# SynBio-Design: Building new infrastructures and territories with Synthetic Biology

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**Abstract.** Which kind of imagination do we need for the future of our planet? In the past 150 years, we have completely transformed our biosphere. Today we have arrived at points of no return in global warming! The temperature of the Arctic Ocean will increase by 3-5°C by mid-century. This will lead to disastrous ocean acidification, sea-level rise, and worst of all the thawing of the permafrost that will release 1 trillion tons of carbon dioxide into the atmosphere. In this paper, we argue that building with biology will be the most important force to transform our planet. Since 2006, Synthetic Biology (SynBio) has surfaced as the fastest-growing technology in human history. SynBio involves emerging techniques that allow us to design, edit, and engineer all kinds of living organisms. In this paper, we elaborate on its potential development in growing infrastructures and its impacts on architectural thinking.

**Keywords:** Synthetic Biology, Bio-Architecture, Climate Change, Biotechnology, Architecture.

## 1 Our Biosphere after 150 years

In the past 150 years, we completely transformed our planet. Today human industrial processes determine most living organisms and ecological systems in the world. We have fully manufactured a world for our controlled fauna and us. If we look at mammals by weight on earth, humans are 36% of the mammals, 60% are our livestock and just only 4% are wild mammals (a number that has continued to decline every decade).

After 150 years, our industrialized world is unveiling its horror. The latest reports from the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Environmental Program (UNEP) show that we are quickly arriving at points of no return in the warming of the Arctic Ocean (UNEP, 2019). This will inevitably lead to disastrous ocean acidification, sea-level rise, and worst of all the thawing of the permafrost (Schoolmeester, 2019). The permafrost has sequestered underneath its ice sheet one trillion tons of carbon dioxide and methane that will be gradually released into the atmosphere. Thus, carbon “emission reduction” efforts are necessary but are certainly insufficient. We quickly need to pivot into “negative emissions” visions that will allow us to develop carbon removal at a massive scale (Masson-Delmotte, 2018).

### 1.1 Climate Change is a Deep Crisis of Imagination

When we architects propose ways to mitigate climate change we tend to go back to just slightly improved industrial technologies with which we created the emergency. We are in a deep crisis of imagination!
In this paper, we propose that biology is a much more sophisticated platform to transform our planet. We provide a summary of how our concepts of biology have changed and how we have moved into a new era of biotechnology. But we also argue that this new era is not only about new material technology but also needs a new spatial imagination at the planetary scale.

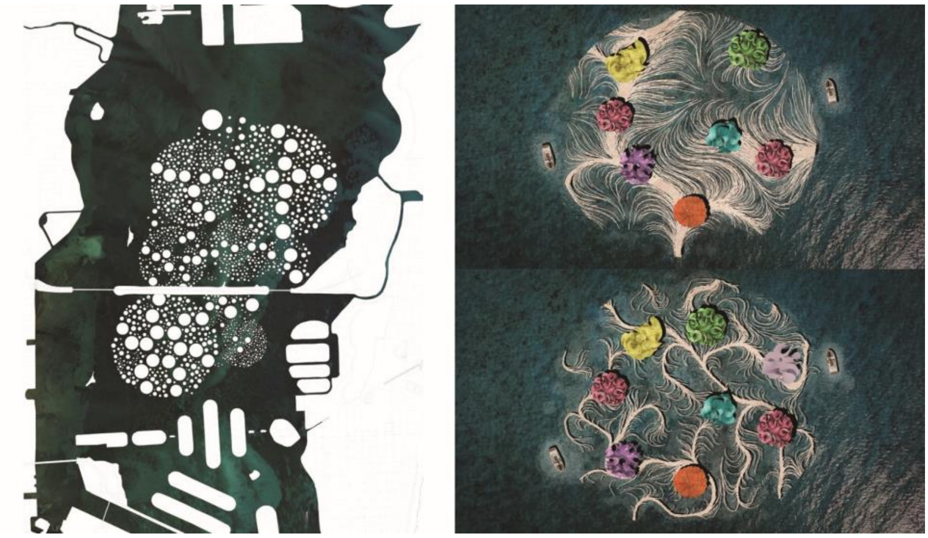

Figure 1. The proposal envisions a series of islands that grow in Biscayne Bay by reengineering cyanobacteria. A biological circuitry allows cyanobacteria to capture carbon dioxide in the water via photosynthesis and transforms it into finely layered rock material. The process is similar to the living stromatolites that were abundant in the Precambrian age. Cyanobacteria created the earth’s atmosphere. Left image: Site plan, Design 7-8 Studio, 2018. Right image: a project by Daniela Romero & Solange Salinas (Alfredo Andia Design 8 Studio, FIU, Fall 2019).

## 1.2 Nature and Biology

Nature has been an evolving concept! The field of biology of the 1800s emerged from the voyages of authors such as Charles Darwin and Alfred Wallace did into the practically untouched nature during that period. By the 1900s, biological studies began to move away from travels and into labs that began to study life principles. The discovery of the “DNA structure and function” in the 1950s was a major breakthrough in lab biology. By the last decade of the 20th century, the genetic branch of biology began to gather traction as DNA reading (DNA sequencing) and DNA writing (DNA synthesis) expertise accelerated.

## 1.3 Programmable Biology: Synthetic Biology (SynBio)

Since 2006, Synthetic Biology (SynBio), the field dedicated to finding ways to rewrite or recode biology has surfaced as the fastest-growing technology in human history. SynBio involves emerging techniques that allow us to design, edit, and engineer all kinds of living organisms. Today we can manufacture molecule by molecule: lab-grown meat, bio-grown leather, milk, wood, plants that do not need fertilizer, fuels, fragrances, fabrics, novel pharmaceuticals, mRNA vaccines, and even age-reversal techniques. Synthetic Biology was officially born in 2006, but it is growing by a factor of 10 times per year, by comparison, computer technology has been rising by a factor of 1.5 times per year (Church 2014).

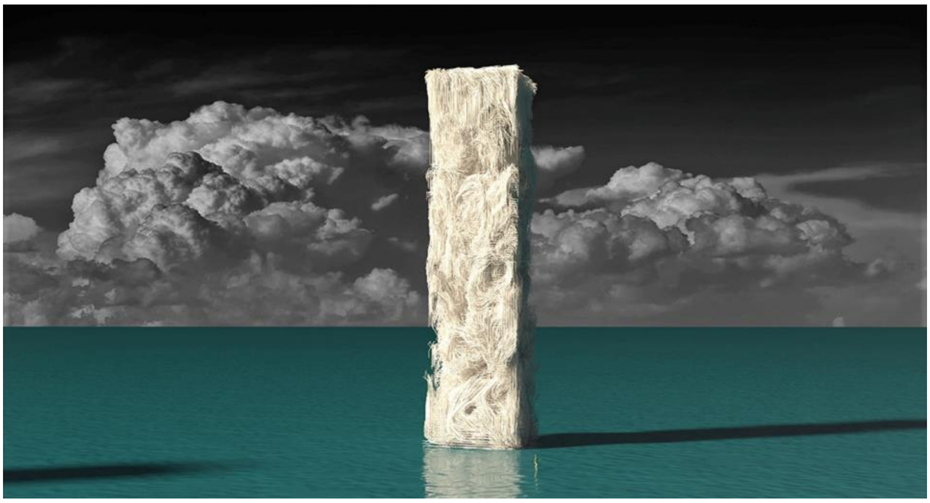

Figure 2. An emergent fragile habitat in Stilsville, Florida, that grows with different strategies such as curl noise, recursive growth, and DNA plexus. The project reflects on the spectrum of fragility in which we could nurture our SynBio habitats. Project by

Bryan de la Cruz and Juan Moreno (Alfredo Andia Master Project Studio, FIU, Spring 2021).

## 2 SynBio in the Construction Industry

We think there are two generations of possible tactics for the future of SynBio in construction. An emerging number of startups are developing lab-grown products that aim to replace existing materials. However, we think that the real potential of SynBio will involve soon a more advanced narrative of engineered living materials that will allow infrastructures to grow locally around the world.

### 2.1 First Generation: Lab-Grown Materials

A rapidly growing number of lab-grown materials are surfacing today. BioMASON is using a Bacillus strain to facilitate the formation of calcium carbonate that creates bricks from sand at room temperature. Companies such as Ecovative and MycoWorks use fungal mycelium to create bricks, walls, and wall insulation materials. Lingrove uses plant-based fibers and resin to create lab-made wood. Wooddoo makes transparent wood. Moreover, others like Modernmeadow, Tomtex, and Vitrolansinc made lab-grown leather. These approaches have the potential to affect the processes of building today without altering significantly design and construction delivery. In our studio work, we think that there is a huge value in pursuing first generation projects, but, at the rate the technology is developing, we think that these are temporary visions.

### 2.2 Second Generation: Engineered Living Materials (ELM)

A more advanced vision for SynBio in construction is to engineer new living materials from cells, bacteria, fungi, biological seeds, or the orchestrated growth of multiple organisms in an accelerated timeframe.  ELM become a funded research program at DARPA in 2016 with a particular vision stated as: "imagine that instead of shipping finished materials, we can ship precursors and rapidly grow them on site using local resources. And, since the materials will be alive, they will be able to respond to changes in their environment and heal themselves in response to damage" (Darpa, 2016). Several authors have developed wide-ranging reviews and taxonomy that summarize projects in this novel direction (Nguyen, 2018; Gilbert, 2018; and Srubar, 2020). We believe that soon this second generation of SynBio technologies will challenge the design of human spaces. We could imagine a future in which SynBio producers could deliver bio-ingredients and ecosystems to a specific site from which we can grow and make our habitats.

## 3 SynBio-Design Projects

Which type of human spaces we can generate with these new methods? In the following pages, we describe the themes we have developed in several studios.

### 3.1 Carbon stabilization Infrastructures: Reengineering Cyanobacteria

As stated above, the UNEP and IPPC reports state that the only way out of climate change is through new carbon removal methods. Which organism naturally removes carbon dioxide from our planet today? 100% of the oxygen on earth is a biological product. The earth did not have an oxygenated atmosphere until photosynthetic cyanobacteria emerged between 3.5 to 2.5 billion years ago. These bacteria transform Carbon Dioxide (CO2) and water (H2O) into sugars that are used for energy and as a byproduct of the photosynthesis processes Cyanobacteria releases oxygen (O2) into the air. Even today, 100% of the oxygen all living organisms breathe comes from cyanobacteria or descendant organisms: such as cyanobacteria in our oceans, and in plants and tree species that absorbed cyanobacteria via endosymbiotic evolution. Cyanobacteria life forms in the sea (such as the Prochlorococcus, algae, and oceanic plankton) are responsible for between 50-to-80% of the oxygen production on the planet.

Cyanobacteria, when they die, can create living rocks in the ocean like the stromatolites that were abundant in the Precambrian age. A lab led by Wil Srubar at the University of Colorado Boulder has already created a bio-concrete, using “synechococcus” cyanobacteria (Heveran, 2020). This bio-concrete grows and reproduces at an exponential rate. They were able to keep alive the cyanobacteria for 30 days. For example, if you create a brick with this biomaterial and you divide it into smaller parts while the cyanobacteria are alive, each part is capable of growing back again into a new whole brick in hours.

By re-designing a biological circuitry with cyanobacteria in shallow waters. We could capture excess CO2 from the atmosphere and create entire new islands and buildings from cyanobacteria bio-cement in just days. The only thing we need is water and redesigned cyanobacteria. In Figure 1 we envision a series of islands that grow by themselves using re-engineered cyanobacteria in the shallow waters of the Biscayne Bay, in Miami, FL, which is usually just 3-to-5 ft. deep.

### 3.2 Sea-Level Stabilization towers

In the work of our studio, we imagine how we can grow large bio-infrastructures that can absorb and retain seawater like sponges and cactus. We could grow with SynBio these desalinization towers all over the world (figure 3). These Bio-towers could absorb excess seawater from the melting ice sheets and glaciers to the point that we could stabilize sea level rise. We could control and reshape our current coastal areas and these sponge towers can contain bioreactors and all kinds of infrastructures from which we can obtain food, energy, and raw materials, locally.

The Miami desalinization tower project is an infrastructure that could absorb about 6 million cubic feet of seawater. The growth of the design is based on voxels of calcium carbonate that arrange in Semper knot structural formations as a byproduct of cyanobacteria circuitry. These sponge towers could be a sea-level stabilization strategy for the planet. The ocean surface area is about 1,680 million sf. If we calculate that sea-level rise will be around 6 feet by 2100, the earth will gain around 10,800 million cubic feet of seawater volume. If we could gradually grow 1500 of these infrastructures around the world, that could absorb the extra seawater, we could maintain the sea level we have today.

Figure 3. Desalinization, absorption, and retention tower proposal for Miami Biscayne Bay proposal that follows the process of growth via aggregation through a Semper's knot weight distribution. Project by Renzo Lopez (Alfredo Andia Design 8 Studio, FIU, Spring 2018).

### 3.3 Bio-fibrous structures

A series of fibrous-based skin habitats were developed based on the ability of fibrous infrastructures to capture $CO_2$ from the air. The fibrous structures can be injected with synthetic micro-fluidics like the ones developed at the Max-Plank Institute and increase carbon sequestration 100 times more than using the same tree volume.

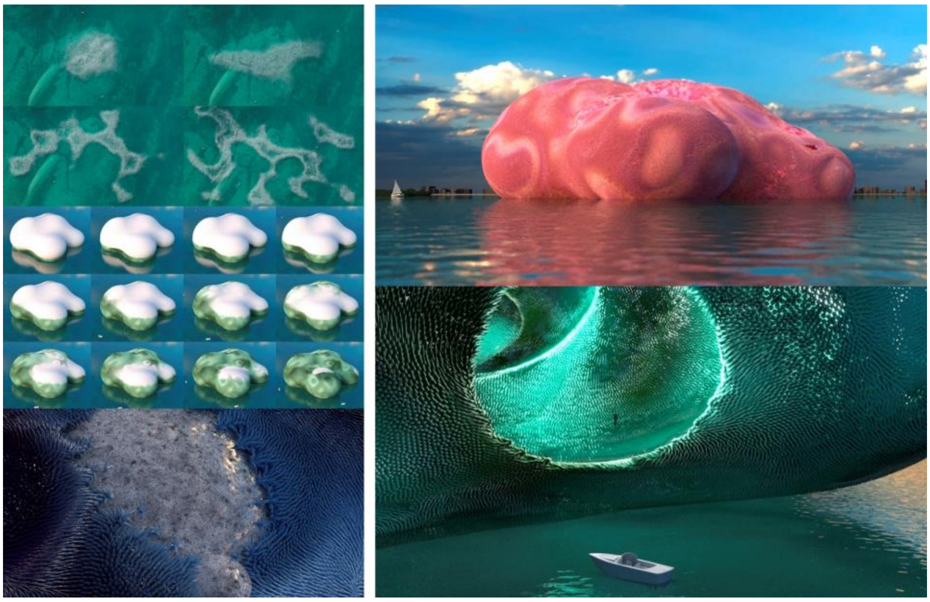

Figure 4. This project is an island/concert hall that grows from the shallow Biscayne Bay. Project by Carmen Alvarez and Steve Rivera (Alfredo Andia Design 8, FIU, Spring 2021).

Figure 4 depicts an island/concert hall that grows from the shallow Biscayne Bay via a metaball structural formation. The surface is covered by synthetic biological fibrous organisms that capture CO2, fuels energy, and provides changing illumination to the structure. The fibrous skin is an advanced version of the glowing nanobionics plants developed at Strano Research Group at MIT.

### 3.4 Bio-foods and the form of food

Plant-based food and lab-grown meat has been one of the earlier successes of synthetic biology. Companies such as Impossible Foods, the Not Co., or Ecovative are creating products that imitate and replace current products. Some companies are even creating scaffoldings that simulate the texture of steaks, bacon or egg. However, if we can transform proteins into any taste or shape why does food in our near future has to look like our old burgers, bacon, or steaks? Why vegetables cannot have the crunchy taste of pizza or the consistency and smoothness of marshmallows?

As we enter into this new era, we will have to redefine our design territories. A new freedom of forms will imply that food could have not only any shape, any texture, or consistency but also addresses its politics. In our studios, we have worked on eatable buildings. Buildings with bio-surfaces with engineered bacteria that could clean dirt, eat toxins, and detect any pathogens.

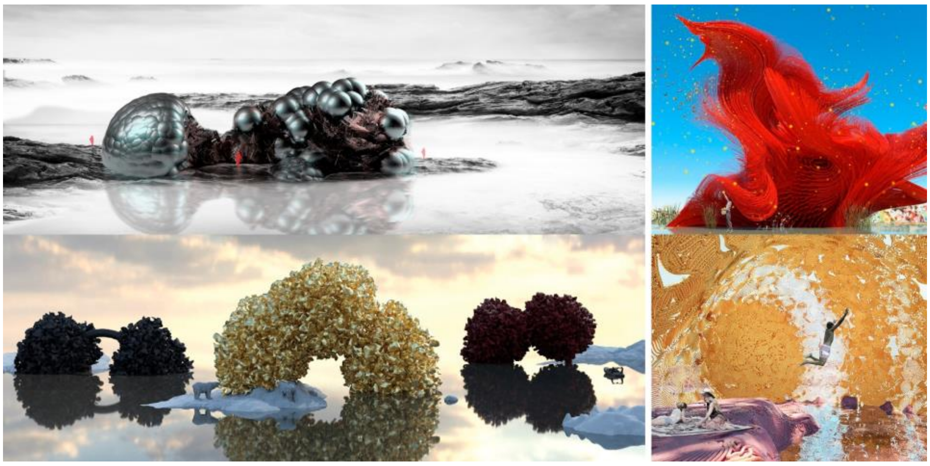

Figure 5. Left images: SynBio habitats in the artic offer both bioengineered food and refuge for explorers. It also is designed to provide nourishment for wild mammals, such as polar bears, that encounter longer periods of starvation due to climate change every year. Project by Jessica Milton and Karen Quezada (Alfredo Andia Master Project Studio, FIU, Spring 2021). Right images: Visceral creatures are habitats that are covered with synthetic fibers that perform photosynthesis. They are capable of capturing carbon dioxide at around 100 times more efficiently than trees. The project is based on research from the Max-Plank Institute that combined synthetic biology with micro-fluidics. Project by Aldo Escobar and Kathryn Leblanc (Alfredo Andia Design 8, FIU, Spring 2021).

Food is also a critical issue for a large number of species on our planet, especially for the dwindling number of mammals in the Arctic. In figure 5 we developed a project for the Arctic Polar Bears, which are encountering increasing food supply shortages and are increasingly resorting to cannibalism to survive. In this project, we propose habitats for Arctic explorers that also could have bio-reactors that could synthetically produce food for Polo Bear. As the devastations of climate change unfolds and we enter into a bio-technological era, a new human-animal relationship.

### 3.5 Bio-String structures

Spider silk is one of the strongest materials on earth. It is stronger than steel and more resistant than Kevlar. There is an increasing number of startups, such as Spiber Inc., that are already growing synthetic spider silk in their labs and are being used in products developed by Adidas and North Face. When will synthetic spider silk move into architecture? In the history of art, design, and architecture, we have a very limited experience with string structures.

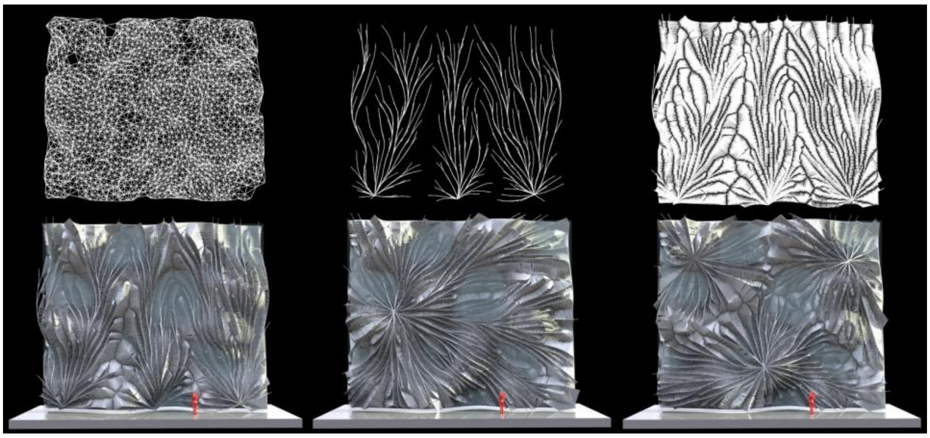

Figure 6. This façade uses a process of growth based on the shortest path logic using sting structure. Project by Maria Perez and Richard Salinas (Alfredo Andia Master Project Studio, FIU, Spring 2021).

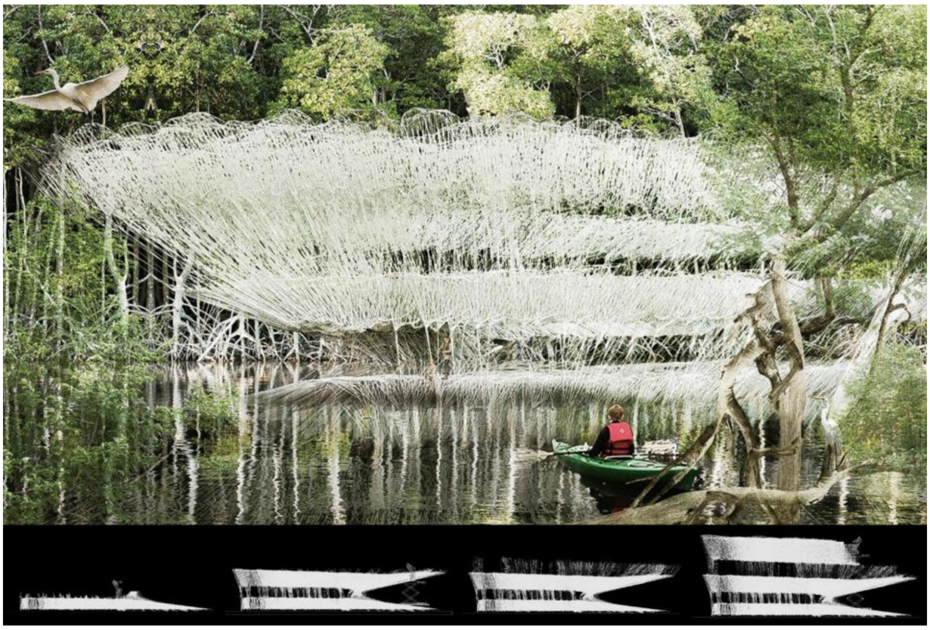

Figure 7. Stages of growth of a string structure using reaction diffusion. Project by Maria Perez and Richard Salinas (Alfredo Andia Master Project Studio, FIU, Spring 2021).

In our studios, we studied synthetic spider silk piping structures and enclosure/façade systems. Figure 6 shows the experiment of string structures in a façade. The growth process allows for the emergence of continuous channels that are able to collect, transport, and store nutrients within the wall. Figure 7 show the work using reaction-diffusion and noise offset to structure string-based forms for architectural settings.

### 3.6 Programmable Bio-matter

“Programmable matter” is a term used in computer science to describe a material that can be programmed by digital code. It is perhaps the most advanced vision on the computing field could affect the analog world. It is often imagined to be made of tiny robots (smaller than sand). Projects named Claytronics, M-blocks, Computronium are the early version of this grandiose vision.

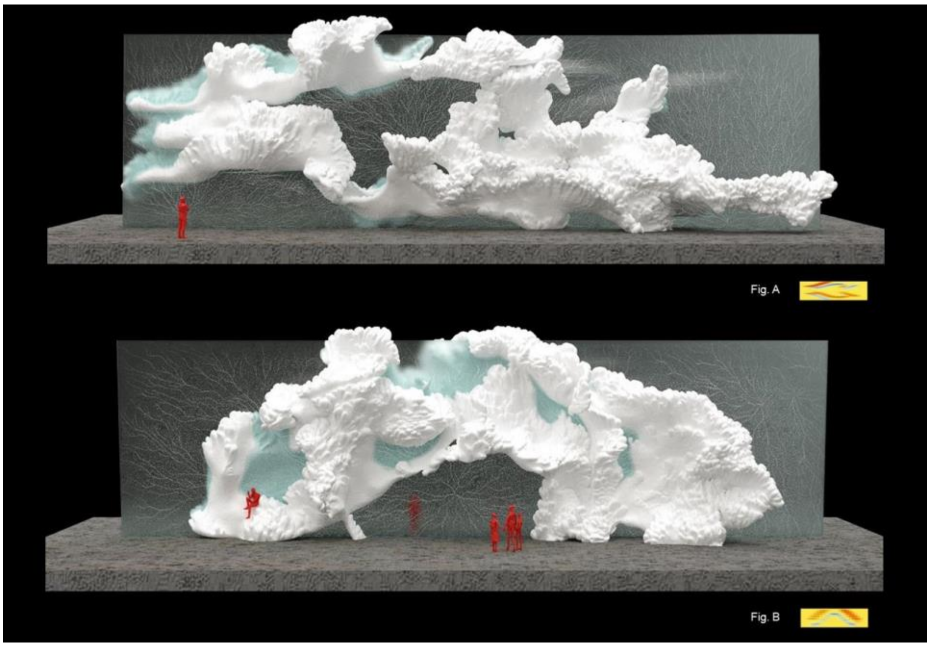


Figure 8. Programmable Bio-Matter. A series of walls designed to react to stiffness and solar radiation levels and wind forces of the site. Project by Maria Perez and Richard Salinas (Alfredo Andia Master Project Studio, FIU, Spring 2021).

However, biology is a much more sophisticated way to alter matter than traditional computing. All living organisms are made of programmed biological matter. For example, the broken antlers of a Dear is an organ that can regrow almost an inch per day and knows exactly when to stop. Therefore, in our studios we imagine that in the future we could have a kind of generic bio-matter, a highly intelligent biological entity that is made of living cells, that can bio-compute, store, retrieve and process data encoded in its DNA (figure 8).

We experimented with bio-matter that uses form-finding workflows using recursive growth. A group studied façades that use recursive growth bio-matter that propagates by two conditions: solar radiation and structural stiffness (figure 8). Other students have used the bio-matter to grow skin structures over a scaffolding that was made from fast a growing shrubs that later dissolves.
We have also explored a growing bio-matter organism that could develop catenoid formations. Catenoid structures would allow bio-matter to develop spatial materialization from a single plane that twist as it grows. This project was based by research of artificially produced cells at The Technical University of Munich that demonstrated how cells could communicate, which in a more advanced version could also lead shape control (Dupin, 2019).

## 4 Conclusion: SynBio Zeitgeist

Every major innovative period comes with a design paradox. Generally, we are unable to imagine the new! The design of the new usually has strong references to the immediate past. For example, when automobiles first emerged, they resembled their direct predecessor, the horse carriage. However, over time, the car evolved and every one or two decades the automobile reinvented itself following a particular zeitgeist, or the spirit of its time. In the 1950s followed the curves of planes and today, as we face an era of irreversible climate change, electric car projects from companies like Tesla, Lucid and Nio are transforming once more our vision of what is car mobility. Similarly, the first generation of SynBio products (2006-to-2021) has been highly concerned with developing a viable industrialized biology. For example in the food industry, one of the biggest success story has introduced viable plant-based meats that sell in most cities in the United States today.

But we ask: are we really going to remain in this new biological era eating SynBio foods that resemble our old burgers or bacon? Can we redesign our foods beyond that? In architecture, we are also trapped in this paradox. Will our architectural design imagination in this new era be reduced to just replacing elements of our contemporary buildings and cities? In our work, we propose that the final zeitgeist of a SynBio era will be how we weave our bodies in “pure experiences” with our biosphere (in the epistemic notion of experience inaugurated by philosophers William James and Kitaro Nishida). Imagination is critical!

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