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The energy of the green: green facades and vertical farm as dynamic envelope for resilient building

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The energy of the green: green facades and vertical farm as dynamic envelope for resilient building

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Abstract. The paper shares the results of a design submitted to a competition launched by the University of Wageningen, focusing on the retrofitting action of one of the existing towers of the former Bijlmerbajes prison complex in Amsterdam. The effort of an interdisciplinary team was oriented to demonstrating that it is possible to imagine the architectonic environment as a living organism, being part of the new food production chain, sponsoring zero kilometer products and increasing buildings' sustainable comfort while reducing their energy consumptions. Promoting a healthy lifestyle, an awareness of how to environmentally friendly behave and keeping the ecological footprint as low as possible were the main goals we wanted to achieve with our retrofitting and regenerative proposal of the GreenTower.

1. Concept

We designed a building that wants to communicate the significance of urban farming in this spatially consolidated world. In order to achieve this, we designed something more than just a building; we designed a landmark: a building that in all its parts shows that food production can now be achieved in cities (Carta, 2013) [1]. This building is much more than wood, steel and concrete; a building that itself is the Land! With that in mind, we created a living bio-skin: we kept the old structure and replaced the existing facade with a new transparent one made in ETFE (Ethylene tetrafluoroethylene), a fluorine-based plastic, integrating a system of micro-algae production within the cushions. As ivy grows on old abandoned buildings without affecting their structure, our new facade symbolically gets "eaten up" by nature, like green plants growing on ruins. The bio-skin winds like a climbing plant and hugs both sides of the tower, as if to symbolize the branches of a tree. The façade system arises from a geometrization of ivy leaves, associated with the elementary shape of the triangle.

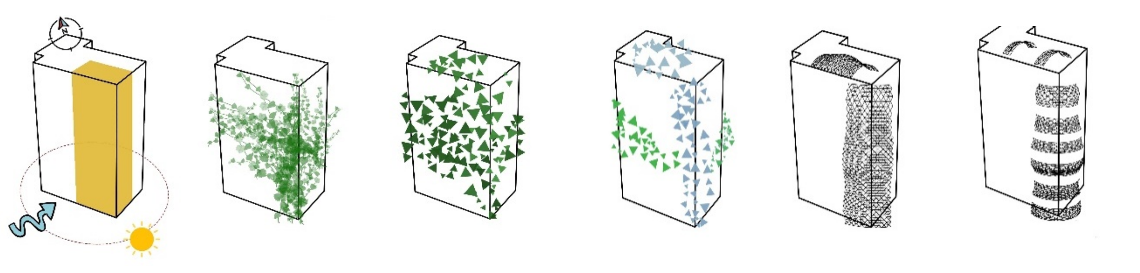


Figure 1. Concept diagram. Choose the sunniest part, here the nature "eats up" the building and after that the ivy becomes a triangular form. Differentiate the geometric ivy, the blue one is mobile, the green one is fix. The roof cover and the angular skin are mobile: the two different options, open and close surface.

2. Living skin: New food technologies and energy concepts

For a total integration of the production part in all parts of the GreenTower we want to go one step further and create a truly living bio-skin: not only making the farming visible through the transparent facade but directly integrate it in the ETFE elements.

Our green facade should improve the air quality in the most efficient way possible, especially because we are located close to the highway and train rail. The most efficient plants are algae, which grow ten times faster than any other plant and produce about 70% of the atmospheric oxygen (Chinnasamy et al., 2012) [2]. Integrating them in a building's facade can be a solution to the air pollution in metropolises and contribute to a cleaner environment, especially in areas with limited space for agricultural land (Fong et al., 2013) [3]. As a pilot project we want to include a system of tubes in the transparent facade, which leads a nutrient fluid through the envelope allowing algae to grow within our structure. The system can be combined with a waste water treatment system and aquaponic system, recycling nutrients, supporting the development of a sustainable water management.

2.1.Shadowing Potential

Depending on the species and the concentration of the micro-algae within the ETFE cushions, it is possible to vary the transparency of the single panels. In fact, exposed to the solar radiation, algae grow more rapidly increasing their density, reducing the transparency of the ETFE panels, for themto function as a natural sun-blind. Moving our facade triangles with the sun's course allows us to use this shading potential in the maximum way, protecting indoors and exploiting the sunlight for the vertical algae farm.

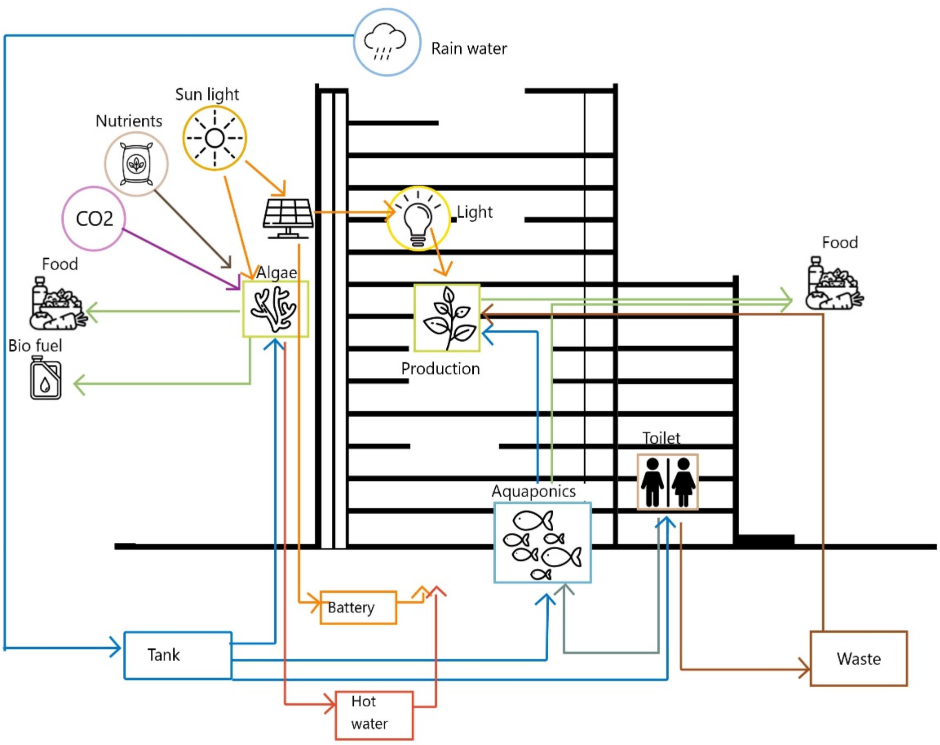


Figure 2. Integrated Algae production system

2.2.Circularity: Bioreactor- Façade and Energy production

Algae are in comparison to other plants the most efficient ones, growing ten times faster and absorbing incredible amounts of carbon dioxide. Compared to terrestrial plants micro-algae have various advantages (Chinnasamy et al., 2012):

- higher product yield in terms of area and time
- no competition with agricultural acreage

But also on a smaller scale the production of algae features many advantages: as they not only require sunlight and carbon dioxide but also nutrients, the farm can be integrated in a total water circulation, a concept to recycle and reuse water and nutrients. The importance of this is obvious: water is one of our highest goods and has to be protected facing the qualitative threats of industrialization and pollution increase as well as the quantitative threats in the Middle East and North Africa (Aboulnaga et al., 2019)[4]. Reusing grey water plays an important role in a sustainable water management.

The coupling with treated waste-water enables two facts: On one hand the grey water gets purified when passing through the facade elements, dissolving the majority of nitrogen and phosphorus and thus can be reused afterwards for toilet flushes or plants irrigation. On the other hand, the nutritional value of the Biomass increases, providing qualitative food for people and animals. Additionally, this water circle can be complemented by an aquaponic system.

The water containing the algae gets heated up by the sun and provides energy for the heating of our building during the cold days, or, for the general preheating of water. Once harvested, the produced biomass can be used for cosmetic products or as a nourishing food supplement. Compared to terrestrial plants, micro-algae have not only the advantage of a higher product yield in terms of area and time but their biomass contains no waste e.g. roots and stems (cellulose). The biomass can be transformed into biogas and thereby electricity, which is especially interesting given the high yield of biofuel produced by algae.

3. Greenhouse Design: Structure and covering materials.

The façade system brings together three goals: origami structure, movement and production, creating a living Greenhouse.

3.1.Materials and goals

After a recognition of the state of the art [5], it appeared to be clear that the most efficient material to be used for integrated micro-algae cultivation was the ETFE: Ethylene tetrafluoroethylene, a fluorine-based plastic. Among others, the advantages of using an ETFE facade for algae production are (Le Curyer. 2008) [6]:

- *High Light Transmission & UV-Transmission:* ETFE shows high translucency by transmitting up to 94–97% of visible light (380– 780 nm) and 83–88% of UV range (300–380 nm) and absorbs a big part of transmitted infrared light, a quality which can be used in order to improve the energy consumption of the buildings. ETFE allows in comparison to glass a higher light exploitation, better growing conditions and an abdication of pesticides, because of the UV's bactericidal effect.
- *High Resistance:* ETFE was designed to have high corrosion resistance and strength over a wide temperature range. It has a relatively high melting temperature (hardly inflammable), excellent chemical, electrical and high-energy radiation resistance properties.
- *Sustainability:* ETFE is ecologically friendly: Its production consumes little energy in comparison to other cladding materials and after its long life it is easily recyclable.
- *Weight:* ETFE film has approximately only 1% of the weight of glass and thereby allows higher spans with filigree substructures. Being light and small storage needy, it is easy to transport the material to site, again lowering its carbon footprint.
- *Insulation:* A standard four-layered ETFE cushion presents a U-value of around 1,5 W/(m²K), that gets further improved by the trapped air inside and thus lowering heating costs.
- *Low Maintenance:* The surface of the ETFE- pillow is anti-adhesive and thereby self-cleaning, because dust and mud will not stick onto the surface. Low cleaning/ maintenance costs are the result. ETFE has a long service of life (at least 25-35 years).

- *Customization:* The material allows various modes to personalize the foil, for example with the integration of LED-lights or the possibility to stamp thin photovoltaic modules on the surface. In our case the space between the cushions enables the possibility of inserting algae.

Temperature, pH, light, nutrient quantity and quality and CO_2 flow rate are the major factors that influence the photosynthesis activity and the behavior of micro-algae growth rate (Blionva et al., 2015)[7]. For this reason, the mobile facade system is located in the part which is best exposed to solar radiation. The movement starts from the south-east side to south-west, following the sun path in order to optimize solar radiation gain. The southern element, unlike the lateral elements, is mobile and contains algae. The side elements are applied to a fixed structure, which gives it a sinuous movement. The south façade is separated into 4m height horizontal bands, with a number of variable elements, creating alternate planes when opened and a single sinuous surface when closed. The kinetic facade gives the building a double benefit: algae can find the best growing conditions following the sun path and, at the same time, act as a solar shield and as thermal insulation.

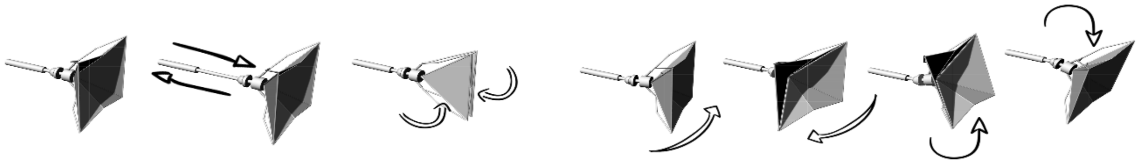


Figure 3. Facade joints permitting the ETFE triangular cushions movement

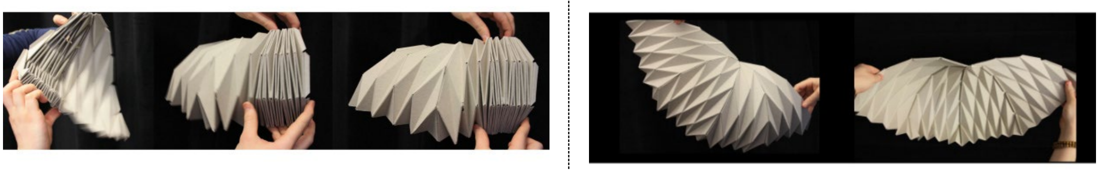


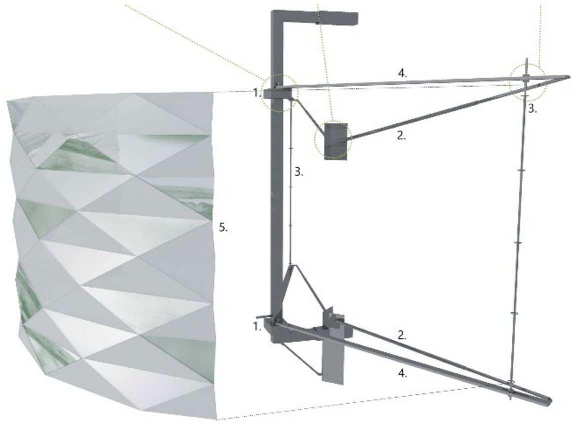
Figure 4 a-b. Origami concept

3.2.Origami module

Keeping in mind that the project concept was based on triangular forms, we researched a scheme that allowed us to create a mobile structure. The chosen one, "origami", is a simple scheme based on horizontal and diagonal lines. Pushing the surface sideway we produce automatically two movements: compression and curvature, creating a semicircle. Thanks to this characteristic we are able to divide the façade into horizontal bands, from close-up it seems like a straight and continuous surface, but if we want to open it the surface results curved and discontinuous. The movement changes during the day and during the year, creating an ever-changing surface. The individual triangles are generated by welding of the plastic material. The triangles may contain the algae, but also solar cells and led illumination.

***3.3.** Origami structure*

The structure consists of simple metallic elements and the surface containing the algal solution. The elements that generate movement have been studied to simulate the movement of the hands, which force on the external sides generating the consequent crushing (Fortmeyer et al., 2014) [8]. To reproduce this movement the surface is attached by means of rings, which in turn slide on vertical rods. The vertical rods must be able to move, because when the surface closes, it generates two movements: it bends to close and moves towards the centre, holding onto horizontal slots. The horizontal arms, on which the slots are located, allow the surface to have greater stability and connect it to the two hinges, upper and lower. The upper hinge besides having the rotary movement of the two arms, also acts as a trolley and moves on the vertical axis, to favor the crushing of the surface. The telescopic elements connect the structure to the building, attaching to the arms and connection plates. It is precisely from the telescopic elements that the movement starts, retracting brings the arms closer to the building and extending them away (Tribuiano, 2013) [9]. The two upper elements are positioned obliquely to allow the upper arms to lower with the upper hinge.



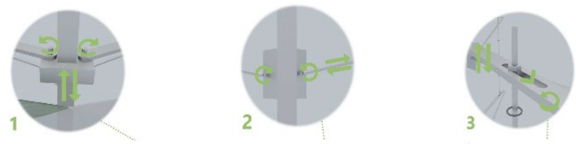
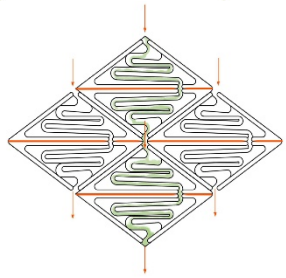


Figure 5. Façade System:
1. hinge
2. telescopic element
3. sliding rod
4. mechanical arm
5. origami
6. algae dynamic flux



4. Conclusions

As a research project, born for an international competition, we tried to develop a solid concept that could put together the advantages of a kinetic facade with the vast opportunities that the algae cultivation could offer. Nevertheless, we realized that the combination of these two systems entailed some considerable issues to be solved:

- the algae are produced within the ETFE cushions and need water to grow. Every triangular cushion is 179x45 cm; considering a constant depth of 10 cm needed by the water to flow, we would have a volume of 4 cubic meters, equivalent to 4 tons of water for each cushion. In order to reduce the stress that the water pressure would have on the structural joints, we studied a way to connect adjacent cushions in order to keep a constant "gravity algae flow" that conceptually goes from the top to the bottom of our facade.
- When integrating the gravity algae flow with a kinetic facade we had to understand that the connection between the ETFE panels will interrupt at the beginning and at the end of the each single origami structure. This interruption would have two consequences that could bring to two different design solutions: i) the gravity algae flow stops when the facade is opened, thus, the kinetic facade would not be able to move freely but should follow the algae production cycle; ii) we have not just one, but several gravity flows, one for each band of the kinetic facade. In this second case, the collection tanks would be disposed on each floor where the kinetic facade creates a discontinuity moment in the algae flow.
- Regarding the choice of micro-algae, we had to fulfill the temperature needs of the various species. In the warmer period from May to October, the Amsterdam's weather would permit the use of Spirulina, a genus of cyanobacteria, like *"Spirulina Platensis"* or *"Spirulina Pacifica"*, which are the worldwide most produced micro-bacteria. During winter, from November to April, the Spirulina does not grow very efficiently for lack of sufficient sun exposure and temperature. For this reason we decided to integrate the algae production with the so-called Ice algae, which have other needs thereby fit winter conditions.

As a research project we based our design on the literature and the analyzed case studies. For a better understanding of the integrated system more experimentations and simulations are required. Based on the data in our possession, mostly extrapolated by the BIQ project in Hamburg (4), we made an estimation of the biomass final output: considering that the total surface of the facade occupied by algae production is approximately 240 sm, from which we subtracted 20% of non-productive area located between the algae tubes, our bioreactor produces 15 grams dry biomass per square meter per day, resulting in a yield of 3000g per day. The converting into Biogas equates to an energy gain of 4,500 kWh per year.

Figure 6. Facade elevation

Figure 7. Building section

Nevertheless, considering the productive goal of our Green Tower, we preferred to hypothize that the the whole algae yield would not be transformed into biogas but instead used for research purposes: as a food nutrient and product that can be sold to cosmetic industries. The calculation of the BIQ shows that 1g of dry biomass corresponds to 23kJ food energy, the amount of one standard bar of chocolate. According to our calculation, our reactor surface produces more than 25.000.000kJ per year, the equivalent of 10.000 bars of chocolate. Finally, our research wants to set basic criteria for the design of a productive building for the circular city of the future. The integration of algae within the kinetic facade through the use of the ETFE cushions must be developed further with the construction of scalable prototypes. Throughout the prototypes, it will be possible know, with far better certainty, what kinds of species could fit such facade design, and the exact amount of produce that could be yielded. Such architectonic research, based on stimulating projects like the one proposed by the Wageningen University, should then be put in practice to validate the theoretical apparatus.

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