FUTURE COASTAL CITIES WITH BIOROCK INFRASTRUCTURE

Alternative Coastal Futures with Biodesign

JENNIFER GAUTAMA[1], CHRISTINE YOGIAMAN[2] and
KENNETH TRACY[3]
[1,2,3]*Singapore University of Technology and Design*
[1]*jennifer_gautama@yahoo.com* [2,3]*{christine_yogiaman|
kenneth_tracy}@sutd.edu.sg*

Abstract. Despite having the potential of being a durable building material, Biorock, a form of calcium carbonate formed by the electro-accumulation of minerals dissolved in seawater, has never been applied on an architectural level due to its slow accretion process. This paper aims to plays out the possible narrative of this slow accruing material process in the incrementally submerged coastline of Jakarta, to empower local marginalized communities to self-construct a "new city" for habitation using Biorock, especially where building material resources may be limited. Urban cores with basic communal, housing and aquaculture facilities will be established using Biorock as the main building structure, which would be harvested in response to the gradual sea level rise.

Keywords. Biorock; Accretion; Aggregation; Coastal Floods; Biodesign.

1. An Introduction: Sinking Jakarta

Currently, Jakarta now stands at the threshold of climate change with 40% of the city predicted to be completely submerged by 2050 (Kimmelman & Haner, 2017). Instead of finding solutions to save Jakarta from further damage, giant sea walls are simply being erected and plans have even been made to move the capital to Borneo (Gorbiano, 2019). Jakarta currently sits around 3m below sea levels and is prone to coastal floods.

1.1. CAUSE: SEA LEVEL RISE AND LAND SUBSIDENCE

The two main causes of coastal floods are 1) sea level rise and 2) land subsidence. For Indonesia, the general rise of sea level in 2030 will reach 15cm to 18cm. In 2050, sea level could increase by 25cm to 30cm, 40cm to 48 cm in 2080, and finally 50cm to 60cm in 2100 (Sofian, 2010). However, sea level rise accounts for only a small % of why the capital city may be submerged. The bigger reason behind the sinking capital is attributed to its rapid subsidence. There are four factors contributing to land subsidence in Jakarta, namely - excessive groundwater

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extraction, pressure from building and construction, natural consolidation of alluvium soil and tectonic activities. Jakarta is sinking at an average rate of 7.5cm a year, in some places up to 17cm (Bakker, Kishimoto, & Nooy).

1.2. CURRENT SOLUTIONS AND THEIR INFECTIVENESS

To combat the issue at hand, the Giant Sea Wall Jakarta was constructed as part of The National Capital Integrated Coastal Development program (NCICD). It commenced in 2014 and is expected to materialize by 2025 (Bakker, Kishimoto, & Nooy). However, this might not be sustainable in the long run. Firstly, the construction of the outer sea wall in Jakarta Bay will have a profound impact on the fishing communities in North Jakarta. A Rapid Environmental Assessment, conducted by the Danish Hydraulic Institute in 2012, estimated that due to the current reclamation, 586.3 hectares of aquaculture area in Jakarta Bay will be lost, causing ten of thousands of people to lose their livelihoods (Bakker, Kishimoto, & Nooy). Besides, there have been reports of constant leaking. The sea wall has also collapsed several times in 2007 and 2019, giving way to sudden coastal floods that inundated neighborhoods for days. In these scenarios, flood levels can reach up to a height of 0.4m to 2.0m.

2. Design Methodology

This clearly shows that the sea wall is not a reliable solution in the long run. Not only is it ineffective, but is also detrimental to communities around. This paper instead seeks to explore alternative methods of living through an enduring fabrication of a new living system that will eventually evolve into a sanctuary for communities to live in against unpredictable climatic conditions. “Biodesign fiction” (Camere & Karana, 2018) which has gained traction over the years would be used as a speculative design approach to envision how biology could be useful in future, provocative scenarios. This paper will specifically delve into the Biorock process which involves marine electrolysis and its potential to grow limestone building components, exploring how nature and human can design a co-produced space in an urban context.

2.1. INTRODUCTION TO BIOROCK

Biorock refers to the cement-like substance formed by electro-accumulation of minerals dissolved in seawater. The process, developed by Wolf Hilbertz, was patented in 1979. It was determined that a low voltage would accrete aragonite, a form of calcium carbonate suitable as a building material (Goreau, 2012). The material is three times harder than Portland concrete, becomes stronger with age and have self-repairing properties (Goreau, 2014). Until today, it has been mainly used for the restoration of coral reefs which do not maximize the strength of this material. Despite the technical breakthrough, little exploration has been done to employ Biorock as a construction material.

There is yet an architectural scale application of this promising material accretion methodology due to its slow accretion process. The dependency of accretion on natural cycles renders this process into a speed that is not typical to current material production standard practice. With low voltage, the Biorock can only grow up to 2cm per year. However, in the context of marginalized and informal communities, this natural material accretion can be a sustainable procedure to gain building material resources.

2.2. APPLICATION

The study plays out the possible narrative of this slow accruing material process in the incrementally submerged coastline of Jakarta (Takagi, Esteban, Mikami & Fujii, 2016). Economic gridlocked and dis-empowered governess create the inevitable reliance on community and alternative source of funding infrastructure development. Hence, the implementation of Biorock infrastructures becomes a feasible solution to “grow” a new city.

The research simulates over a period of 100 years the process of accretion and unit aggregation based on relationships and rules referenced from water access based on the changing water levels. Wireframes are first harvested and left to accrete Biorock to achieve structural components within substantially deep waters, in the initial coastline of Jakarta. To identify where the components would be harvested, ocean current directions during the spring and monsoon seasons are first determined, as currents are essential in the accretion of Biorock to happen. The intersection of current direction during the two seasons are taken as harvesting nodes (Figure 1).

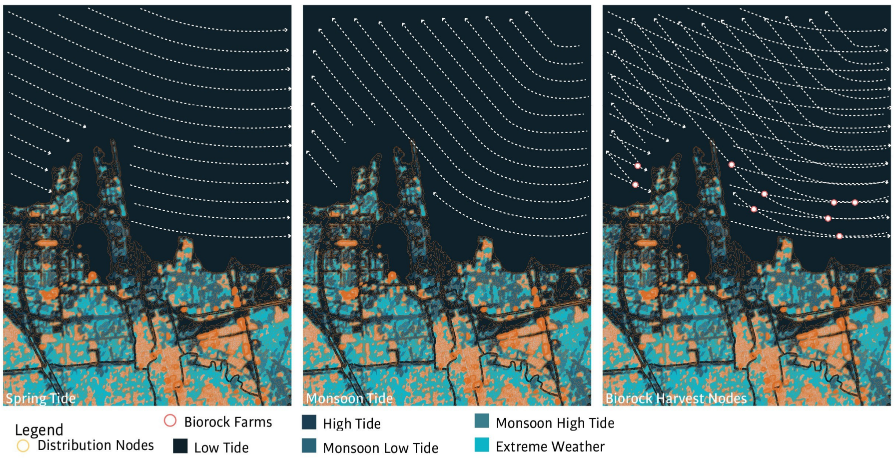

Figure 1. Left to Right: Ocean current direction in Spring, Ocean current direction in Monsoon, Potential Harvesting Nodes.

The components are then transported to various sites to be assembled. The changes in tidal conditions would cause different levels and areas of submergence daily, monthly and yearly. Due to both sea level rise and land subsidence, it can be said that Jakarta is sinking at approximately 10cm per year. Daily, tidal heights vary by about 1m. During the monsoon, tides may increase by 1-2m and up to 5-8m during extreme weather events. Due to the constantly changing floodplains, specific routes for the transportation of Biorock will be mapped out to reach selected cores by 2050 (Figure 2). These cores may then further extend out to create branching networks.

Figure 2. Biorock transport routes Year 2030, Biorock transport routes Year 2050, Node Expansion 2070, Node Expansion 2090.

In both Figure 1 and Figure 2, the orange areas represent plots of unaffected dry land, whereas the different shades of blue represent areas inundated due to sea level rise. The darkest shade of blue represents the areas covered at low tide during the non-monsoon season. During high tide, monsoon season and extreme weather conditions, increasing amount of land become inundated, as represented by the different shades of blue.

It is important to note that while these cores may not necessarily be the first few pieces of land to be completely submerged first, they are at least submerged daily at high tide in the initial years. Firstly, this allows the components to be transported when connecting water bodies are created to the selected cores at specific times of the day. Secondly, the fact that these areas are not submerged all the time also allows the communities to further add on components during moments of low tide much more efficiently as compared to when the area is submerged. Finally, these components can further accrete daily to create a strong structural foundation for the urban cores during high tide.

2.3. UNIT GEOMETRY

The modules are 3-Dimensional T shapes of varying heights and lengths (Figure 3). The angle of the T shape may vary which allows either square-shaped or diamond-shaped enclosures to be formed when joined together. The modules may be connected to one another at the edges and on top of one another. The module is broken down into two main parts - it would mainly be composed of a wireframe surface that allows the accretion of Biorock to occur (Figure 4). However, edges where the modules may connect would be made of a metal that would not allow accretion to happen.

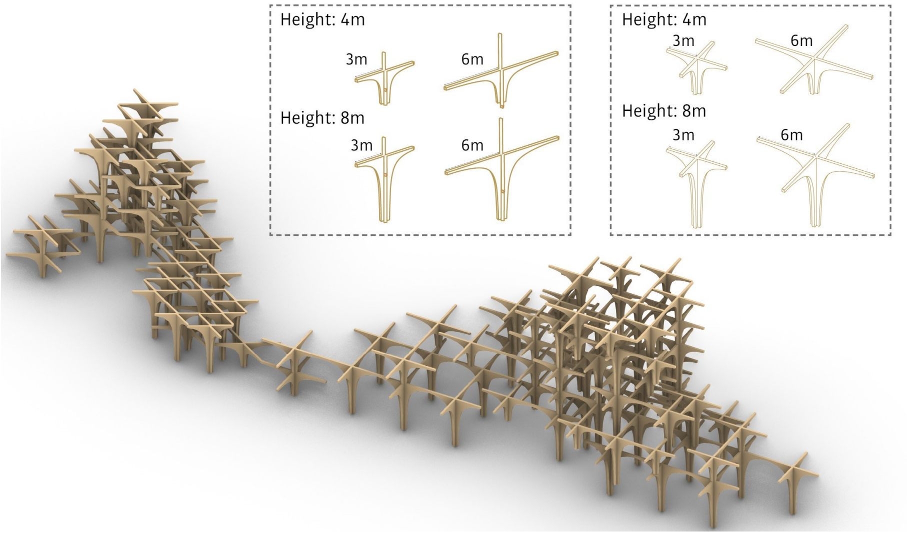

Figure 3. Catalogue of various modules and basic aggregation of square and diamond enclosures.

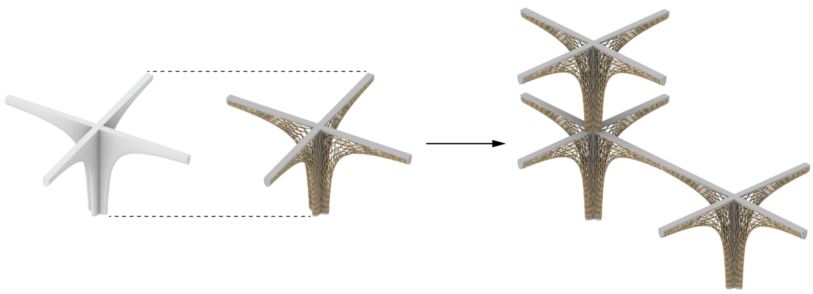

Figure 4. Detailed breakdown of module.

Depending on the amount of time left to accrete Biorock, the components would have different strengths and densities (Figure 5). With this, components that have more accretion may be used as the building foundation, while lighter components are stack towards above it.

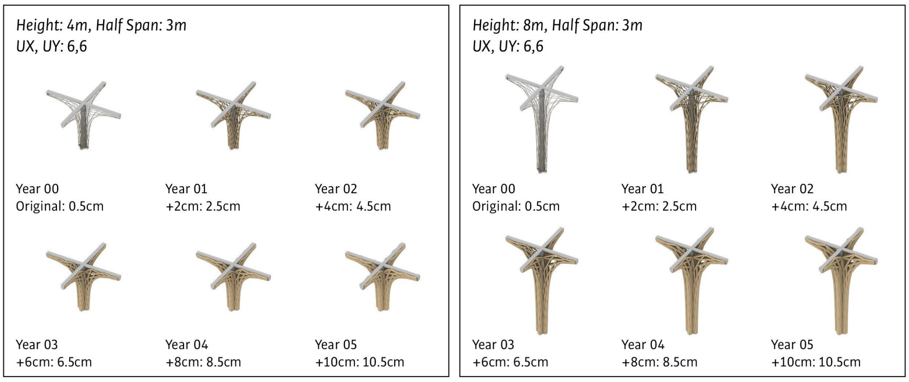

Figure 5. Accretion on wireframes over a period of 10 years.

However, it is also acknowledged that Biorock may not accrete uniformly on the wireframes, hence affecting the overall stability of the structure. Currently, there is not a solution for this. However, if the structures do indeed have significant irregularities, post processing of the wireframes may take place. For example, where accretion on certain areas of the wireframes are lacking, concrete may be added as a substitute. For wireframes with accretion that are too irregular to be post processed, they may be use for the restorations of coral reefs and marine life around the submerged Jakarta.

Currently, there is also lack of information available on the implementation of Biorock as a construction material. Hence, it is uncertain how the proposed wireframe structure, in addition to the accretion build-up on it, may work. While it would be most ideal to conduct physical one-to-one scale studies with the proposed structure, the structural feasibility of the wireframes and the accretion of the Biorock on the modules, may also be analyzed using Karamba (on Grasshopper), which allows us to input information on materials' volume, strength and density. With this analysis, one would be able to better understand the minimum and maximum accretion build-up on the wireframes necessary to construct various structural configurations on site.

Another important component of the infrastructure would be wooden floors and walls that would subsequently be added to the infrastructure after the wireframes Biorock modules have been aggregated (Figure 6). The walls would be placed in between the axis of the Biorock components connection points as shown in the exploded axonometric in Figure 6. This creates a variety of room configurations. Walls may also be designed to be removable to allow for different uses of space to happen from time to time.

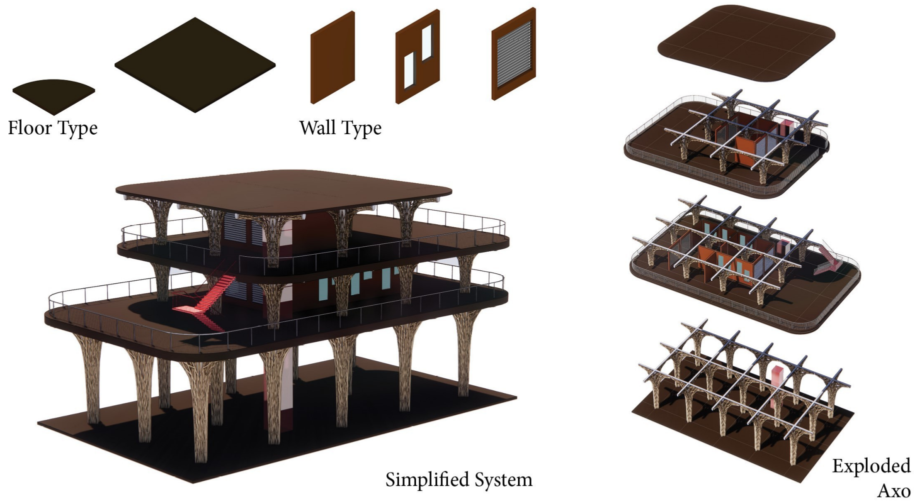

Figure 6. Basic wireframe modules aggregations with walls and floors.

3. Coastal Futures: Final Massing

Wasp, an aggregation Grasshopper computational tool, is used to simulate a time-based build-up of the large scale slow growing infrastructure. Wasp, allows one to input components and their connection points, that are to be aggregated within a volume or line of path. Using this logic, aggregation may be applied within existing buildings using areas of volumes as a constraint. On the urban landscape, aggregation would occur along predetermined paths that accounts for existing urban conditions, essentially creating an elevated walkway and connecting buildings that remain above the floods.

Selected nodes, where the Biorock were transported to initially, will become urban cores and are characterized by the dense, large and high build-up of the modules. These cores would usually surround urban buildings left behind. They would be made of square-like modules of various sizes. The core urban nodes would initially comprise mainly of housing, communal facilities and domestic industries. As these urban cores develop over time, they may also grow outwards, creating a branching network system that supports other programs such as aquaculture, a program that would be an ideal addition given the fact that the entire landscape would be fully submerged eventually (Figure 7). While this paper only shows the potential form of one potential Biorock island at one site, there will be numerous similar islands replicated throughout Jakarta at the selected nodes highlighted in the mapping in Figure 2.

While it was mentioned earlier on that Wasp is used to simulate an urban build-up, it has its limitations in attempting to control the overall output geometry it may form. If the singular units as shown are left to aggregate, very random geometries would be generated, as shown in Figure 3. While some degree of randomness is acceptable, one would like to be able to control the infrastructural system that would be formed eventually. This is especially so for the aquaculture system. Hence, to have a greater degree of control over the aquaculture system, initial forms representing routes and various types of aquaculture hubs are first designed from the singular diamond shapes units in Figure 3. These larger units are then aggregated to form a branching network extending for the communal and housing core. On the other hand, the communal core can be aggregated using the initial singular units as the spaces created could be more informal.

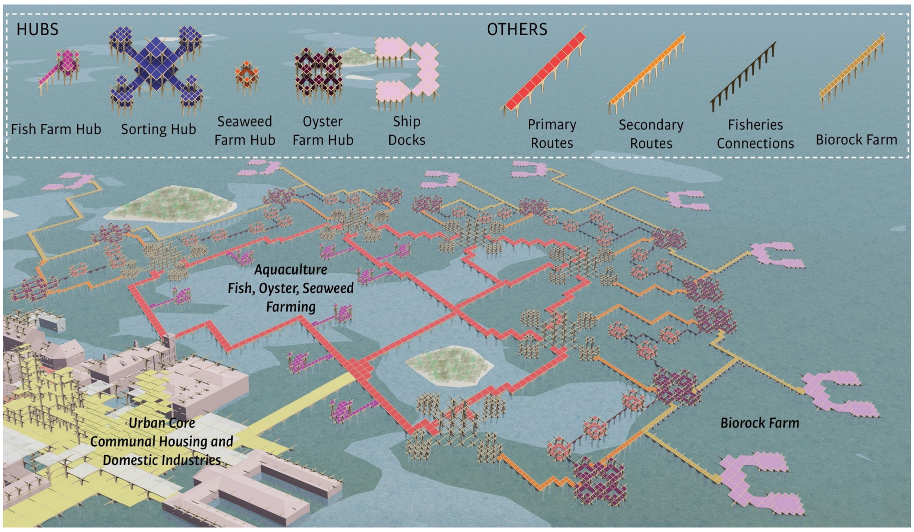

Figure 7. Aerial View and Components.

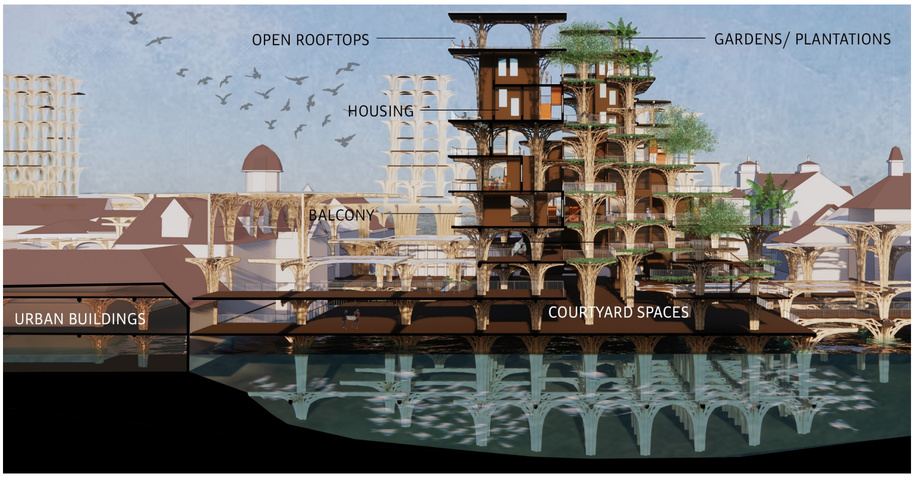

Figure 8. Section of urban core highlighting various spaces.

Within the dense communal housing nodes, large volumes would also be identified, which would be inputted into the script to disallow modules from being aggregated within those selected areas. This would create another layer of spatial quality within the urban landscape. These large volumes of spaces within the dense cores may be identified as large communal spaces (Figure 8 and 9 and 10). On the other end, towards the edges of the aggregation, the aggregated modules will change from its square-shaped formation to diamond-shaped, which signals the dispersal of the "Biorock" islands towards the edges (Figure 9).

Figure 9. Various Views.

Figure 10. Perspective view - high tide conditions in 2050.

4. Conclusion: Future Self Sustaining Systems

Finally, while developments in the initial phases would be focused on building infrastructure to create spaces to live and work for communities, the building system may eventually expand to support more complex programs such as water harvesting, intensive aquaculture and even energy production. Biorock not only have benefits as a building component, but have also been proven to be able to increase the productivity rate of aquaculture and even produces hydrogen gas, as a potential energy source. With all these potential functions and their outputs, a self-sustaining ecosystem may be developed to support communities living in future flooded landscapes (Figure 11).

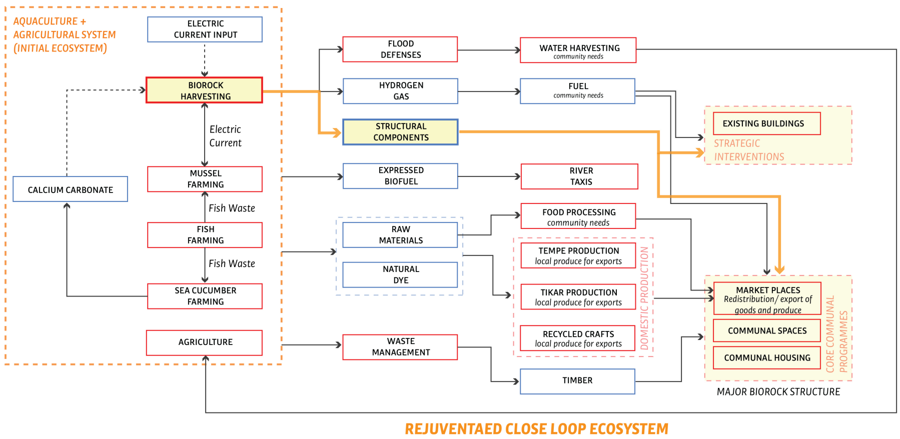

Figure 11. Potential Self Sustaining System.

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