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FACADE FARM: SOLAR MEDIATION THROUGH FOOD PRODUCTION

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Abstract

Soilless agricultural systems such as hydroponics and aquaponics, which deliver nutrients to growing plants via water, are relatively new, and only now are they being considered as serious alternatives to conventional agriculture.

The increased role of technology within agriculture offers possibilities for architecture too. The accommodation of such systems in building facades could offer many benefits beyond just the increase in agricultural production needed to support the 7 billion world; the façade might also improve thermal comfort, offer acoustic benefits, create vegetation shading systems, develop a revenue stream for the building and also offer other psychological benefits for users and citizens.

The paper describes the result of an innovative collaboration between academia, architectural practice and manufacturing, culminating in the design of a series of food-producing facades, which can be deployed in differing ways: at a window-scale for hospitals, a façade-scale for offices and at a building-scale for supermarkets. The design utilises a hardware/software concept of the biotic façade that allows the technological and the biological to work in a synergistic way.

Keywords: facade, cooling, shading, ecological, environmental, scalable.

1. Aim

The aim of this paper is to understand the benefits of integrating technical food systems within double skinned facades. This includes the impact it can make on total domestic food production and reduction of food imports, the environmental benefits of encapsulating crops within facades and the idea of the facade as an economic generator.

2. Introduction

The developed world depends upon the provision of global trade to maintain and extend the lifestyles that most have become accustomed to. This dependency on imports, however, is based upon an assumption that this process of global trade is sustainable in the long term. To varying degrees, developed countries import food, animal feed, water, energy and technical goods to sustain their large populations. Without the provisions brought about by global trade, these developed regions would have great difficulty in supporting their populations utilising only the land available within their boundaries.

Most developed countries are capable of producing food to support a reduced population. However, cities currently lack the capacity to support even a fraction of their populous through the production of food. The Chartered Institution of Waste Management (Environmental Body) (IWM (EB)) in association with the Greater London Authority, Biffaward, and Best Foot Forward Ltd, compiled a report in 2002 entitled 'City Limits'. Within this report the City of London was critically analysed in order to determine its ecological footprint in relation to its geographical area. The report determined that, by taking into account all perceivable inputs including food, water, energy, transport, materials, waste and tourism, the City of London was found to rely upon an area 293 times its size (IWM (EB), 2002). This is equivalent to twice the size of the UK. In total, three earths would be needed to support the worlds 7 billion population if each person lived as one did in London. The report concluded that of the 49 million global hectares required to sustain London, it is food that contributed the second largest impact of all activities, requiring 20 million global hectares;

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equivalent to 120 times the size of London's geographic area. When looking at food in this way it can be seen that feeding cities is an intensive and demanding activity and one that puts significant strain on the natural world. A transition from global dependency will be required in the future to reduce the ecological footprint of cities and increase their resilience to shock and to change. One way in which this transition may manifest itself is to look toward hyper-local production of food and energy, plus the provision of hyper-localised water treatment and processing. With 87 percent of developed regions estimated to be living in cities by 2050 (United Nations, Department of Economic and Social Affairs, 2012) it can be assumed that the majority of this hyper-localised production will occur in and around cities, and more specifically within or upon buildings.

3. Food Production in Cities

The city finds itself in an unanticipated position where it can drastically reduce its ecological footprint and positively affect its impact on the earth. That is to say, that mankind, as a species, has increased the surface area of the planet rapidly and nowhere more so than in cities. The areas that cities now occupy, which would otherwise be flat, have been elevated and four or more sides/walls added to them multiple times. These surfaces, even in the shade, acquire vast amounts of light and heat that are more than capable of supporting plant life. If the right shade loving or shade tolerant crops are chosen for north facing surfaces, there is no reason why all four sides, including the most productive south elevation, cannot produce vast amounts of food to help support city populations.

These surfaces have the possibility not only to become ecologically productive but also to help mediate internal conditioning. The majority of facades within the city are subject to fluctuating levels of light, glare and thermal gain. All these create the need for either the adaptation of the façade through the operation of blinds and opening/closing windows, or facilitate the need for energy intensive air conditioning equipment. If crops are grown within a facade, they can offer the possibilities of a passive reduction of solar glare, the retention of heat within a growing space, and the creation of thermal mass (in the form of moving water). This will minimise the need for traditional air conditioning and change the economic and environmental model for facades.

The role of the façades in the future will change. Not only will they be sophisticated climate modifiers, but they will also be productive surfaces that help to contribute to hyper-localised food production. For future resilience, cities will require the implementation of many things, one of which may be the introduction of complex ecological facades within the urban fabric, which reduce energy use, maximise growing space and increase bio-diversity.

4. Soilless Growing Technologies

Nearly all food today is grown in soil, but within urban areas, and more importantly within or upon buildings, soil-based agriculture may not be the best method. This is due to the large proportion of contaminated land in many urban areas - a byproduct of the industrial revolution - as well as its additional weight, which adversely affects its ability to be retrospectively added to buildings. Thus, localised food production within cities depends upon alternatives to soil based practices. One such alternative is to use technical food systems. These hybridised systems, utilising technical products such as glass, plastic, and mechanical pumps, allow food to be grown directly in nutrient rich water.

There are two recognised methods in which food can be grown within technical food systems. These include hydroponics and aquaponics. These techniques utilise similar equipment in order to grow food, but the way in which they deliver nutrients to crops is very different. Hydroponic systems utilise nutrients that are added manually into a recirculated water system. The adding of nutrients to the system requires regular testing in order to maintain the optimum nutrient and pH levels. Aquaponics on the other hand aims to develop an ecosystem between fish and crops which becomes self regulating and autonomous. Aquaponic systems are dependent upon the naturally occurring nitrogen cycle to make nutrients available to crops. The system utilises waste Ammonia (NH_3) - produced by the fish as a byproduct of respiration – and, through the natural colonisation of Nitrosomonas and Nitrobacter bacterias within the system, converts the waste Ammonia primarily into Nitrite (NO_3) and later into Nitrate (NO_2). This conversion serves two functions. Ammonia is toxic to fish and, if allowed to accumulate within the water supply, it would kill them. The second function of this process is that Nitrate is an available form of Nitrogen - a plant's largest nutrient requirement - which plants can easily take up across the surface of their roots. The fish, bacteria and crops live symbiotically, much as they would within a natural ecosystem.

In both hydroponics and aquaponics, crop roots are in direct contact with the nutrient rich water. As such, the crops use little effort in acquiring nutrients and can instead utilise a larger proportion of their energy reserves to grow. As a result, yields are substantially increased (in some cases up to four times) and water use is reduced by a factor of up to ten when compared to traditional agriculture (Bernstein, 2011). Through the growing of crops indoors or under glass, a protective environment is created which increases resilience to shock events such as storms, prolonged rainy periods, temperature shifts or dry spells. Their reduced weight, through the use of Nutrient Film Technique (NFT) - a growing channel utilising only a few centimetres of water - allows such systems to be successfully retrofitted into or onto existing buildings without compromising the buildings' structural integrity.

5. Elevated Aquaponic System

Fig. 1: Internal view of the urban farm in Manchester, England.

As part of the Manchester International Festival 2013, Queen's University Belfast was approached to design and implement an elevated aquaponic food system within a disused mill in Manchester, England. The project itself was a 12-month engagement and included the design, construction and commissioning of one of the very first elevated farms within the UK, comprising one of the largest NFT systems in the UK.

The system was partially contained within the building and partially upon the roof, where light levels were highest. The more visually engaging components of the system were contained on the second floor of the building. This included fish tanks, a filtration/mineralisation system and deep rooted crop bags placed in the south-facing windows (Fig. 1). The system on the roof consisted of the NFT system for growing leaf crops, which was contained within a large polytunnel, capable of growing 4,000 crops at any one time.

The system is relatively simple in design: There are 12 fish tanks which are fed with filtered, clean fresh water returning from the NFT system on the roof, as a result of bacterial and crop filtering actions. The overflow from the fish tanks collects in a sump, and the water is pumped to the filtration/mineralisation bank where it drains consecutively through a series of siphonic containers comprising of expanded clay balls and worms. The expanded clay balls provide the large surface area needed upon which nitrifying bacteria can colonise. The worms within the filtration/mineralisation unit aid in the breakdown of solid waste. When the water is nitrogen rich and free of solid waste it is pumped toward, and drains through, the silicon bags hanging in the south facing windows. These deeper grow bags afford the cultivation of fruiting plants such as tomatoes and peppers, which require significantly larger root systems in order to grow. The water is lastly pumped up to the roof into the polytunnel where it flows down through 34 nutrient film channels, each 14m in length, in order to grow leaf crops (Fig 2.). The water flows back down to the fish tanks, where the process can start again.

Based on a growing season of eight months, consisting of four harvests, the system is capable of producing up to 16,500 crops per annum. Based on sale values of between £2 (€2.5) and £4 (€5) per crop, the system could generate between £33,000 (€41,000) and £66,000 (€83,000) per year. The material cost of the system was approximately £30,000 (€37,000), which indicates a healthy return on investment for future projects.

Although the aquaponic system and urban farm was successful, it was clear upon completing the project that it may not necessarily be good practice or cost effective in future to locate these systems within buildings.

They not only take up space within structures that could otherwise be utilised as office or residential space, which would generate income, but they also create issues related to flooding and water ingress from open water systems - i.e. a mixture of pressurised and unpressurised plumbing. Containing technical food systems in buildings also greatly reduces the amount of light available for crop growth. Restricting these systems in the future to the external skin of buildings - i.e. rooftops and facades - would eradicate both of these issues in addition to freeing up the floor plan of buildings for commercial or residential activities. Such systems would allow additional capital to be generated by buildings whilst positively improving the ecological footprint of cities.Fig. 2: View of the roof-top polytunnel and crops

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6. The Facade Farm

The untapped potential of facades as growing space is apparent. Facades are the most basic of climate modifiers; a component that separates internal conditions from exterior conditions. The possible relationship between farming and facades could produce a future symbiosis between biology and technology on a scale never seen before. The vertical surfaces of architecture, which generally experience too much glare or too much heat gain, would be the perfect sites for the growing of plants, which in turn would reduce both glare through foliage and heat gain through transpiration.

The elevated aquaponic system constructed in Manchester combined with the almost perfect conditioning of double skinned facades for plant growth led to the development of the ‘facade farm’: a twin walled glass facade, capable of growing crops within its cavity, decreasing building energy consumption and creating economic return from what would otherwise cost money in order to maintain. In addition to this, where optical transparency is not required, energy could be captured electrically or thermally and monitoring systems could be added to reduce human interaction in achieving thermal comfort.

The conceptual development of the façade farm and delivery of a working prototype, in addition to the design and implementation of the larger aquaponic system, was always based on a differentiation between technology and biology. The technology being the façade itself and the materials that constitute it, and the biology being the living things the facade envelops. It is important to make this differentiation as the biotics of the system should not be determined and the façade developed around it. Instead, the façade should be capable of supporting numerous combinations of living things, in order to maximise output and adhere to global positioning, climate, culture and orientation. The plants and aquatic living things should be changeable, dependent on the primary goal of the vertical surface. Taking this into account the façade has been a development between the hardware: the technical materials of the system; and the software: the living things encompassed within it. The idea of a hardware/software interface, much like a computer, allows the software to be changed easily, dependent upon the needs of the user, and upgrades to be made to the hardware as and when required to increase the efficient functionality of the overall system. The hardware/ software analogy will help the future development of the façade farm by informing an upgradable system that is open to supporting many different species in the goal of achieving complex urban ecologies.

The development and initial testing of the facade farm fell into two categories; theoretical and practical. The theoretical testing primarily focused on a desktop study in order to determine light capture on multiple orientations of facades, and the ability of such a facade to support life based on Photosynthetic Active Radiation (PAR) values. PAR is the threshold value of energy needed for photosynthesis to occur. The practical portion of the testing was conducted through the use of a 1:1 constructed prototype. This prototype would enable data to be gathered as to how many crops could be grown within the cavity of a double skinned facade, as well as determine whether the miniaturising of the larger system was successful.

Fig. 3: Facade farm design and single bay extracted for environmental simulation.

An initial desktop study was conducted to determine the thermal impact of a simple double skinned facade (single glazed external and double glazed internal) on adjacent spaces. This testing was conducted through the extraction of a single bay from an initial design proposal for a supermarket facade system (Fig. 3); a design in which food could easily be harvested and sold within the hour to customers. A horizontal plane was introduced in order to test the light capture as if it were a row of crops. Please note: all the theoretical testing was conducted using Autodesk Ecotect, a simple environmental analysis tool which can easily measure metrics such as light and heat capture. All simulations were run between the hours of 8am and 4pm, and all light data was based on that of an overcast day in order to determine the worst case scenario for the facade farm. Please refer to (Tab.1) for the data parameters of the glazed surfaces used within the simulation.

	Single Glazing (Exterior)	**Double Glazing (Interior)**
U Value (W/m2.K)	5.6	1.4
Solar Heat Gain Reflectance	0.88	0.41
Visible Transmittance	0.9	0.67

Tab. 1: The data parameters used within Autodesk Ecotect in order to conduct the theoretical testing of the facade farm.

Testing the effects of double skin facades on heating and cooling loads, it was found that a simple double skinned facade can reduce the sensible heating loads of adjacent spaces by approximately 40 percent in winter and reduce the cooling load by over half during summer (Fig. 4). The results of the test also showed that the heating and cooling loads throughout the year remain almost constant. Therefore, the energy demand of the building is much easier to predict and, as such, any power generation - such as integrated PV's or evacuated tubes - combined as part of the facade becomes easier to design and integrate.

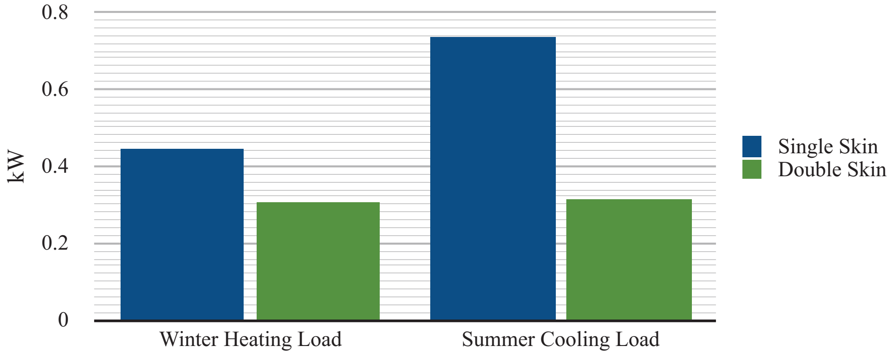

Fig. 4: Effect of double skinned facades on heating and cooling loads of adjacent spaces.

6.2. Performance as growing space

After the positive effects of a simple double skinned facade were confirmed via the simulation software, the ability of such a facade to support life had to be determined. Some plant species require a minimum of 1MJ/m2/day of light energy to survive, which is approximately 7,900 lux or 0.28 kWh/m2. To obtain maximum growth rates, however, they require 3MJ/m2/day, which is closer to 23,700 lux or 0.83k Wh/m2 (Badgery-Parker, 1999). The simulation was initially conducted on a facade facing due south on an overcast day, therefore providing the worst case scenario for testing. If a facade facing due south was unable of containing and promoting life, then the design would need to be changed before further testing could ensue.

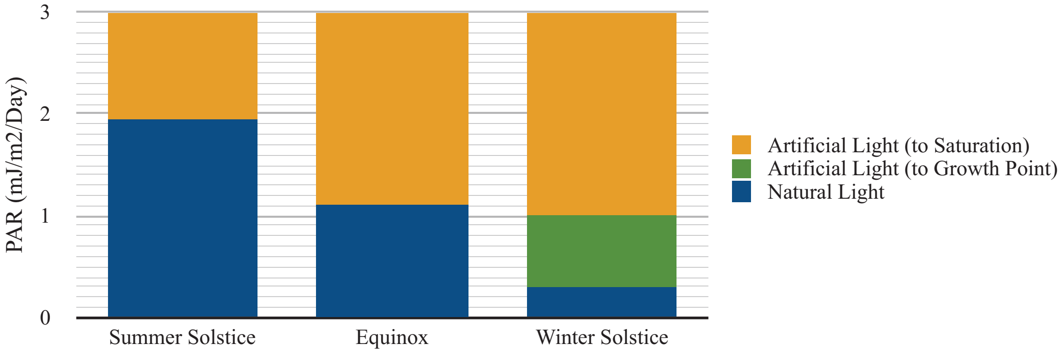

Fig 5: Energy accumulated by a south facade with minimum energy at 1MJ/m2/Day to initialise plant growth.

The results confirmed that during the summer solstice and the equinoxes, the south façade could easily achieve the minimum light levels of 1MJ/m2/day (Fig. 5). It is only during the winter that artificial lighting would be needed in order to achieve the minimum growing conditions. In all cases, the simulation showed that artificial lighting would be needed to hit peak growth rates on overcast days. Further analysis was undertaken to research the importance of orientation on the development of the façade farm and its ability to support life. It is know that the south façade receives the most energy from the sun, but the desktop study discovered that it was possible to grow on all orientations during the UK summer time (Fig. 6). In winter, however, none of the orientations would reach the minimum energy constraints without further energy input from the building. Please refer to (Tab.2) for full results of facade orientation and seasonal testing.

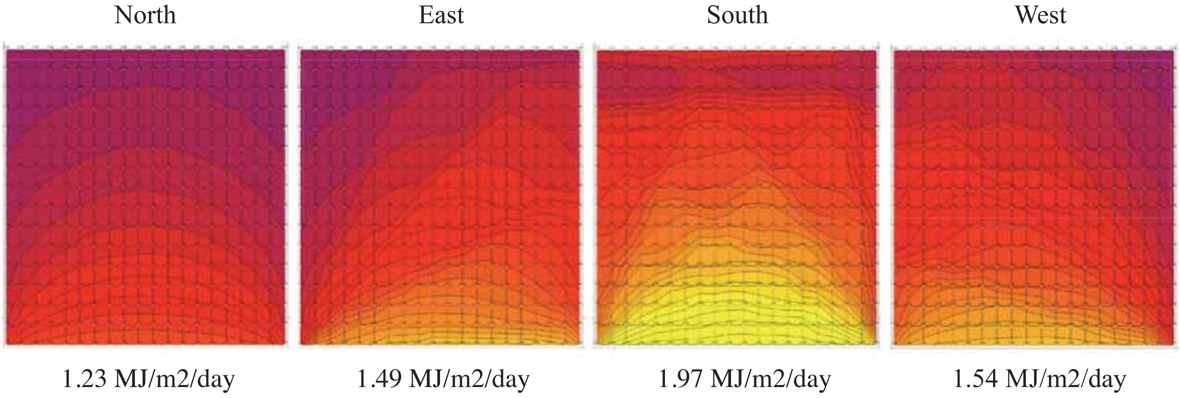

Fig 6: Energy received by a horizontal planes positioned within a double skinned facade in summer for all orientations

	(MJ/m2/day)			
Orientation	**Summer Solstice**	**Equinoxes**	**Winter Solstice**	**Annual Average**
North	1.21	0.79	0.30	0.77
East	1.48	0.92	0.31	0.90
South	1.99	1.14	0.36	1.16
West	1.56	0.90	0.30	0.92

Tab. 2: Annual light energy capture within facade farm for all orientations.

It is apparent from the data recorded that facades hold great potential for future integration of complex ecological food systems. The future benefits of such a façade can only be proposed at this stage but they could hold many benefits. The foliage of plants plus the incline of growing channels can aid with the regulation of internal light levels and the addition of water to the façade allows for a varying level of thermal mass to be displaced and moved when needed. Dependent upon the thermal transmittance required, the irrigation flow rate of the system could be increased or decreased in specific areas, diverting warmer water to cooler areas in order to equalise cooling loads during summer and vice versa during winter.

7. Prototypes

The delivery of a functioning prototype is the end product for this first phase of research. The first constructed prototype took all the available research from the larger aquaponic system, which occupied a whole building, and miniaturised it into a space 3m high, 2.5m wide and 35cm deep (see Fig. 7). This space housed all the components seen within the larger system, including fish tanks, filtration/mineralisation unit, ionisation tank, and growing channels. This first prototype was a static two pump system. The first pump moves water from the fish tank, to the filtration/mineralisation beds, which then enters the ionisation tank. The ionisation tank acts as a highly oxygenated body of water, which encourages the development of beneficial bacterial colonies. This helps break down the fragments of solid waste that may be left over after filtration. The second pump takes water to the top of the double-helix growing channels where the plants are provided with much-needed nitrogen, returning clean fresh water back to the fish tank. The prototype of the facade farm was capable of delivering 15 crops/m2, including the space required for fish tanks and filtration. If this was applied to a south facing supermarket facade in the order of 50m x 6m, the facade would be capable of producing 4,500 crops at any one time.

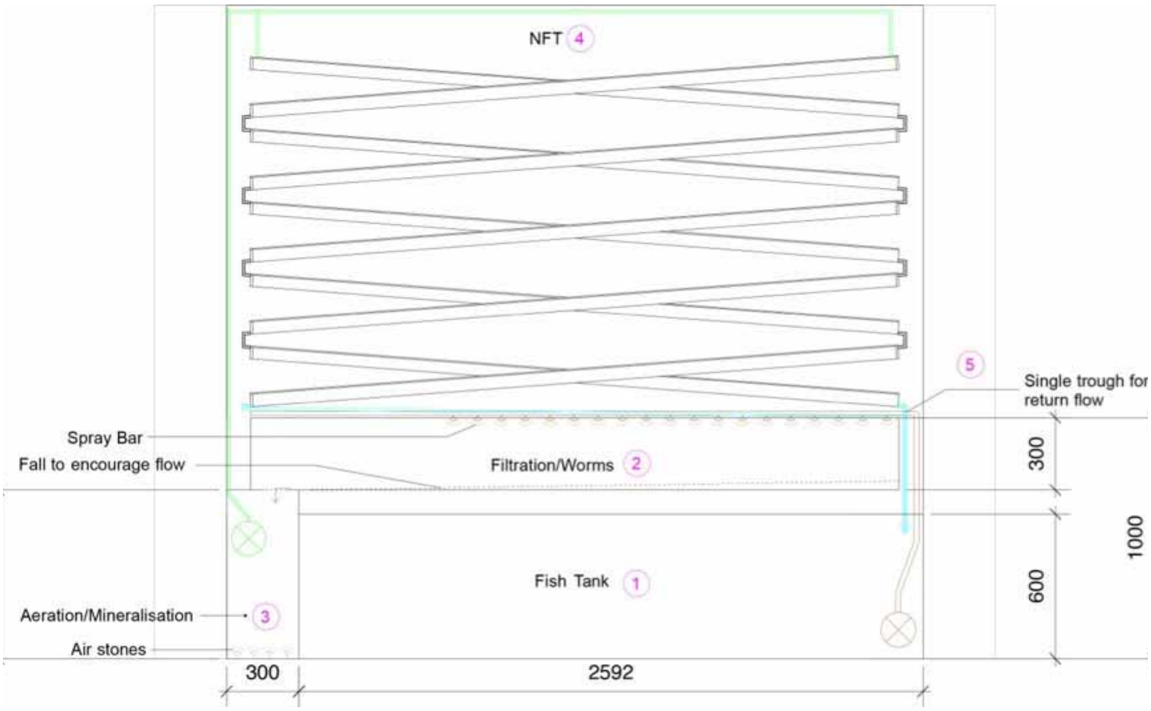

Fig 7: Single bay prototype schematic of facade farm

The crops within the system - including purple basil, rocket lettuce and strawberry plants - all grew at increased rates, proving that the scalability of such a system is possible (Fig. 8). These systems can be relatively small, or very large, depending on the requirements of the user. The success of the real world prototype, plus the data gained from theoretical testing, proves the ability of double skinned facades to grow food and to reduce building energy demand, both of which increase economic return. It is estimated that the addition of the aquaponic equipment within the cavity of a double skinned facade would cost an addition £300/m2 (€375/m2). However, it is possible that the sale of the 15 crops grown per m2 - based on four harvests per year and a sale value of £4 (€5) each - could offset this additional cost within the first year of operation, with the cost of the double skin facade being offset within another three years after that.

Fig 8: Single bay prototype of facade farm with view showing internal crop growth

The last stage of the research, which is still to be conducted, is to embed a double height prototype within an existing building envelope in order to test the effects of both growing crops and reducing energy demand in a controllable experiment. This will include the testing of both internal and external temperature, lux level, relative humidity and CO2, plus the monitoring of fish tank temperature and pH level of the system. All these data streams when identified together will give a clear indication as to whether such a facade will operate as expected when integrated with architecture, and give an indication of its overall performance if applied to a whole city. This double height prototype is designed to be a motive system (Fig. 9). This is to say that the grow beds are moved vertically upwards and then return vertically downwards, and will themselves be ‘dipped’ into a nutrient rich reservoir and rotated around the whole façade until they end up where they started. It is hoped that a motive system will negate the need for circulating water with pumps, creating a pressureless system. Being double height will provide invaluable research into the implementation of the facades beyond that of just a bay-by-bay approach of the initial prototype. The intent of the double height experiment is to provide a viable answer as to how these food-producing facades can be utilised to maximise production in varying situations across the existing urban fabric.

Fig. 9: Motive double skinned and double height aquaponic facade farm.

8. The Future Contexts of Facade Farms

As mentioned previously, there are many positives beyond that of just growing food from a sociological, economical and environmental standpoint. These possible multiple benefits of the food façade helped nurture the concept from the beginning. From this, three main contexts were identified for the development of the façade. These were office buildings, the largest proportion of current building stock in the city; supermarkets, a place in which food can be grown and sold with no need for transport; and hospitals, a place where the biotics of the facade and the aroma of therapeutic crops would aid in recovery times. These contexts were determined to maximise on the current building stock available and minimise food transport, whilst increasing resiliency and providing psychological wellbeing to all people. In all cases, the facade would act as a biological filter where polluted air enters the façade, and is 'cleaned' before entering the building plan. The crops would reduce the CO2 level incrementally whilst increasing the oxygen level, but due to the increased humidity of the cavity, dust, soot, and dirt particles would be captured and be prevented from entering the building environment.

Vertical space will become a resource in future cities and currently offices have access to vast quantities of it. There is a large proportion of the city that is dedicated to the provision of office space so it becomes increasing important to consider the façade farm in this context. Office space has notoriously high cooling loads due to high occupancy and large amounts of electrical equipment. The main benefit to the office archetype will be to reduce solar gain and solar glare into the plan of the building, whilst creating an economic generator from the vertical surfaces of the building.

Within the context of the supermarket, the beneficial relationship between food and shop is apparent. There are many places in which food is grown, but in what better context can food be grown than where it is sold? Unlike the harvesting of crops within offices, in supermarkets they could be harvested when needed. A supermarket might even employ 'pick your own' at ground level. The environmental benefits seen within the office archetype will still be apparent but due to the deep building plan associated with large supermarkets, the primary goal will be to maximise production and, in turn, maximise profit. The additional benefit of hyper-localised food production is that, due to its freshness, it would require far less refrigeration, which in turn would lead to a further decrease in building energy demand.

The final context considered for this research lies far beyond energy performance and into the psychological wellbeing of people. Hospitals are places in which people recover from illness and injury. To decrease the length of recovery from such ailments, the psychological wellbeing of the patient needs to be addressed. This starts with the positive effect of good food. The addition of a food-producing façade in such a context would allow for a varied diet in addition to dedicated diets dependent on patients' needs. In this context, the fish contained within the facade would be, in some cases, purely for decoration and engagement. They would increase relaxation levels and would engage with patients, especially providing engagement opportunities for people with learning difficulties and other disabilities. The main crop yield could be interspersed with aromatic plants such as lavender, which would aid relaxation and decrease recovery times whilst providing defences against pathogens due to the antibacterial nature of its oils.

9. Conclusions

Food production in the city is in the early stages of a renaissance. The façade farm attempts to tie emerging aquaponic agricultural technologies with environmental control functions, to develop a new model for façade design, one which links the technological with the biotic, seen as an analogy between hardware and software.

It is safe to say that façade farms will do much more in the future beyond growing food; they will also play pivotal roles in the lives of people and possess the ability to fundamentally change the way architecture and cities are perceived. They will reduce food miles, minimise CO2 production, create economic return for cities and buildings, clean the air, aid in the recovery of hospital patients, improve the working conditions in offices, positively affect nutrition and produce organic food.

The future of food producing facades is dependent on utilising the existing infrastructure that is currently available. This maximises the potential of the city as it is today, without the need to build new structures to accommodate these new systems. The existing city has so much to offer and, as such, can help reduce the ecological footprint of each and every human being living within them.

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