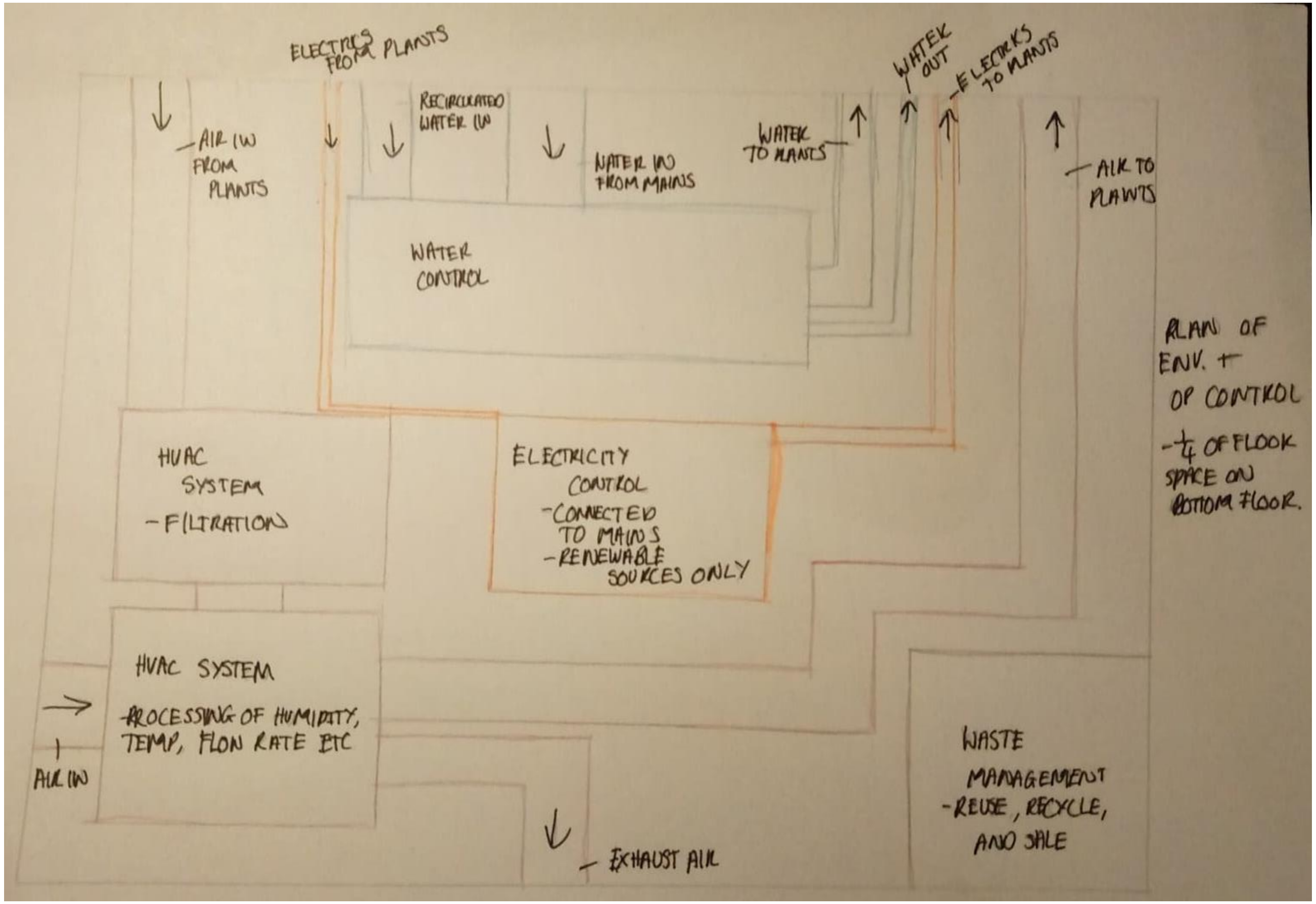
- Involve spraying the roots of plants with mist or nutrient solutions
- Use less water than hydroponic systems
- Without any growing medium

Block diagram of Water system (Aeroponics)



Environmental and Operational Control

This is a basic layout of the sort of control room we will aim to operate. This should enable an operator to constantly monitor growing/environmental conditions, allowing optimum growth of crops.



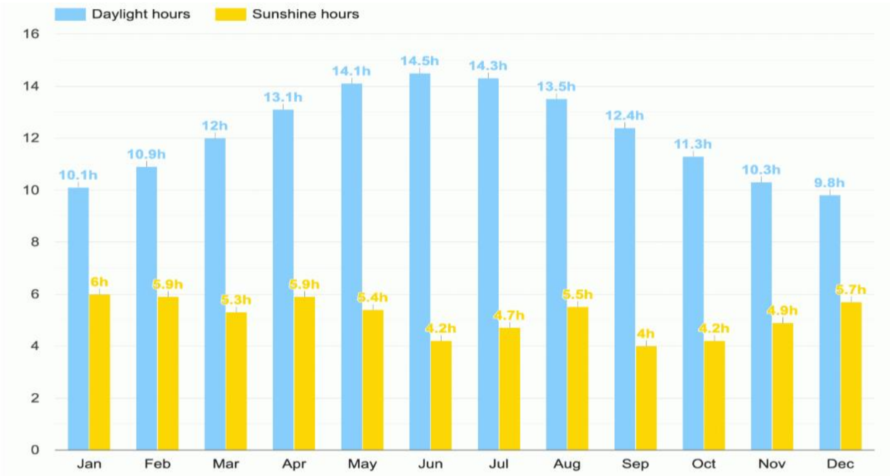
Lighting

The initial design for the lighting is based on the articles read and the requirements table. LEDs are preferred over HPS lights in terms of efficiency, control, flexibility and lifespan. In fact, most of the vertical farms in the world use LEDs.

Benefits:

- 70% more efficiency over regular lights
- Faster harvest cycles
- Cooler operating temperature
- Dust and water resistant (New LED production line comes along with IP65 or IP66 ratings)

Average daylight and sunlight hours in Tokyo:



Average monthly sun hours in Tokyo, Japan

A control system and sensors will be used to control the LEDs in order to enhance the growth of the crops. The sensors feed the system with information such as crop temperature, DLI and PPFD helping the grower to ensure that the crop receives the right amount of light and grows at optimum temperature.

Morphological Chart

The morphological chart below is a development of sorts from the requirements table (and the section brainstorms). It summarises the key features of our design that need to be implemented into the final schematics and drawings. We have continued with the colour coding system.

Features (identified from the requirements table)	Means (identified from initial concepts)				
Energy supplier	Solar power	Wind power	Natural gas	Hydropower	Nuclear
Farming products	Cattle	Fish	Poultry	Starchy foods (rice, potatoes)	Cruciferous vegetables
Lighting	Halogen bulbs	Compact fluorescent	LED	Incandescent	HID
Transmission	Belt conveyor	Gravity roller	Ball transfer conveyors	manually	
Planting method	Soil	In-vitro growing	Hydroponics		
Building location	On top of a supermarket	Build a new structure	On top of a university	On top of an office	

Watering method	Aeroponics	Drip method	Sprinkler irrigation	Surface irrigation	Localized irrigation
Growth systems	Horizontally stacked	Vertical growth (vertical)	Vertical growth (slopes)	Vertical growth (cylindrically)	

TRIZ Contradiction Matrix

Triz Contradiction Matrix

Worsening feature -> Improving feature	Level of automation	Convenience of use	Productivity/ yield	Emissions	Employment	Energy efficiency	Waste management	Versatility	Effects of community	System Complexity
Level of automation				15	15, 5			11		
Convenience of use	25		1, 28	32, 40	5	28	27, 34, 40	4	27	7, 16, 29
Productivity/ yield		30		25, 21	20, 25	27, 15	27	12	20	17, 30
Emissions	2									29
Employment	34									
Energy efficiency	2		19	22	5		22	4		5, 8
Waste management	34			25						
Versatility	6	16, 34		27		2	16, 27			14, 20
Effects on community			11			3	39	11		11
System complexity		9, 26, 27			12	18		15, 28		

The TRIZ table allowed us to make many advances our design. The key design feature it allowed us to identify was the merging of the control systems (lighting, air flow, heating etc.) to a central system within the control centre of the building on the bottom floor. This will increase convenience of use, level of automation and energy efficiency. However, on the TRIZ matrix, it would decrease employment which would be a negative for the community and make the system more complex. Within the vertical farm, the need for employment must be kept low. Unlike other cities, Tokyo has very high employment rates and therefore, there is not a very large available population to work. The merging of systems to make the vertical farm more automated works in our favour in this instance. In the requirements table, the HVAC, lighting and water systems are specified to be as automated as possible with little employee involvement. The merging of those systems allows this to work.

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H.A.Z.O.P.

We developed a HAZOP to address the specific element of a sprinkler system into our design. This should be something that we think about when we move onto develop the enhanced floor plan.

Intent	Guidewords	Consequences	Causes	Hazard?
Water	More	Minor flooding on the floor	Faulty shut-off system	N, minor flooding will not be a problem, as workers will be evacuated beforehand
Water	No	Fire is not put out and rages	Pump/valve failure	Y, if the fire is not put out it can potentially burn workers and spread causing death
Switch	No	Can't be triggered manually by workers	Faulty switch	Y, inability to trigger the system manually can also cause the fire to hurt people
Detection	No	System doesn't stop fire	Faulty sensor failure	Y, if a fire starts and there is no one to see it, the detection system failure will lead to damage
Detection	Other than	Workers get wet, some crops/equipment may be ruined	Overly sensitive sensor	N, a false activation of the system would be inconvenient, but would not pose any serious risks
Dispersal	Late	Fire has time to spread and cause harm	Delay between sensor and action	Y, if the delay is too significant the fire could get out of hand or harm someone before being controlled
Dispersal	Early	Fire is put out very quickly, but triggered easily	Sensor is very sensitive and has a quick response	N, the fire would be put out very quickly, however, would be set off by very small fires – so it would have to be enforced

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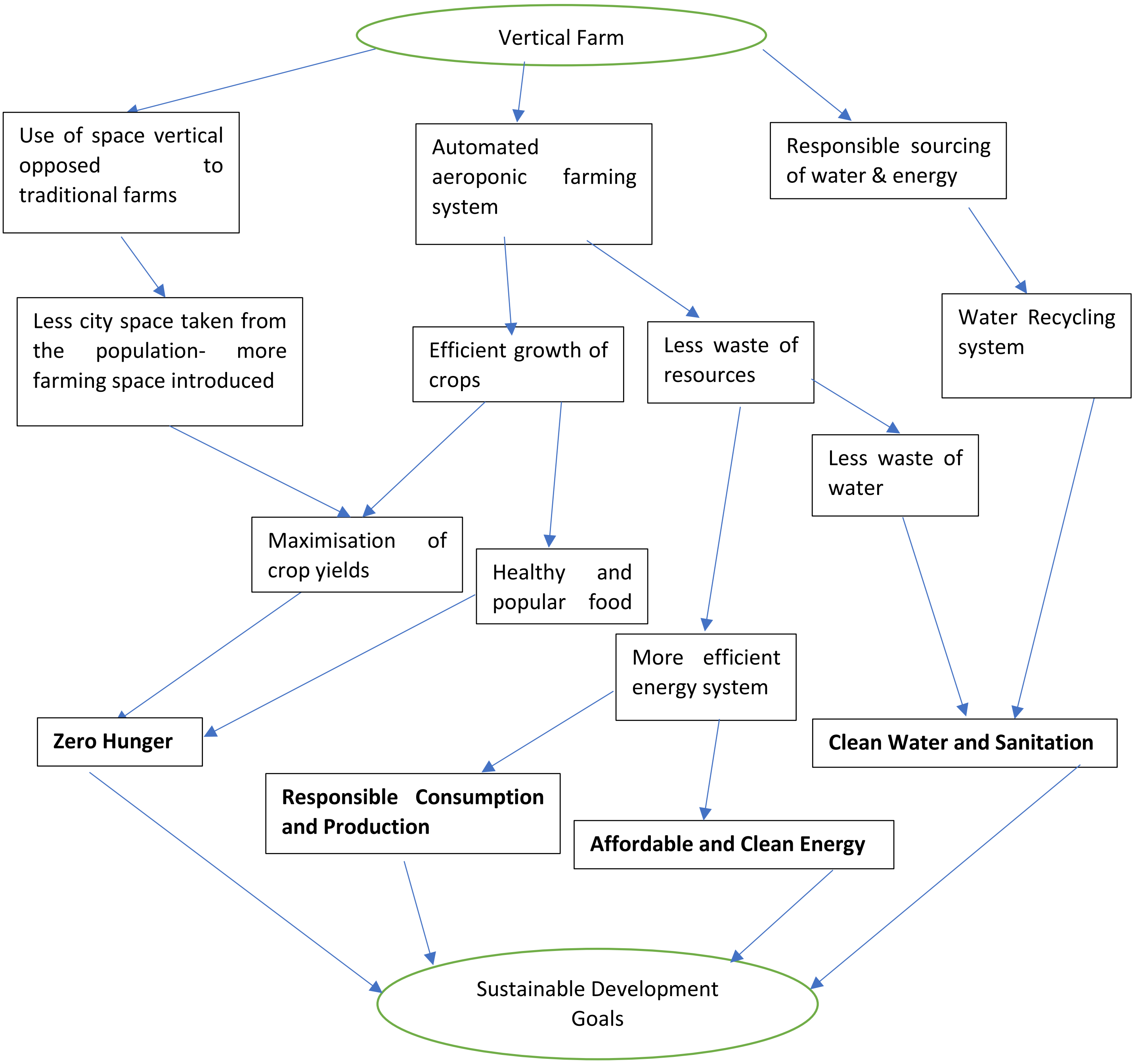
				that there is no smoking etc indoors

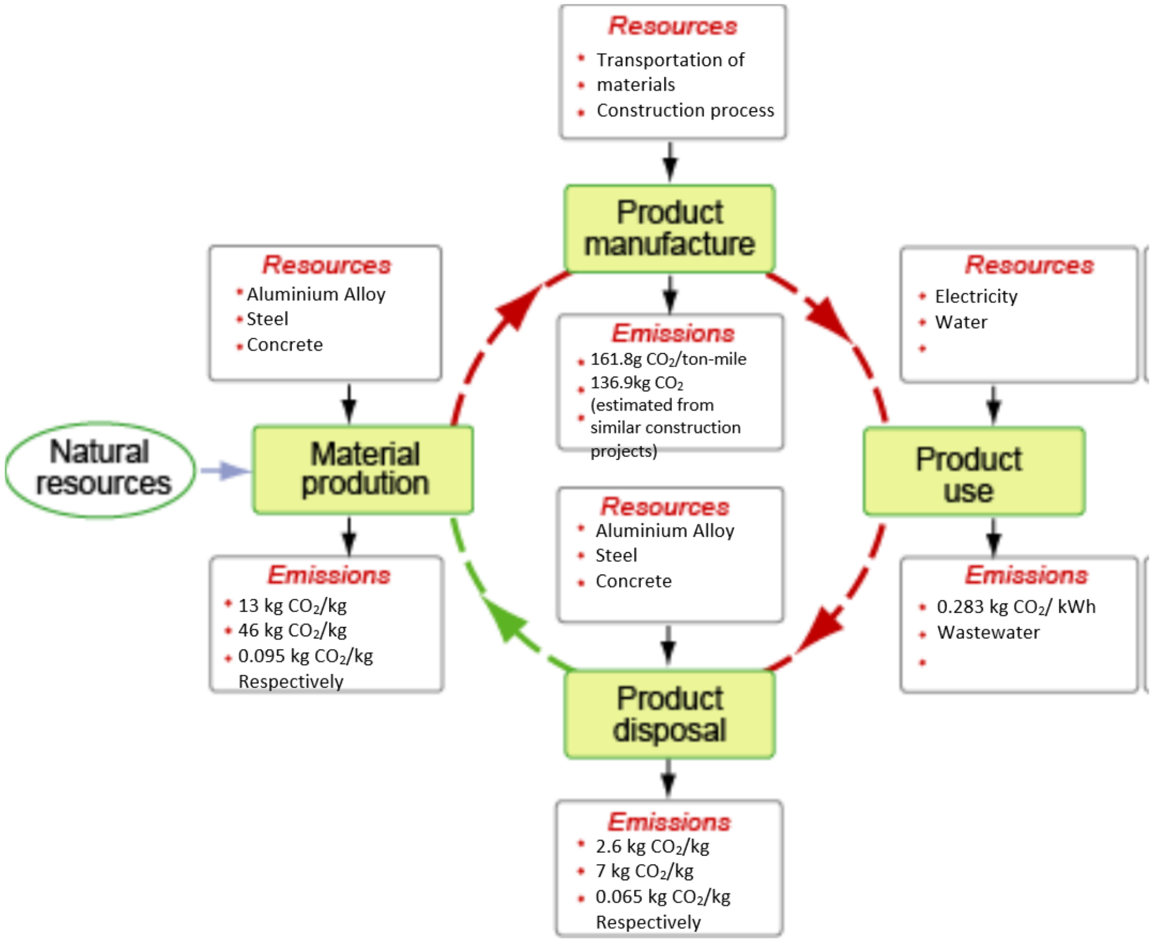
SUSTAINABILITY

Progression of the United Nations Sustainable Development Goals (SDG)

Below is the causal diagram for the vertical farm. The main goals that our solution will progress are zero hunger, responsible consumption and production, affordable and clean energy, clean water and sanitation. We are progressing the zero-hunger goal by building a vertical farm which maximises space available for farming. We are also adopting a very efficient and advanced farming system- both of these factors mean that we can produce a lot of food with minimal resources, which should help feed a growing population. By also sourcing resources responsibly, recycling certain waste (for instance with water), and employing an efficient farming system, we can aid the goals of responsible consumption and production, affordable and clean energy, clean water and sanitation



Life Cycle Analysis



FINALIZED DESIGN

Design Rationale

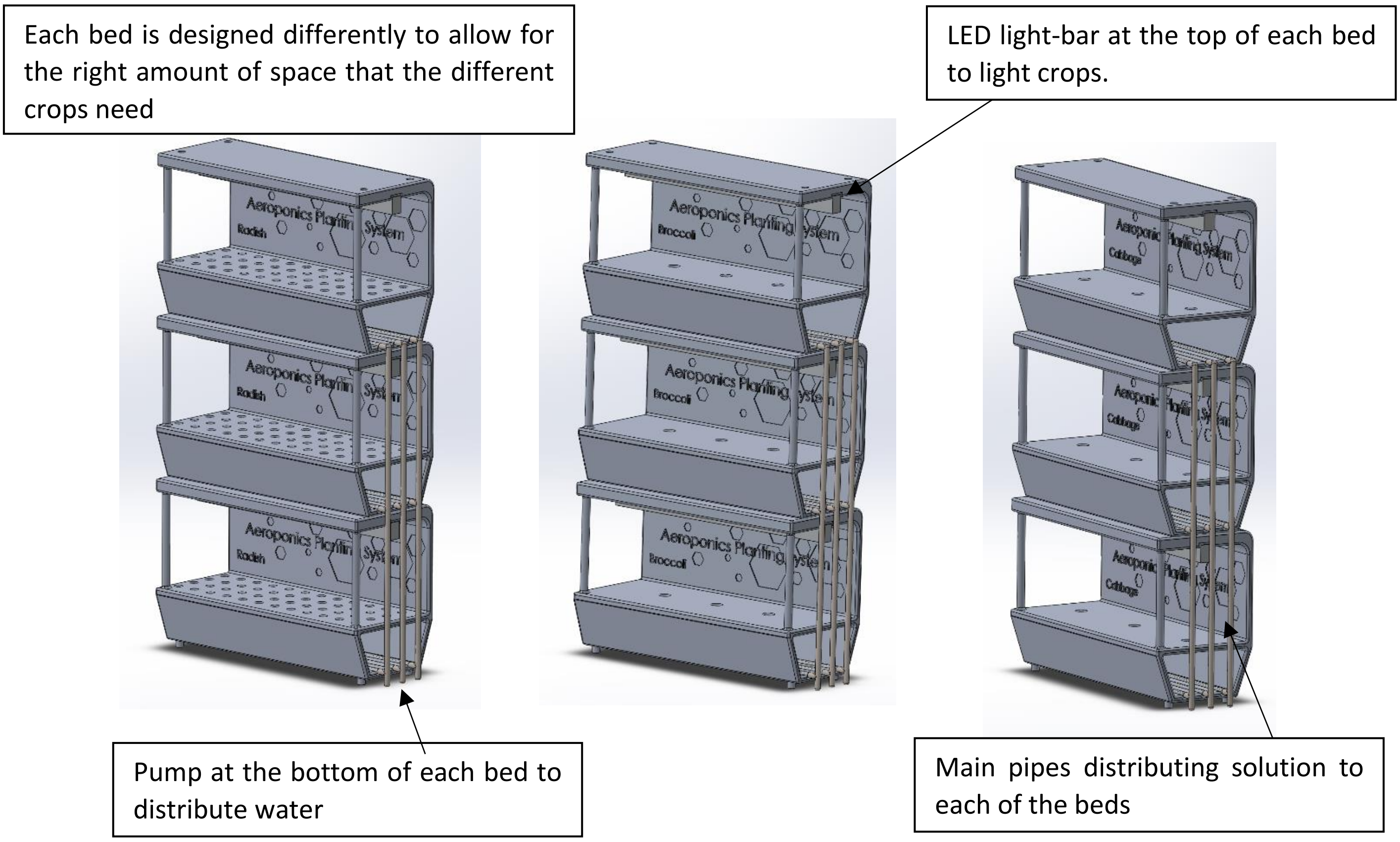
There is a clear path of development through our design. For instance, we have designed a basic sprinkler system based on the HAZOP that was done, the designs for the structure have gone from one basic 2-D floor plan to a 3-D CAD rendering and 4, in-depth floor plans for the structure. This combined with renderings of the individual beds (a development from the farming block diagram) is a developed and final design for the vertical farm. Other specific examples of development are the detailed HVAC system analysis based off of the original basic control room floor plan, and the energy flow diagram based off of the original brainstorm of energy flows in and out of the system.

Design Schematic

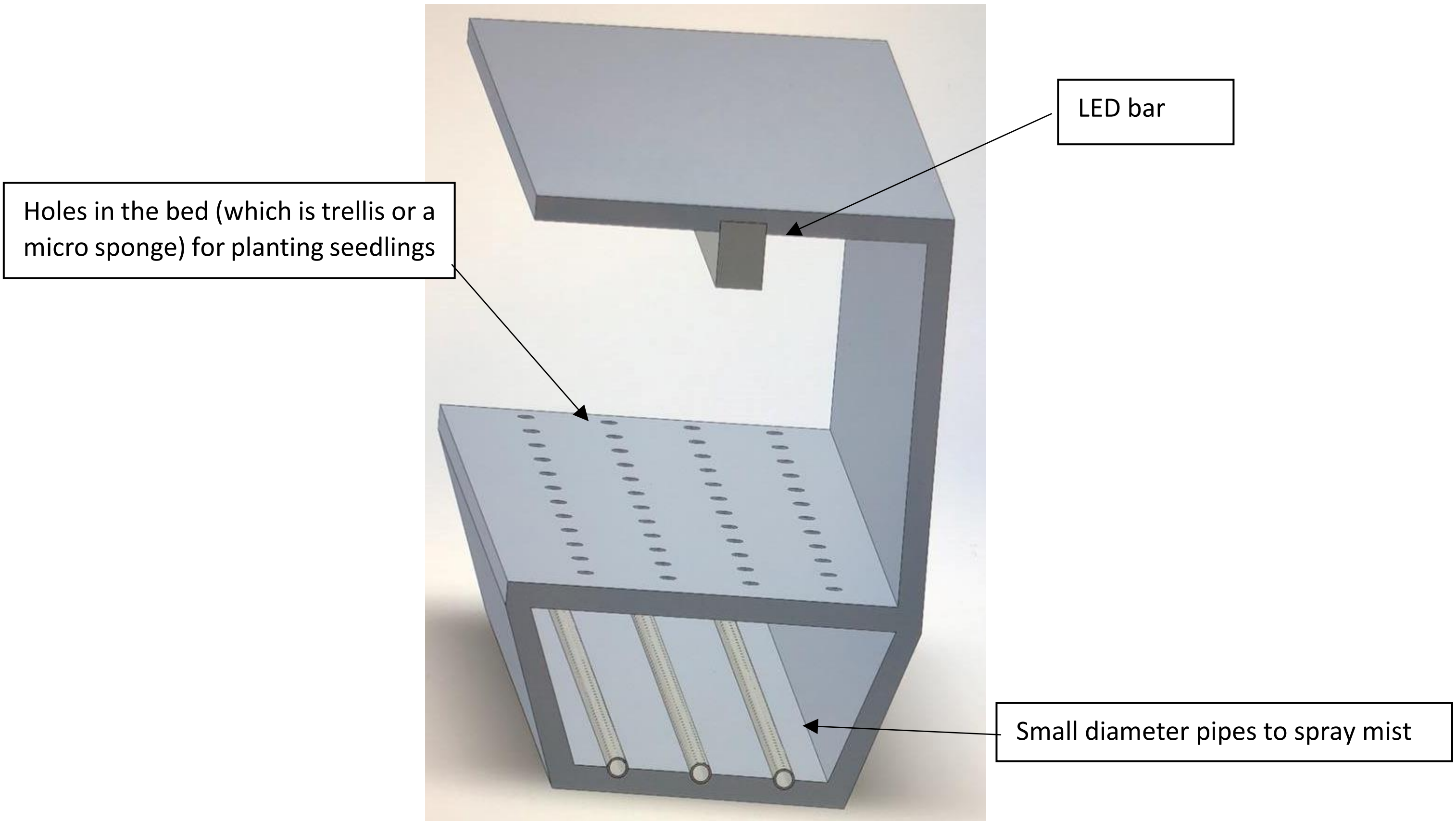
Our final design schematics are split into different our specific sections; however, we have also developed some 3-D CAD to demonstrate how lighting, water and farming comes together to form the actual aeroponic beds to be used in the vertical farm.

<u>CAD Renderings</u>

To demonstrate exactly how it is that the farm will work, we have combined 2-D floor plans with a 3-D model of the individual aeroponic beds. This means that where you can see the aeroponic beds in the floor plan, the following CAD designs are representations of what will actually be in place.



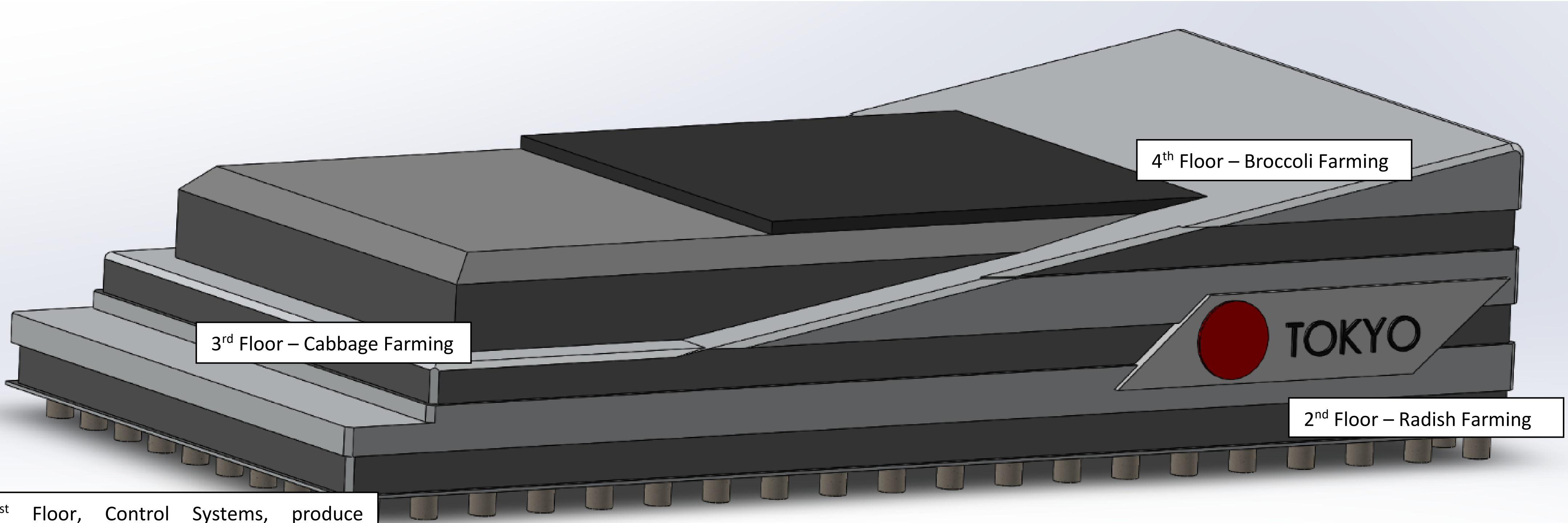
This is how all the beds will look stacked on top of each other in 3's, however in the actual vertical farm an additional layer would need to be added to the cabbage and broccoli stack. You can see from these renderings how the pipe network works, to transport the water/nutrient solution to each of the aeroponic beds. Below is a close-up figure of an individual bed. You can see from this the small diameter pipes that run below the holes where crops are planted. These are what pump the mist of the water/nutrient solution to the roots of the plant. You can also see in more detail where the LED's are placed to provide the light for the beds. This is a development of the water, lighting and farming original concepts/brainstorms as it has combined the sections together. This is also a specific development of the basic 2-D schematic of an aeroponic system produced in the original farming section.



Structure

Final CAD Rendering

Façade is shown here halfway open, it slides out across the glass to allow for variable sunlight penetration



The Cardinal dimensions of the structure are 100x50x30 m

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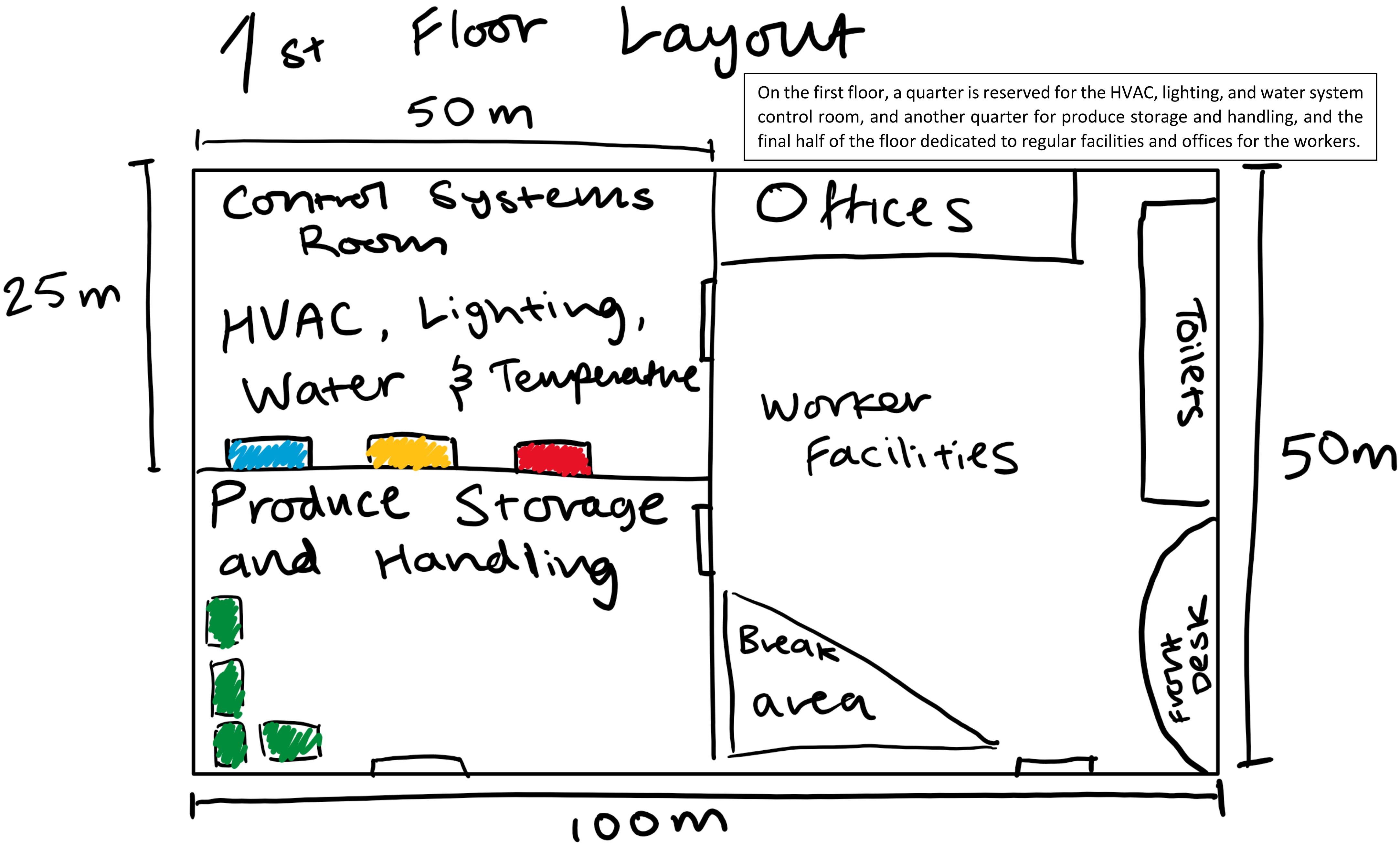
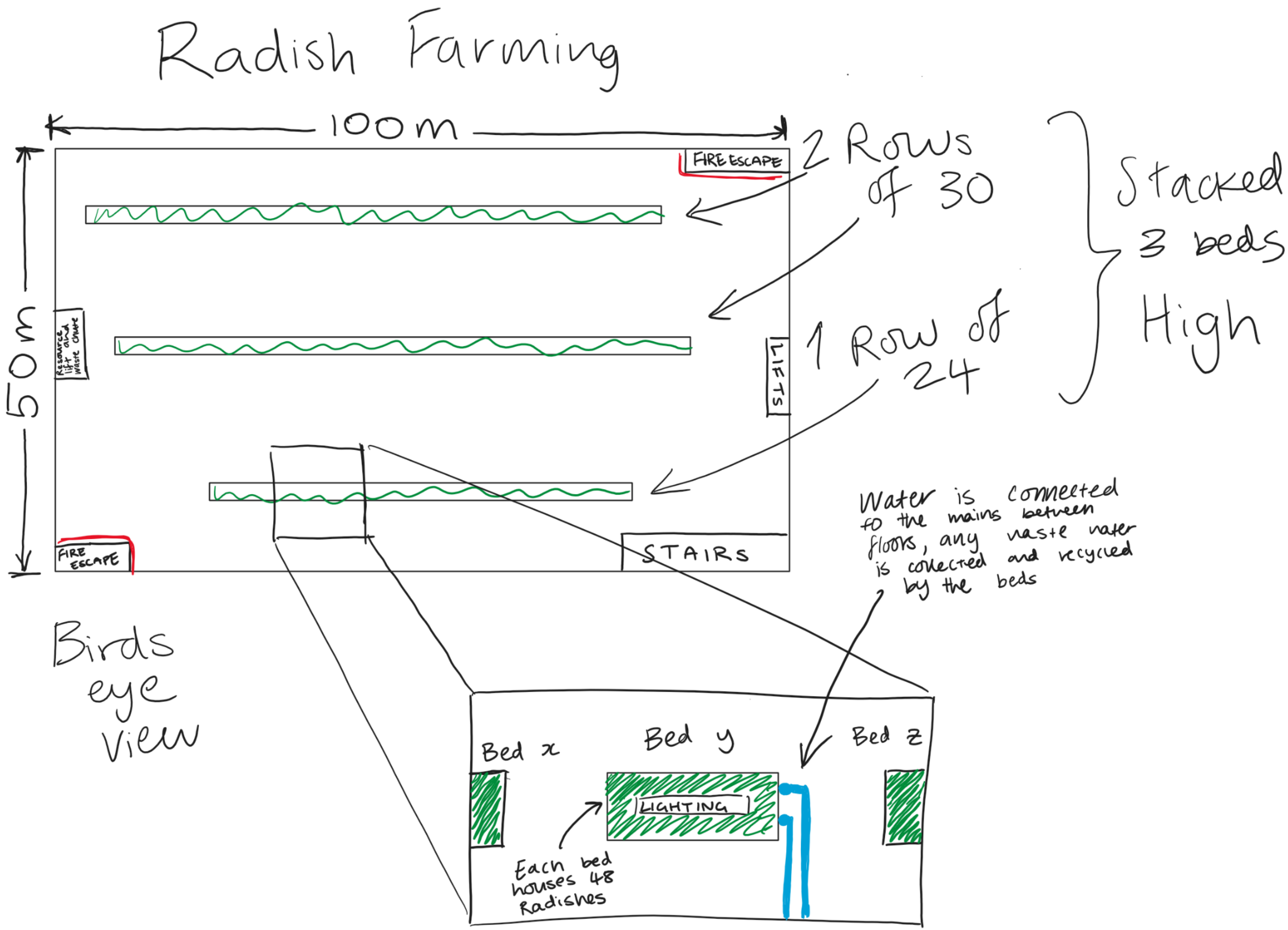
Finalized Design

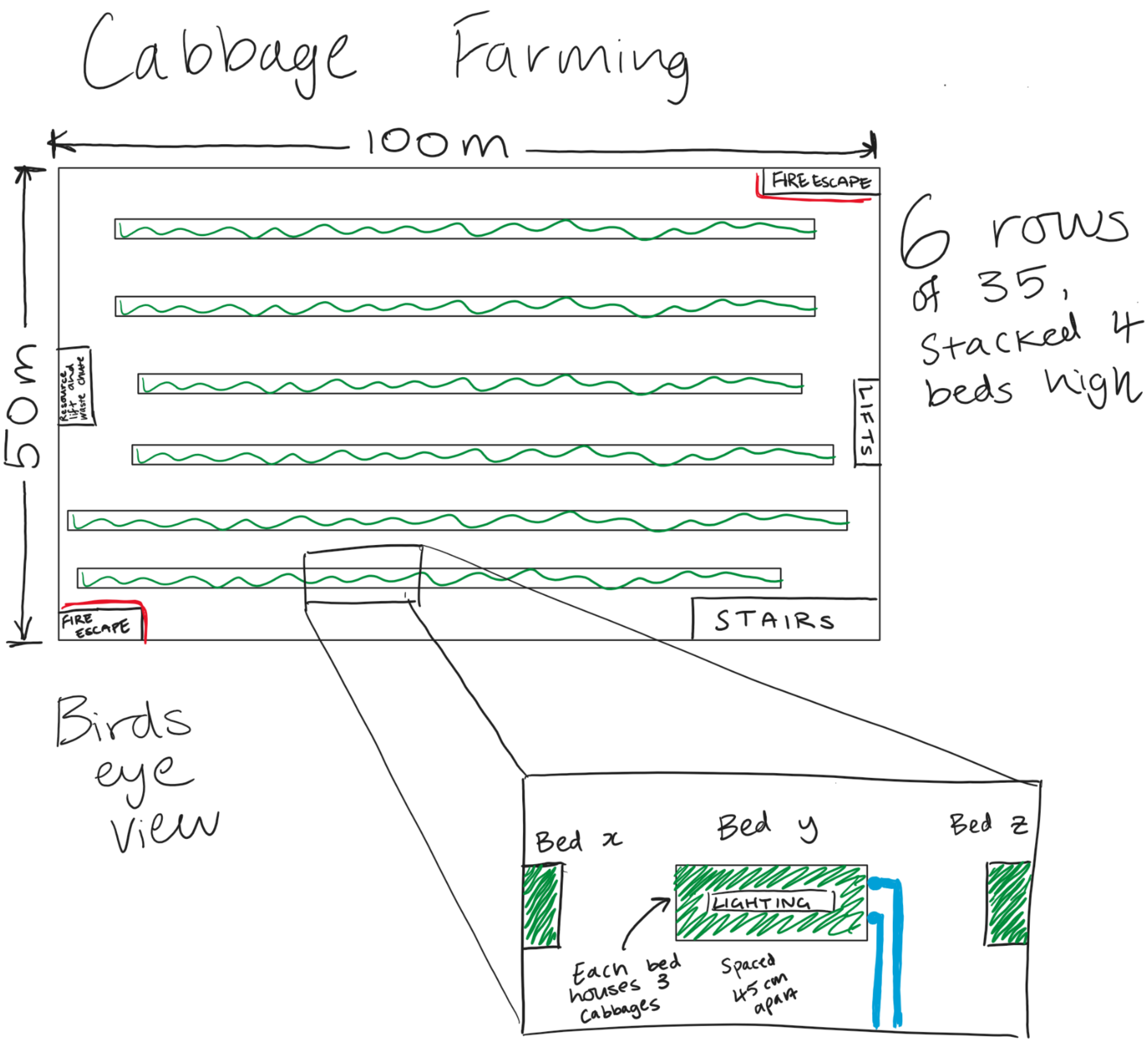


On the first floor, a quarter is reserved for the HVAC, lighting, and water system control room, and another quarter for produce storage and handling, and the final half of the floor dedicated to regular facilities and offices for the workers.

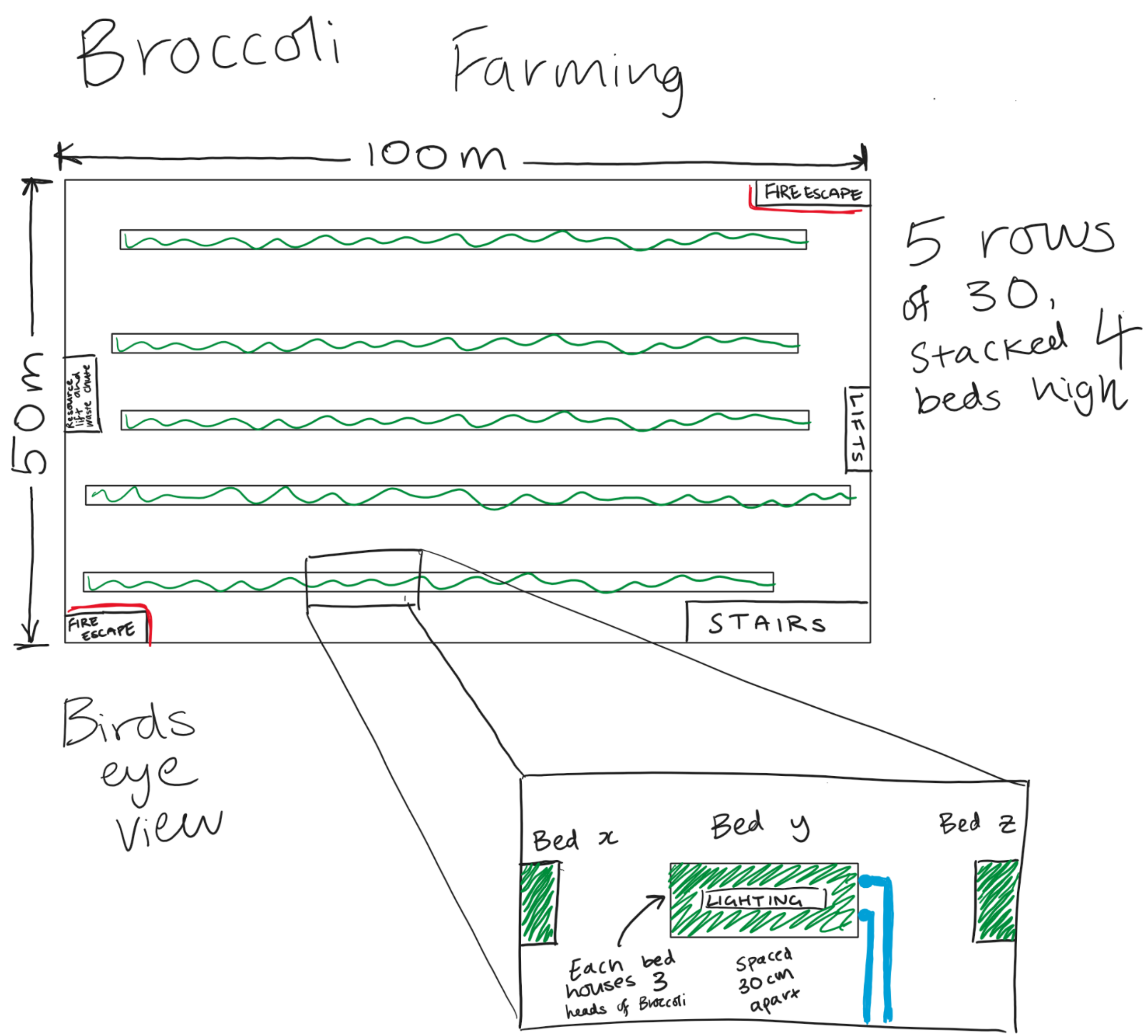
Finalized Design



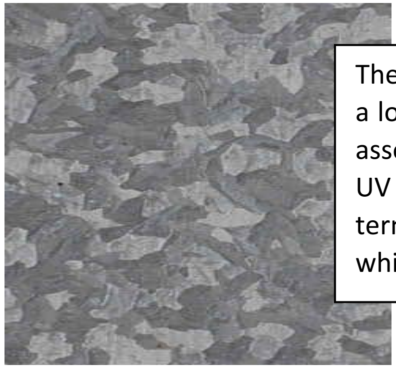
Finalized Design



Finalized Design



Chosen Materials



The material chosen for the roof is a galvanized steel, which is very corrosion resistant due to its protective coat of sacrificial zinc. The substrate would be a low carbon steel AISI 1015 and would be readily available in most industrial sizes. It has excellent weldability characteristics – meaning that it can be assembled and attached in place easily, as well as built into the retractable system, as well as being very durable against fresh and saltwater, as well as UV radiation, making it ideal for roof material. Furthermore, it is entirely recyclable – which helps to increase the sustainability of the overall structure. In terms of sustainability, the galvanised steel has an embodied energy of 38.1-42 MJ/kg during primary production and a CO_2 footprint of 2.87-3.16 kg/kg, which is fairly high for dense material, however galvanised steel is heavily recycled, with 52.3-57.8% of all in current supply being recycled.

The material chosen for the cladding is aluminium wrought alloy 3105, which is very common for this external application on buildings. It is extremely corrosion resistant, which makes it ideal for an outdoor application, as well as being very fatigue resistant with a stress range between 44.5-60.3 MPa, it also has an impact toughness of 12.8-17.3 kJ/m^2, which means that it would be able to withstand most extreme weather conditions. Additionally, it is a very workable and formable material, which means that it can be shaped to suit the buildings design relatively easily, increasing the functionality of the material. As for sustainability, SLC has an embodied energy of 188-207 MJ/kg and CO_2 foot print of 12.1-13.3 kg/kg, this may seem very high, but aluminium 3105 is a very lightweight material, so the volume produced is very high. Furthermore, aluminium 3105 is fully recyclable and is globally one of the most recycled materials

The material chosen for the infrastructure is structural lightweight concrete (SLC) which is often used in the infrastructure of buildings. It comprises of lightweight coarse aggregates – which reduces the strength-weight ratio, but when combined with steel reinforcing bar can be cast on site and used to form custom shapes that are very strong. It has a compressive strength of 11.3-28 MPa, a bending strength of 1.2-3 MPa, and a Young's modulus of 11-21 GPa. Furthermore, the material has low permeability which makes it suitable for weather resistant applications, particularly since it can be poured into custom forms to suit the required need. As for sustainability, SLC has an embodied energy of 0.779-0.859 MJ/kg and CO_2 foot print of 0.116-0.128kg/kg, whilst this is not excellent, for this type of material and its properties it is one of the best, and is fully recyclable, with 13-14.4% of all SLC in current supply being recycled.

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The site which I chose for the building was part of a university complex. The reason for choosing to build on top of an existing building lies in the fact that Tokyo is an extremely dense urban area, and therefore land is scarce – so in order to save space and still be fairly central, it made more sense to build on an existing structure.

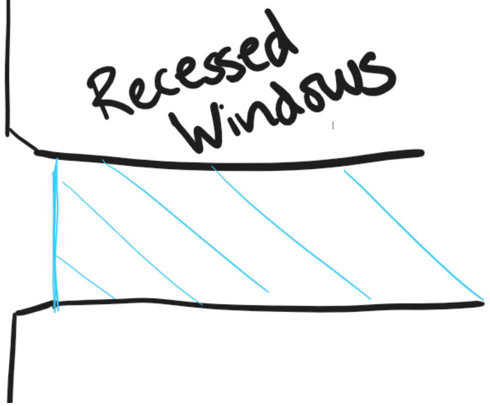
Location

However, this also means that the foundation considered has to be viable and safe – as a result of this I have chosen to use several shallow foundation pillars along the bottom of the building, which fix the structure in place at key points, without weakening the existing building.

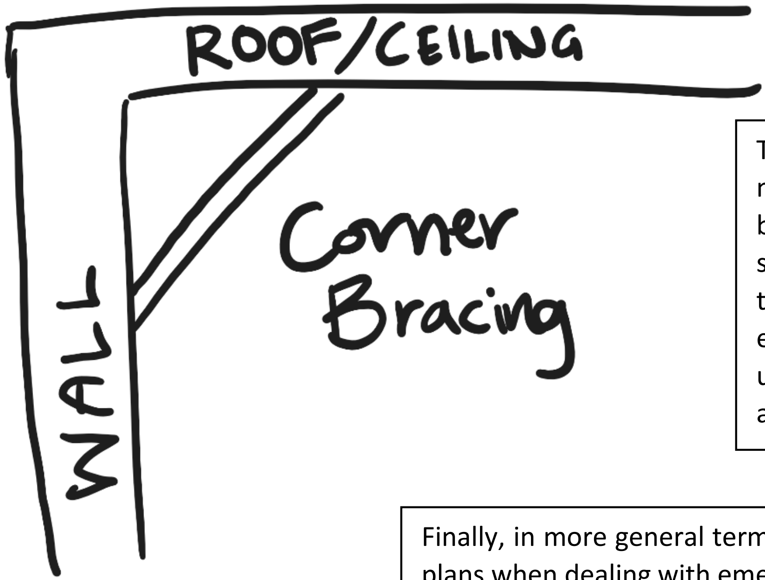
In addition to that, it also means that the infrastructure for electricity and water is already there and easily accessed.

External Actions on Structure

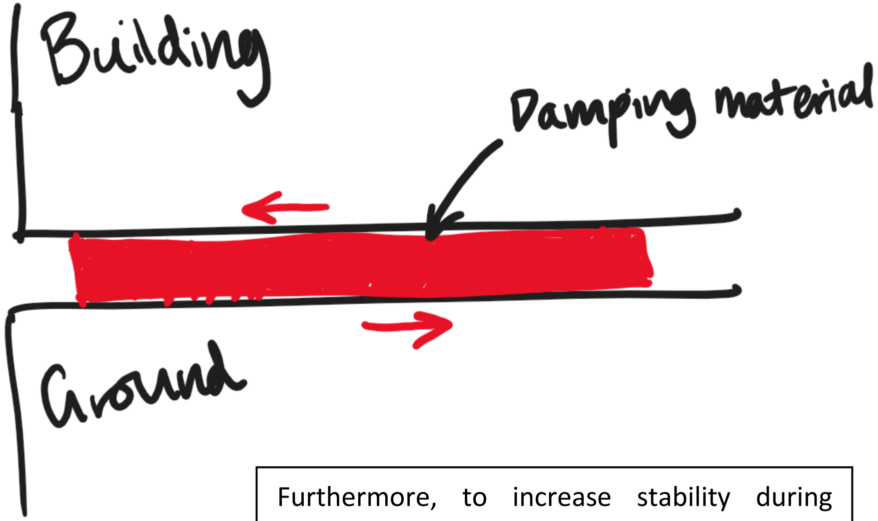
As for the external factors which would affect the safety and stability of the structure, I have identified a few key factors; extreme weather, natural disasters, subsidence and durability.



To counteract extreme weather conditions such as high velocity winds, hurricanes, and hail, the windows on the structure have been recessed and given a concave form, to help distribute loads and prevent shattering



To reduce building pancaking in the most cost-effective method, corner bracing is introduced throughout the structure. This can potentially reduce the effects on the building earthquakes and sudden impacts by up to 30% and is an extremely cheap and easily implemented method.

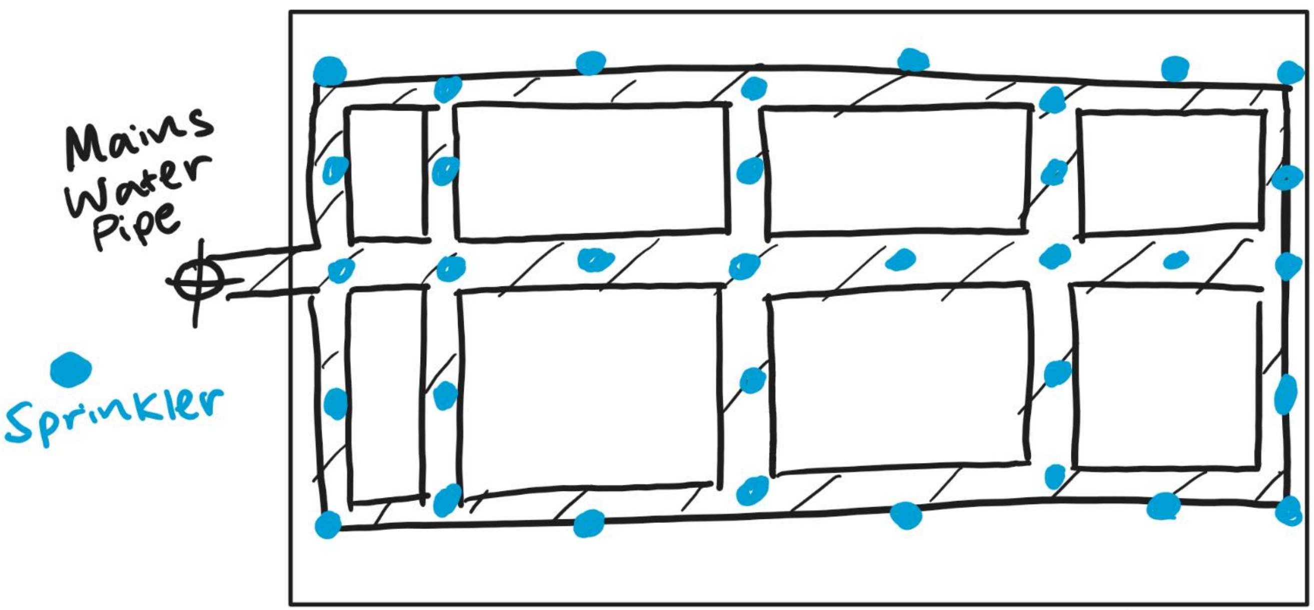


Furthermore, to increase stability during earthquakes and other disasters which would cause the structure to shake – the structure has been installed with damping material between itself and the ground, which helps to mitigate movement and reduce the forces exerted on the structure.

Finally, in more general terms, the building has been made safer and more stable by having clear codes of conduct and plans when dealing with emergency situations, as well as installing fire escapes and extinguishers throughout.

As well as this, as a development from the HAZOP study we have developed a basic floor plan layout for the sprinkler system. This would overlay the floor plan for each level of the building. This is just a basic concept schematic of how the system would be set up.

Sprinkler System Schematic

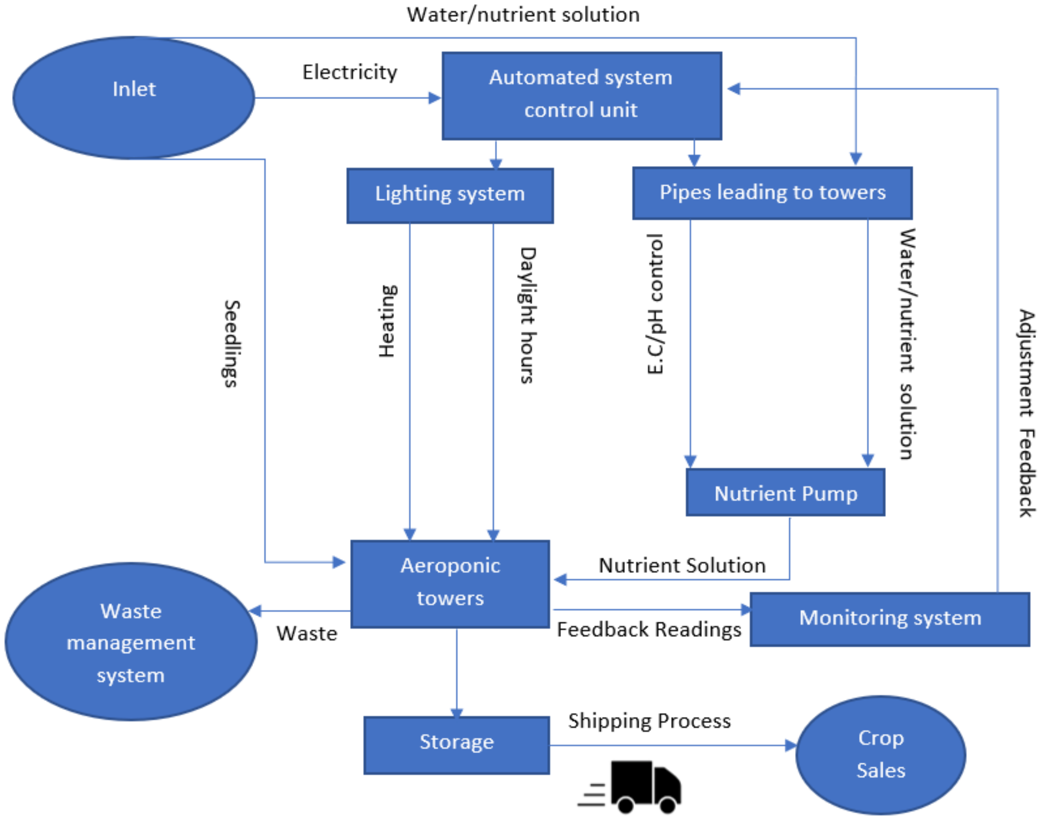


The Same Water System is also used for the Aeroponics Beds

Sprinklers have an effective radius of 3m, so can be spaced 6 m apart, which means for our floor size, 192 sprinklers are needed

Farming

In the previous CAD section, the specific design of the aeroponic beds has been demonstrated. This is a major component of the farming discipline section. The figure below is a block diagram representing the inputs and outputs as part of the farming system. One key development we have made is that rather than have in-house soil beds, we will buy in seedlings that have begun germination (typically 4-7 days into planting). This is because it will require much less labour for manually moving seeds, and will reduce our waste as we would have to refresh the soil beds.



This is a brief schematic, but to go alongside this is a table with the basic information needed to grow each of the crops.

	Cabbage	Radish	Broccoli
pH of soil	6.5-7	6-7	3.5-6.5
Daylight hours required	6	8-10	14-16
Optimum temperature	18-21 degrees Celsius	10-20 degrees Celsius	12-18 degrees Celsius
Harvest	4-6 weeks	3-4 weeks	7-11
Space between seeds	45cm	7-10cm	30-40cm
Nutrient ratio (N,P,K)	10-10-10	10-10-10	10-10-10

Attached in the appendices is a patent reference that inspired these designs, or indeed for a product that we could incorporate into the farm.

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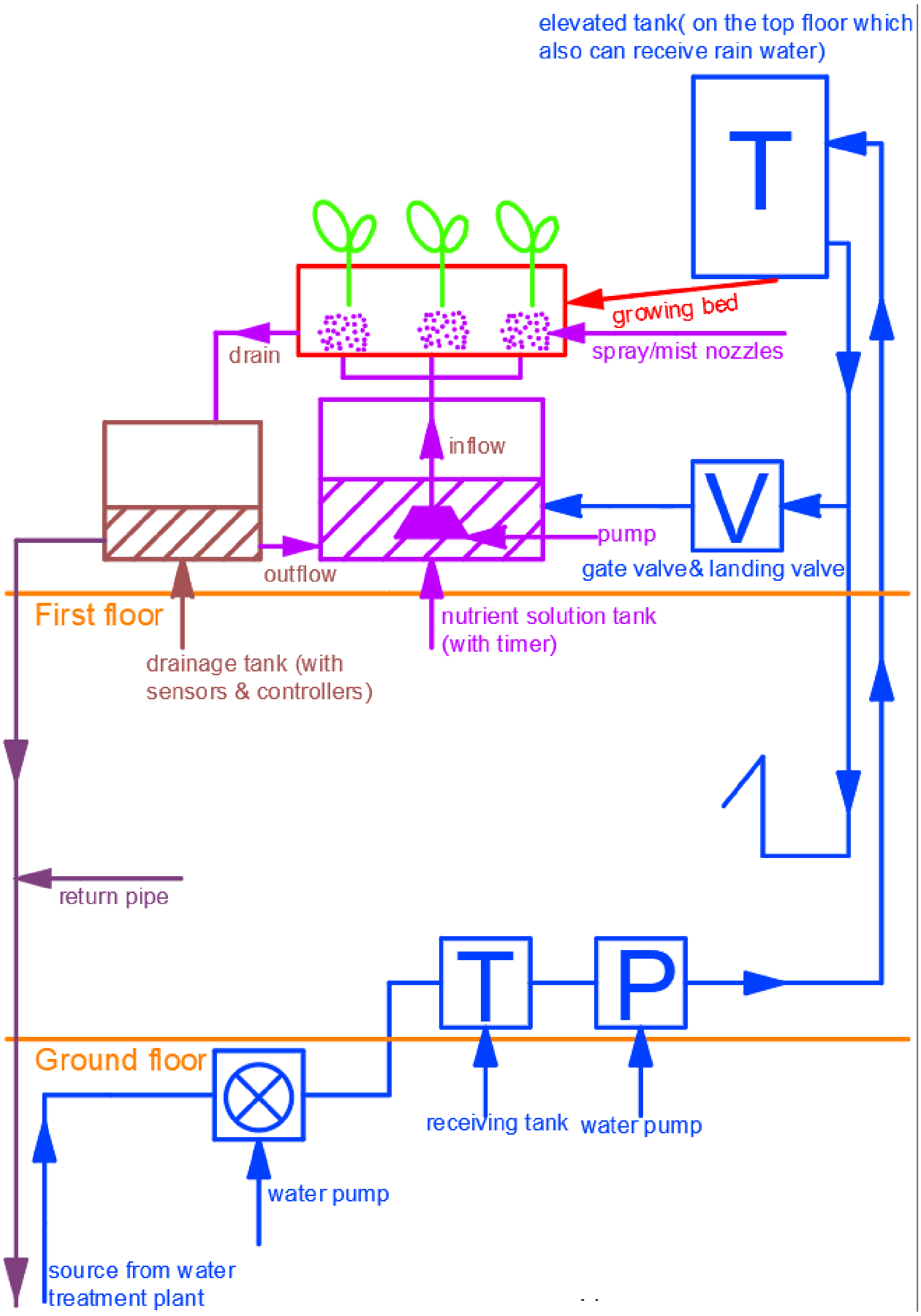
<u>Water</u>

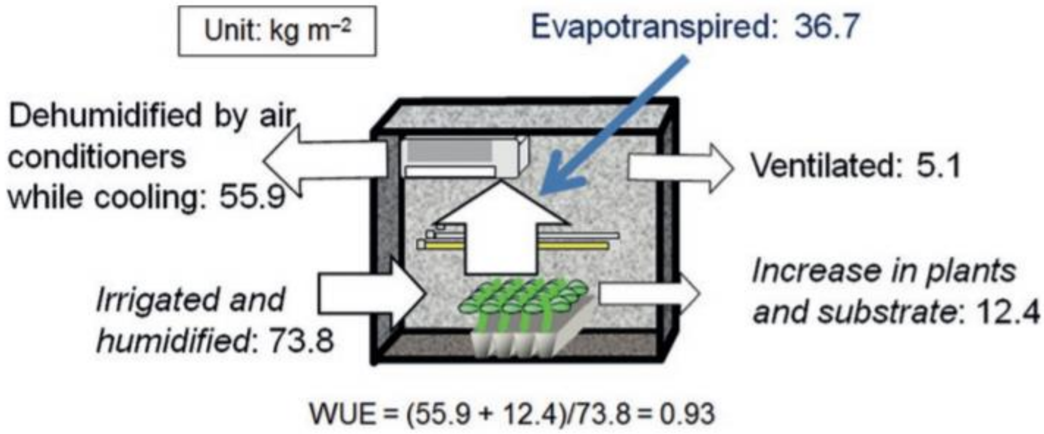
Developed design in building (one floor example)



- Pipes should be parallel to the walls and columns of the building and their diameter should be larger than 50mm
- As long as you can guarantee the water delivery, two tanks and growing bed can be put at any place in the same floor
- The reason why adding drainage tank is that sometimes the discharged water cannot be recycled directly, and if the sensor detects that the nutrition is not enough, it means the water needs to be drained.

Ways to reduce the loss of water in systems:

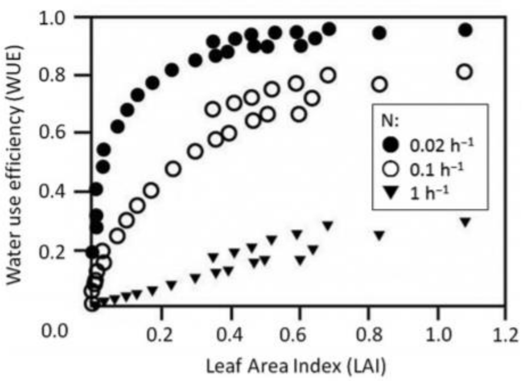
- Closed plant production system instead of greenhouse



According to an experimental result of water use efficiency (WUE) for 14 days in the closed transplant production system. In the case of a greenhouse, the evapotranspired water cannot be reused. Relative humidity was kept at about 80% and air temperature at 30 °C.

WUE is 0.93–0.98 in the plant factory with artificial lighting PFAL and 0.02–0.03 in a greenhouse, meaning that WUE of the PFAL is approximately 30–50 times greater than that of a greenhouse.

- Increasing leaf area index and a high level of airtightness



WUE of the closed plant production system as affected by leaf area index (LAI) and N (number of air exchanges).

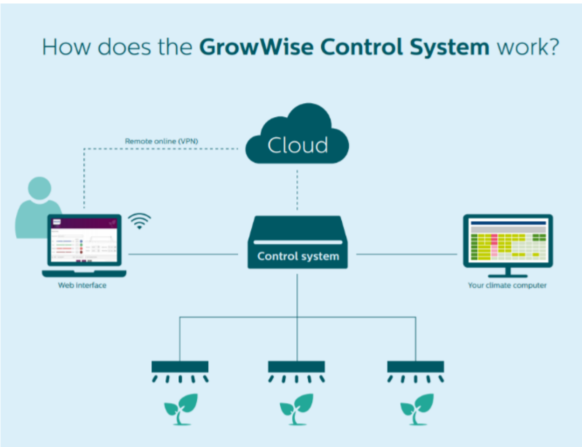
Lighting

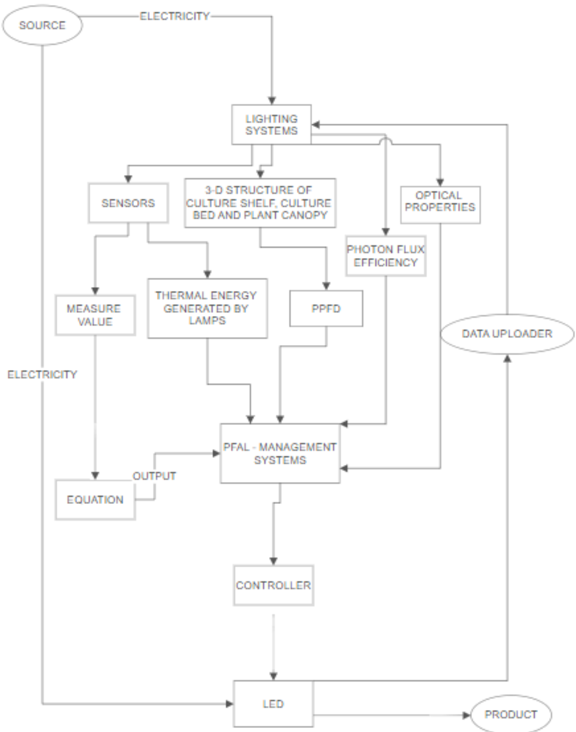
Philips' GreenPower LED production module 3.0 would be the best fit for the project as it allows growers to control both light and temperature separately to optimize light levels and gain more control of growing conditions.

LED lights are preferred as they are more efficient and easier to control when it comes to dimming and on-off cycles. They have longer lifespan along with the ability to emit only red and blue spectra while cutting out the unnecessary wavelengths within the light spectrum and to discharge less heat compared to any other lighting system.

Philips' GreenPower production module 3.0 complies with the IP66 and UL ratings for wet conditions. Also, thanks to its robust design, high efficiency and long lifetime the operational cost is minimized.

As noted in the farming section, plants don't need to be constantly lit. Tokyo gets an average of 10 hours and 53 minutes a day, so lighting will be controlled using the grow wise control system.

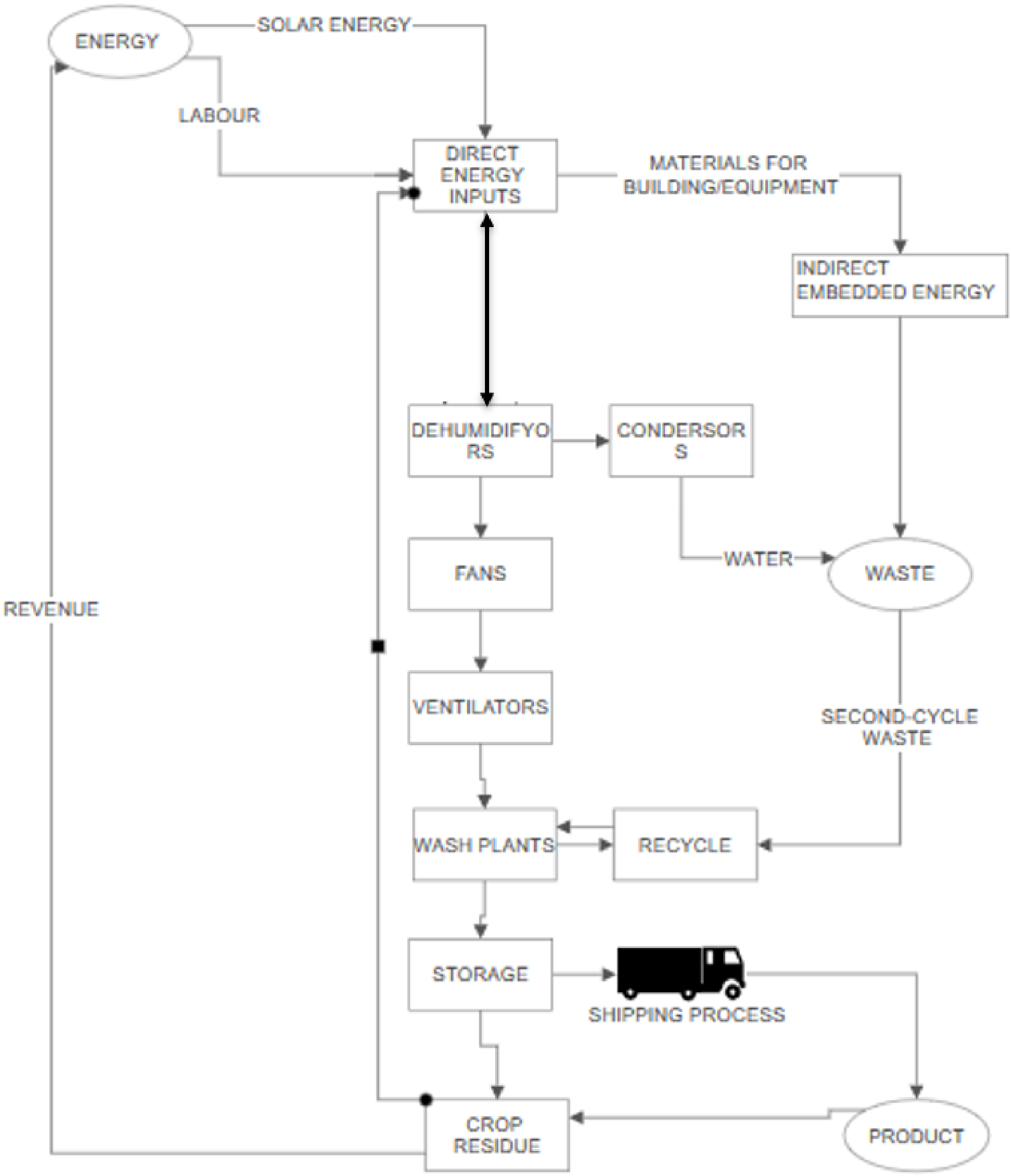




GrowWise control system will be used for the vertical farm. The system allows growers to form their own settings for maximum production of the crop by controlling the 4 main colour spectra: Deep Red, Far Red, Blue and White along with intensity, light distribution and light duration. It will be integrated into a logistic systems and sensors helping the grower to create a better light recipe and maximise production. The system is designed to make it easy to upgrade and manage, thus making it future proof. Above is also a block diagram - a schematic demonstrating how the lighting system will work. Attached in the appendices is a patent reference for our specific lighting system.

Energy

This is the developed block diagram to summarise energy processes within the farm. One of the slight changes made is that the conveyor system will no longer be in use, as it is clear when developing the floor plan this won't be appropriate.



Here is also a developed diagram demonstrating the energy flows in the system.

(see next page)

Belt conveyor

Forced convection between 0.5-1 m/s required to temperature differentials between shelves.

Conveyors to move plants.

Fans to promote air circulation

Air ventilators

A 10 watt LED bulb will require~648 kW of energy per

Average 18 hours of lighting needed for

Energy used for technical equipment.

Induce flow of carbon dioxide/ oxygen at a balance to promote optimum growth.

Monocrystalline,polycrystalline, Thin-film solar panels are commonly used and are the most efficient

Energy used for artificial lighting.

Dehumidifiers

Main energy flows in our vertical farm.

To maintain a stable climate and to provide a system to recycle water.

Monthly average solar radiation for tokyo ~ 11.2 MJ/m²

Commercial solar panels are on average 2m² in size.

Hydroponics systems

Energy gained from solar panels.

Pumps required for drip systems, nutrient dilution.

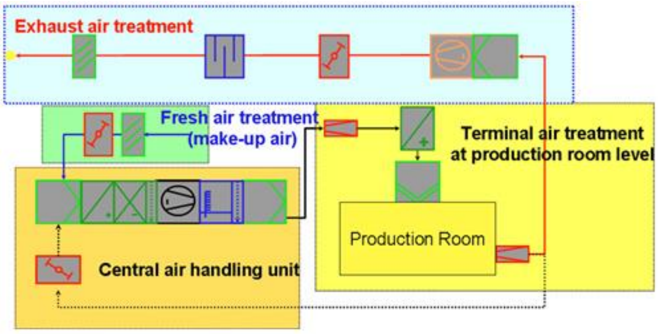
A single monocrystalline solar panel at an average efficiency of 27% could produce ~ 6.048 MJ a month.

Solar panels to be placed south-facing along the side of the building, optimising surface area covered and also facing sunlight.

Environmental Control and Operations

HVAC sub-systems

1. Handing of incoming fresh air – elimination of coarse contaminants, and controls for air recirculation.
2. Central air handling unit – air will be conditioned to correct requirements e.g. humidified, heated, cooled.
3. Air handling in rooms – pressure differential and air distribution
4. Air exhaust system – filtration before release



The above diagram shows the arrangement for the HVAC sub-systems which will be located on the bottom floor – taking up roughly ¼ of the floor space. This will also be an area for the other systems so they can be controlled from the same place. For example, the water, air, electrical and HVAC systems will all be in the same area. Therefore, they can be controlled by one operator from central place with 'merged' systems.

- Humidity should be increased during photoperiod and decreased in the 'night' period.
- CO_2 concentration should be kept at 400ppm.
- Ventilation and air flow allows uniformity of air temperature. However, the air speed should be around 0.5 m/s. Over 1m/s will harm plant growth.
- As much air as possible needs to be reconditioned for reuse before it goes through the exhaust system. Release of CO_2 should not be too much of an issue as it is needed for the air.

Waste management

- Need a circular waste system
- Reuse and recycle into useful products – no landfill
- Low emissions
- Trade any plant-based waste to be converted to building materials.
- Any other solid waste should be dealt with in a sustainable manner.

Labour

- Look at employing from both the city and surrounding local countryside
- 1 person per floor usually. However, 5 per floor at harvest.
- 2 cleaning staff and 2 maintenance staff

Autonomous and smart devices

- Nutrient delivery system – efficient and reduce waste
- Temperature and air composition control – semi-automated – for control of conditions by workforce
- Automated moving roof

Plan for Semester 2: Detail Design

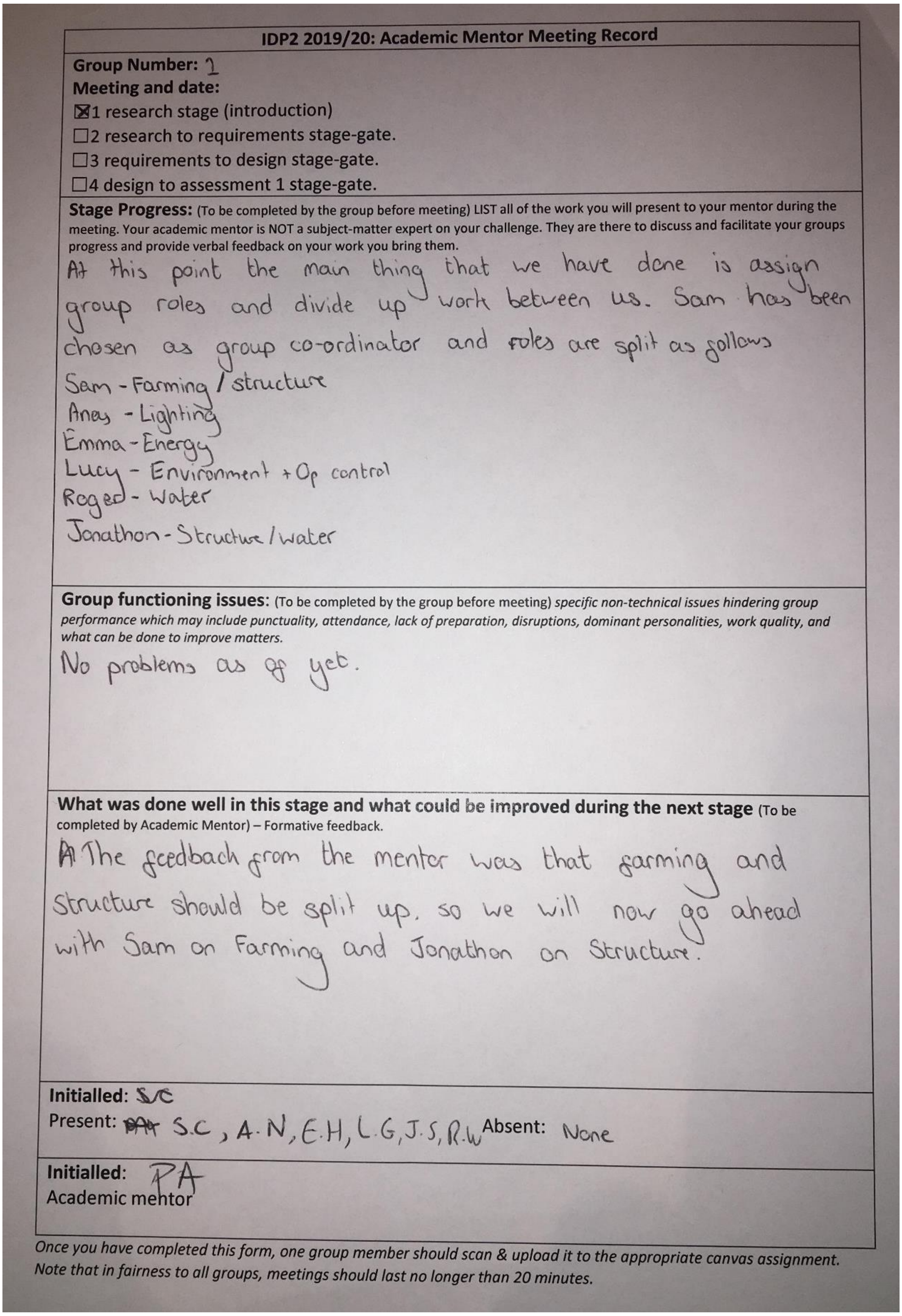
It goes without saying that each of the engineering disciplines will vary - and as such this allows them to cover all the bases and provide a fairly extensive understanding of each segment of our design with our different skill sets. For example, an electrical engineer could choose the lights and do the circuitry, but a materials engineer would be able to use suitable materials for heat etc, whilst a civil engineer would understand how to incorporate it into the structure, and a mechanical engineer could work out the loads on the fixtures and throughout to ensure it was safely secured. In semester 2 it is vital that the disciplines come together to work on the key elements of our design; the retractable roof, structural design and specifications, and the energy use and control of the vertical farm.

APPENDIX

APPENDIX A: Meeting Log

Date	Agreed Actions	Attendees
01/10 2019	We completed the icebreaker activity, and also decided who would lead the different systems of the project. We also set up a chat to be able to contact each other and a google document to share files. Split up the research papers between us also. Attempting to get into contact with the academic mentor.	Everyone
08/10 2019	This week we started the reading of all of the club journals and began to record the information. We also completed the lab this week which was the Belbin test. This gave us an idea of how to work together as a team.	Everyone
15/10 2019	In the lab this week we completed the Gantt chart for the rest of the project. We also continued with our individual studies of the recommended journals with some members doing their own individual research.	Everyone
22/10 2019	In the labs we completed the first sustainability worksheet. Other than that, we reported back to each other all of the findings from our research so that we could move to the requirements stage.	Everyone
29/10 2019	This week we completed individual objective trees for each of our sections. We also completed the second half of the sustainability labs	Everyone
01/11 2019	Met with academic mentor regarding our objective tree. It was suggested to us that we needed to change this and email it back to him for approval.	Sam Cook and Jonathon Sill
05/11 2019	This week we focused on trying to get the objective tree up to scratch and from this began to compile an in depth requirements table.	Everyone
12/11 2019	This week we simply focused on the health and safety worksheet as well as finishing the requirements table.	Everyone
19/11 2019	This week we completed the business enterprise lab and also carried on with our requirements table.	Everyone
26/11 2019	Met with academic mentor to go over the finalised requirements table and also to ask for advice over the initial brainstorms that we were creating.	Everyone
03/11 2019	This week we began to move onto developing our designs from the basic brainstorms that we initially had. We completed this for each section, and in particular began the creation of CAD. We also filled in any gaps in the past lab worksheets, and completed the TRIZ matrix and morphological chart	Everyone
06/11 2019	Some group members met at the library to move on with design work.	Sam, Anas, Jonathon, Emma, Roger
10/11 2019	Final meeting with academic mentor. We were given last bits of feedback regarding how to change our final designs. We also compiled the entire report together ready for submission.	Everyone
11/11 2019	Recorded executive summary and power point	Lucy, Emma, Jonathon

APPENDIX B: ACADEMIC MENTOR MEETING FORMS



IDP2 2019/20: Academic Mentor Meeting Record

Group Number: 1
Meeting and date:
☒1 research stage (introduction)
☐2 research to requirements stage-gate.
☐3 requirements to design stage-gate.
☐4 design to assessment 1 stage-gate.

Stage Progress: (To be completed by the group before meeting) LIST all of the work you will present to your mentor during the meeting. Your academic mentor is NOT a subject-matter expert on your challenge. They are there to discuss and facilitate your groups progress and provide verbal feedback on your work you bring them.

At this point the main thing that we have done is assign group roles and divide up work between us. Sam has been chosen as group co-ordinator and roles are split as follows
Sam - Farming / structure
Anas - Lighting
Emma - Energy
Lucy - Environment + Op control
Roger - Water
Jonathon - Structure / water

Group functioning issues: (To be completed by the group before meeting) *specific non-technical issues hindering group performance which may include punctuality, attendance, lack of preparation, disruptions, dominant personalities, work quality, and what can be done to improve matters.*

No problems as of yet.

What was done well in this stage and what could be improved during the next stage (To be completed by Academic Mentor) – Formative feedback.

The feedback from the mentor was that farming and structure should be split up, so we will now go ahead with Sam on Farming and Jonathon on Structure.

Initialled: S/C
Present: ~~PA~~ S.C, A.N, E.H, L.G, J.S, R.W Absent: None

Initialled: PA
Academic mentor

Once you have completed this form, one group member should scan & upload it to the appropriate canvas assignment. Note that in fairness to all groups, meetings should last no longer than 20 minutes.

IDP2 2019/20: Academic Mentor Meeting Record

Group Number: 1

Meeting and date:

- ☐ 1 research stage (introduction)
- ☒ 2 research to requirements stage-gate.
- ☐ 3 requirements to design stage-gate.
- ☐ 4 design to assessment 1 stage-gate.

Stage Progress: (To be completed by the group before meeting) LIST all of the work you will present to your mentor during the meeting. Your academic mentor is NOT a subject-matter expert on your challenge. They are there to discuss and facilitate your groups progress and provide verbal feedback on your work you bring them.

At this point all research has taken place as well as parts of the project plan such as the gantt chart. We have also completed seperate objective tree's ready for review from our mentor.

Group functioning issues: (To be completed by the group before meeting) *specific non-technical issues hindering group performance which may include punctuality, attendance, lack of preparation, disruptions, dominant personalities, work quality, and what can be done to improve matters.*

Group is functioning well.

What was done well in this stage and what could be improved during the next stage (To be completed by Academic Mentor) – Formative feedback.

Feedback from our mentor was that the objective tree shouldn't be split up because it is important to see links between different sections. We will complete this before moving onto the next stage.

Initialled:

Present: S.C, J.S   Absent: rest of group.

Initialled: PA

Academic mentor

Once you have completed this form, one group member should scan & upload it to the appropriate canvas assignment. Note that in fairness to all groups, meetings should last no longer than 20 minutes.

IDP2 2019/20: Academic Mentor Meeting Record

Group Number:
Meeting and date:
☐1 research stage (introduction)
☐2 research to requirements stage-gate.
☒3 requirements to design stage-gate.
☐4 design to assessment 1 stage-gate.

Stage Progress: (To be completed by the group before meeting) LIST all of the work you will present to your mentor during the meeting. Your academic mentor is NOT a subject-matter expert on your challenge. They are there to discuss and facilitate your groups progress and provide verbal feedback on your work you bring them.

We have now completed the requirement table. As a group we also started some design concepts because of a delay between meeting our mentor and being pushed for time.

Group functioning issues: (To be completed by the group before meeting) *specific non-technical issues hindering group performance which may include punctuality, attendance, lack of preparation, disruptions, dominant personalities, work quality, and what can be done to improve matters.*

A ~~worry~~ slight worry about completing on time.

What was done well in this stage and what could be improved during the next stage (To be completed by Academic Mentor) – Formative feedback.

Casual diagram needs to be completed.

Initialled:
Present: J.C, J.S, L.G, E.H, R.V, A.N   Absent: —

Initialled: PA.
Academic mentor

Once you have completed this form, one group member should scan & upload it to the appropriate canvas assignment. Note that in fairness to all groups, meetings should last no longer than 20 minutes.

IDP2 2019/20: Academic Mentor Meeting Record

Group Number:
Meeting and date:
☐1 research stage (introduction)
☐2 research to requirements stage-gate.
☐3 requirements to design stage-gate.
☒4 design to assessment 1 stage-gate.

Stage Progress: (To be completed by the group before meeting) LIST all of the work you will present to your mentor during the meeting. Your academic mentor is NOT a subject-matter expert on your challenge. They are there to discuss and facilitate your groups progress and provide verbal feedback on your work you bring them.

Between the last meeting we have completed our seperate designs for each section. All other work has been completed and added to our final document.
- Our only issue is we are slightly confused over the format of the final submission.

Group functioning issues: (To be completed by the group before meeting) *specific non-technical issues hindering group performance which may include punctuality, attendance, lack of preparation, disruptions, dominant personalities, work quality, and what can be done to improve matters.*

No functioning issues

What was done well in this stage and what could be improved during the next stage (To be completed by Academic Mentor) – Formative feedback.

Feedback on final design and report

Initialled:
Present: S.C   Absent:

Initialled:
Academic mentor

Once you have completed this form, one group member should scan & upload it to the appropriate canvas assignment. Note that in fairness to all groups, meetings should last no longer than 20 minutes.

APPENDIX C: RESEARCH JOURNAL CLUB REPORTS

Group number: 1 Person leading this discussion:

Journal Paper:

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* This paper has addressed a problem that with increasing areas of cities and declining of farmlands, our production of food will be reduced, so appropriate vertical agriculture systems with various technologies should be utilized in different residential apartments to provide maximum production with minimal environmental impacts while minimizing the use of land. Background：Paper tells us that urban agriculture will probably be more important because of the increasing areas of cities and declining of farmlands, such as Dubai which has 127,621 buildings in urban areas versus 6,460 rural buildings and Florence surrounded by orange and olive groves and wheat fields
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* What I have learned from this paper is that: I.The reasons why vertical agriculture becomes important are reduction in food waste, adaptive utilization of built context and revenue generation. ①According to the UAE Food Bank the cost of discarding food in Dubai amounts to AED 282 annually. ② Apartment buildings of Dubai estimate to 432,023 most of which provide the possibility of adaptive reuse of balcony spaces for urban agriculture [2]. The coexistence of apartment residents along with agricultural production will reduce labor costs of growing food otherwise in green houses. ③The vertical farming market is expected to reach $9.9 billion by 2025 in which the increased use of Internet of things (IoT) sensors for producing crops is under research. II.The technologies applied in vertical farming are Hydroponics, Aeroponics and Aquaponics. ①The most widely used vertical farming system is Hydroponics in which mineral and nutrient solutions in water are used to grow plants. This method does not use soil or gravel as an inert medium. The plant roots are submerged in the nutrient solution, which can be monitored and circulated with the help of smart systems and devices. ②The technology of Aeroponics was developed by The National Aeronautical and Space Administration (NASA) which was interested in finding efficient ways of growing plants in space. This indoor technique is a step forward from Hydroponics since it allows rapid growth of plants with no soil in an air/ mist environment. ③This is a ‘bio-system’ which combines water and fish in the same ecosystem. Waste from the fish tank is used to fertigate the hydroponic production beds。 III.Several types of structure are suitable for different vertical farming, which are adaptive reuse of buildings, modular units and shipping containers, rooftops and balconies and other innovative structures. IV.Comparative analysis of farming structural systems used in vertical farming. Other information I require is the specific information about Hydroponics used in vertical farming such as how much water may be consumed daily and the factors causing waste of water.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*
I can summarize information from paper, and give useful and practical knowledge to my teammates for group session and conclude information about Hydroponics from this paper and make a table about water used in vertical farming.

Actions:

1summarize information that we have learned

2discuss the elements of the vertical farming

3exchange the knowledge from different paper

4search for more knowledge.

….

Group number: 1 Person leading this discussion: Lucy Grimes

Journal Paper: Is it time to take vertical farming seriously?

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*
The paper states the 5 main reasons why vertical farming should become a reality:

1. It would provide year-round, affordable food which would reduce the malnutrition of the global population. Currently around 2 billion people are faced with this problem.
2. This type of farming would be healthier and reduce the resources needed. There would be no need for harmful pesticides in food which contribute to health issues. It would be unaffected by droughts and floods etc. It would only need the space of a footprint of the building and therefore field space would be saved. It would use only 5% of the water that is currently needed. Cutting down on water usage dramatically improves sustainability especially in low income countries where there is poor management of desalinisation, irrigation, drainage, waterlogging of soil and water pollution.
   2b. Using the most appropriate technologies, yields of vegetables are higher and growth cycles are shorter. Lighting is essential for this – certain LED wavelengths are optimal for growth.
3. The supply chain for a vertical farm is short as the food is grown very near to where it will be consumed. Less emissions are produced from transportation and the food is very fresh.
4. Climate change and the extreme weather conditions that are associated cause uncertainty currently in agriculture. Crop losses, yield variation and therefore prices are an issue. They would not be with the vertical farm.
5. Vertical farming will be better able to cope with the food pressures of an ever-growing population, with many people living in urban areas. There will also be less need for calorie-dense packaged foods that last as people will be able to access much more fresh food. Therefore, the health of the population will be improved especially in areas such as hearts and diabetes.

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* - Seasonality and 'price volatility' would not be an issue as the crop would be regular and year round, not affected by the weather or conditions. - It would require no soil, no pesticides, very little land in comparison and only 5% of the water. - The water in the country would improve as there would be less contamination and less pressure on the systems as less would be being used overall. This is a much more sustainable rate of use of the water resources in the country. - The vertical farm should have latest in lighting technology as certain LED wavelengths are optimal for growth and, along with other technologies, will produce a higher yield with a shorter growth cycle. - Importation of foods will no longer be as common as the food will be able to be grown in the vertical farm regardless of the natural climate of the country. - CO_2 in the air should be higher than normal as this results in better plant growth. - Issues of climate change and extreme weather conditions will not need to be addressed in the project as they will not affect the vertical farm. - Vertical farming will be a sustainable way to provide food for a large and growing global population.
Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* - The type of food that is grown should be affordable vegetables and staple crops which would reduce any malnutrition issues in Tokyo and the surrounding local countryside. - The crops should be organically grown as this will improve health in the city by the reduction of chemical such as pesticides. - Technologies including light and gas control need to be implemented for best possible yield and plant growth.
Actions: 1 Research the type of food that should be grown in the vertical farm and their optimal growing conditions to get the right type of lighting and other factors. 2 Consider the most natural ways to farm without the use of chemical supplements to ensure the health of the surrounding population. 3 Ensure there are low emissions, especially when considering the transport of the food after growth and the packaging, or lack thereof, there should be.

Group number: 1 Person leading this discussion: Lucy Grimes

Journal Paper: Plant Factory, Chapters 10, 11 12

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*

Chapter 10: Growth, Development, Transpiration and Translocation as affect by abiotic and environmental factors.
Chapter 11: Nutrition and Nutrient uptake in soilless culture systems
Chapter 12: Tipburn

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*
Chapter 10: Plant growth depends on the following; temperature, light intensity, light quality, humidity, CO2 concentration, air current speed, and nutrient environment.

- Temperature: optimum leaf temperature for maximum growth rate is 26^{o}c.
- Light intensity: canopy net photosynthesis (which needs to be as high as possible) is affected almost linearly by incident irradiance over the canopy. In general, 1% increase in light leads to 1% increase in yield. Daily photosynthetic photon flux (DLI) goal – how much light the plant gets - is 12-17mol m-2 d-1 for leafy crops. This can be achieved through 18 hours of 185µmol m-2 s-1.
- Light quality: plants have higher photosynthetic efficiency in red lights (700-800nm wavelengths) apart from in dense canopies.
- Humidity: Indirectly affects nutrient uptake, leaf temperature and plant growth. Optimal is increasing humidity through the photoperiod and decreasing through the night period.
- CO2 concentration: Optimal is 400ppm. Increased yield by 52% in vegetative biomass.
- Air current speed: Achieves spatial uniformity of air temperature. Must avoid strong air currents to not put the plants under mechanical stresses. An average of 0.5ms-1 air current is used in many greenhouse settings. Anything over 1ms-1 will harm the plant growth.
- Nutrient environment: Factors are electrical conductivity, pH and dissolved oxygen concentration. These must be kept optimal.

Chapter 11: Nutritional information for plants

- An essential element has the following characteristics; if the element is absent, the plant cannot complete its lifecycle, various deficit symptoms show if the element is absent, only that element can restore the plant (there can be no substitutes possible).
- Essential elements for plants are as follows: macronutrients: carbon, oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, micronutrients: boron, iron, manganese, zinc, copper, molybdenum, chlorine, nickel.
- These are essential, however, there are a number of other elements that are considered 'beneficial' to growth but not essential.
- Refer to table in this chapter for why each of the above are essential to growth.
- In a soilless culture, all plants need to be in a liquid nutrient solution.
- The table shows some of the liquid fertilisers already available and used widely in Japan.

Table 11.5 Typical Formula and Composition of Nutrient Solution

Formula		Concentration (mM)					
		NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg
Enshi (Nat. Hort. Exp. Sta.)		16	1.3	1.3	8	4	2
Yamasaki	Melon	13	1.3	1.3	6	3.5	1.5
	Cucumber	13	1	1	6	3.5	2
	Tomato	7	0.7	0.7	4	1.5	1
	Strawberry	5	0.5	0.5	3	1	0.5
	Sweet Pepper	9	0.8	0.8	6	1.5	0.8
	Lettuce	6	0.5	0.5	4	1	0.5
	Eggplant	10	1	1	7	1.5	1
Hoagland & Arnon (1938)		14	1	3	6	8	4
Holland (Rockwool, Tomato)		10.5	0.5	1.5	7	3.8	1

Date (2012).

- For maximum nutrient uptake, the pH should be controlled at around 5.5-6.5.

Chapter 12: Tipburn is a condition in many plants caused by calcium ion deficiency. It causes cell death or abnormal cell formation. There are two factors affecting this: low concentration of calcium in the nutrients supplied to the plant or poor uptake of those nutrients. It is possible to grow

versions of a plant that are resistant to tipburn. However, the most effective way of dealing with it is to ensure the ratio of calcium in the soil and the amount the plants need is balanced.
Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* This paper gives very specific details about the conditions the plants should be grown in for maximum yield and efficiency. This should be done in a sustainable manner in our project. We should also be aware of the possibilities of an unsuccessful crop if these conditions are not followed and there are deficiencies in the growth systems. In a real-world situation, the employees should be given easy access to all of these details in order for them to carry out the correct procedures and remain vigilant to signs of an unhealthy crop.
Actions: 1 Implement the environmental conditions that are researched in the article. 2 Ensure all sub-systems are capable of delivering the correct conditions for the crops. 3 Allow systems to provide feedback in order to maintain a healthy crop and make changes that are not working. ….

Group number: 1 Person leading this discussion: Emma Howard

Journal Paper: Plant factory: an indoor vertical farm system for efficient, quality food production

Chapters 1:9

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given? This paper starts by explaining problems that come with using current farming techniques with involve outside production and/ or with the use of greenhouses. For example, problems addressed where with: weather issues, insufficient land, insects etc and explains how greenhouses are inefficient. There is good background context as it explains what explains what we require in terms of food production and then it gave examples of problems that we have encountered with our current methods of farming. It then introduces the use of PFAL (plant factory using artificial lights) methods of vertical farming as a solution of food production and then it discusses concepts on how this is possible. For example, they can be used anywhere as not affected by climate or soil fertility, they will use phytonutrients to enhance growth, less need to travel cross country if built in cities on top of existing buildings etc.*
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* This paper has thought of things that we would need to consider/ calculate if wanting to design a vertical farm, for example it has provided equations for things such as CO_2 use by considering photosynthetic rates and respiratory rates and water use efficiency calculations. It also discussed what light frequencies are best for plant growth and it compared efficiencies with more

calculations. It gave examples of how humidity needs to be controlled and which air flow values from fans is required to prevent differentials in temperature. It discussed which plants you should use to make a vertical farming system feasible and efficient enough i.e less than 30cm as to enhance production it would require the use of shelves stacked up on each other With this information I will now have to research what technology I may need in my farm e.g. dehumidifiers, air conditioning units etc. I will also need to find out the energy usage from these systems as I am working of energy flows in our farm.
Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* Using the papers knowledge, I now know to consider the use of LEDS as they are one of the best artificial lights to use to grow plants. I will consider using plants that grow to less than 30cm and that have a high plant density. I will consider using fans/ air conditioning to promote a forced convention at a rate of 0.01-0.02 m/s which was suggested by the article. I will consider using dehumidifiers to maintain a stable environment and I will consider using/recycling condensation.
Actions: 1: I will research plants that grow to less than 30cm and that have a high plant density. 2: I will use calculations provided to consider carbon dioxide levels required, water efficiency, and light energy usage. 3: I will research how much energy will be required for technical equipment such as fans, pumps, dehumidifiers that the paper suggested using. ….

Group number: 1 Person leading this discussion: Jonathan Sill

Journal Paper: Agriculture: A Very Short Introduction

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* Gives a very brief introduction to varying levels of agricultural production, and the principles that determine their differences and functions.

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

- Essentially input > growth > output
- Functionality and efficiency vs cost and feasibility/scale
- Modern methods vs manual methods
- Soils will dictate which crops can grow, depends on parent material, climate, topography of site, organism living in and on the soil etc
- Different species are suited to different conditions and soil
- Soil texture also effects how fertile and workable it is
- Drainage/irrigation can affect workability, growing season, fertilizer efficiency and root depth
- Plants get nutrients through their root system, and oxygen, hydrogen, carbon dioxide and sunlight from their leaves
- pH and mineral vs natural fertilizers is important
- Plants require light, heat, water, and nutrients to varying levels
- Always worth growing crops that are native to the area or suit the natural conditions, as that saves from having to have systems to change the natural conditions
- Prevent and mitigate the effects of weeds, pests and diseases
- Proper spacing is important for crops to grow, as well as not over planting with seeds
- Starch-based foods are the most filling and effective in feeding people
- Multi-use crops are better eg wheat makes bread and barley makes beer, and both can also feed animals
- Animals are not necessary for a healthy diet, and in addition are hard to farm in a VF
- If animals are farmed its important to use every part of their body
- Breeding, feeding, harvesting would all have to be considered and are harder to automate
- Inputs: Land, Labour, Water, Nutrients, Light, Temperature and Time
- Farms differ, inextensive/extensive, simple/advanced technology, large/small, mixed/specialised, tropical/temperate, close/far to market etc
- Sustainability is they key, where the production of the farm produce does not hinder the ability of produce to be made in the future (ie does not have any negative outweighing effects) consider resources finite and infinite, renewable etc particularly for fertilisers
- Adopting organix farming methods is the best way to keep the VF sustainable
- Consider how it will affect the wildlife and landscape
- Climate change could lead to more rain
- Climate affects agriculture but agriculture affects climate change
- In order to be effective, reducing food waste and overproduction is also important

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*
This article gives us a very strong look into the agriculture side of our VF project, and lets us incorporate the knowledge by using it to analyse the most effective crops to grow, and giving a detailed list of factors to keep in mind when we design the structure and suit it to the crops we choose

Actions:

1. Decide which crops it is we want to grow

2. Affirm what conditions it is that each of them grow in

3. Think more broadly about effects on environment and waste

Group number: 1

Person leading this discussion: Jonathan Sill

Journal Paper: Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production, Chapters 13-15

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

Chapter 13 - Functional Components in Leafy Vegetables

- Artificial lighting enables close factor control
- By altering these factors, the vegetables can be grown with desired characteristics as the acclimate to the change in factors
- Low-potassium vegetables can be grown which are have health advantages, but have higher sodium concentration levels
- Done by reducing potassium and sodium in fertiliser 2 weeks before harvest
- Mainly leafy vegetables, but inventor is developing melon, tomato and strawberry variants
- Low-nitrate vegetables are healthier, also done by reducing nitrates in fertilizer, or harvesting in the afternoon which encourages nitrate assimilation
- By controlling light quality and the type of light (often fluorescent lamps), UV-B, UV-A, or blue light, the levels of different nutrients within the plants change (different for different species)
- Depending on the functional ingredient you want to harvest, it can sometimes be better to induce stress onto the plant, in the form of poor typical growing conditions (abiotic stress)
- Stable mass production is the next step – and controlling light quality to increase biomass productivity

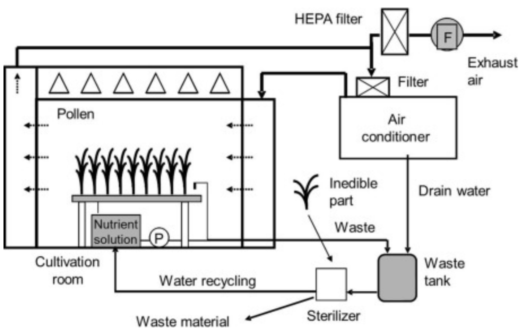
Chapter 14 - Medicinal Components

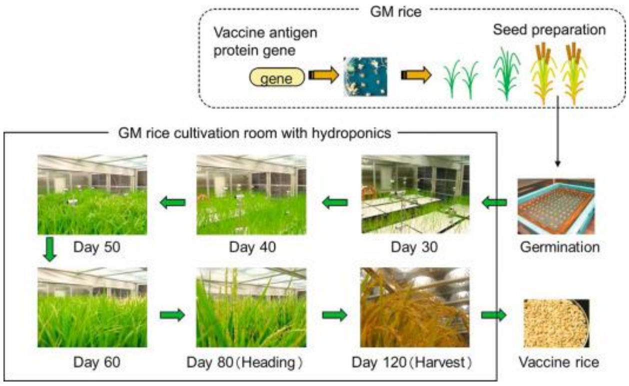
- Previous chapter also applies to medicinal plants
- There is currently no procedure for growing medicinal plants en masse, and is instead based on collecting wild plants
- Controlled conditions allow for efficacy, consistency, year round harvest, safety, and maximised biomass production
- Factors affecting concentrations of secondary metabolites: CO2 concentration and photosynthetic rates, temperature stress, water stress, spectral quality and UV radiation

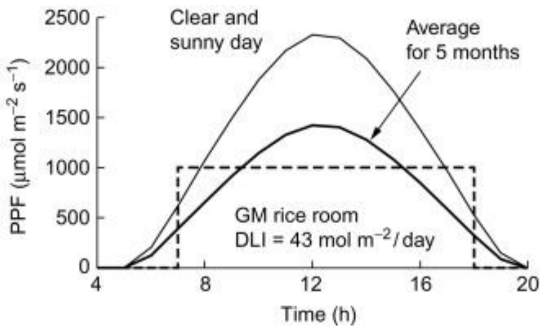
Chapter 15 - Production of Pharmaceuticals in a Specially Designed Plant Factory

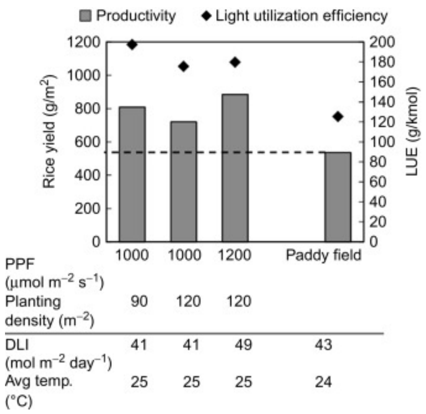
- Plant factories proposed, developed, and implemented inJapan in the 1980s
- GM plants can be used to reduce costs, be more resistant, grow faster, etc
- Oral vaccines, functional proteins, and pharmaceutical material can be grown with GM host plants (such as rice for the cholera and influenza vaccines)
- Ideal light conditions for rice - light intensity at 1000 µmol m− 2 s− 1 PPF and light period at 12 h day− 1 so the Daily light integral reached 43 mol m− 2 day− 1
- Air temperature at 27 degrees celsius for light period, and 23 for dark period, so daily average was 25.
- Relative humidity set at 70% and CO2 concentration was set at 400 µmol mol− 1.
- Plant density between 90-120 per metre squared, effects lighting efficiency and productivity

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* Plant factories exist in Japan and we can look at these as case studies, we could look at pharmaceutical plants however we are more focused on solving a hunger problem. It is also clear that controlling the type and intensity of lighting will highly impact crop growth.
Actions: **1.** Most of this paper was slightly irrelevant for our vertical farm it would seem, but it is clear that a artificial controlled lighting system needs to be employed in our vertical farm. Below are some of the figures shown in the journal.









Group number: 1 Person leading this discussion: Jonathan Sill

Journal Paper: The vertical garden city: towards a new urban topology

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* Argues that Ebenezer Howards concept of the garden city although outdated and misconstrued in some ways, had goals and conservation ideas which are more relevant today then in his age. It also goes on to highlight modern innovations that could aid the garden city, as well as constraints – all from a more architectural point of view. (also focuses on Australia)
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* • Australia has a particularly tough challenge with regards to future agricultural developments • VFs can be incorporated into normal buildings, transport etc

- Architecture has been forced to accept more densely packed designs
- Stresses the importance of taking vertical space to be as significant as horizontal space
- New urban topology
- Incorporation into modern architecture as opposed to solo builds

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*
Can use the paper to give inspiration as to the outer façade of the building as well as the geometric form, to find one that is both multi-functional and aesthetic

Actions:
1. When designing a floor plan consider making good use of space, with densely packed floors. As well as this making use of a multiple floor system as a vertical farm enables more farmland without expanding horizontally.
2.Incorporate modern technology into our design build, this can be achieved through the design of the moving façade.

Group number: 1 Person leading this discussion: Jonathan Sill

Journal Paper: Vertical farming: a summary of approaches to growing skywards

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* Inefficient crop yield per unit area of cultivation – this paper clarifies the main types of vertical farm (VF) and discusses how more research is needed into this area to determine its feasibility as a substantial adage to global food production.

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

- Agricultural production needs to increase yields as population increases
- Population increase will cause loss of farmland however
- Soil-free growing systems are appealing for urban use (suited for horticultural crops)
- Types: 1 stacked horizontal systems and 2 vertical growth surfaces
- 1 – multi level traditional growing platforms, rock-wool or similar instead of soil. Uses hydroponics, aquaponics and aeroponics, often use nutrient recirculation systems, in glasshouses or controlled environment facilities, usually just one crop or similar crops at a large volume, shorter the crop = more levels and compact
- 2 – harder to harvest, can be exposed to urban pollution, light availability is a factor, more compact, also uses soil alternatives and nutrient supply, more efficient per unit area for cylindrical
- Crop choice in both is limited – mainly small leafy vegetables favoured due to fast growth and small size
- Start-up costs are very high, but running cost moderate
- Usually designed for urban areas but can be anywhere even rural
- Glasshouse more expensive than CE due to custom form, but CE requires artificial lighting
- Estimated to produce 1kg of food for around 3-4 Euros, so costs can be recouped rapidly depending on crop and market price (i.e expensive veggies and fruit)
- Reduced environmental impacts, but not as much as often suggested
- GHG production fairly high
- Have to find balance between energy efficiency and water efficiency

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*
Gives a good general explanation of the types of VF and also considerations to take into account and its implications on success

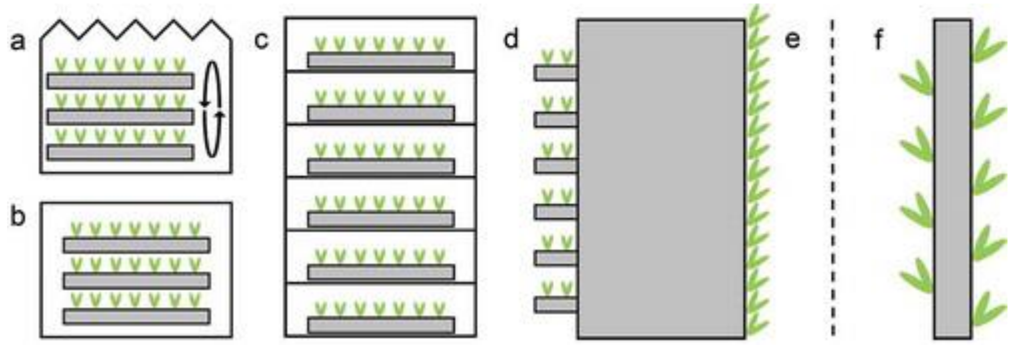
Actions:

1 Decide on the type of VF that we want
Type B

2 Firm up location to allow other parts to be decided

3 Think about GHG

4 Choose crops and farming methods
Image below is from journal



Group number: 1 Person leading this discussion: Anas Najeeb

Journal Paper: Assessment of light adequacy for vertical farming in a tropical city

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*
This paper raises the challenge of adequacy of light in compact cities where amount of space is limited for urban farming which further asks the important question whether it is possible to grow leafy vegetables which require high amounts of sunlight and form a significant staple diet in many Asian countries. To answer this, a study was conducted measuring photosynthetically active radiation (PAR) and daily light integral (DLI). The study also assessed how PAR varied at different height, configuration and façade orientation.

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*
- This study confirms the potential for vertical spaces to support urban farming.
- PAR gradually increased in height and was heavily influenced by façade orientation and design configurations.
- Vertical agriculture can be considered a way of delaying heat transfer to buildings.
- Use of additional illumination to extend the photo-period to 16-24 hours and disperse the intensity of instant PAR levels allowed increased biomass in many crops.

• Plants with root zones cooled to lower temperatures display higher levels of photosynthesis.
Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* The idea of measuring PAR and DLI can be helpful in choosing the appropriate crop for the vertical farming project. Cooling of rootzones can be implemented in the project to increase photosynthesis.
Actions: 1. Research further on devices used in vertical farms to measure and monitor PAR and DLI. 2. Exchange the idea of cooling roots for increased photosynthesis. 3. Research the daylight and sunlight hours of Tokyo.

Group number: 1 Person leading this discussion: Anas Najeeb

Journal Paper: LEDs for photons, physiology and food

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* This paper discusses how light-emitting diodes (LEDs) are not only energy-efficient than other lighting systems but also shows how it can play a major role in improved performance and control of human health and growth of plants. The paper does this by explaining how LEDs are already in play in clinical and non-clinical applications and their potential in enhancing human performance in terms of psychomotor vigilance and neurocognitive responses such as cognitive throughput sustained attention and more. It also shines a light on the benefits of LEDs on the growth of plants by discussing the effects of each element of LED on plant anatomy.
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* • Unlike other lighting systems, LEDs can be easily altered in terms of intensity, light distribution and spectra making it to be called engineered light. • Exposure to white light can enhance subjective and objective alertness. • LEDs may be useful in decreasing some forms of cancer • The interaction of plants with different wavelength, intensity and time of exposure • Speaks about a formula which can provide a grower a rough idea of the Efficacy of production. • LED based farming in a controlled closed environment can reduce the need of pharmaceuticals for pests & makes water recyclable by condensing the water vapour in the AC and returning it to the root zone.
Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* 1. By using the understanding of how plants interact to different lighting conditions to tailor the right lighting settings for our vertical farming crops.

2. Using the Efficacy of production formula, I can ensure that the crop chosen can be harvested with more efficiency.
Actions: 1. I will research about LEDs used in vertical farms. 2. I will research further about how plants react to different settings of lighting. 3. I will use the Efficacy of production formula.

Group number: 1 Person leading this discussion: Anas Najeeb

Journal Paper: Plant Factory – Chapters 22, 23 and 24

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*

Chapter 22: This paper discusses about design and management systems that is essential to understand and manage various fields like LS (Light sources and Lights systems), environmental measurement and control, management of energy and more.

Chapter 23: This Chapter discusses automated technologies used in PFALs by examining a leading large scale PFAL in Japan. This factory used a seedling robot system, an automated cultivation system and LED light sources.

Chapter 24: This paper discusses about Life Cycle Assessment which is a useful tool in quantifying environmental aspects of a product's life cycle.

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

Chapter 22:

- PFAL-D&M systems consist of design, management and database.
- There are 2 types of data acquisition and upload. The first type is installed in an existing PFAL to acquire information for research for the to be built PFAL while the second type is installed in the newly built PFAL to compare with the first information or previous information and control various systems.
- PFAL- Design consists of sections such as "housing and infrastructure," "measurement and control," "requirements, constraints and specifications" and "equipment and facilities". The design subsystem is processed in the cloud service area.
- Lighting system are designed to respond to the software and stimulate the lighting environment using the values given from PFAL-D subsystem using mathematical equations.
- The PFAL-M subsystem deals with sections such as "plan and finance", "marketing", "PM" and " development and renovation". This system is further divided into customer development, data, control, vision, missions, etc.
- COP (Coefficient of Performance) is affected by cooling load and temperature difference between inside and outside.

Chapter 23:

- For large-scale seedling diagnosis, a robust, high-speed image processing system is usually adopted. An image is taken to analyse the size and shape of the seedling.
- The seedling diagnostic system consists of a blue chlorophyll excitation LED and a high-sensitive, high-resolution, cooled charge-coupled device (CCD) screen. A germination panel is carried into the dark using an automated conveying device where the

fluorescence emitted by the chlorophyll pigment of the plants excited by the blue LED light is captured. Using the data calculated (size, shape, chlorophyll fluorescence intensity, etc), the seedlings' suitability is quantified by a predetermined evaluation function.

- To achieve minimise the amount of bacteria in the production area, safety, unmanned operation and reduce labour costs, a shuttle-type transfer robot is used to move the cultivation table.
- A cultivation panel washer is used to prevent the breeding of bacteria.
- Sharp increase in phytoplankton worsens quality. The increase is caused when light hits on nutrient solution.

Chapter 24:

- LCA can evaluate environmental impacts through the analysis of inventories of included processes in a target life cycle.
- The procedure for collecting inventory data for each stage of the life cycle starts on the basis of the data requirement, especially what type of data is required for the stage: foreground or background data.
- Foreground data means that the data can be accurately applied to the target items, while background data can be derived from specific or temporal averages.
- Techniques of evaluation of the life cycle impact allow practitioners to identify direct and indirect effects by omitting environmental loads from the target life cycles.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*

These chapters will be beneficial to set up systems, robots and assessments required to run the vertical farm smoothly.

Actions:

1. Research further on control systems and find suitable lighting control system for the vertical farm.
2. Research about management systems in a vertical farm.
3. Research more about automation systems used in vertical farms.

Group number: 1 Person leading this discussion: Rongsen Wang

Journal Paper: A Comparative Analysis of Vertical Agriculture Systems in Residential Apartments

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*

This paper has addressed a problem that with increasing areas of cities and declining of farmlands, our production of food will be reduced, so appropriate vertical agriculture systems with various technologies should be utilized in different residential apartments to provide maximum production with minimal environmental impacts while minimizing the use of land.

Background：Paper tells us that urban agriculture will probably be more important because of the increasing areas of cities and declining of farmlands, such as Dubai which has 127,621 buildings in urban areas versus 6,460 rural buildings and Florence surrounded by orange and olive groves and wheat fields

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

What I have learned from this paper is that:
I.The reasons why vertical agriculture becomes important are reduction in food waste, adaptive utilization of built context and revenue generation.
①According to the UAE Food Bank the cost of discarding food in Dubai amounts to AED 282 annually.
② Apartment buildings of Dubai estimate to 432,023 most of which provide the possibility of adaptive reuse of balcony spaces for urban agriculture [2]. The coexistence of apartment residents along with agricultural production will reduce labor costs of growing food otherwise in green houses.
③The vertical farming market is expected to reach $9.9 billion by 2025 in which the increased use of Internet of things (IoT) sensors for producing crops is under research.
II.The technologies applied in vertical farming are Hydroponics, Aeroponics and Aquaponics.
①The most widely used vertical farming system is Hydroponics in which mineral and nutrient solutions in water are used to grow plants. This method does not use soil or gravel as an inert medium. The plant roots are submerged in the nutrient solution, which can be monitored and circulated with the help of smart systems and devices.
②The technology of Aeroponics was developed by The National Aeronautical and Space Administration (NASA) which was interested in finding efficient ways of growing plants in space. This indoor technique is a step forward from Hydroponics since it allows rapid growth of plants with no soil in an air/ mist environment.
③This is a 'bio-system' which combines water and fish in the same ecosystem. Waste from the fish tank is used to fertigate the hydroponic production beds。
III.Several types of structure are suitable for different vertical farming, which are adaptive reuse of buildings, modular units and shipping containers, rooftops and balconies and other innovative structures.
IV.Comparative analysis of farming structural systems used in vertical farming.

Other information I require is the specific information about Hydroponics used in vertical farming such as how much water may be consumed daily and the factors causing waste of water.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*
I can summarize information from paper, and give useful and practical knowledge to my teammates for group session and conclude information about Hydroponics from this paper and make a table about water used in vertical farming.

Actions:

1.summarize information that we have learned

2.discuss the elements of the vertical farming

3.exchange the knowledge from different paper

4.search for more knowledge.

….

Group number: 1 Person leading this discussion: Rongsen Wang

Journal Paper: The Vertical Farm: A Review of Developments and Implications for the Vertical City

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* Issue：food security, urban population growth, farmland shortages, “foodmiles”, and associated greenhouse gas (GHG) emissions Background：As cities try to cope with rapid population growth—adding 2.5 billion dwellers by 2050—and grapple with destructive sprawl, politicians, planners and architects have become increasingly interested in the vertical city paradigm.
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* Reasons for vertical farms: food security, climate change, urban density, Health, the ecosystem and economics. Automatic management Closed-Loop Agricultural” Ecosystems “Closed-loop agricultural” ecosystems intend to mimic natural ecosystems that treat waste as a resource. the waste of one part of the system becomes the nutrients for the other. Ananaerobicdigesterisabiogasrecoverysystemthatconvertsfoodwasteintobiogastoproduce power and heat Renewable Energy Integration within City Infrastructure：the vertical farm will collect organic waste, carbon dioxide, manure, CO2, and excess heat from plants and factories, and transform these into biogas for heating and cooling. Multi-Functional In addition to farming, the multifunctional vertical farm incorporates functions such as office space, hotel, and retail space as well as residential and educational uses. Advancements in greenhouse and supporting technologies such as multi-racking mechanized systems, recycling systems, LED lighting, solar power, wind power, storage batteries, drones as well as computing power, software applications, databases
Impact: *Consider how you can incorporate elements of the papers’ knowledge and contribution into your design* I can summarize information from paper, and give useful and practical knowledge to my teammates for group session and conclude information about Hydroponics from this paper and make a table about water used in vertical farming.
Actions: 1.summarize information that we have learned 2.discuss the elements of the vertical farming 3.exchange the knowledge from different paper 4.search for more knowledge.

Group number: 1 Person leading this discussion: Lucy Grimes

Journal Paper: The Urban Bio-Loop

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*

- Problem: construction is unsustainable in the way it is being handled currently with the use of 'high impact materials, non-reversible building solutions, low efficiency processes and manufacturing.'
- Considers how organic waste can be managed alternatively from the traditional methods of incineration, landfill and composting and used as a resource for construction and architecture projects.
- Focusses on a circular economy where using waste products in construction benefits the economy.
- It can then be 'fed back in' to the bio-cycle at the end of its life.
- Looks into technical, social and economic standpoints of using waste in this way.
- Considers how cities could become self-sustaining in using organic waste in building construction materials.
- 30% of EU waste comes from construction
- Would benefit both the economy and the environment by reducing CO_2 involved in construction and converting low-value waste into a more valuable product.

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

- Relevant main areas for the use of bio composites in contruction: Interior wall partitions and finishes on interiors, thermal insulation, residential or industrial carpeting.
- Natural fibres can be used in construction; flax, hemp, jute and natural resin. They are fast growing and regenerate in short cycles. Lightweight, durable and have good mechanical properties.
- Straw has been identified as suitable in the UK by DEFRA (Department for Environment, Food and Rural Affairs)
- Seasons will affect the availability of the raw materials. The materials on offer will change through the year but there will still be some on offer all year round.
- Biocomposites reduce the embodied energy of a material.
- BIQ Hamburg had an outside surface that cultivated micro-algae to generate heat and biomass as a renewable energy source.
- The Mushroom Tower was a temporary structure that used mushrooms as its base building material. Bricks were grown in 5 days and once the structure was used, it was taken down and used as fertiliser after composting.
- There are implications of this method with cost and availability of raw materials.
- To consider applying this to our project, we would need to research associated costs with transport and these materials compared to regular building materials. We would also need to research the impact that using these materials would have on the design eg. Is there limited weights or forces that these materials can withstand compared with regular materials. Is this method of building suitable for our city? Tokyo is earthquake prone and therefore we will need to consider closely this element.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*

- There are many elements of this paper that can contribute to the design of the structure. We can consider the use of certain biocomposite materials.
- If they are not suitable for the main structure then they can be used for insulation, interior structures, and farming systems.
- The energy generation by the micro-algae would also be an applicable idea for this project.

Actions:

1 Research the financial implications and practicality of using the biomaterials in the construction of the building and look at more case studies of how this has already been done with previous buildings. 2 Consider how this would reduce the waste and emission involved with the structure. 3 Implement what has been learned from the paper into the key design aspects of the project. With details of costings, emissions, effect on the local economy, and suitability for the environment in Tokyo.

Group number: 1 Person leading this discussion: Emma Howard

Journal Paper: Vertical farming: sky scraper sustainability.

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* The main issue this paper addresses is the fact that by 2050 there will be a population of roughly 9 billion people which puts a strain on earths resources I.e having enough resources for food production. Which therefore leads to the idea of indoor vertical farming. It says that there are currently no studies to quantify/validate this concept, so there is little information this article can compare its research too, however it focuses on possible concepts and it tries to build models to suggest whether the idea of vertical farming could be feasible.
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* *This paper has outlined many concepts that need to be considered to make vertical farming possible which will help as I know what information I need to research before making decisions for possible designs. It highlighted that the main energy demand will be for lighting and water pumping, but energy will also be required for propagation, fertilization, irrigation and harvesting.* Understanding things like this will helps to consider other factors such as what shape/size the building should be as we need enough room for solar panels to provide energy for these processes. It has recommended that plants should have 18 hours of light each day and therefore once research has been done on the weather in Tokyo, we can understand how much energy will be required in an average day. The article published some research on how much CO2 is produced per KG for lettuce in an artificial environment and compared it with field grown, this information was useful but research on more vegetables would be useful as demands for a city would require many different crops.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* As the article focuses on trying to understand if vertical farming is feasible it has considered many factors and it has provided estimates which can be used when trying to figure out how to design or own farm for example now I understand how much light is needed for a plant per day so once I've found out how much solar radiation Tokyo has in an average day I can calculate how much energy we need to use on lighting per day. It recommended using either LED or high-pressure sodium bulbs for artificial farming, therefore this helps as I can now compare the 2 which will provide the best quality/ efficiency for my production. It provided with rough data on how much water is required per square feet so once, designs for structure are made it will be easier to understand roughly how much water is required per day.
Actions: 1) I will research how much solar radiation Tokyo has in a day and also how this changes throughout the year as vertical farming is expected to be efficient and therefore rely mainly on solar panels to provide energy. 2) I will research data on different vegetables to understand how much energy they require to grow/ their carbon footprint in artificial conditions to understand whether using vertical farming will be efficient or not compared to land grown which can ultimately decide which vegetables can be grown 3) Decisions on how tall and wide the building will be considered as how wide it is affects how many solar panels we can fit but also how tall needs to be considered as it will provide more space but also it will require more energy as it gets taller to pump the water up to each level.

Group number: 1 Person leading this discussion: Sam Cook

Journal Paper: Agriculture: A very short introduction

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* Various different aspects of agriculture. The most relevant parts for our interests are the issue of modern farming and future farming methods. Also addresses the different categories of soils and crops, which is useful to understand given the nature of our project.
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* **<u>CROPS</u>**

Arable farming of root crops, seeds, protein and oil crops etc… are what provide the majority of human and animal food. There is use of fertilizers, pesticides, herbicides, fungicides and insecticides to encourage crop growth. Nitrogen, phosphorous and potassium are the essential nutrients for plant growth. Soil is a mix of air (normally 25 percent), water (another 25%) minerals (roughly 45%) and other organic matter.
The carbon cycle is necessary for plant growth. In this paper is a table of different soil minerals and their characteristics. Soil texture is a key part of its fertility. Sand drains easy but is not fertile and needs lots of water. Clay soils are more fertile but harder to work (due to larger surface area of pores and it is chemically reactive.) Loams or clay loams in general seem to be the best choice. Water is obviously important to crop growth and so artificial drainage is used-tile, pipe or mole drains. The paper talks of tables of soil classifications, which may be something that requires further investigation.
Plants get their major constituent elements—carbon, hydrogen, and oxygen—from the air they take in through their leaves and the water taken up by their roots. Apart from those, they require three elements in large quantities (macronutrients), another three in rather smaller amounts, and very small amounts of another eight, usually called the micronutrients.
What most manures and mineral fertilizers do is add to the amount available at the nitrate stage of the cycle. Sulphur calcium and magnesium are three nutrients that may not occur enough naturally. A PH between 6 and 7 is ideal for nutrient availability. Choice of manure, or organic/inorganic fertiliser will influence nutrient levels (particularly of the big 3). It is key to make sure soil is maintained.

The speed at which the crop grows depends upon the rate of photosynthesis, and that in turn depends upon light, temperature, the carbon dioxide concentration and the availability of water and nutrients. As the temperature and light intensity increase so does the rate of photosynthesis, as long as water is available. Increasing CO2 in greenhouses is good as it is CO2 that is the limiting factor. Research is currently going on to identify the genes responsible and to use them to produce a C_4 variety of rice. Optimum temperature for rice germination is 30-35. Day-length as well as temperature affect plant growth.

Need to understand further whether we would need to be aware of weeds- Farmers have developed numerous strategies for weed control. It is important to sow uncontaminated seed at the right seed rate into a fertile seedbed to give the crop the best chance of competing with weeds. Crop rotation is also used.
The most widely grown crops are rice, wheat, maize, potatoes, cassava and yam.
Further research may be required into specifically what type of crops it is that we want to grow.

The farmer prepares a seedbed, sometimes by ploughing to bury the remains of the previous crop, then cultivating to break down the clods of soil, before depositing the seeds in rows using a seed drill. They are then ready to grow when the soil warms up in the spring, and so maximize the period when they can photosynthesize most effectively. Once the crop is established it may be given one or more dressings of fertilizer, and herbicide and fungicide sprays. Harvesting takes place when the grain has filled and matured, in the case of cereals and oilseeds, and when little further growth is expected in the case of potatoes and sugar beet.
This is obviously a very basic outline of the process, and it should be clear that it involves many different decisions, about the best way to prepare the seedbed, which varieties to plant, what seed rate to use to produce the optimum plant population, how much fertilizer to use and when to apply it, which weeds, pests, and diseases might threaten the crop and how to combat them, when to harvest, and so on, all of which may vary from farm to farm, field to field, and even within the same field. Crop rotation again is key, we need to research which cycle would be most effective. In some rice-growing areas the land may remain fallow until the next rice crop is sown, but in some parts of

South East Asia, where the soil is suitable for cultivation in the dry season, the rice may be rotated with pulses, maize, or vegetables.

LIVESTOCK

The article discusses challenges regarding keeping livestock outdoors but this should not be an issue as part of a vertical farm. The sort of accommodation provided on farms is enormously variable. At one extreme there are simple buildings, little more than a roof, to keep the rain off; at the opposite extreme are controlled environment houses with artificial lighting, ventilation, and temperature control in which fattening pigs and broiler chickens may spend the whole of their lives. Egg laying by hens is stimulated by increasing day length, so if the birds are reliant on artificial lighting the farmer has greater control over their laying pattern. Control over day length also impacts crop growth. Animal welfare must be considered. Crowded housing may also induce stress in animals, as does hunger and thirst, and a stressed animal is more vulnerable to disease. There is information into animal health and disease although this may be for now, outside the scope of our key research. An intensive system is one which concentrates animals on a relatively small land area but uses a lot of labour, equipment, housing, and concentrated feedstuffs, whereas an extensive system uses more land and fewer of the other inputs. Thus most commercial pig and poultry units in developed countries would be described as intensive. Need to supply animals with food, water, shelter and heat (this could be automated.) Milking also needs to be taken into consideration. Knowing mating patterns and when births will occur is important- again will this be important to our research? Also knowing when they are ready for slaughter or not.

Agricultural products and trade

They are responsible for providing what are often classified together as 'ecosystem services': farmland is a habitat for many different kinds of wildlife, farmers may use (or allow other people to use) their land as a site for solar panels or wind-powered electricity generation, and many farming landscapes are beautiful to look at, so that farming produces a resource for the tourism industry. Food is however the most important. Do we also need to consider transportation of goods afterwards? There are also 2 tables dictating the most common worldwide crop and livestock products. When considering crop selection it may be useful to consider other uses some of the crops have, ie maize can become cornflakes or livestock feed or oil from soya beans can be used in the basis of margarine etc… Consider not just how many animals but how many animal products will be produced from livestock- this is because we want the most efficient farm. Pig production is large because of how quick they are ready to be slaughtered, and many cows aren't slaughtered due to their use for milk.

China is the biggest producer of pig, chicken, sheep, and goat meat, the US of beef and turkey meat, and India and Pakistan dominate buffalo production. Camel meat is the only product in which African countries dominate the market, with Sudan, Somalia, Kenya, and Egypt among the larger producers.

For staple foods, such as rice, maize meal, pasta, bread, or potatoes, the demand will not change much. Conversely, the market for luxury foods will be much more affected by the price level, because they are not a vital part of the diet, so a small price increase might cause a big decrease in the quantity consumed, and vice versa. There is also useful input regarding family economies related to food.

We are not a subsistence farm. A table shows that Japan is not a big exporter of farming goods, but is in the top ten of importing farming goods- this could be good to look further into.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*

One element of the paper's knowledge is the impact of balancing nutrients and pH levels in the soil/growing medium of the plants. This will need to be found out about each of the crops we choose to grow and monitored in our system-this suggests a level of automation could be used.

This paper also outlines the basic process of farming, which impacts how the farm needs to be set up.

Actions: 1. Research what it is that is imported, and see if we can grow these instead (is It viable in this environment) 2. Find a location and decide if this will be viable for livestock. The first impression is that no it will not be worth it. 3. Would have had to decide on a choice of soil, however from other group research we will not be using a traditional farm.

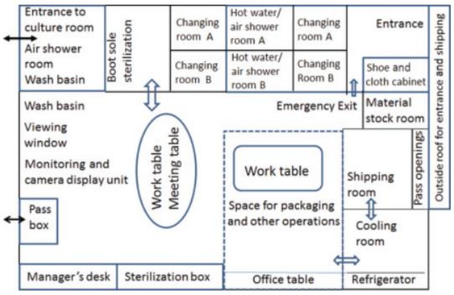
Group number: 1 Person leading this discussion: Sam Cook

Journal Paper: Plant Factory

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

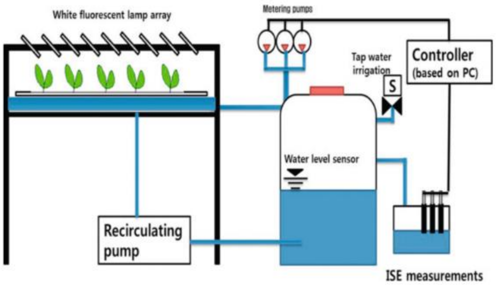
- In a plant factory with artificial lighting, manual operations need to be improved continually to stop waste, inconsistency and overburden.
- There are three principles relating to: human body, workplace arrangement and design of equipment.
- There is info on the PDCA cycle although this seems irrelevant
- In large productions most processes such as seeding, unloading and weighing are automated or semi-automated.
- There is a useful diagram of a standard PFAL, describing the layout and necessary features.



- Ion electrical conductivity based hydroponic systems are the most commercially viable choice but suffer from nutrient imbalance.
- Disinfection systems are also employed to prevent disease- such as UV light.
- "For growing leafy vegetables in general, the main hydroponic systems used are the DFT and NFT systems. In the DFT system, nutrient solutions are supplied to the plants whenever the water level in the culture bed becomes lower than the set value, and are recirculated and supplied to the bare roots of plants, at constant time intervals, in the culture bed with a 1/100 slope." Unused nutrients go back to the tank to be able to see

how much has been used. Aeroponics can also be used which sprays nutrient solutions directly onto plants.

- Electric current sensors indicate the amount of ionized nutrients in solutions.
- Ideally want to do real time measure of the 13 nutrients in hydroponic solutions, but EC sensors are currently more realistic. This means control the ion concentrations and minimize nutrient in balance by injecting stock solution.
- There are specific calculations but I believe these may be irrelevant.



- To disinfect plants hydroponic farms, use filters, heat, ozone and UV radiation. (There is more information that is not currently relevant.)
- Specific example of seeding for leaf lettuce for germination of 98%: Choose preferably treated seeds, prepare a seeding mat, prepare a volume of nutrient solution, press mat to remove air, soak mat in nutrient solution, seeds are sown in the mat, covered in film and then moved to germination place- 7-10cm vertical trays with artificial light, controls for temperature etc, then moved to a germination place.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*

To start with, this part of the paper names a few specific hydroponic systems to consider using. These may be the systems we use to incorporate in our final design. As well as this, it gives some basic ideas as to how a hydroponic farming system actually functions, which is a key part of building our design for the vertical farm.

Actions:

1. Look at other possible hydroponic systems/ any other farming systems that do not employ the use of soil.

2. Choose some specific crops to grow, and research specific information about said crops, for instance the amount of space or time that they need to grow.

3. Consider how much of the farming process needs to be manual and how much of the farming process needs to be automated- find a balance between the two.

Group number: 1 Person leading this discussion: Sam Cook

Journal Paper: Website collection

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*

This is a combination of websites that simply gave some useful background information towards how to grow certain crops (the ones we will grow in our vertical farm.) Below are the references for each of the websites:

Reddy, J. (2019). *Growing Hydroponic Cabbage, Planting, Care, Harvesting | Gardening Tips*. [online] Gardening Tips. Available at: https://gardeningtips.in/growing-hydroponic-cabbage-planting-care-harvesting [Accessed 14 Oct. 2019].

NoSoilSolutions. (2019). *How To Grow Hydroponic Broccoli - NoSoilSolutions*. [online] Available at: https://www.nosoilsolutions.com/how-to-grow-hydroponic-broccoli/ [Accessed 15 Oct. 2019].

Luv2garden.com. (2019). *Hydroponic Radishes - Proven Techniques to grow High Quality Radishes Quickly*. [online] Available at: https://luv2garden.com/hydroponic_radishes.html [Accessed 15 Oct. 2019].

Simply Hydroponics LLC (2019). *Simply Hydroponics – Replace bulb*. [online] Available at: https://www.simplyhydro.com/system/ [Accessed 16 Oct. 2019].

Baessler, L. (2019). *Radish Plant Fertilizer: Tips On Fertilizing Radish Plants*. [online] Gardening Know How. Available at: https://www.gardeningknowhow.com/edible/vegetables/radish/fertilizing-radish-plants.htm [Accessed 16 Oct. 2019].

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

Across the few websites that were used, the information can be summarised in the table below. This is the essential information as to how to grow the crops we want to grow.

	Cabbage	Radish	Broccoli
pH of soil	6.5-7	6-7	3.5-6.5
Daylight hours required	6	8-10	14-16
Optimum temperature	18-21 degrees Celsius	10-20 degrees Celsius	12-18 degrees Celsius
Harvest	4-6 weeks	3-4 weeks	7-11
Space between seeds	45cm	7-10cm	30-40cm
Nutrient ratio (N,P,K)	10-10-10	10-10-10	10-10-10

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*

This doesn't necessarily change any physical elements of the design that we need to change, but it is information that would be relevant in the real-life construction and operation of the vertical farm. It does however bring to attention the elements required as part of the aeroponic bed, for instance lighting, heating, a controlled water/nutrient solution. It also demonstrates the different beds will need to be tailored towards the specific crops due to their spacing demands.

Actions:

1. Incorporate this information into the design of the aeroponic bed system, and any farming schematics later down the line.

APPENDIX D: DIVISION OF ROLES

Structure- Jonathon Sill

Farming – Sam Cook

Lighting- Anas Najeeb

Energy- Emma Howard

Water- Rongsen Wang

Lighting- Anas Najeeb

APPENDIX E: CALCULATIONS

Average vegetable intake per day (Japan): 275g

Cabbage share of vegetable intake: 10.8%

Radish share of vegetable intake: 10.2%

Broccoli share of vegetable intake: approx. 2%

This equates to 29.7g, 28.05g and 2.75g daily (respectively)

Multiply by 365 = 10.8kg, 10.2kg and 2kg (respectively)

Multiply by 2000 as we supply 2000 people= 21600kg, 20400kg and 4000kg respectively

Average cabbage weight: 1kg

Average radish weight: 0.338kg

Average Broccoli weight: 0.225g

Hence, cabbages required per year = 21600/1= 21600 cabbages

Radish required per year = 20400/0.338 = 60355 radishes

Broccoli required per year = 4000/0.225 = broccoli

Cabbage harvest cycle = 6 weeks: 52/6 = 8.6 harvests per year

Radish harvest cycle = 5 weeks: 52/6 =10 harvests per year (approx.)

Broccoli harvest cycle = 6 weeks: 52/6 = 10 harvests per year (approx.)

Cabbages per harvest = 21600/8.6 = 2500 approx.

Radish per harvest = 60355/10 = 6030 approx.

Broccoli per harvest = 17777/5.3 = 3500 approx.

(Note: radish is much more popular in Japan than broccoli, and as such we will double radish production and half broccoli production. This also makes sense because radish requires much less space and so the farm will be much more efficient.)

We used this data to design floor plans and aeroponic bed sizes/spacing.

APPENDIX F: Patent references

Nicole, C. Hangfeng, JI. Tanase, C. Onac, G. Peters, M. 2014, *Horticulture lighting system and horticulture production facility using such horticulture lighting system*, WO2014037852A1

A light system consisting of a control unit designed to monitor the light intensity of local light at a location and to prevent a change in the photosynthetic photon flux density (PPFD) of local light at a location of an average more than 50 µmol / sec / m2 over a predetermined period of time by controlling the contribution of horticultural light to local light. The system also has lighting devices which are compatible in a horticulture production facility. It is designed to work for large-scale use making it suitable for managing light with ease in a vertical farm.

Harwood, E. Martin, T. 2010, *Method and apparatus for aeroponic farming,* US8782948B2

The patent referenced above is for a specific aeroponic bed. When constructing our vertical farm we want to either employ a bed such as this, or design one for ourselves which is very similar. This patent describes the pipe and pump system underneath the beds containing the crops and also shows how crops can be stacked in beds.

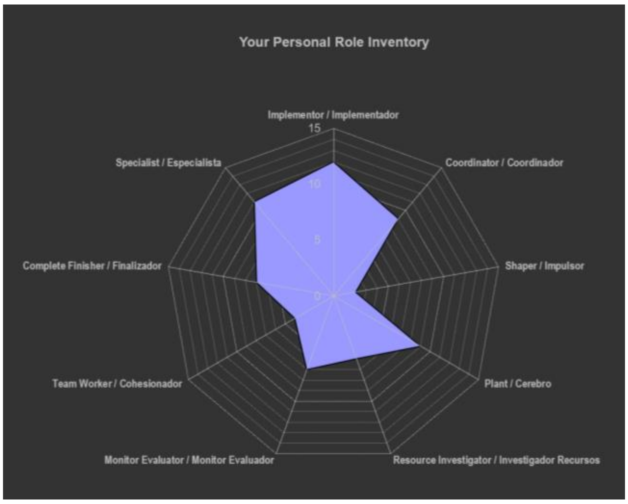
APPENDIX G: WEEKLY LAB DESIGN ACTIVITIES

Hopes and Fears

Hopes	**Fears**
We hope to work well as a team. We aim to do this by playing to each other’s strengths and by approaching any disputes professionally.	One of our fears would be to not meet the deadline of the submission through being overwhelmed
We hope to creative an imaginative or innovative design. We do not want to simply replicate pre-existing solutions.	Another fear is that although we wish to work well as a team there may be a lack in team cohesion.
We hope to learn some new skills and grow some knowledge as part of the IDP 2 module.	Linked to the first point, we fear being able to balance IDP work with other modules.
We hope to create a credible design, and one that with maybe a few adaptations could be adopted in a real-life scenario.	We fear making ineffective use on time, which would be one of the factors causing us to miss deadlines.
We hope to have an equal share of work across all team members.	We fear having a poor design that doesn’t have any real-life application.
We hope to use our initiative to conduct useful and in-depth research.	Our final fear is being able to accurately represent any concepts we can imagine.

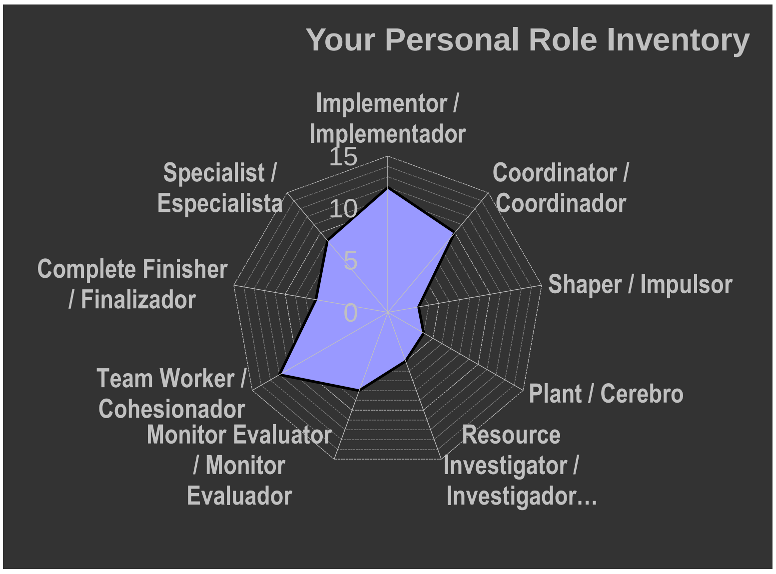
Complete Belbin results

Anas-

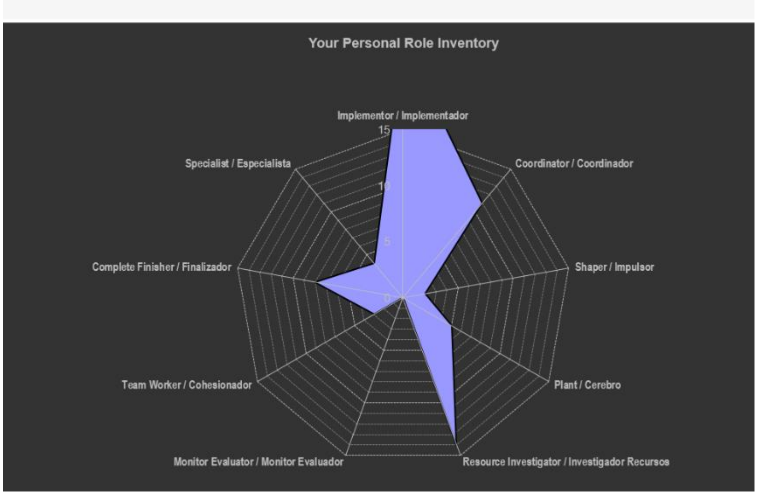


Lucy-

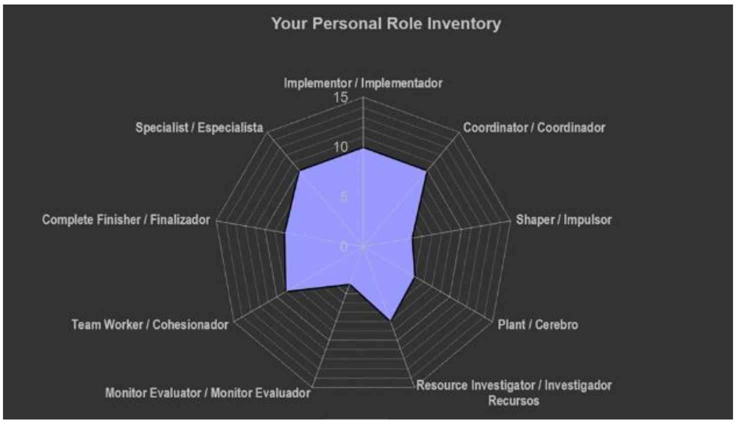
Emma-



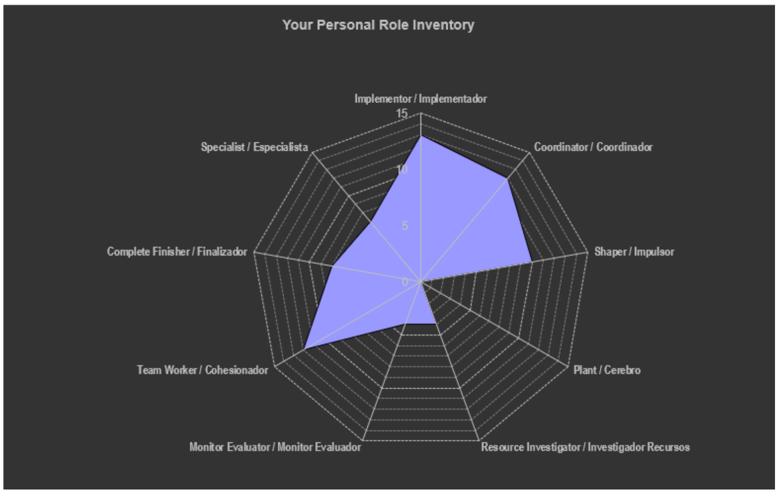
Rongsen-



Jonathon-



Samuel-

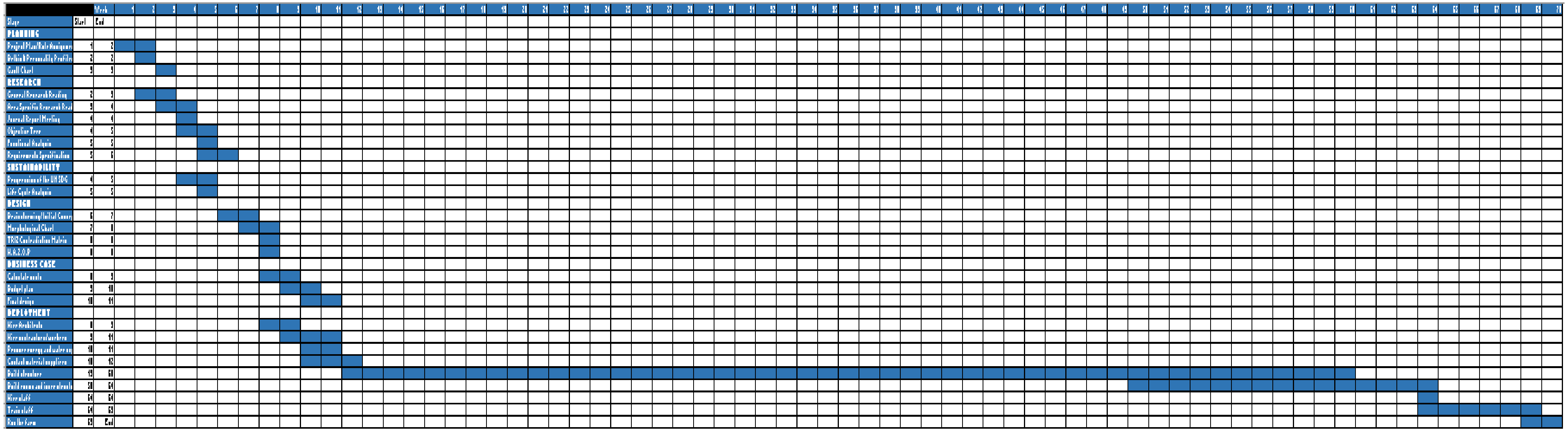


Gantt Chart

It is difficult to demonstrate this is a whole due to its size. This is a close up of the headings and week start and ends:

		Week
Stage	Start	End
PLANNING		
Project Plan/Role Assignment	1	2
Belbin & Personality Profiles	2	2
Gantt Chart	3	3
RESEARCH		
General Research Reading	2	3
Area Specific Research Reading	3	4
Journal Report Meeting	4	4
Objective Tree	4	5
Functional Analysis	5	5
Requirements Specification	5	6
SUSTAINABILITY		
Progression of the UN SDG	4	5
Life Cycle Analysis	5	5
DESIGN		
Brainstorming/Initial Concepts	6	7
Morphological Chart	7	8
TRIZ Contradiction Matrix	8	8
H.A.Z.O.P	8	8
BUSINESS CASE		
Calculate costs	8	9
Budget plan	9	10
Final design	10	11
DEPLOYMENT		
Hire Architects	8	9
Hire contractors/workers	9	11
Procure energy and water supply	10	11
Contact material suppliers	10	12
Build structure	13	60
Build rooms and inner structure	50	64
Hire staff	64	64
Train staff	64	69
Run the farm	69	End

And on the next page is an overall look at the entire chart:



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Sustainability Lab Worksheets

1. **Group Sustainability Literacy Test (Sulitest) Results:**

Who in your group has the best sustainability literacy in each of the four categories?
How does your group fare overall compared to the world benchmark?

Group Member	**Sustainable humanity and ecosystems**	**Global and local human-constructed systems**	**Transition towards sustainability**	**Role to play, individual & systemic change**	**Total (avg)**
Sam Cook	100%	70%	88%	75%	83.25%
Jonathan Sill	63%	80%	100%	50%	73.25%
Lucy Grimes	100%	80%	88%	50%	79.5%
Emma Howard	88%	70%	50%	75%	70.75%
Rongsen Wang	63%	70%	50%	25%	52%
Anas Najeeb	88%	100%	100%	100%	97%
World Bench mark	**63%**	**52%**	**48%**	**48%**	**52.75%**

2. **Positive and Negative Impacts of project**

Environment Impacts	**Impact**	**Societal Impacts**	**Impact**
Land	Will increase the land available as it takes up less land than traditional farming methods. However, will reduce the land available in the city as that is where the farm will be built.	Fertility	As general health increases, fertility is likely to increase. However, in a city like Tokyo birth rate is not governed by fertility but the level of development in terms of when women have children in their careers.
Water Demand	Will increase water demand to the city centre. But decrease it to the surrounding countryside where the farming would	Population	Due to improved health, the population will increase as people will live longer. This is not necessarily a good thing for a city

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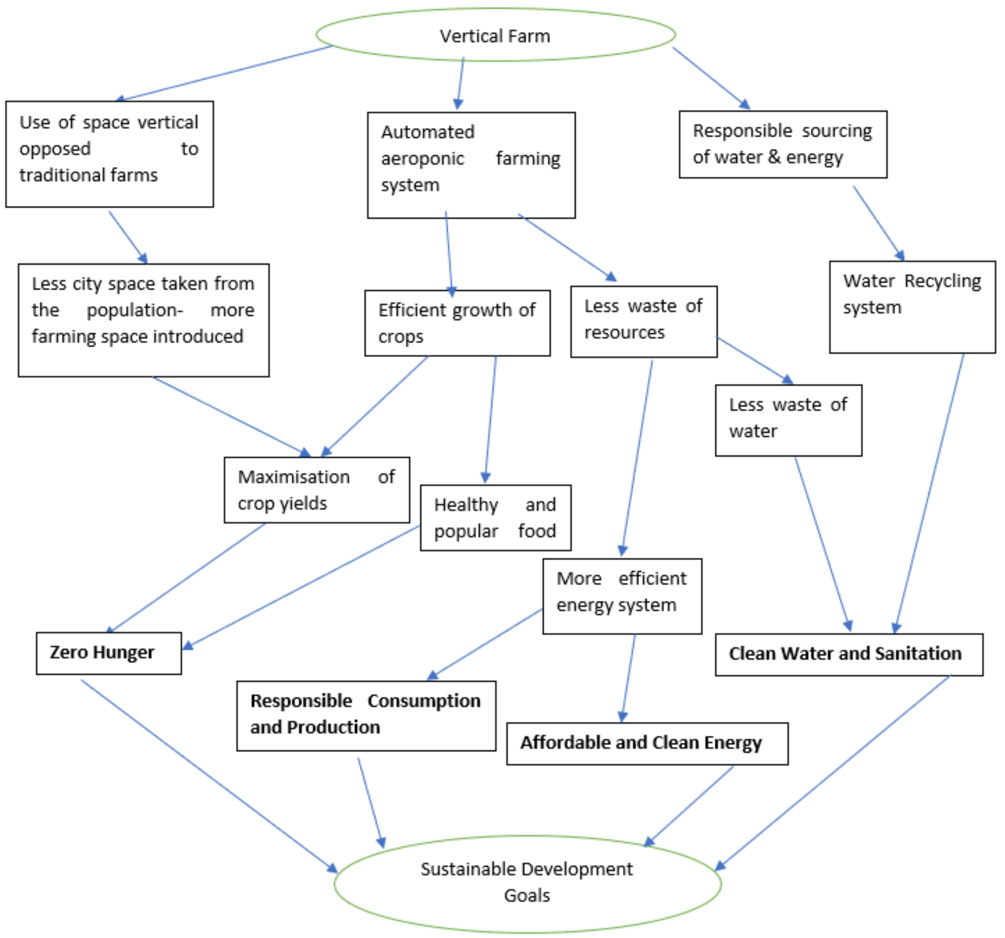
	otherwise be taking place.		like Tokyo and will increase the demand even more for food.
Water Supply	Water supply may be slightly compromised for the immediate surrounding city as the farm will use it.	Mortality	A better diet and less emissions from food production will reduce mortality. A healthier diet for expectant mothers will reduce infant mortality.
Emissions and Waste	The project will produce as little emissions as possible so will hopefully reduce the amount overall for the city. The project will be zero waste so will not affect the city's waste system. However, waste products will be sold on for useful purpose such as building materials which will make the city more sustainable.	Health	Overall health will improve as everyone will have access to the more affordable healthy food. Also, as the food will travel less from growth to consumption, emissions will be reduced and lung and eye conditions will improve.
Soil	Due to the hydroponics system, local soil is unlikely to be affect by the project. However, soil in the surrounding countryside will be able to recover from being over farmed meaning that it will regain nutrients that have been lost due to past intensive farming.	Education	Children may be better able to concentrate in school with a healthier diet. However, some may not go on to higher education if they can be trained at the farm that they otherwise would do.
Bio Diversity	Will not affect biodiversity in the surrounding	Vehicles	The use of vehicles to transport food will decrease as the

	farmland. However, growing only certain crops will mean there is no biodiversity within the farm itself.		food will be consumed very close to where it is grown.
Material Consumption	As much of the project as possible will use materials which are waste products of other processes. However, it is inevitable that some materials will negatively affect the surrounding environment.	Infrastructure	This will improve as the latest and most efficient technologies will be used for the building. However, in the process of building the farm, infrastructure resources will be depleted for the rest of the city.
Electricity Generation	Renewable energy such as solar panels can be used in our design to generate electricity and reduce the amount needed through non-renewable sources. Hopefully it will eventually reduce the amount of electricity produced overall.	Employment	Increase employment, there may not be enough unemployment in Tokyo to have enough labour for the farm.
Energy Supply	Energy supply to the immediate area will increase for construction. However, this will reduce after the building process and not affect the environment as negatively.	Income Distribution	Train some of the lowest earners which will then increase their overall earnings and income will be better distributed.
Energy Consumption	Energy consumption will increase in the immediate area due to lighting, HVAC, water supply and during the building process. However, long term energy	Poverty	Train workers so they have more employable skills for the future and will be able to earn – reducing poverty

	consumption will decrease due to the lack of transportation of goods.		

3. Casual Diagram



4. United Nations 2030 Sustainable Development Goals:

SDG Goals (including links)	**The SDG target your project could progress (and How)**
GOAL 1: No Poverty	Increases the GDP in the country, as well as increasing the number of jobs available to those who are impoverished, increasing opportunity
GOAL 2: Zero Hunger	Provide cheap and nourishing food throughout the nation from the Tokyo region
GOAL 3: Good Health and Well-being	By producing high quality food produce, it would increase the general health of people in

	the local area, especially if more natural fertilisers are used and no preservatives.
GOAL 4: Quality Education	N/A
GOAL 5: Gender Equality	Provide equal opportunities for all genders within the project throughout its lifecycle
GOAL 6: Clean Water and Sanitation	Use waste water to provide the crops with nutrients, whilst removing it from the water system
GOAL 7: Affordable and Clean Energy	Use energy provided from a sustainable source which is neutral to the environment
GOAL 8: Decent Work and Economic Growth	Introduce more jobs throughout the company at primary, secondary and tertiary levels
GOAL 9: Industry, Innovation and Infrastructure	Give opportunity for future-forward companies and individuals to add to the project – and leave a lasting inspiration once complete
GOAL 10: Reduced Inequality	N/A
GOAL 11: Sustainable Cities and Communities	When running, give a substantial impact on the sustainability of Tokyo, by increasing the amount of local produce – and reducing the negative impacts of transport
GOAL 12: Responsible Consumption and Production	N/A
GOAL 13: Climate Action	Raise awareness within the community of the seriousness of climate change, and provide aid and funding to environmental organisations working within the region
GOAL 14: Life Below Water	N/A
GOAL 15: Life on Land	N/A
GOAL 16: Peace and Justice Strong Institutions	N/A
GOAL 17: Partnerships to achieve the Goal	N/A

Exercise A: Life-Cycle Thinking

1:

Product	Energy intensive phase
Coffee Maker	Material Production
Bicycle	Production manufacture
Motorbike	Production disposal
LPG fired patio heater	Production use

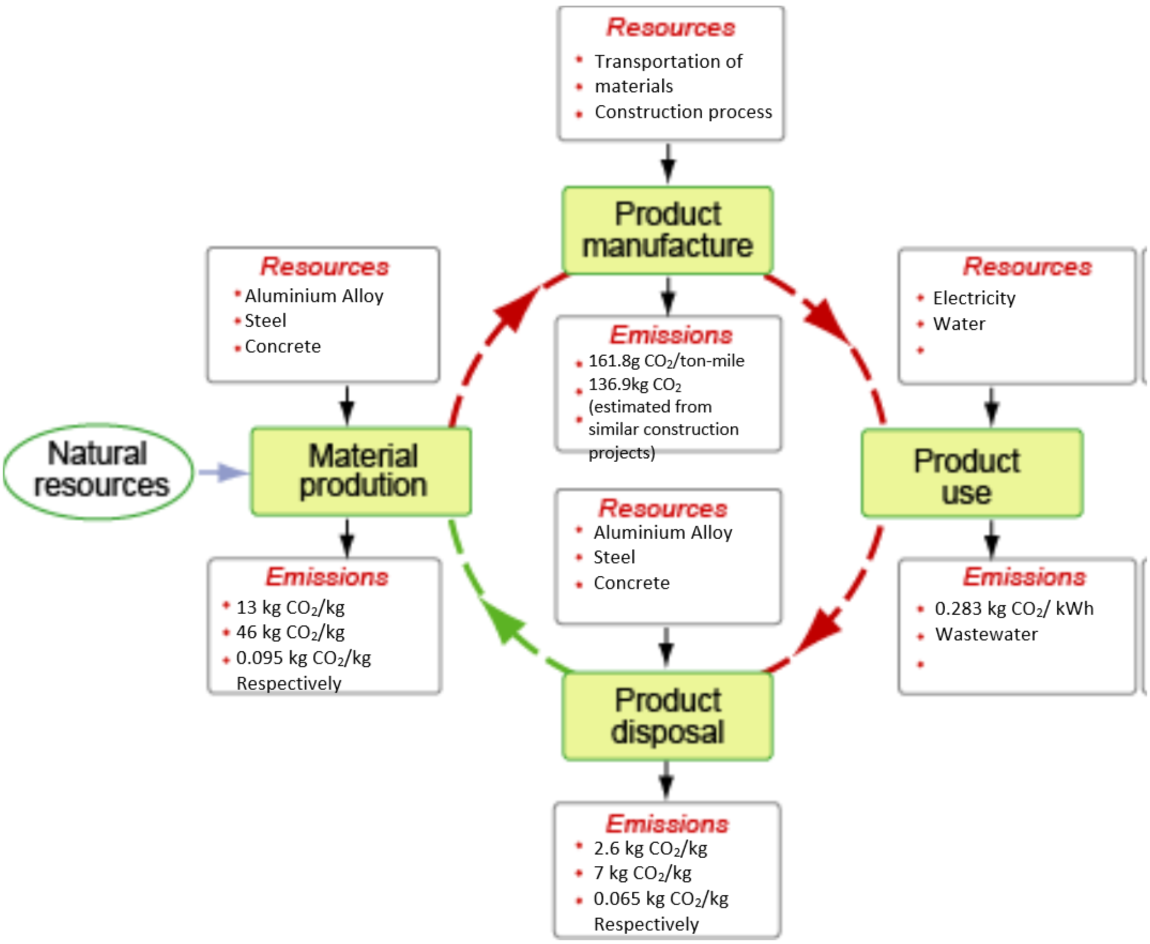
2:

Product	Functional unit
Washing machines	using 500 Watts for 0.25 hours a day most **use** only 15 to 30 gallons (56.8 to 113.6 L)
Refrigerators	2.4kWh per day

Lighting	A 100-watt classic light bulb for a full year use 876 kWh of energy
Public transport	The average **fuel** consumed **per** kilo- meter for all passenger and cargo **trains** is 7.97 L/ **km**

3:

	Material	Manufacture	Transport	Use	Disposal
Materials resources (high use =0, none =4)	0	1	4	2	3
Energy Use (high use =0, none =4)	4	1	2	0	3
Global Warming (much CO_2 = 0 , no CO_2 = 4)	4	2	3	1	0
Human Health (Toxic emissions or waste?)	2	3	4	1	0
Column Totals	10	7	13	4	6



Business Case Worksheet

Exercise A:

Answers to questions:

1	D
2	C
3	B
4	A
5	C
6	A
7	A
8	A

Please check your answers with PGTA.

Exercise B: Business Organisation / Commercial

1.

- Registered company
- Private (Limited) company
- Separate entity to shareholders
- Owned by private investors, founders and management

2.

- Initiative company, providing solutions for urban farming issues
- Sustainable and efficient
- Focus on social factors such as local supply and demand criteria
- Engineering organisation
- Auto-agriculture

3.

- Inventory
- Current assets
- Fixed assets
- PPE
- Building
- Vehicles
- Workforce

Exercise C: PEST

Political factors:

- Local area zoning rules
- Taxation and grants
- Employment legislation

Economic factors

- Investment
- Gross National Product (GNP)
- Energy cost

Social/cultural factors

- Lifestyle
- Consumerism
- Demographics

Technical factors

- Research and development
- Speed of technology change
- Product lifecycle

Exercise D: Marketing analysis

- There is a demand for the chosen produce
- Advertise in the local media such as newspapers and radio
- Advertise to the students that attend the university that we build on top of
- Promote on billboards in the city centre
- To market, we would promote through environmental groups as they have common goals