Form Follows Science: An Approach for Reversing the Anthropocene

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Abstract

This thesis presents a three-part approach where scientific research drives the materialisation and formation of architectural designs that strive to make the invisible effects of anthropogenic environmental change undeniably apparent. I argue that architecture is a provocative storyteller. Thus, the approach outlined in this paper is centered around the narrative of the Anthropocene and how architecture can make it seen. This thesis is complementary to a project which was developed in collaboration with architecture student Sarah Perrino and Associate Professor at the School of Architecture Prof. Julie Larsen.

Executive Summary

Stories have intensely formative power. They can shape who we are, what we do, and how we perceive reality. Storytellers, then, can potentially influence the values and behaviors of the people around them. Depending on who tells the story, this could be good or bad.

According to Nicholas Mirzoeff, one of the leading theorists of visual culture, the narrative of the Anthropocene is currently controlled by those who benefit from it. The Anthropocene is a geological age named for the detrimental consequences that human activity began to have on the environment. Mirzoeff tells us that the Anthropocene is fueled by the imperialist conviction that *nature is a thing to be conquered,* "an enemy to be subdued" (217). In response to this colonialist visualization, Mirzoeff urges us to construct a *counter*visualization wherein the impending reality of the Anthropocene is revealed. In a blatant act of resistance to the capitalist culture which controls the current narrative, he is urging us to tell a visual story that exposes the truth of anthropogenic environmental change.

As a contribution to Mirzoeff's call to action, this thesis presents a three-part approach for telling that story through architecture generated by scientific research. Stage one is the development of the narrative, wherein we curate a thorough understanding of the current state of the Anthropocene. Appealing to our natural preoccupation with the self, it is crucial that the narrative emphasizes the consequences the Anthropocene has on humans.

The second stage is the design of a counter-narrative, which involves the production of a structure that serves to combat the effects of the Anthropocene and rewrite the future of our

shared planet. It is in this stage where form follows science as scientific research informs the materialization and formation of an ecologically responsive and aesthetically compelling design.

Ecologically responsive design refers to the adaptability that the structure has to the ever-changing conditions to its environment. It asks the question, how does the environment impact this structure? And in turn, how does this structure impact the environment? This thesis argues that the relationship between nature and this manmade object should be almost symbiotic. Otherwise, we risk creating a stagnant and fixed form that might only worsen the Anthropocene. This approach, which practices cautious speculation and experimentation, should be driven by current scientific knowledge of materials, technology, and the environment.

Aesthetically compelling design is concerned with the formal expression of the structure or the shape that it assumes. Does the form attract attention to itself? Does it encourage passersby to investigate and interact with it? Most importantly, does it generate questions that lead to Anthropocene education?

This leads us to the final stage, the diffusion of the complete narrative. The complete narrative is the story that the architecture tells once it's built. It's made up of the past narrative, the current counter-narrative, and the potential narrative of a better future. Diffusing the complete narrative is focused on answering the question of *how* passersby engage with the structure. After all, locals and tourists cannot learn the narrative surrounding it without interacting with it. The message delivered by the complete narrative should emphasize the complex interconnectedness of all things and how all human activity has consequences that eventually affect the human world. This message is intended to plant the seeds of a worldwide movement toward reversing the Anthropocene.

This thesis builds upon Mirzoeff's proposal of countervisualizing the Anthropocene with a structured approach focused on telling a visual story through scientifically-generated form.

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Preface

A year ago, I took my first introductory course in architecture. I was inspired by the idea that architecture could be used to inspire lasting social change. By the end of the course, I wanted to find some way to merge my background in science with my budding interest in architecture to advocate for the protection of our natural resources and the cultures that depend on it.

That is how this thesis came about. It serves as my first attempt to engage in the current discussion surrounding scientifically-driven architecture. As with any first step into uncharted waters, this project has its weaknesses. I wanted to take this opportunity to critically evaluate my work as a reference for my future endeavors. For one, a year of exposure to architectural discourse is not enough to hone a nuanced understanding of all of the issues and debates within it. As such, this thesis lacks a thorough literature review. In addition, given the right time and skillset, the final proposed design would have been the calibrated result of many iterative tests.

While the scholarly contribution of this thesis might be small, it is still a crucial personal achievement. While I do not have the benefit of a five year architecture program, I was able to demonstrate that my training in physics gives me a unique perspective in design. My fluency in science and ability to process technical research journals enabled me to generate creative ideas and become an equal participant in the design process.

We all have to start somewhere. I am proud of where I started and I’m excited to see where I will go.

Acknowledgements

Combining my love for science, architecture, and the environment in one thesis was a daunting task, so I'm grateful to all the people that helped make it happen.

Thank you to my mentor and advisor, Professor Joseph Godlewski, for introducing me to architecture and your constant support. I surely would not be on the current path I'm headed without you.

Thank you to my reader, Professor Eric Schiff, for allowing me this unusual opportunity. My time with the Physics Department challenged me and opened a world of possibilities to me.

Thank you to my partner in crime, Sarah Perrino, for being an awesome person to work with. You taught me so much.

Thank you to Professor Julie Larsen. Your guidance gave my ideas structure and direction. Thanks for always pushing me to do better.

Thanks Andrew for helping me stay sane during this journey.

Last but not least, thank you to the people at the Renée Crown Honors College for introducing me to interdisciplinary thinking. Thank you for encouraging me to find a connection between my seemingly random interests.

CHAPTER ONE: Introduction

Architecture has the ability to tell powerful stories. In 1948, this became painfully apparent to the indigenous people of the Enewetak Atoll whose home became a testing ground for American nuclear weapons. The Runit island test site—which was once sprawling with "breadfruit trees heavy with green globes of fruit and crabs dusted with white sand" (Jetnil-Kijiner)—was suddenly "engulfed in an inferno of blazing heat" and reduced to a smooth concrete dome.

Fig. 1 | The Runit Dome, built into the crater of nuclear weapons test "Cactus" to seal irradiated debris.

Is this dome architecture? While not intentional, it has become a symbol of death and sickness among the locals, a tomb that tells the story of a tropical paradise lost. As the modernist architect, Adolf Loos, would put it, "something important happened here" (Godlewski xi). Its nondescript surface boasts no more beauty than a bicycle shed, but it tells a crucial truth. It tells us that unless we work to reverse the Anthropocene, our planet's fate as a concrete monument to our carelessness will be solidified.

In order to reverse the Anthropocene, we must first make its existence undeniably apparent to the public. This task is not an easy one as most effects (such as climate change) are difficult to perceive in everyday life and almost invisible. Fortunately, as shown by the Runit Dome, architecture can help us depict these invisible narratives in a provocative way. For instance, while nuclear radiation is invisible to the naked eye, the dome stands as a visible reminder of the radioactive dangers that still exist there.

However, architecture cannot achieve this alone. This project strives to implement the design approach posited by architect Martin Bechthold and scientist James C. Weaver in "Review of Materials Science and Architecture." Typically in architecture, science enters during the construction phase, after the design has been mostly finalized. In this approach, science actively participates in the design process and becomes a "catalyst for novel architectural design" (1). That means studying the bizarre things a material is capable of, then using those performative capacities to generate a formal spectacle. As science informs our decision-making, science and architecture become equal collaborators in design.

This thesis breaks down an approach for reversing the Anthropocene into three parts: the development of a narrative, the design of a counter-narrative, and the diffusion of the complete narrative.

What follows is a demonstration which is done in collaboration with architecture student, Sarah Perrino. This demonstration is focused on the ongoing disappearance of seaweed beds due to rising sea surface temperatures. Specifically, this project focuses on the decay of nori (edible seaweed) along the coast of Futtsu, Japan.

CHAPTER TWO: Developing a Narrative

First, we need to decide what story we want the architecture to tell.

Inextricably Connected

According to a 2018 report conducted by the Japanese Ministry of Environment, the mean global sea surface temperature (SST) has increased at a rate of 0.53°C every 100 years between 1891 and 2016 (MoE). This mean temperature is projected to continue increasing through the 21st century (IPCC). These projections are calculated based on the Representative Concentration Pathway (RCP) model recognized by the Intergovernmental Panel on Climate Change (IPCC) of the United Nations. Shown below are the best and worst RCPs, or the possible scenarios depending on predicted greenhouse gas emissions in the decades to come. This graph is taken from the IPCC's ongoing AR6 Synthesis Report, due for release in 2022:

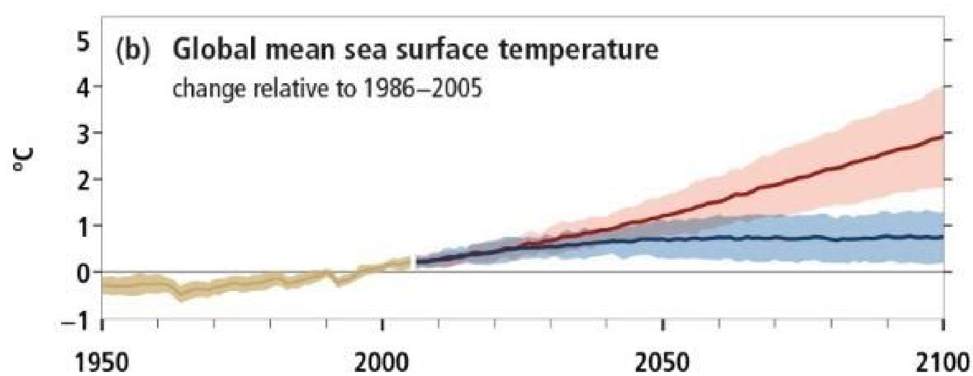

Fig. 2 |Past and future changes in the global mean SST. Purple indicates historical observed changes. Yellow indicates historical modelled changes. (Purple and yellow overlap.) Blue shows RCP2.6. Red shows RCP8.5.

Anthropogenic climate change, while difficult to perceive in daily life, is an indisputable reality. Since the natural and human worlds are inextricably connected, this man-made geological machine sets off a chain of events that eventually circles back to us. So while global warming itself is almost invisible, its eventual consequences on the human world won't be.

In some places in the world, we can already start to see those consequences threaten our economies and way of life. Along the coastline of Futtsu, Japan, rising SST is hindering the growth of nori, a centuries-old staple in Japanese diet and a critical component of sushi. Local nori farmers have been struggling to keep their trade alive.

According to biologist Kyosuke Niwa of the Tokyo University of Marine Science, nori is especially vulnerable to rising SST because it thrives in cool conditions. Members of the local cooperative say that the resulting crop has been brown, tasteless, lacking in nutrients, and overall unsellable. Satoshi Koizumi, the head of cooperative, says that the conditions are so difficult that "people are giving up" (Harding).

Fig. 3 | A nori farm along the coast of Japan. Source: H. Grobe, *Nori* wikipedia page, 1965.

Unintended Consequences

While we cannot single-handedly cool the ocean to a temperature suitable for nori growth, there exists another threat to nori that we can directly address. In addition to rising SST, local farmers say that well-intended efforts to regulate agricultural runoff has accelerated the death of seaweed (Harding). These runoff reduction measures were put in place to prevent the contamination of surrounding soil, groundwater, and bodies of water. However, after decades of exposure to agricultural wastewater, nori became dependent upon the nutrients that it contained. Once these regulations were put into effect, local farmers noticed a drastic decline in the quality of their crop. Niwa tells us that our only hope is to change the way wastewater is handled (Harding).

This project intends to do just that. We can design a counter-narrative where there exists a controlled method for reusing this byproduct of agriculture as a nutrient source for nori. If the wastewater were collected, filtered to a non-toxic concentration, then transported *directly* to a nori farm, nori growth could be reinvigorated while preventing the excessive nutrient pollution of surrounding areas.

Simultaneously, this project can indirectly combat rising SST. As mentioned, it's still true that we cannot single-handedly cool the ocean because contending with climate change must be a global effort. If this project can diffuse the story of the threat rising SST poses to nori through architectural storytelling, it would contribute to the expansion of that global effort. We will return to storytelling in chapter four. In the next chapter, we focus on designing a counter-narrative.

CHAPTER THREE: Designing a Counter-narrative

By designing a counter-narrative, we are creating something that reverses the current trajectory of our narrative and catalyzes an alternate future. For us, that means designing a structural system that combats the decay of nori. Ultimately, we are rewriting the dismal future of nori.

Runoff Aqueduct

In a 2019 study, scientists at the University of Miyazaki found that "treated sewage showed great potential as a nutrient resource for seaweed" (Suzuki 24). In a water salinity of between 10%-20%, a minimum concentration of 35.4 mg-N L^{-1} of nitrogen and 4.2 mg-P L^{-1} of phosphorus fostered the healthiest possible nori (Suzuki 23).

The question of transportation remains. Rome's iconic aqueducts are known not just for their formal elegance but also their practical simplicity, as it relies on gravity alone to transport large volumes of water. Our design strives to utilize this simplicity. The aqueduct will begin at a strawberry farm sitting roughly a mile from Futtsu's coastline. After nearby runoff is caught in a gravel-filled trench, an automatic analysis and treatment system will ensure that only the above concentrations of nitrogen and phosphorus enter the aqueduct, to prevent eutrophication due to excess nutrients. A balanced quantity of nutrient-rich runoff is finally transported to a nori farm. With this primary function in mind, how does this aqueduct become a formal spectacle?

Equalizing Form and Material

Before we can consider form, it's crucial to note that architecture does not exist in a vacuum. The environment continually affects it and architecture continually affects the environment. Thus, a project is never really 'finished'.

Rather, a project begins with interaction. It begins when living beings engage with the structure according to their unique needs and social behaviors. It begins when ecological conditions and forces exert themselves on the structure. Since these needs, behaviors, and conditions are ever-changing, so too is the project. We can't design for the future with a stagnant system—we need a form that is simultaneously aesthetic and responsive.

How do we accomplish that? In *Morpho-ecologies*, architects Hensel and Menges say we can take a cue from developmental biology:"In natural morphogenesis, formation and materialisation processes are always inseparably related. By contrast, architecture is prioritizing form-generation over inherent material logic" (Hensel 20). Here, biology takes a bottom-up approach to design, where *form and material are equally prioritized*. Applying this approach to architecture, we should treat materials as "generative drivers in the design process" rather than a post-design decision.

Giving materialization a more dedicated role in design means reviewing scientific literature for a uniquely performative material. From that literature, we can determine a material that gives rise to an ecologically responsive form.

Ecologically Responsive

This is where science enters to catalyze novel architecture, as Bechthold and Weaver tells us. For the runoff aqueduct, the hollow and thick-walled culms of moso bamboo that thrive in temperate climates make it the ideal candidate for a wastewater pipe. Current literature on environmental science tells us that moso bamboo can generate the aesthetic and responsive form we're looking for.

What truly sets moso bamboo apart is the way it responds to the environment while it's still alive. Bamboo actually plays a role in reducing greenhouse gases as it can absorb "more than 62 tons of carbon in hectare every year" (Emamverdian). Its dense network of roots also prevents the onset of soil erosion as it binds and stabilizes the earth (Shinohara). Known to some as "vegetal steel", bamboo's flexibility and high tensile strength also make it resistant to earthquakes, a property that is especially crucial in a region that sits in the earthquake-prone Ring of Fire (Peters 47). Most notably, in a process called phytoremediation, bamboo absorbs and thrives from any excess agricultural runoff that still sits in the ground (Emamverdian). A runoff aqueduct made of living bamboo, then, becomes a gear in the symbiotic machine that it works to preserve.

Since biology has already perfected the design of ecologically responsive forms, why not let it take the lead? This is where form follows science. By approaching materialization from a scientific perspective, and using that approach to inform the design process, a "new functional and expressive application" of bamboo arises (Bechthold 1). We call this new application bent bioarchitecture.

We've discussed at length the materialization of bent bioarchitecture. What will be the formal expression that arises from this research?

Aesthetically Compelling

Just as the Runit Dome is a spectacle that draws us into a provocative story, this aqueduct will act as an aesthetic spectacle that appeals to the public's curiosity. Here, we lay down the foundations for narrative diffusion. The hope is that its unique form will generate questions and an opportunity to educate. How will this formal spectacle be achieved?

This is where the "bent" in bent bioarchitecture comes in. In Costa Rica, a bamboo farmer and craftsman named Brian Erickson discovered that the shape of living bamboo can be guided using tires (Figure 4a). These successful experiments were conducted on *Guadua angustifolia*. Since this thorny species of bamboo only thrives in tropical climates, it would be unsuitable for growth in temperate Japan. Moso bamboo still stands as the ideal candidate for bent bioarchitecture. It can be speculated that the tire method works on moso bamboo as it already exhibits this adaptable bending behavior in nature. In Figure 4c, we see how a stalk of moso bamboo grew to circumvent some underbrush that has since been removed (Meckes).

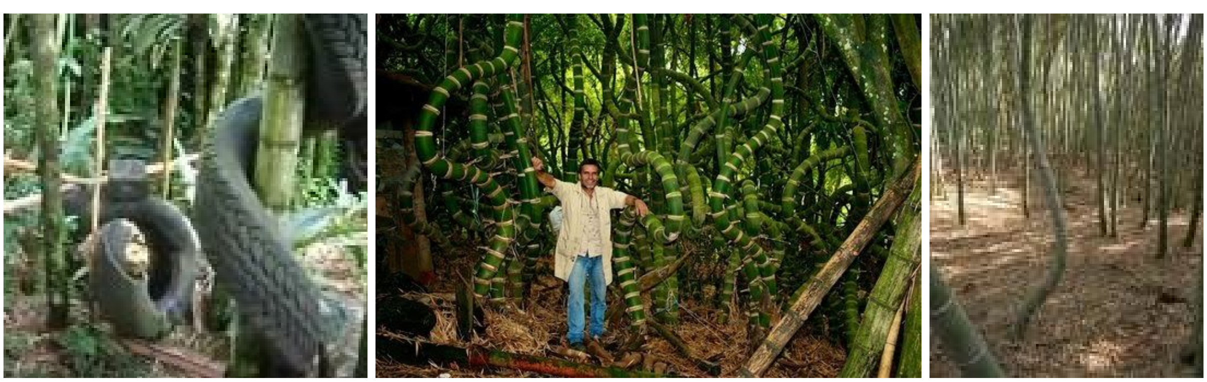

Fig. 4 | (a) Guided growth tire method. A cut tire is enclosed around a bamboo sprout. As the bamboo grows it is forced to follow the path defined by the tire. Source: Erickson. (b) Results of the guided growth method. The pictured species is *Guadua angustifolia*. Source: Erickson. (c) The natural bent growth of moso bamboo, demonstrating its potential for shapeability using the tire method or some equivalent. Source: Meckes.

These living twisting forms are applied on a larger scale to generate a series of arches which serve to support the aqueduct pipe (Figure 6).

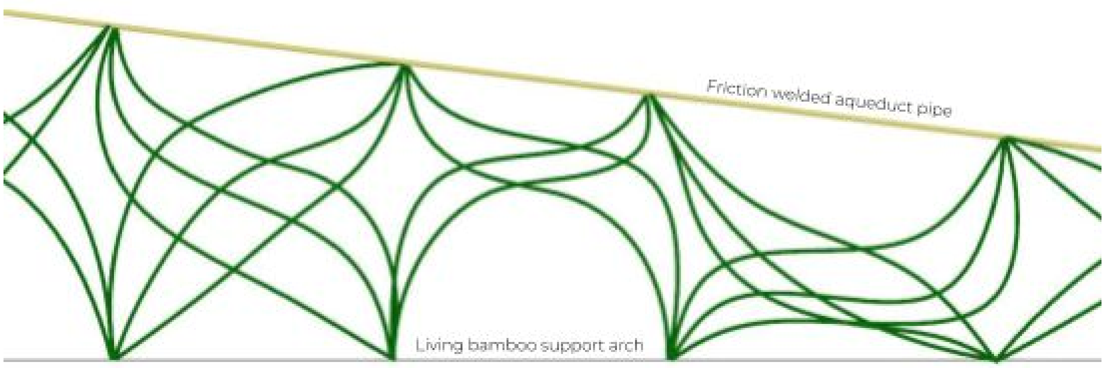

Fig. 6 | Simple schematic of bent bioarchitecture, demonstrating variable, organic form.

Segments of the closed aqueduct pipe are friction welded together to ensure maximum bondage and minimal leaking. As in metal welding, wooden elements are rubbed together until pyrolysis (thermal decomposition) occurs. As the elements cool, they "bond permanently as the softened material hardens into the dark welded interface" (Bechthold 4). Out of this seconds-long process we produce a high-strength bond (Figure 5).

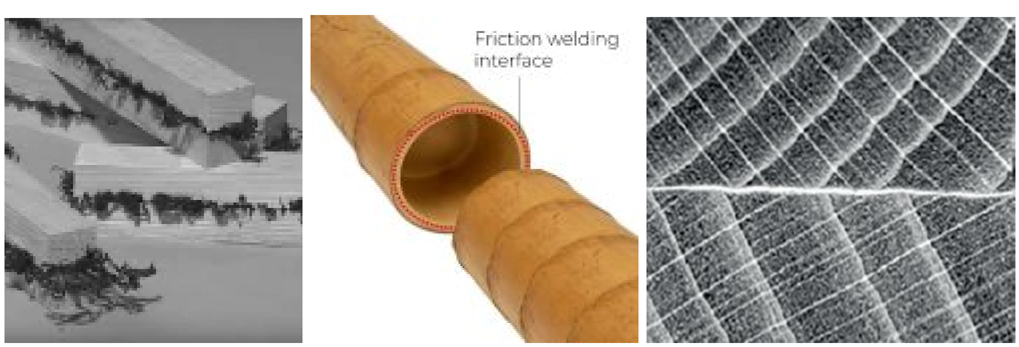

Fig. 5 | (a) Result of linear friction welding. Shavings can be swept off. (b) Section of 5’ wide moso bamboo aqueduct pipe. Welding interface shown. (c) Magnified x-ray of the interface between each element.

By combining these elements, the result is a twisting, variable form that gradually rises out of the earth. Because the aqueduct’s form straddles the line between natural and manmade, it doesn’t quite blend in with the natural or manmade surroundings along its path. It’s a formal spectacle that calls attention to itself and raises questions.

CHAPTER FOUR: Diffusing the Complete Narrative

While the formal spectacle is effective for turning heads, locals and tourists cannot learn the narrative surrounding it without interacting with it.

The complete narrative is the story that the architecture tells once it's built. It's made up of the past narrative, the current counter-narrative, and the potential narrative of a better future. Direct engagement points must be created for the diffusion of this complete narrative to be initiated.

Hiking Path

Kyoto's ever-crowded Fushimi Inari Shrine is known for a series of gates called the Senbon Torii.

Fig. 7 | (a) Senbon Torii in Kyoto, Japan during off-hours. (b) Its usual crowded state.

Where will this path take me? How far does it go? These are the kinds of questions generated by this mysterious and seemingly endless tunnel. It almost draws you in and compels you to discover what's on the other side. To recreate this peculiar feeling, the aqueduct arches can aggregate to form a tunnelling path from the strawberry farm to the nori farm (Figure 8).

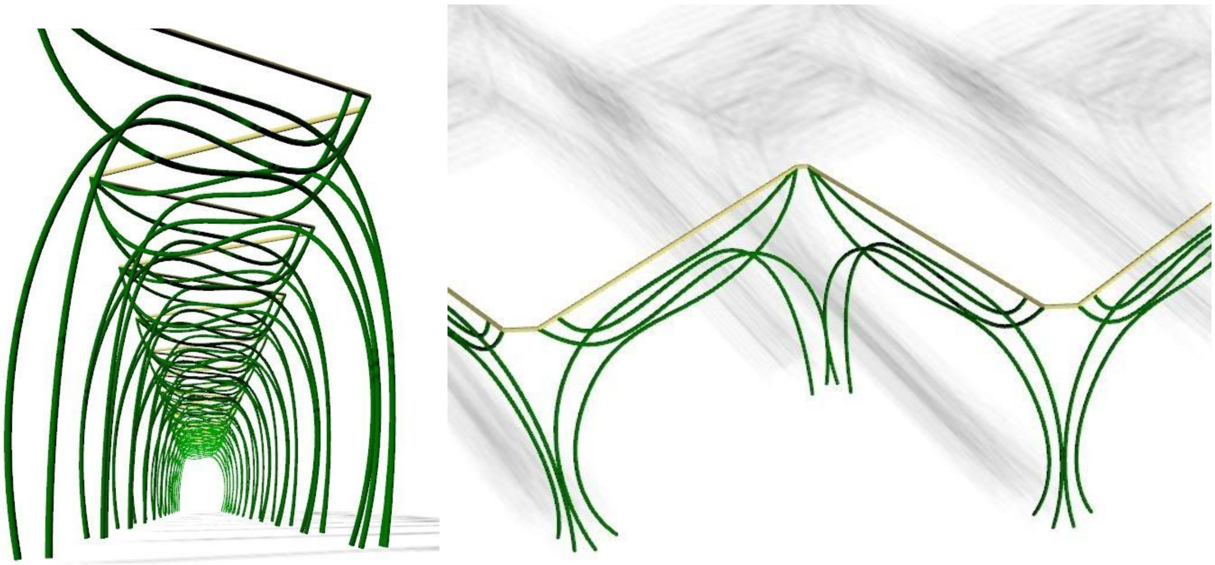

Fig. 8 | (a) Perspective of tunneling archways. (b) Aerial view of zig zagging archways.

The primary mode of engagement with the aqueduct then is a hiking path (Figure 9). This nonlinear path to Tokyo Bay follows a few main roads and passes through populated sites, to ensure visibility. The arches zig-zag to allow access at any point along the path.

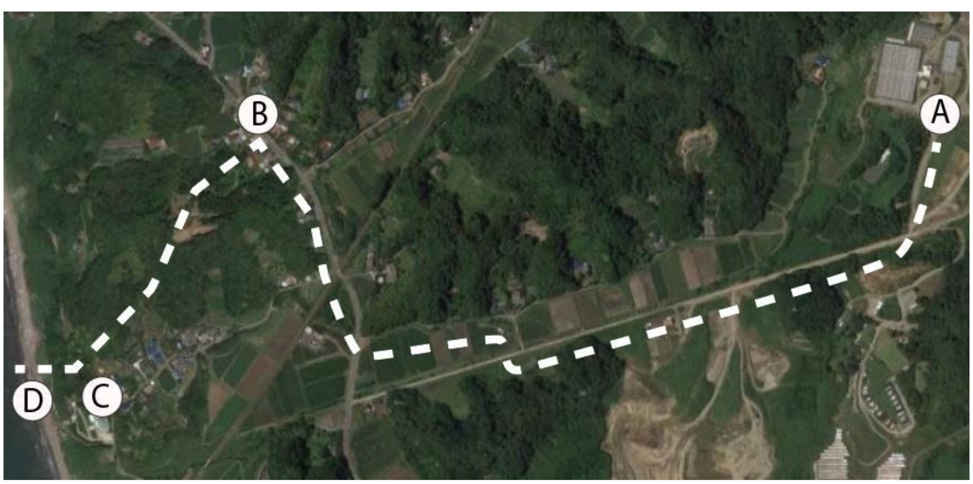

Fig. 9 | Hiking path map. (a) Strawberry farm where locals and tourists can enjoy strawberry picking. (b) Sasageku Community Center, a gathering place for community classes and events. (c) Yasaka Shrine (d) Nori farm

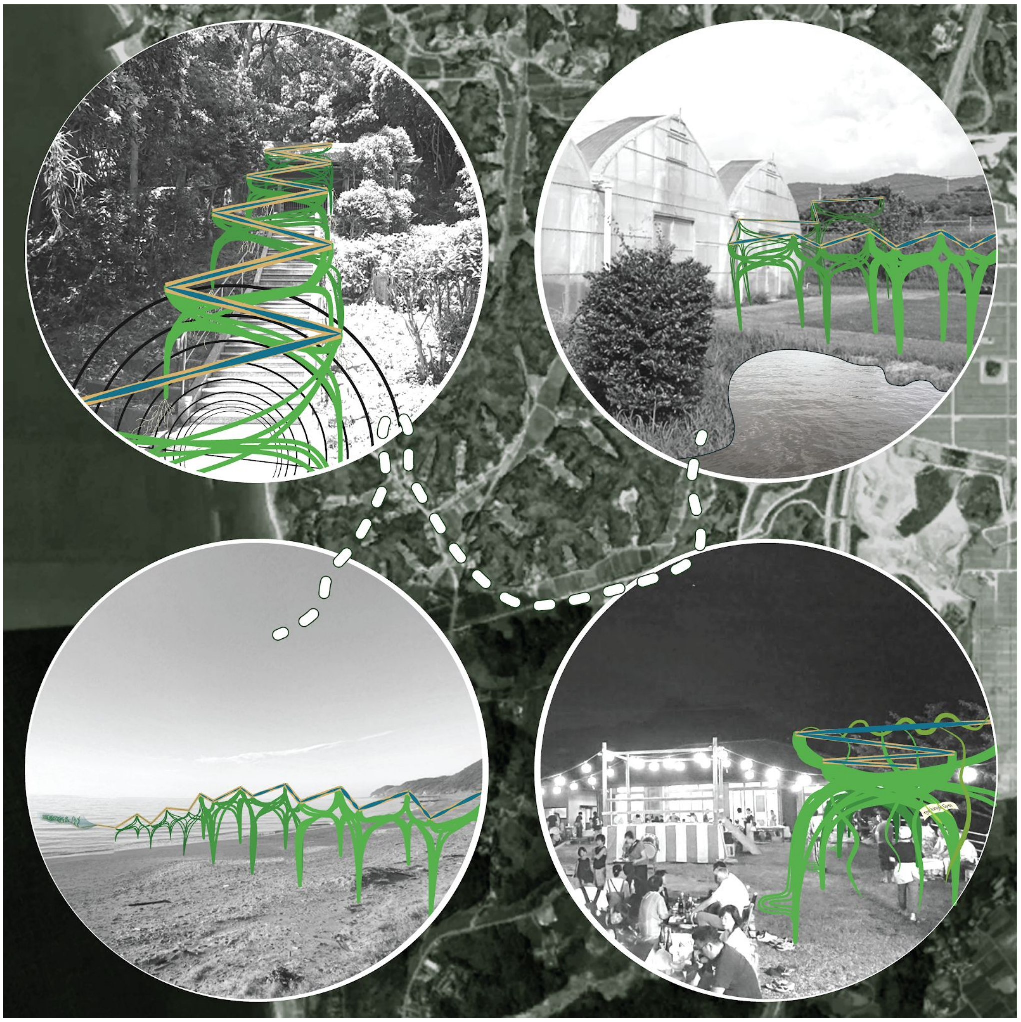

Fig. 10 | Perspectives of each site imposed on the path map. Top right: strawberry farm. Bottom right: community center. Top left: shrine. Bottom left: nori farm. Drawing produced in collaboration with Sarah Perrino.

Due to the variable nature of the twisting forms, variable moments of engagement arise. Figure 11 explores some of the variations that arise. We see the structure sometimes stretching over a busy road, people sitting on lower extruding curves of bamboo, and children climbing and swinging on the structure. As seen from the multiple possibilities, this structure has no clearly defined way of interaction. It opens up itself to the interpretation of those who engage with it.

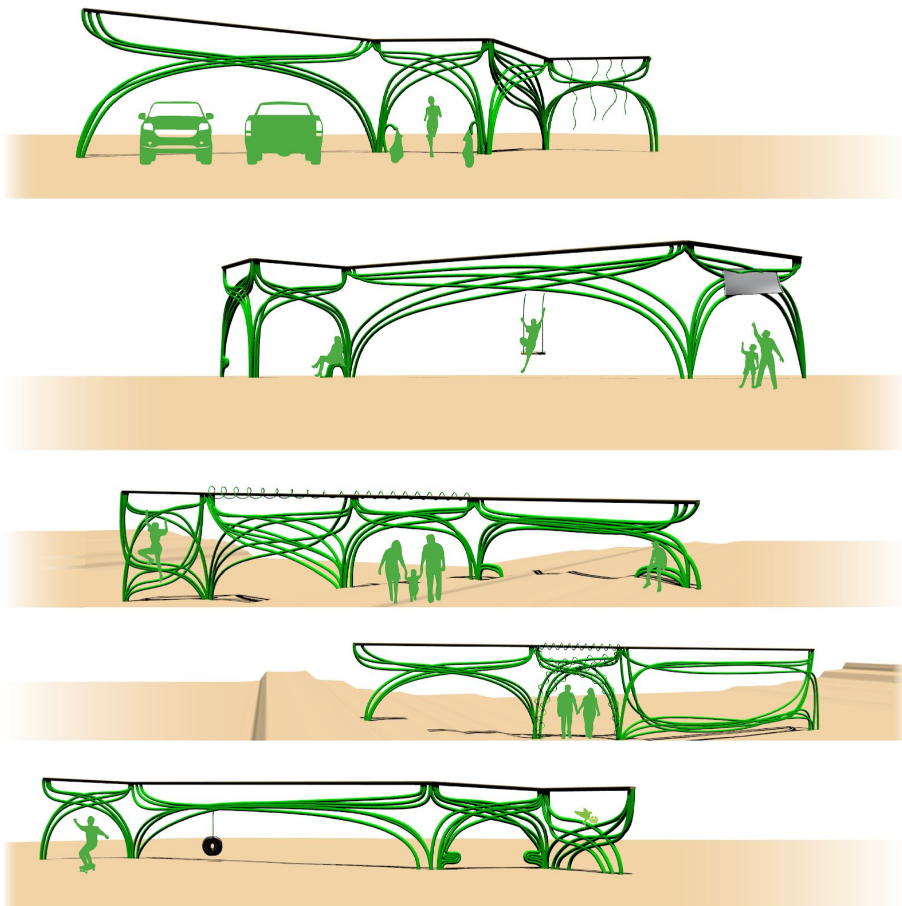

Fig. 11 | Varied form and forms of engagement. Drawing produced in collaboration with Sarah Perrino.

Nori Stand

How will the complete narrative be conveyed? Perhaps we can give passersby the opportunity to enjoy the results of the structure. Nori stands will be placed along the path where three types of nori will be stocked and sold. The first is pale brown nori that was grown without the nutrients provided by the aqueduct, to tell the narrative of the past. The second is healthy green nori that was fed nutrient-rich runoff, to tell the counter-narrative of the present. The third is a nonexistent nori, to remind us that the future is still unwritten and the way that it unfolds is up to us.

Signs

Because the structure is itself a living thing, onlookers will begin to see how deeply connected all things are. Signs along the path will explain how the living structure decontaminates and strengthens the earth they walk on, cleans the air they breathe, and nourishes the nori they eat.

The core message delivered by the complete narrative then is this aforementioned concept of complex interconnectedness. As cohabitants of this finite planet, the natural and human worlds continually affect each other. By emphasizing our interconnectedness, we start to see how our actions not only affect nature but, ultimately, us. The onlooker is then faced with the question: will I stand by as global human activity continues to worsen the conditions which threaten the survival of nori and the beloved cultures which surround it? Or will I seek out a role where I can do my part to preserve our planet and way of life? These questions are the seeds that gradually sprout into a worldwide movement.

CHAPTER FIVE: Conclusion

As we've seen with the Runit Dome, architecture can be a powerful storyteller. This thesis presents a three-part approach for scientifically-driven architecture that tells the story of manmade global warming.

The approach first calls for the development of a narrative, which involves curating an understanding of the current state of the Anthropocene and how it has affected the human world. In our demonstration, the narrative was the decay of nori due to rising SST and regulations on agricultural runoff. Most importantly, we see how climate change has threatened the livelihoods of local farmers and a beloved global industry.

The next stage is designing a counter-narrative, which means producing a public structure or installation which works to reverse anthropogenic effects and rewrite the future of the Anthropocene. This process includes the use of scientific research to inform materialization, an approach posited by Bechthold and Weaver. For this stage, we proposed an aqueduct designed to transport a balanced concentration of nutrient-rich wastewater to a nearby nori farm. Current literature on environmental science suggests that living moso bamboo is the ideal material for its ecologically responsive properties.

This material choice gave rise to bent bioarchitecture, a formal spectacle that laid the foundations for the final and most crucial phase of the approach: the diffusion of the complete narrative. The purpose of this stage is to further develop points of engagement where opportunities for climate change education can take place. For the runoff aqueduct, a hiking path was designed along which onlookers can realize our inextricable connection with nature.

As the effects of global warming are almost impossible to perceive without rigorous scientific observation and analysis, education surrounding the Anthropocene can be easily dismissed as fear-mongering alarmism. By reframing the narrative from one centered around impending doom to one centered around the ways the Anthropocene has begun to affect our everyday lives, we can more effectively invoke a sense of global urgency and ultimately reverse the effects of anthropogenic climate change.

Critical Statement

The bent bioarchitecture design was initially inspired by the work of Full Grown, a design company that guides the growth of trees to create expressive furniture and art. They call their work a kind of "Zen 3D printing".

Fig. 12 | Diagram of Full Grown's approach to guided growth. Source: Full Grown's website.

Inspired by the idea that nature had its own 3D printer, I started to ask myself if lucky bamboo sculptures could be scaled up to the size of an architectural object.

The design approach in this thesis was primarily informed by Bechthold and Weaver's belief that science should be a generative driver in the design process. Hensel and Menges present a way of including science in the design process as they implore designers to equally prioritize materialisation and formation. Thus, design decisions are based on current research in materials and environmental science.

My work advocates the design of structures which behave symbiotically with its environment. By demonstrating how inseparably connected everything is, my work evokes the question: how am I connected to the people, plants, animals, and landscapes around me? How do my actions impact these things? What role can I play in preserving them? Reversing the Anthropocene cannot be done single-handedly, so my work strives to kindle the flames of a global movement.

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