Synthetic Biology Imaginations for the Biscayne Bay, Florida

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Abstract. This project attempts to reimagine Miami and coastal communities with the advent of climate change and the rise of biotechnology. We develop a speculative vision/plan for the Biscayne Bay estuary that envisions infrastructures that grow by themselves using synthetic biology. In this paper, we elaborate on how Synthetic Biology has evolved to become the fastest growing technology in human history, its potential in the development of large-scale infrastructures, and its impact on the future imaginations of Architecture.

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

1 Introduction: Our Biosphere

Which kind of imagination do we need to transform the way we have occupied our planet since the industrial revolution? 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. We, humans, are 36% of the mammals on earth by weight, 60% are livestock and just only 4% are wild mammals.

However, this 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 our planet. The March 13, 2019, UNEP report states that “even if existing Paris Agreement commitments are met, winter temperatures over the Arctic Ocean will increase 3-5°C by mid-century” (UNEP, 2019). The 2019 report from the IPCC states that 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 as the arctic inevitably warms up in the coming decades. 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 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. Many of us end proposing carbon-reducing techniques with current construction methods with exaggerated claims that we are solving climate change. We are in a deep crisis of imagination!

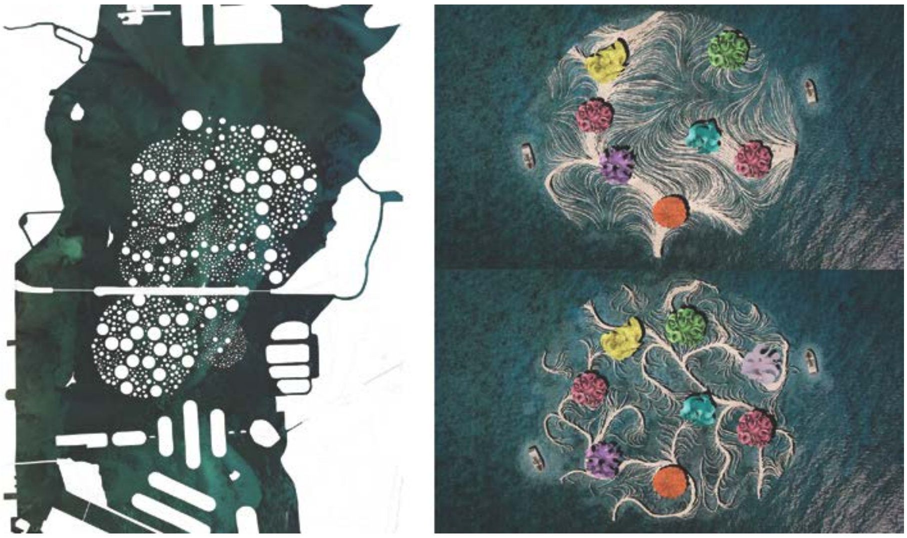

Figure 1. The proposal envisions a series of islands that grow in Biscayne Bay by reengineering cyanobacteria. A biological circuitry allows cyanobacteria to capture carbon dioxide in the water via photosynthesis and transforms it into finely layered rock material. The process is similar to the living 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).

2 Vision: Building with Biology

Where is the new vision? In this paper, we argue that in the past 150 years we have redesigned our planet with mechanical methods and processes that are based on the industrialization of a few inert materials. We propose here 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.

2.1 The History of Oxygen

If we talk about climate change and carbon emissions, first, we need to understand that the oxygen we breathe, our atmosphere, is 100% a biological product. 3.5 billion years ago there was practically no oxygen in the air, the atmosphere was composed mostly of Nitrogen (N_2), Carbon Dioxide (CO_2), and Methane (CH_4). Anaerobic microbes that did not need oxygen to survive populated the oceans. Between 3.5 to 2.5 billion years ago, the ancestors of cyanobacteria emerged in the oceans. Cyanobacteria organisms had the novel ability to perform photosynthesis. These bacteria transformed Carbon Dioxide (CO_2) and water (H_2O) into sugars that are used for energy. As a byproduct of the photosynthesis processes Cyanobacteria released oxygen (O_2). The planet was full of Carbon Dioxide and water so Cyanobacteria began to proliferate around the planet and bubble by bubble, they filled the atmosphere with oxygen between 2.4 to 2 billion years ago.

2.2 Cyanobacteria: The Great Oxygenation Period

Cyanobacteria were so successful that they nearly killed all other types of life on earth. Cyanobacteria filled the atmosphere with so much oxygen that our planet began to freeze even depriving cyanobacteria of access to sunlight. By chance during that period, volcanos began to explode on earth releasing enough greenhouse gases that warmed the planet again. The life forms that survived inherited a warm and oxygenated earth that proved perfect for the multicellular organisms that evolved and inhabit the world today.

Still today, 100% of the oxygen that is in the atmosphere comes from cyanobacteria or descendant organisms. The cyanobacteria life forms on the ocean (such as the Prochlorococcus, algae, and oceanic plankton) are responsible for between 50-to-80% of the oxygen production on the planet. In addition, all the photosynthesis that occurs in plants and tree species on land has emerged by life forms that absorbed cyanobacteria via endosymbiotic evolution.

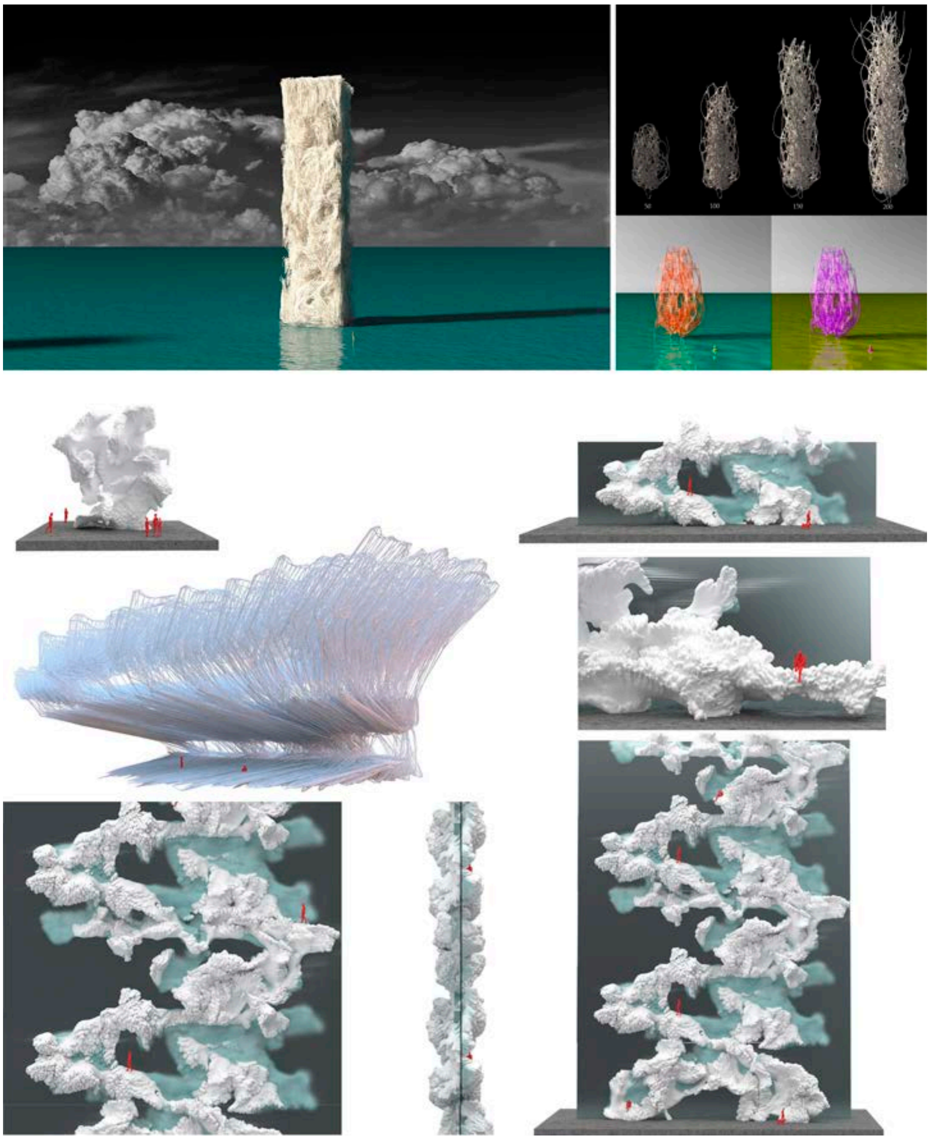

Figure 2. These two projects are proposed for the Stiltsville area. Top images: these growing towers that works with different growth strategies such as curl noise, recursive growth, and DNA plexus. The project reflects on the spectrum of fragility in which we could nurture our SynBio habitats. Project by Bryan de la Cruz and Juan Moreno. Bottom images: habitats for an emerging "feral society" that diverges from the contemporary domestication of the built environment. It also develops a "mutualist" relationship with biologically designed systems. This project works with processes of growth based on reaction diffusion, differential mesh growth, recursive growth, fibers, shortest path, noise offset, evolution based on solar radiation, stiffness evolution, and others. Project by Maria Perez and Richard Salinas (Alfredo Andia Master Project Studio, FIU, Spring 2021).

2.3 Cyanobacteria bio-circuitry to build islands and cities

Cyanobacteria has a bigger impact on our design work in the Biscayne Bay. Early in the development of our proposals to build islands in the Florida Biscayne Bay, we consulted one of the leading SynBio scientist, George Church from Harvard University. He suggested that by reengineering cyanobacteria we could build the islands we were proposing in just days. Most of the Biscayne Bay is shallow (up to 3-to-5 feet deep) which is a perfect wet environment for maintaining cyanobacteria alive. When cyanobacteria grows in the ocean, it can do enormous amounts of carbon dioxide sequestration in the surrounding water. In the process, cyanobacteria capture calcium carbonate and minerals that form a crust. Layer by layer cyanobacteria in shallow water can form finely laminated rock material. The process is similar to the stromatolite rocks that photosynthetic cyanobacteria organisms produced abundantly in the Precambrian age.

A group led by Wil Srubar at the University of Colorado Boulder is developing a living building material, a type of bio-concrete, created "by inoculating an inert structural sand-hydrogel scaffold with Synechococcus," a type of cyanobacteria (Heveran, 2020). They have produced a method that allows cyanobacteria colonies to survive up to 30 days in a solution of sand and gelatin. This bio-concrete grows and reproduces at an exponential rate. 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. This project is a good case for architects to challenge our industrial design imagination. It advances a new aroma and acuity from which we can began to reconceptualize visions for our cities, biology, and nature.

3 Nature and Biology

Nature has been an evolving concept in the arts and sciences. Biology of the 1800s was based on voyages into the practically untouched nature at the time. This lead to the immortalized "theory of evolution" by authors such as Charles Darwin and Alfred Wallace. By the 1900s biological studies began to move away from travels into the natural environment into labs that began to study life principles, which obtained a major breakthrough with the discovery of the "DNA structure and function" in the 1950s. 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 were propagated by the accelerated power of computers and new gene-editing techniques.

3.1 Synthetic Biology (SynBio) Growing by the power 10

Since 2016, 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. 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 at a factor of 1.5 times per year (Church 2014).

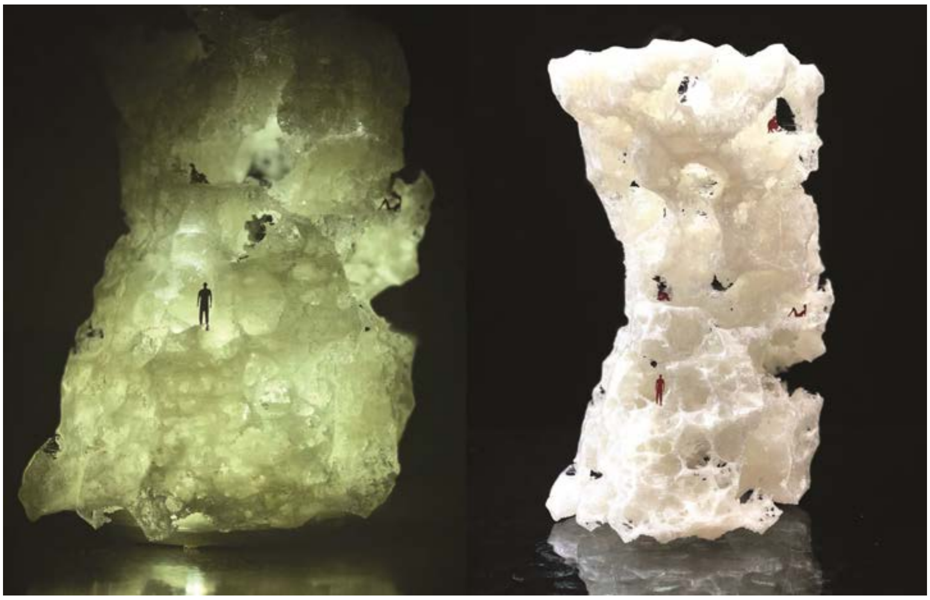

Figure 3. A living structure motivated by the process of secretion of calcium carbonate in corals. Image: project by Rosanna Rodriguez (Alfredo Andia Design 8 Studio, FIU, Spring 2019).

3.2 Bio-Design Envisioning

The SynBio community emerged as a “maker” movement in the 2000s around the IGEM student competition, the Biobrick foundation, and the emergence of CRISPR Cas9 in 2013. A significant number of the earlier pioneers of SynBio derived from engineering and computer science. They were interested in “making” or “manufacturing” life rather than understanding the principles of life that controlled the ethos of traditional biology (Roost 2017). Today, as the first generation of SynBio matures into disrupting major industries it is also a time to begin to question if these narratives are only about industrializing biology for a profit, or can we transform the symbiosis of humans with our ecosphere? A new generation of discourses is emerging in the SynBio diaspora that searches for more deep integration with design and art communities (Ginsberg 2014). The work we present here is in the direction of that integration.

3.3 Bio-Cities

How can SynBio alter our infrastructures and cities in coastal communities vulnerable to sea-level rise? In this project, we visualize a series of islands and buildings in the estuary of Biscayne Bay which grows by using living matter. Based on previous research on a gene circuitry that uses bacteria that can precipitate calcite to solidify sand we envision the growth of a series of islands over the shallow Biscayne Bay as a way to create a “living shoreline” for relocating populations from Miami threatened by sea-level rise. These growing territories will have increased soil pressure that will self-transform according to the levels of rising seas. The proposed system of islands works like atolls that will create defenses from currents and surges.

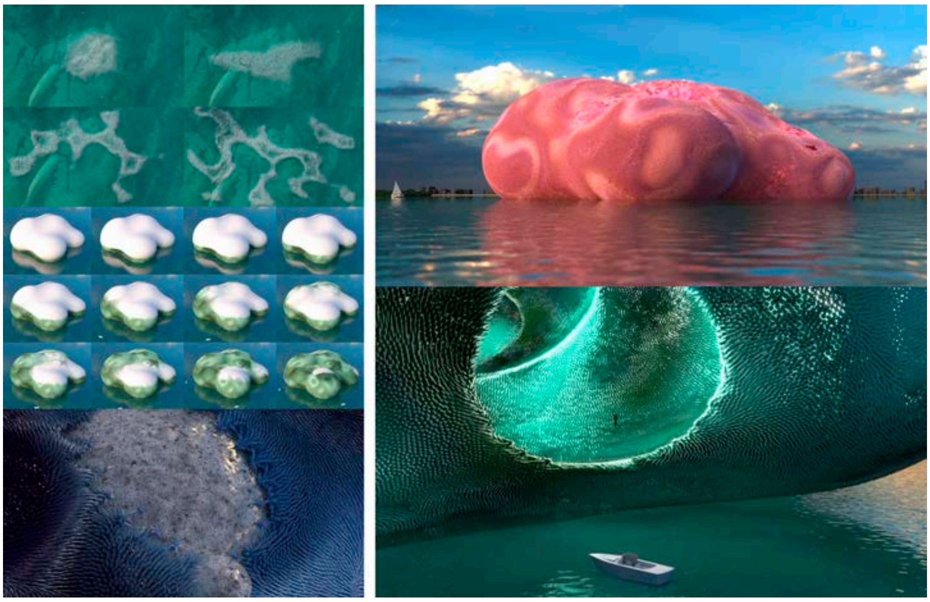

Figure 4. This project is an island/concert hall that grows from the shallow Biscayne Bay via a metaball structural formation. The surface is covered by synthetic biological fibrous organisms that captures CO_2, fuels energy, and provides changing illumination to the structure. Similar to the glowing nanobionics plants developed at Strano Research Group at MIT. Project by Carmen Alvarez and Steve Rivera (Alfredo Andia Design 8, FIU, Spring 2021).

The infrastructures above the islands are designed for living, entertainment, work, food production, and functions such as water desalinization. Synthetic Biology can make living matter fully programmable. In this project, we try to challenge our imagination and move more deeply into bio-aesthetics. We find the process very difficult to visualize with traditional architectural methods and thinking. One of the main drivers is to observe biological agents that could activate spatial evolution and how our bodies will be augmented in a SynBio age. Each project we work on is developed based on a particularly desirable condition. We study particular processes of growth, and investigate what makes an organism develop its shape.

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).

4 Nature and Biology

In our design visions, the understanding of current synbio projects has been critical. But one main question that haunts us is how we can challenge our design imagination? Are our industrial ghosts relevant in this new era? Most SynBio research and production occurs today is at the nano-scale. We think there are two generations of design-manufacturing tactics that are emerging at the macro scale of Synbio in construction that is relevant to answer these questions.

4.1 First Generation: Lab-Grown Materials

An increasing number of startups in that SynBio sphere are beginning to produce a large number of lab-grown materials. 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. And others like Modernmeadow, Tomtex, and Vitrolansinc made lab-grown leather. These approaches have the potential to immediately 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 thing that these are temporary visions.

4.2 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 goal of creating a new class of materials that combines the structural properties of traditional building materials with attributes of living systems…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 summarizes a large number of emerging projects in this novel direction (Nguyen, 2018; Gilbert, 2018; and Srubar, 2020). We believe 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 specific site from which we can grow and make our habitats.

Technology vs. Fiction

Fiction can be a taboo in architecture. The method of making in SynBio inhabits in a different epistemic space than traditional scientific discovery, by celebrating making synthetic biology has a more deep relationship with seeing, with envisioning (Roosth 2017). In our proposals for the Miami Biscay Bay, at first, we tried to find existing SynBio techniques, some described above. We studied processes that could produce quick methods and low-energy practices of biomineralization such as sporosarcina pasteurii bacteria, synthetic protein, and collagen to produce artificial bone materials, synthetic spider silk, and others. However, after conversations with several SynBio researchers, we were convinced that the next plateau of SynBio was envisioning, fiction, not just technology. A space in which the next generation of SynBio designers could begin to reimagine itself.

5 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. But 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. 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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