Cosmotic, Aquatic.

Exploring the Potential of Computational Design in the Preservation of Aquatic ecotones.

Aya mohanna

Department of Architecture and Project, La Sapienza University of Rome, Italy.
Author: aya.mohanna@uniroma1.it

Abstract

This paper looks at the possible role of computational design ecologically in the fight against the loss of the aquatic Ecotone. As climate change keeps altering all the natural aspects of our planet, and as our kind continues to sabotage its ecologies, coral reefs come in focus. Aquatically, coral reefs count as a fertile zone for biodiversity. Usually being the Ecotone between land and sea, these barriers host many species and riches. However, due to the excessive abuse caused by human activity be it world-wide pollution or direct human contact, these reefs are constantly bleaching and breaking. In 2016, the Architecture Association gathered a group of international architecture students and professionals in a visiting school in Jordan titled “Hyperbolic Reefs” looking at the possibility of recruiting new computational methods to preserve and possibly regenerate the Ecotone. It was considered that new simulation techniques along with parametric design could contribute into the assessment and prevention of the catastrophic results.

The two-week event was divided into chapters and was initiated by a series of lectures and discussions conducted by worldwide leading architects and experts who presented an important material to build upon. Then, the participants underwent a site visit to the coral reef of Al-Aqaba, collecting data, samples and media and recording insights and local testimonies. The third step of the experience was to assimilate the material and data and discuss openly the ways that computation could lead to a better coral life. Several software and tools were assigned to produce a design that would help attenuate the compromise of the coral reef through computation. An archive of data was produced and exhibited to the public.

The results of this brief exercise was a number of suggestions and future aspirations triggered solely towards revitalizing the Ecotone. Issues such as the abundance of irresponsible snorkeling and diving, many governments’ indifferent policies towards the coral reefs, global warming, climate change, coral bleaching and aquatic architecture were confronted through parametric projects ranging from purely architectural to abstract human capsules. Computational tools allowed the reproduction of the whole system digitally, the precise tracing of the corals’ patterns, dimensions and colors, simulation software predicted the role of light and heat in certain zones, and parametric programs provided an incomparable flexibility in the designing process, going completely in sync with the fragile and intricate aspect of a coral unit. 3D printing was also an integral factor in the presentation and study of the presented models.

This study’s scope was to expand the use of computation in a theoretical way to reach new and creative prospects, and to raise awareness to the situation of the coral reef and the risks facing its degradation.

Keywords: **Computation, Artificial reefs, Performance Architecture, Aquatic, Coral resilience, Regeneration, Detoxification.**

Introduction

The discussion of coral reefs has been repeatedly cast on an international level in the recent decade. Following the repercussions of El Niño and what it caused of coral bleaching worldwide, the attention was then moved to the global threat to coral reefs due to human activities. Coral reefs maintain an integral importance environmentally and economically for bearing the richest ecosystems worldwide and for their role in several fields in human activity. However, due to continuously increasing climate issues along with many other damaging factors, phenomena of bleaching and coral mortality have been widespread globally. Events of skeletal destruction and loss of coral reefs are compromising the rich Ecotone and endangering the local species. This was confronted by relatively scarce attention and weak policies to fight against the menacing situation.

On an international scale, some countries are starting to look into alternative solutions to preserve the coral diversity and help save the inhabiting species under danger. This comes in both direct and indirect ways; such as enclosed protected zones and the implementation of complex structures on the shallow end of the sea called artificial reefs. These reefs are executed in many ways and forms and with a wide spectrum of materials and theoretically offer an alternative skeletal structure to corals and their dwelling species. Applications of these artificial installations are still very minimal and preliminary with small effect on a macro scale, but they offer an assuring start to the regeneration process.

On a more promising scope, scientists have noted the existence of coral zones and societies that have been naturally fighting off bleaching and resisting the toxic environment that would otherwise contaminate the reef. This led to the extensive study of the potential factors that would enforce the corals and make them resilient to bleaching elements. These factors range from naturally intrinsic factors to extrinsic factors related to the surroundings of the zone or the external effects of the undamaged area. A list of key components was produced to better understand the dynamic of corals and how they manage to self-preserve.

This paper suggests the idea of implementing the resilience factors of corals and their preserving environments in the production of artificial coral reefs, in a way that would take the idea to an advanced level and to further expect a better outcome of these structures, instead of their current state as discarded non-degradable materials in the ocean. The use of computation is thus suggested and encouraged, due to its rising importance and convincing effects on an architectural platform. Computation will function here on many steps of the design, from conceptualization to implementation with the use of software that will generate possible solutions, tools that will simulate natural elements and therefore grade the spatial performances of the volumes and programs that will chronologically predict the aspect of the skeletal structure. All these steps will be showcased in a case study underwent by a group of design students and young professionals in 2016 that put computation into testing in order to come out with potential designs for the artificial reef of Al Aqaba, Jordan.

This paper will showcase therefore the big potential computation has in the synthesis of natural factors in the architectural design of artificial reefs with an amplified performance.

Aquatic Ecotones

Aside from their striking vista and attractive features, coral reefs are the bearers of the richest ecosystems on earth. These structures that are situated between the shore and the ocean, are very important for the sustainability of our environment and life. On a natural level, they house a great variety of species and aquatic animals and form the architectural skeleton for their habitat and their first defense from direct exposition to the natural dangers from both the shore and the deeper side of the ocean. Coral reef importance lies in the fact that it's the natural Ecotone between land and sea; it thrives with very few nutrients, it protects the shore and the frontier cities from possible tsunamis and mega-waves, and forms a rich environment for developing businesses such as fishing and local craft-making. Also, with the fast rise of the tourism business as an important pole of world economy, coral reefs have become an essential attraction for divers and tourists around the world. Along with the traditional benefits, corals are recently being tested and used for medicine production after the decline of antibiotics due to the secretion of self-defensive chemicals by corals. [2]

Unfortunately however, human activity has seriously damaged a considerable part of this natural asset; the pacific aside, 70% of total coral reefs are endangered. The main components that jeopardize corals are those that cause pollution and disease to the ecosystem. This includes mainly over-fishing, unstudied tourism, shore constructions which lead to sedimentation and coral suffocation, freshwater flooding and more. However, the main precursor of coral damage nowadays is climate change and its symptoms such as increased hear, changing water levels, changing percentages of carbon which affects the algae-coral balance, and severe exposition to UV light and chemicals. [1]

Ultimately, the most affected areas under high risk of climate change are regionally the southeastern Asian reefs, the Caribbean and the Indian Ocean. Other regions with considerable threat are the Middle East and some zones in the Atlantic and the Pacific. The most damaged areas are namely the shores of Indonesia and Australia, with small to no protection of the reefs. Today, protected areas are spreading; however, the serious effort of enclosing and shielding the reefs from the elements is still preliminary and falsified. Over 56% of the coral reefs are under low to high threat of damage and bleaching, and face life-threatening risks.

If not promptly healed, the bleached corals due to hazardous components never regain their health and color and face unavoidable mortality. In a span of 2 years after, dead corals decompose and the skeletal scene of the once diverse coral reef is drastically changed. Coral reduction compromises the ecosystem; the absence of architectural complexity for the dwelling of species will finally limit their survival chances and larvae cultures will reign the shallow waters. Additionally, the nearby towns will lose a critical aspect of their economical state and will be exposed to serious threats from mega-waves and deep water predators. [8]

Artificial Reefs, Current State and Potential

In order to tackle the menacing factors that cause coral mortality, nations worldwide have been seeking methods and policies to help regenerate and revitalize the aquatic Ecotone. Some interventions include the enclosure and the shielding of the coral zones from direct contact, making them inaccessible to tourists, fishermen and other elements. Other countries are taking it a step ahead and are attempting to quicken the regeneration process of the damaged ecosystem by the implementation of artificial reefs.

Basically, they're the addition of particular structures and volumes with features close to coral skeletons in hopes to encourage the regeneration of the area and to quicken the rehabilitation process of the corals [4]. As a spectrum of used materials, artificial reefs are often non-degradable structures made out of concrete, castoff tires, discarded automobiles, and shipwrecks. Less often, plastic, PVC, metal and ropes are installed. The main issues when setting an artificial reef are its environmental effects and expected performance; materials should not produce any chemicals, should not decompose, and assigned forms for the new host structure should be complex, void from the inside, with a certain amount of complexity in its entrances in a capsule-like volume [5].

International laws have been put together to guide the execution of artificial reefs, but it still faces issues of corruption, lack of effective management, and the results for these structures are still quite minimal. Studies suggest a need for alternative artificial reefs, ones that would be less superficial and that would look into depth at the performance of the potential solutions [5]. These solutions would take into consideration the repetitive contact of human elements and limit it, while understanding completely the nature of the local species and their specificity in order to better produce a unique and positive result. This would change drastically the reality of artificial reefs that would therefore be offered as an efficient solution to coral mortality. In order to understand the specificity of corals and what harms them, a thorough study on coral weakness and defense mechanisms should be underwent.

Resilience in Corals

Despite the global devastation of the state of coral reefs, experts have noted a repetitive pattern of resilience in some zones that would otherwise be affected. A detailed and close study to the main influences behind the defiance to bleaching in these small localities helped gather a series of factors, intrinsic and extrinsic, that helped the corals thrive under compromising conditions. A study gathered the case studies and organized a set of circumstances in which corals are less affected by means of pollution and disease.

This list includes factors that naturally attenuate bleaching precursors such as UV light exposure, light deficiency, water warming, and varying water levels for long spans of time. The defense mechanisms tackling light exposure were selectively, the existence of a natural shading structure on the beach, cloudy regions and generally turbid waters. Those that tackled warmer waters however were areas with exceptionally strong currents and channels, areas exposed to water upwelling, brief exposure to air, the interchanging stream of water that would flush toxins out, and generally colder regions. As to intrinsic factors, corals that were repetitively exposed to changing temperature for short spans of time and that get exposed often to air and interchanging water levels have learned to overcome these factors and grew unaffected by them on the long term [1].

This study could lead into a design that would revitalize the coral reefs. A structure could ecologically and sustainably reinforce the resilience of corals and help them fight against the elements. Just like detoxification architecture that is aiming to reintegrate nature with the urban landscape through effective biomorphic structure [6], this policy could be extended to sub-aquatic structure that would "renaturalize" the damaged areas and tackle the menacing damage done by tourists, climate change and other causes mentioned above. Examples of detoxification architecture in packed cities have proved that an efficient choice of materials and policies along with good management could help in mending the damage done by humans, leaving the rigid forms and presenting a new experimental spirit [6].

A synthesis is thus proposed, to take the artificial reef domain a step forward, forming structural hubs in the shallow waters that would both have the shielding features of artificial installations and train the damaged corals for a better defense mechanism and a stronger resistance on an extended time span. This would help reintegrate the species with the existing corals and potentially help the regeneration of these corals which will subsequently restore the ecosystem and quicken the healing process of the region.

Establishing quite a design and form would require advanced technologies and techniques, for this matter is very fragile and trial and error are not an option in many cases. This promotes the need of new ways of design that would optimize the performance of the forms and generate a series of solutions that are in grade of testing before implementing them on site.

Computational Possibilities in the Regeneration of Corals

This employs the idea of a structure that would use the analogy of corals in order to come up with the solution. Going from the bottom up, studying the specificities of the corals and their construction, extracting every detail concerning patterns, textures, skeletons and internal spaces.

A call for an experimental design in a fragile nature also requires the employment of techniques that would generate parametric shapes following biomimetic principles of design. Understanding biomimetic design is to understand the way biological elements function; a heterogeneous structure at best, multilayered and offering a differentiation of scale and shape, biological elements are a set of composite materials that could be translated into high-end materials in execution, heavily hierarchal and marked by their multilevel structure ranging from Nano to Macro, suggesting fractal design and parametric analogy [9].

Fortunately, computation offers the biggest chance of the best solution due to the tools it offers through the whole designing process. In fact, computational architecture has been on the rise recently and has produced a collection of experimental outcomes that otherwise would not be executable by traditional design techniques. The rising wave has been present in difference phases of the design process from conceptualization to solution generation up until performance testing. It is helping redefine some once concrete norms and notions of spaces, culture, human dynamic and environment. Faced with a challenge to create a both aesthetically pleasing structure and one that is also high in performance, computation comes in handy in offering a variety of solutions and the ability to test each of these solutions' performance and efficiency [6][8]. In our case of advanced artificial reef design, the set of characteristics and leading factors are human-decided. However, the outcome is ought to be a production of a computational model to be tested depending on the context.

The scope of this process is to extract the biggest number of solutions and proposals by using parametric design and fractal digital productions and then employ other computational tools to extract knowledge from these outcomes. A main benefit of this method, aside from the possibility to explore many designs choices, is to allow the designer to review the possible configurations in an early stage of the design. Afterwards, computation would go hand in hand with the design process to get to a concrete point following the abstract phase; genetic algorithms could be installed, and additional software could mimic the natural surroundings of the project and allow a systematic prediction of the parametric design's performance [8]. This process follows four phases described below.

At first, computation allows the extraction of preliminary data such as environment and other information provided by the designer. This allows the virtual recreation of the current state of the project and allows the withdrawal of some complex natural volumes otherwise impossible to regenerate.

Secondly, a list of criteria is offered to the software and an extensive search in volumes and parameters allows the origination of parameterized attributes that would offer a unique set of projects with experimental volumes and diverse aesthetics. The third step then follows; a step both personal and technical: it involves the subjective selection of the designer for the more aesthetically pleasing designs and then involves simulation and virtual reality prediction to assess the expected performance of each and every configuration offered.

The last step would be to run a processing tool equipped with the right parameters and equations that would deduce the future aspect of the artificial reef after the colonisation of corals in a specified time frame, something otherwise unfeasible without the available computational apparatus.

Application

To showcase this analogy in a practical frame, this chapter will present the proceedings of the 2016 AA visiting school in Jordan, under the title *Hyperbolic Reefs*, which looked closely into addressing the issue discussed in this paper [10].

The beginning of the summit included a basic briefing of the programs and digital instruments to use in the workshop; including Autodesk 123 Catch for 3D scanning and shape extraction, Rhinoceros for modeling, along with grasshopper (parametric design plugin) and beehive, Autodesk Maya for simulation and selection, Processing for the chronological review of the chosen attributes and lastly Keyshot for virtual representation and rendering.

The figures provided below showcase a collection of works produced by the participants of the visiting school that are clear images of the design process [10].

Figure 1. Example of the preliminary scanning and reproduction of a coral unit.

Figure 1 shows the computational regeneration of a skeletal coral structure. 123 Catch was used to trace the voids, protruding branches, shadows and texture of the coral and to map it digitally.

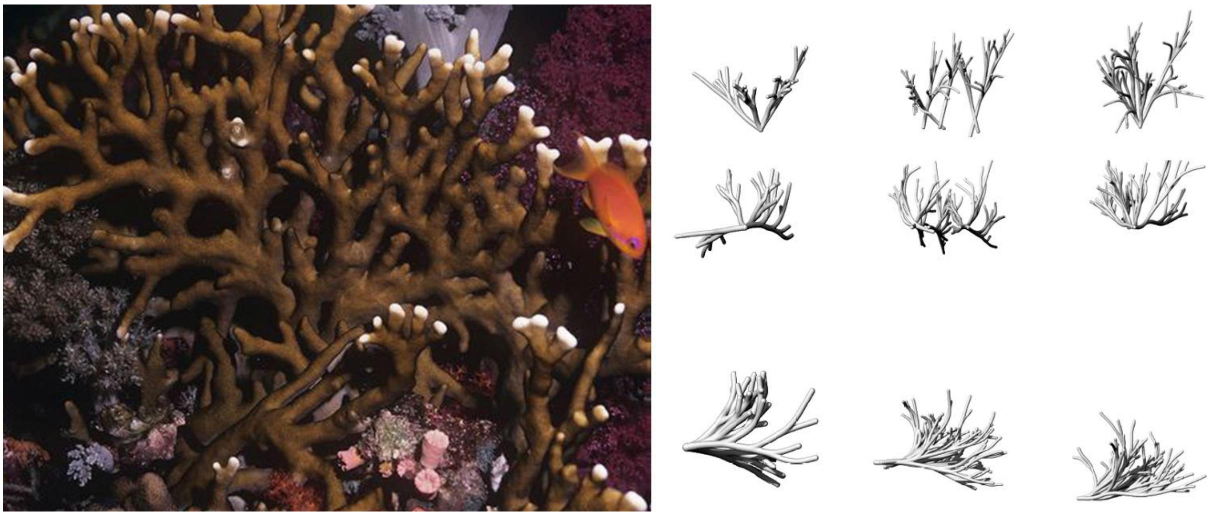

Figure 2. Phase 1: Primary generation of a virtual biomimetic version of the coral.

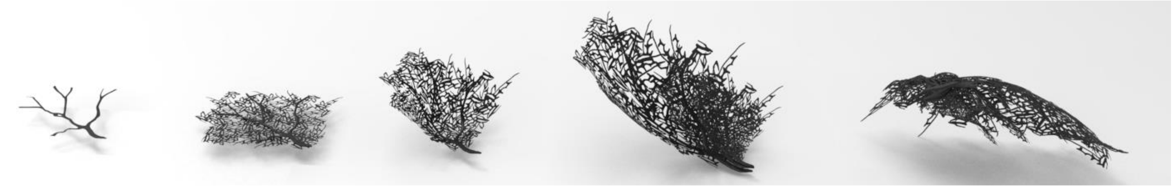

Figure 3. Phase 2: Extracting the coral's modular unit and experimenting with potential generations.

The first phase involved the selection of a primary coral unit that is believed to be persistent and resilient in shape and texture in the studied area. The next step was to scan and regenerate the architectural structure of the species and model it in different ways in order to create an archive of potential generic volumes and shapes for further study. (Figure 2)

Following the first phase, it was possible to excerpt the founding unit of the volume and to experience with it, creating sets of fractal repetitions of the same nucleus and producing potential versions of possible applications to the intended project. This resulted in a wide and diverse collection of choices and shapes that challenged the designers in their quest towards an optimized and positively performing outcome. (Figure 3)

In the work presented in this chapter, the group's concept was to create an artificial reef that would fragment the experience between user and coral, shielding the indigenous species from direct contact and extreme UV light, while visually exposing the tourists to the coral through an inter-system hub, one that would double the notion of the Ecotone it being from shore to sea, and from water to air.

This required undergoing a simulation effort to understand the required volumetric composition following the wanted facilities and to include corals in the colder areas and the ones less exposed to solar radiations and warmer water. Figure 4 shows the application of this simulation on the most efficient volume retrieved.

Figure 5 showcases the intervention that was applied using beehive and rhinoceros to attenuate the opacity of the chosen shape and to allow a better performance to the complex. It studies openings for human facilities and coral capsules. The resulting interference was the application of a porous structure that would diffuse natural light and wind.

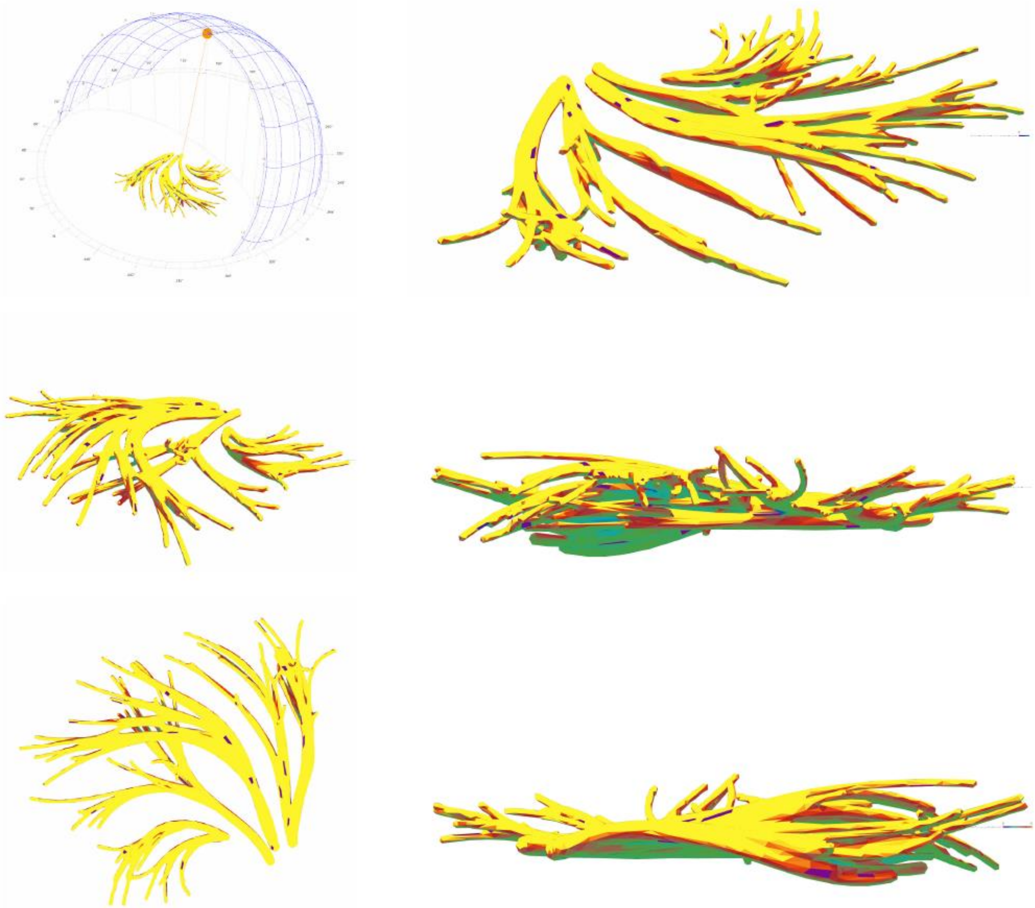

Figure 4. Phase 3: Solar Radiation, Temperature Simulation and Water level diagrams on a selected attribute for performance review

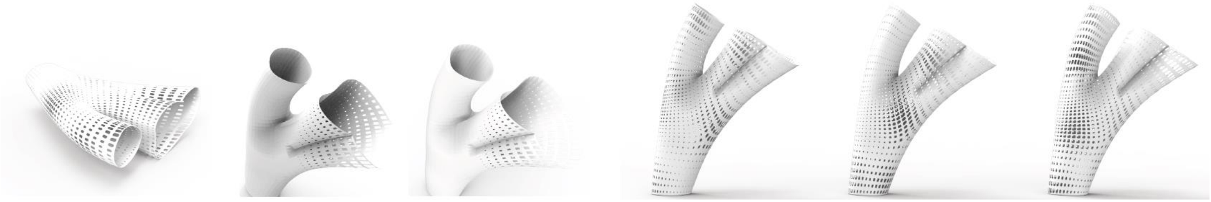

Figure 5. Phase 3: Porosity study following radiation diagrams to amplify the internal performance.

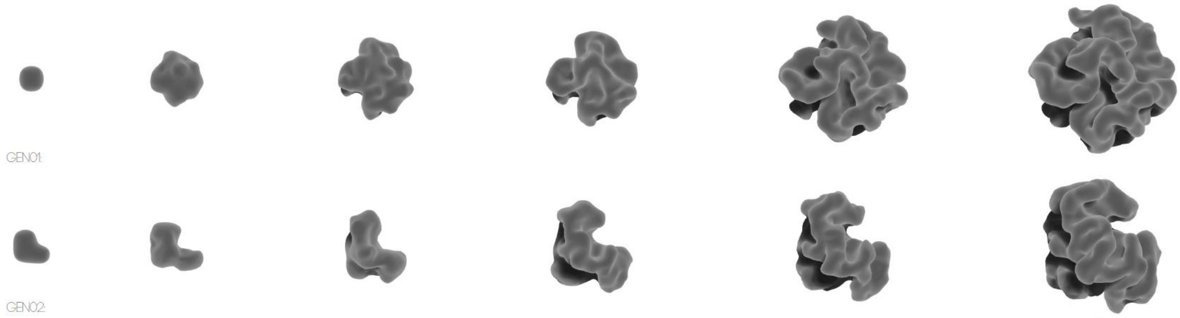

Figure 6. Phase 4: Simulation of growth patterns in Corals.

Following the generated new shape that was now equipped with openings, it was time to predict the growth patterns that would affect the general shape of the structure in a given time frame. The results were generated using Processing and were then showcased in the final outcome. (Figure 6)

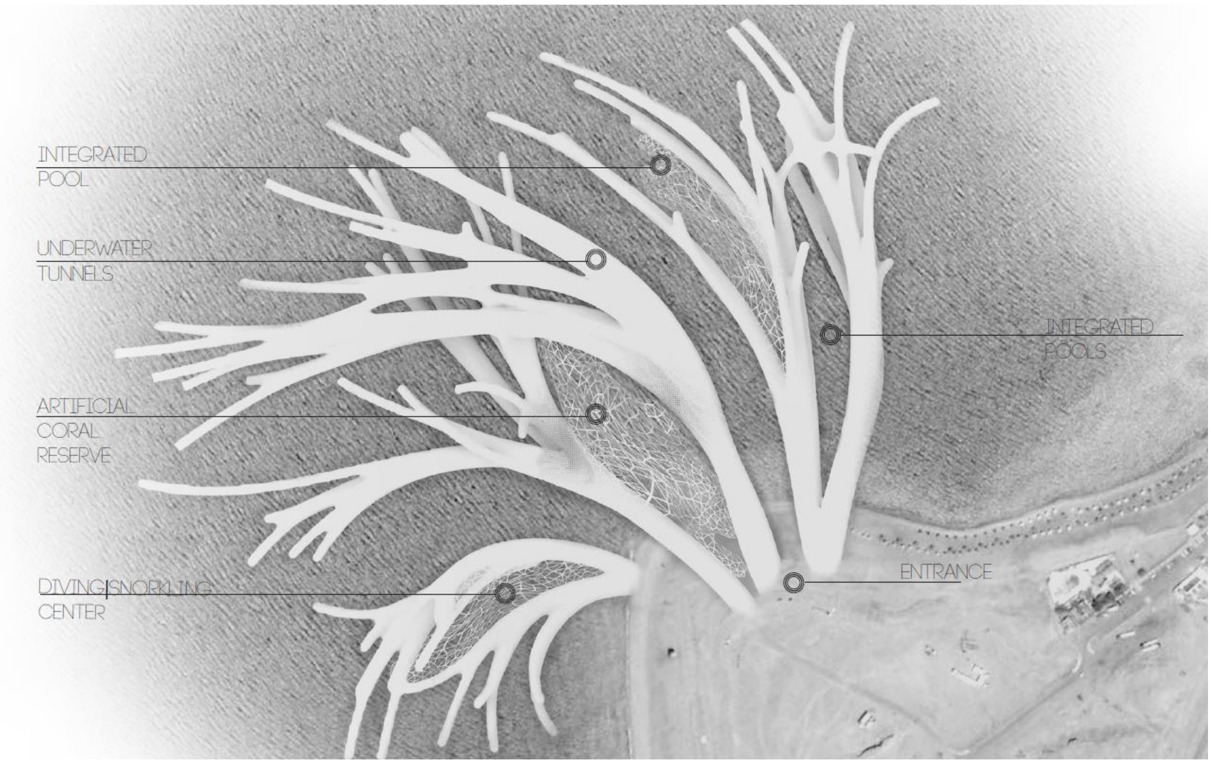

Figure 7. Spatial distribution in the new proposed artificial hub.

Figure 7 clarifies how space is recruited and distributed following openings and temperature exposure along with light and sea slope to help attenuate the direct contact between man and corals and to enclose the endangered species in a shielded zone that is semi-open and efficiently lit and exposed to a continuous current.

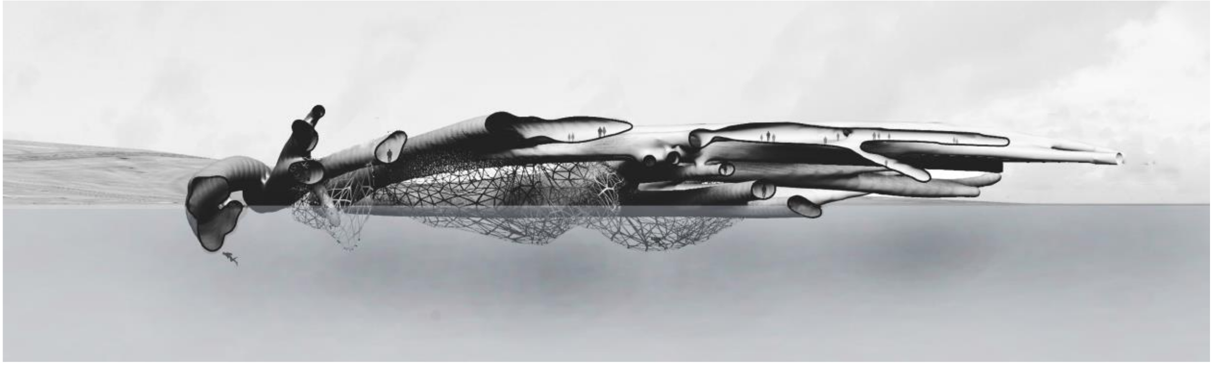

Figure 8. Group 1: Final outcome, cross section.

The final outcome showed in figure 8 emphasizes the importance of porosity natures and openings in the performance of the hub; it also sheds light on the importance of the exchange between the different realms such as the passages between sea and land and the translucent lighting to be diffused to corals through the porous fractal design generated from the experimentation of the founding nucleus.

Lastly, Figure 9 presents an imaginative scene in which the artificial reefs would have been completely developed and grown following the growth patterns studied in figure 6. The once porous links are expected to be colonized by corals once again and to host species that were once menaced in the zone. The figure also displays the user-coral interface in a protected environment that would help corals thrive in an interactive and healthy ambiance.

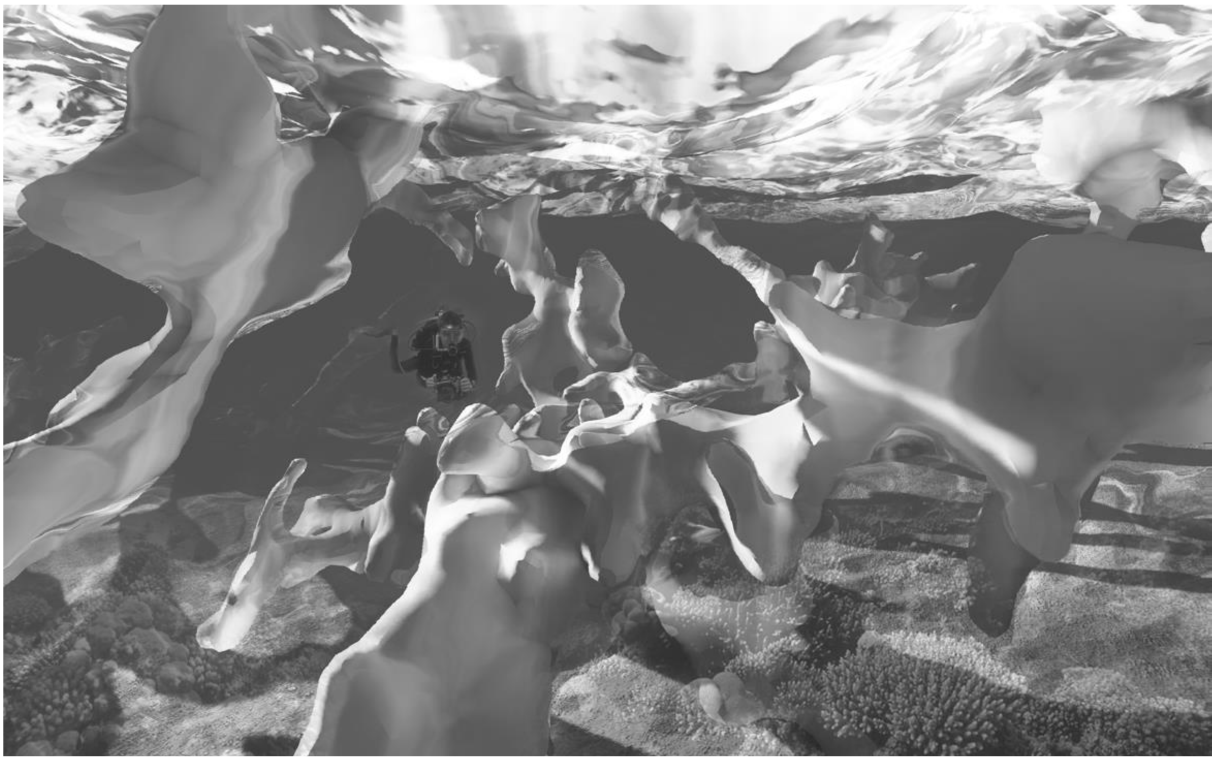

Figure 9. Final outcome: imaginative scheme of future forms.

This was one of many case studies underwent in the visiting school and was directed primarily to the effect of light, radiation and temperature on coral health and survival. Other proposals revealed ideas and concepts such as semi-submerged touristic complexes, human capsule units that would double as exploration pods and artificial coral cultures, museums and awareness centers, and diving facilities. All these projects and ideas were led by a similar analogy of design based on the recruitment of computational methods and simulation in the generation of the general shape and the forecast of its functioning in a specific given context.

Conclusion

This paper investigated the potential development of the concept of artificial reefs in a way that would raise the expected performance of the now weak attempts of requalification, through the employment of computation method as a promising instrument in this quest. It briefly reviewed the importance of coral reefs as crucial economic poles for neighboring cities and vital architectural habitats for a wide spectrum of species. It then discussed the main threats and the resilience factors that should be listed as criteria for any future artificial reef planning.

In this exploration, computation presents itself as a driver to experimental and unorthodox development that would detoxify and revitalize the fragile Ecotone. Computation methods, so far mostly enrolled in mono-disciplinary domains such as math, civil engineering and electrical engineering, has proven to have a potential role in poly-disciplinary practices as well such as architecture and environmental studies tackling global warming repercussions. This is a new horizon that we think should be further carried out in the near future in order to optimize the efficiency of once challenging and obsolete issues in architecture and complex industrial design. This however calls for the adoption of a new attitude towards computation and experimentation and for the setting out of a detailed plan with optimized management that would bring out the finest result and most effectual solutions for today’s problematical issues.

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