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RESEARCH ARTICLE

Integrating Biomimicry and Geoinformatics: A Designerly Approach to Underwater Colonization

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Abstract

Underwater space has been the subject of various scientific fields. In the field of architectural design, projects are generally limited to the areas of construction techniques for underwater as a civil engineering problem; underwater tourism; and underwater research. A much less researched area is ocean colonisation -permanent human settlement of oceans- and its architecture. This paper focuses on a case study of a workshop entitled "Mission Aquarius", as part of the architectural design studio. It treats oceanography in the context of extreme environments, and explores the use of biomimicry as a design approach, and the use of geoinformatics as site selection method. We encouraged students to explore various stages of scientific knowledge at the design level, and to employ various CAD/CAM tools. It is important to emphasize that the curriculum is a studio-based architectural design education with limited access to scientific data. It is aimed to integrate geoinformatics and biomimicry into the design studio, and to allow students to explore new contexts for design.

Keywords: architectural design, biomimicry, geoinformatics, ocean colonization, oceanography

Introduction

The variety of oceans is breathtaking, and marine life is fascinating as well as vital for the future of humanity. Ever since Jule Verne wrote "Twenty Thousand Leagues Under The Sea" in the late 1860s, generations of filmmakers, writers, designers have produced futuristic and imaginary fictions about permanent colonies on or under the ocean (Davison, 2015). Later in 1943, Jacques-Yves Cousteau and Emile Gagnan's invention of Aqua-Lung, the first fully automatic compressed-air breathing apparatus, an early version of today's SCUBA equipment, opened the way to the explorations of shipwrecks and the discovery of previously unknown marine flora and fauna (Chaline, 2017). In later years, the invention of novel deep-sea exploration tools allowed serious discussion of seabed colonies. There are two approaches to ocean colonisation in popular culture. The first one addresses post-apocalyptic dystopian theories, such as in the film Waterworld released in 1995, in which the protagonist attempts to lead survivors to the last remaining land.

The second is an utopian underwater fantasy of underwater living, as in Jules Undersea Lodge in Florida, visualising mankind's long term desire to live under the ocean (JUL). The inventor and entrepreneur of this expensive tourist attraction is Ian Kobrick, an ocean explorer and aquanaut. Koblick and his collaborators own and operate the Marine Lab, a research and training base, and also the Jules Undersea Lodge (Simav et al., 2015, Nuwer, 2013). According to all oceanographic theories life itself arose from the oceans. The ocean is vast, covering 140 million square miles, some 72 per cent of the earth's surface (Terzi & Gazioğlu, 2016). The studies of colonization in underwater architecture should be considered as studies which should be carried out to protect the future of humanity rather than scientific curiosity.

Ocean colonisation is the theory and practice of permanent human settlement of oceans. Such settlements may float on the surface, or exist as underwater habitats secured to the ocean floor, or in an intermediate position.

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There are worldwide, about 10 enterprises seriously engaged in ocean urbanisation research and development (Kaji-o'grady et al. 2007). They are a mix of academic bodies, architecture firms, libertarian venture capitalists and municipal governments, with diverse visions for ocean settlements. However, it is important to emphasise and quote their scientific research perspectives. NEEMO - the NASA Extreme Environment Mission Operations project - has a mission to send groups of astronauts, engineers and scientists to live in Aquarius Reef Base, the world's only undersea research station, for up to three weeks at a time. Operated by Florida International University (FIU), Aquarius is located 5.6 kilometers off Key Largo in the Florida Keys National Marine Sanctuary (NEEMO). This marine sanctuary is part of the Office of National Marine Sanctuaries, a network of underwater parks, as defined by National Oceanic and Atmospheric Administration -NOAA in USA (NMS). Since 1993, the Aquarius shed light on the disappearance of coral reefs, and has been used to train NASA astronauts for space, and research sea life such as sponges.

As explained above, underwater space has been the subject of various scientific fields and underwater tourism. When it comes to designing for underwater environment, the projects are limited to underwater construction techniques as a civil engineering problem, and mechanical underwater design as a mechanical engineering problem. However, there are limited studies regarding the ocean colonisation and its architecture (Koyuncu, 2007). This paper follows a case study method focusing on a workshop entitled “Mission Aquarius”, as part of the studio course ARCH 202 in the spring semester of 2018 at Izmir University of Economics. It treats oceanography in the context of extreme environments, and explores the use of biomimicry as a design approach, and the use of geoinformatics as a site selection method. As in the colonisation of outer space, and the current example of Mars colonisation, biomimicry as an important design approach (Varinlioglu et al. 2018, Leach, 2014). In this world of euclidean geometries, this paper focuses on biomimicry as an alternative design solution, providing unconventional living patterns for humans (Çakır, 2017).

Definition of Terms

Oceans have formed the hub of several civilizations throughout history, leaving evidence through shipwrecks, ancient harbors and submerged settlements. The Ocean, with distinct flora and fauna requires special care as this ecosystem is in danger. The seabed formation in particular requires a holistic research approach. Marine scientists use a range of theories and methods to study the underwater world. Nautical archaeologists, bio-speleologists, underwater photographers, videographers, underwater biologists, geologists all use various equipment and methods to study the living heritage and material culture of the waters.

Oceanography

The ocean, with its enormity and mystery, has ever been part of human consciousness. All these research areas are part of the study of the environment, more specifically oceanography, the science of oceans (Pickard et al. 1990; Okuş et al., 2004, Bayarı, 2018). The properties of oceans that are instrumental in ocean colonization processes includes water salinity, penetration of sunlight, water temperature, and water currents. Salinity, the measure of dissolved salt in water, has the average of 35 grams of salt per 100 grams of water. Chloride and Sodium are the two main elements dissolved in ocean water. The blue spectrum of sunlight travels the best in water, therefore the ocean looks blue. The first 10 meters is the zone in which different colors can be seen. After this, only blue exists. In terms of water temperature, the top layer is warmer due to the penetration of sunlight; the amount of sunlight that penetrates affects life in different ocean zones. Another reason for temperature difference is the thermocline, that is the layer in the ocean where temperature dramatically decreases. It separates the mixed layer of water in terms of temperature and salinity. The ocean current is another reason for water temperature and salinity differences. Ocean currents exist at three main levels in the ocean: surface, mid-level and deep sea currents, and help circulate the Sun's heat and nutrients important for ocean life.

Another important instrument about the ocean colonization is that it needs energy for heating, cooling, lighting etc. Likely energy resources are solar, wind, current, wave, and nuclear. Solar energy comes from the insolation, the radiation from the sun and the effects of temperature. Solar energy is more strongly distributed around the Equator, and these regions may be the best locations for ocean colonies. Similar to wind energy, cold and warm currents are not evenly distributed across the Earth. Upwelling of cold and warm currents, and their interaction may help ocean colonies to produce energy for travel underwater.

Geoinformatics

Choosing the appropriate geographic location is critical for the long-term survival of the colonies underwater. Geoinformatics is the science which develops and uses information science infrastructure to address the problems of geography, cartography, geosciences and other related academic branches (Konecny, 2002). In ocean colonisation, geoinformatics is used in the 3D visualization of the seabed models. In modeling of the seabed, the benthic zone is part of the ocean layer closer to the bottom of the water body, and pelagic zone is including the free water column that interacts with the surface layers of a water body. As well as the geolocation of the site, the colonisation's location in the water column is important. The site selection is made for choosing the best locations to meet the purposes of ocean colonisation. Minimizing conflicts with other colonies and reducing the environmental impacts are other important motivations for the use of geoinformatics.

Biomimicry

In order to decide which structural form best suits the specific underwater conditions, a morphological reference is necessary. The term 'biomimicry' first appeared in scientific literature in 1962 and grew in usage, particularly amongst material scientists in the 1980s. The British architect Michael Pawlyn (2011, 2) defines biomimicry as "mimicking the functional basis of biological forms, processes and systems to produce sustainable solutions". He makes a distinction between 'biomimicry' and 'biomorphism', while in the former nature is used to produce functional solutions, in the latter it is used for unconventional forms and for symbolic association (2011, 2). Yet, he does not favour one approach over the other, but rather focuses on grey zones between biomimicry and biomorphism. In underwater architecture, mimicking living forms can give insights into creative design solutions for human colonisation in future.

Materials and Methods: Workshop of Mission Aquarius

Aim

In this two-week workshop, the aim was to design a biomimetic structure that will function as a habitat for the first underwater colonizers. The students were asked to design a structure which can withstand underwater conditions, that is able to grow, move freely, reproduce, and/or exterminate itself at the end of its useful life. The habitable space(s) were formed in accordance with the geographical and climatological conditions of underwater environments. This involved the consideration of modes and durations of basic human needs, such as eating and sleeping, as well as social needs, and spaces were designed accordingly.

Process

During the workshop, the students worked in groups of six, and shared the workload of various tasks such as research, sketching, technical drawing, digital modelling and model making. The workshop started with a biomimetic process. After an introduction to biomimicry in architecture, each group were assigned a particular underwater plant or an animal to research and analyse. Then they were asked to design a unique structural unit, not by simply mimicking the outer form of the biomimetic organism, but by interpreting its structural formation. They presented their design ideas in sketches, diagrams, and models, etc. In the following stages, they made digital parametric models of their designs using specific software such as Rhinoceros, Grasshopper and special plug-ins, and also produced physical models with using digital fabrication techniques, such as laser cutting and 3D printing.

Objectives

The four main objectives of the workshop were to develop visionary ideas about architectural formations in extreme environments, to improve digital drawing and modelling skills, to introduce biomimicry as an approach to architectural design, and to understand the complex relationship between form and structure. It is important to note that the promotion of underwater human colonization was not specifically cited as the aim of the workshop. In view of ecological damage created on Earth, students were not openly directed towards this aim.

Schedule

The two-week workshop began with guest lectures from various academic fields. Three lectures covered the areas of hydrogeology, geomatics, marine ecology, biomimicry and digital design tools: the geological and oceanographic perspective was described by Prof. Bayarı from the Department of Geological Engineering at Hacettepe University; visualization and 3D modeling perspective, by Dr. Gökhan Kaboğlu from the Institute of Marine Sciences and Technology at Dokuz Eylül University; and marine life, by Ozan Veryeri from Underwater Research Society.

After these scientific explanations, an introduction to the designerly way of viewing the method of biomimicry given by Filiz Keyder Özkan, from İzmir University of Economics. As biomimicry usually brings organic geometries as design products, there was a final lecture on digital tools such as 3D parametric modeling, digital fabrication and virtual reality applications. It is important to state that the students were well equipped with knowledge and skills which went beyond the information and skillset given during the lectures. As design students, they were required to do more research to further develop, interpret and represent their design ideas.

Site

An underwater site clearly differs from a land based site in terms of context. However, multiple satellite images and bathymetric maps show various terrestrial underwater landforms similar to those on land. In this workshop, each group chose a site of 400 x 400 m from Google Earth. They defined their study area as a rectangle and obtained the border coordinates in decimal degree. They entered the coordinates in the website of of USCD (2016) to download their bathymetric data. Later, in Global Mapper software, after checking the map projection, they formed their grid focusing on their study area. They created the contours of the bathymetry by defining contour intervals and limits. In the 3D view, they added contour layers to their image. Finally, after exploring contours into AutoCAD, they made a 1/1000 topographical model of the site within the boundaries of which their structural unit was to emerge, extend and move.

Submission

The physical outcomes of the workshop were the 1/100 site model showing the designed structural unit on site, 3D-printed 1/200 partial model showing a living unit, module or cell. Besides the physical models, they used digital rendered images showing their units, and its relation to the surrounding context from various angles. The rendered models were later uploaded to Sketchfab, allowing the VR experience with Google cardboards or 3D glasses. Overall designs are presented on the workshop website (Mission Aquarius, 2018).

Results

In order to make a comparative analysis of the students' success level in finding unique design solutions for their structural units' growth pattern, unit design and structure, a matrix was formed (Table 1). This was composed of three main columns: use of oceanographic data, biomimetic design approach and use of digital tools. Unfortunately, the initial results showed that very few groups concentrated on the oceanographic data specific for their underwater location derived from bathymetric map. Second, both in their biomimetic design approach and use of digital tools, they placed greater emphasis on growth pattern and structure, as opposed to unit design. The living units are generally assumed to exist as conventional spaces as part of the inner structure, therefore were not necessarily formed using a biomimetic approach. Among the 17 projects, 5 received higher grades based on their successful use of the relevant data, and deserve further analysis.

Table 1. Analysis of the design outcomes (GP, growth pattern, UD, unit design, S, structure). The number of dots in each cell refer to the frequency of the geoinformatic tools and oceanographic data, biomimetic approach and the digital tools in the design outcomes. The highlighted teams are selected for further analysis.

Team	**Site**	**Biomimetic Organism**	**Oceanographic data**			**Biomimetic Design Approach**			**Digital Tools**		
			GP	**UD**	**S**	**GP**	**UD**	**S**	**GP**	**UD**	**S**
1	Baleal	Squid	**	*	**	**	*	***	**	*	*
2	India	Jellyfish	*	*	**	**	**	***	**	*	*
3	**Seychelles**	Coral reef	**	*	*	***	**	***	***	***	***
4	Somalia	Sea Anemone	*	*	***	**	**	***	***	*	***
5	Philippines	Octopus	*	**	*	***	**	*	***	*	*
6	**Atlantic**	Shark skin	*	*	*	***	**	***	***	**	***
7	**Australia**	Whale Baleen	***	**	***	***	**	***	*	**	**
8	Catalina	Sea kelp	*	*	**	*	*	**	*	*	*
9	Bahama	Mantis shrimp	**	*	***	**	*	*	***	*	**
10	**Mexico**	Squid	**	*	***	***	**	***	***	**	***
11	White sea	Jellyfish	**	*	*	**	*	**	**	*	**
12	Philippines	Coral reef	***	*	***	***	*	***	***	*	***
13	Philippines	Leaf sheep	**	**	***	***	*	**	*	*	*
14	**Sri Lanka**	Octopus	*	*	**	***	*	***	***	***	***
15	Australia	Shark skin	**	*	**	*	*	*	***	*	*
16	New Caledonia	Whale Baleen	*	*	*	*	**	*	**	*	*
17	Australia	Sea kelp	*	*	**	**	*	**	**	*	**

Team 3 designed mushroom-like individual living units using the growth pattern of coral reef (Figure 1). Half of these units consists of above-surface geodesic domes to be used as public spaces, and the other submerged half is composed of linear roots, around which private living units are attached in a spiral alignment. With the help of warm currents in Seychelles Sea, these units rotate and produce energy. In an emergency situation, the dome is able to separate from the core unit and travel to other locations to form other units, while the actual core unit shuts itself down.

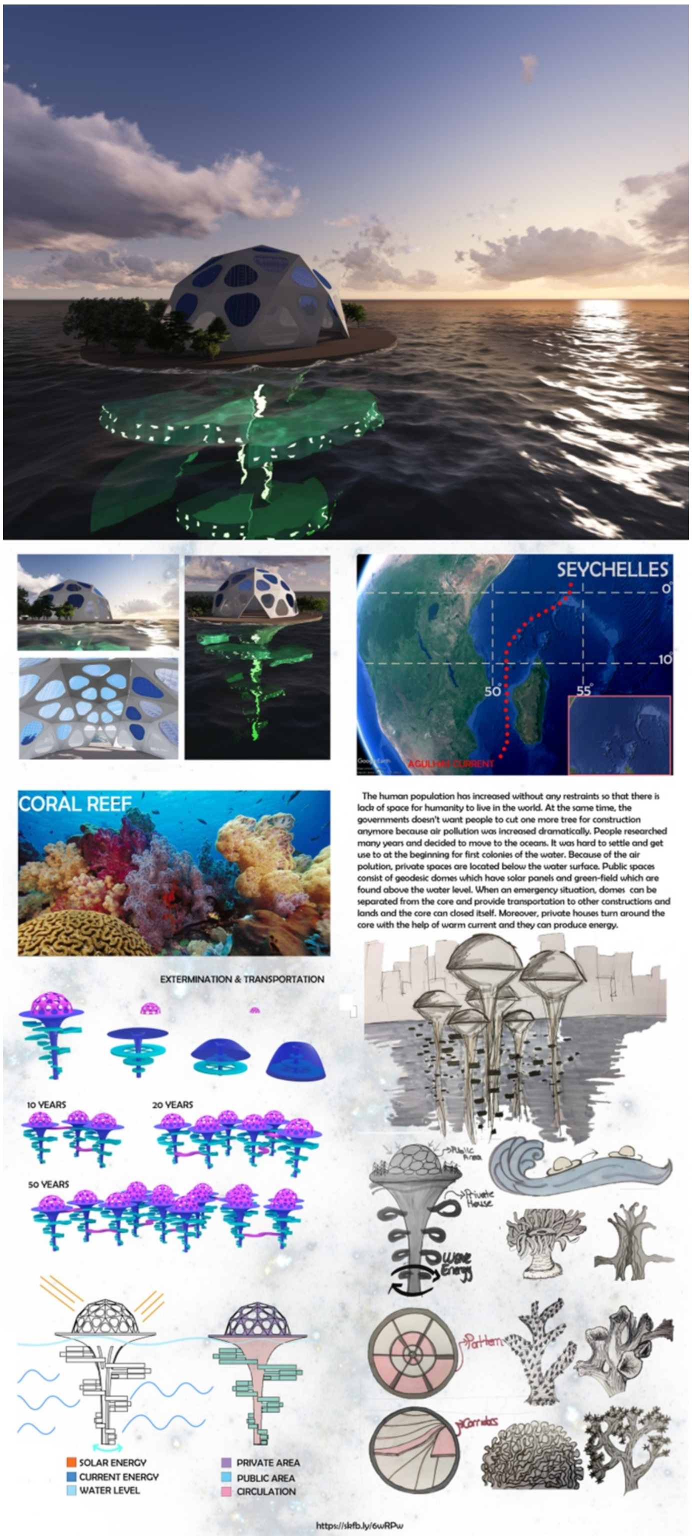

Figure 1. Presentation Board of Team 3.

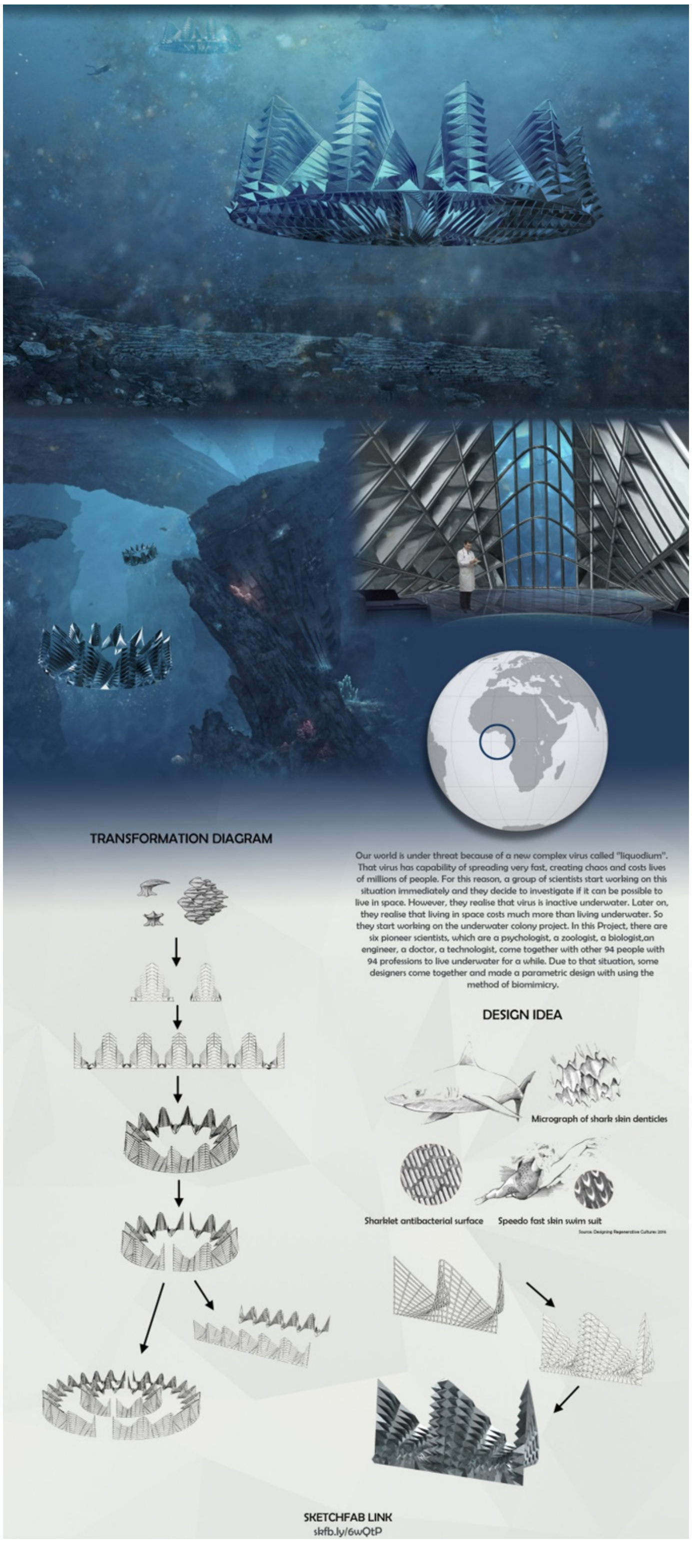

Figure 2. Presentation Board of Team 6.

Team 6 wrote an apocalyptic scenario for their design (Figure 2), according to which the world is under threat due to a complex imaginary rapidly-spreading virus called ‘liquadium’. A group of scientists, including a psychologist, a zoologist, a biologist, an engineer, a doctor and a technologist, realize that the virus becomes inactive underwater, therefore they initiate the construction of an underwater colony. Based on this scenario, the team designed a torus-like structure, the outer shells of which mimic the structural formation of shark skin. The shells move on opposing directions like shark skin, which enables the structural unit to rotate centrally, to move in alignment, or to break into pieces. However, this team did not utilize the oceanographic data as much as other groups.

Mimicking the filtering mechanism of whale baleen, Team 7 designed a spherical multi-layered structural unit that filters oxygen producing bacteria underwater (Figure 3). Exploring the surface and subsurface currents and solar characteristics of the Australian south coast, they aimed to produce energy for the growth process of their units. When the population reaches a certain level, the unit is able to reproduce itself by cell division. The circular discs are made out of calcium so when the time comes for the structure to be dismantled, it melts into the earth and vanishes.

Team 10 designed their structural unit as to grow from smaller modules attached onto the surface of a valley-like underwater formation in Mexico (Figure 4). Each module has flexible arms which give it a sudden squid-like movement. When the modules drift apart from the sea surfaces, their arms connect to each other to form bigger units. The living areas are located inside the arms.

Team 14 analysed the structural formation of an octopus for their design solution (Figure 5). The growth pattern of their unit is based on the spiral formation of octopus’ venteouses in accordance with the golden ratio. As the population of the colony increases, their structure expands to allow space for new living units. In addition, they designed wave pressure panels to resist the strong underwater currents prevalent along the Sri Lanka coastline. Each living unit in their unit has a different function, such as scientific research, education, a hospital and innovative activities.

Discussion and Conclusion

The workshop results have shown that the students follow various design approaches for ocean colonisation, ranging from biomimicry to oceanography. We have argued that in such an extreme environment, biomimicry may function as an alternative design solution, providing unconventional living patterns. Even though their design approaches do not reflect the exact scientific information of oceanography, their underwater colony designs showed an interdisciplinary creativity incorporating oceanography, geoinformatics and biomimicry.

The level of enthusiasm displayed for the projects by the students considerably exceeded our expectations. In their final ongoing design project, following the general theme of the semester, “water”, they are asked to design an Underwater Research Center for the town of Sığacık in the Seferihisar District of İzmir. The center will function as an underwater research centre for scientists, students, researchers and visitors from all around the world. The building complex will include enclosed spaces for research, exhibitions, accommodation, dining and administration. In addition, they were asked to design the exterior spaces within the boundaries of this site on the Earth. We hope, that familiarity with the underwater environment will bring a greater awareness of the environmental concerns.

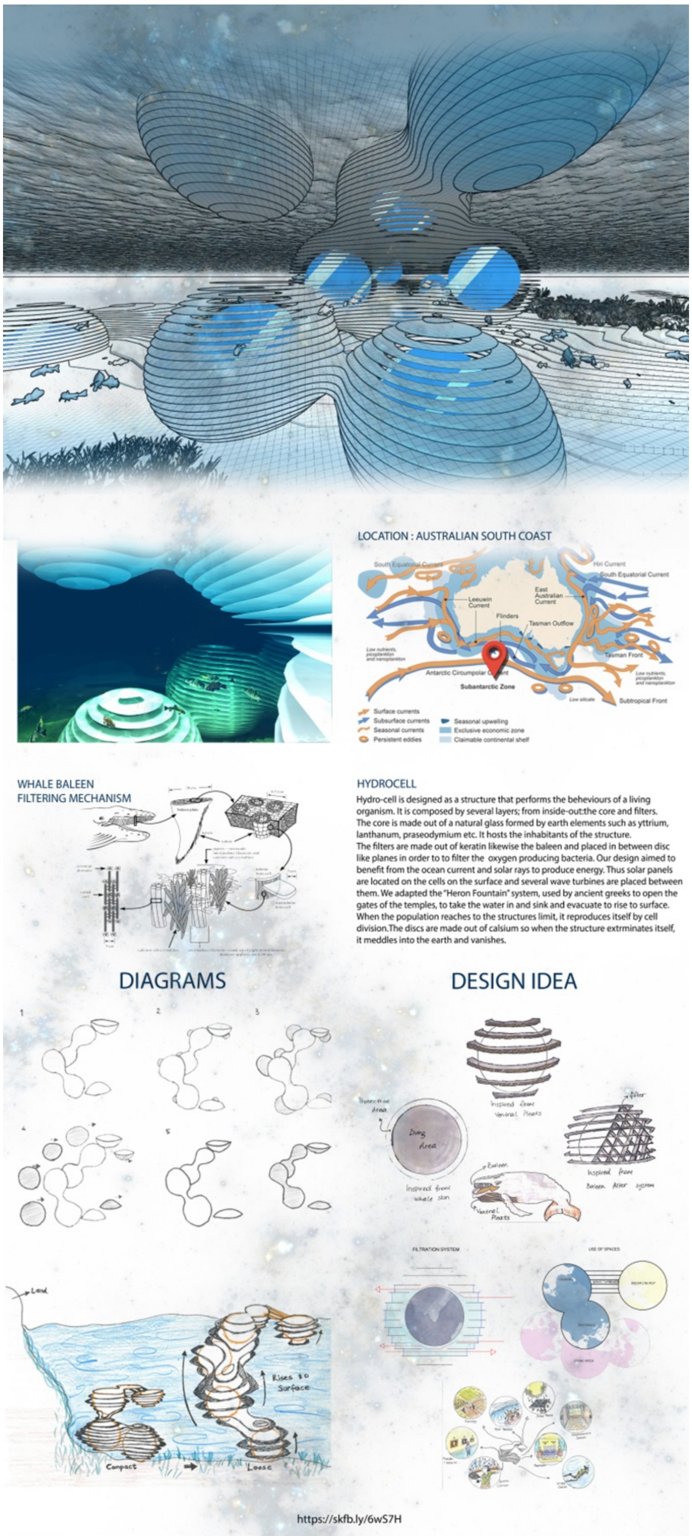

Figure 3. Presentation Board of Team 7

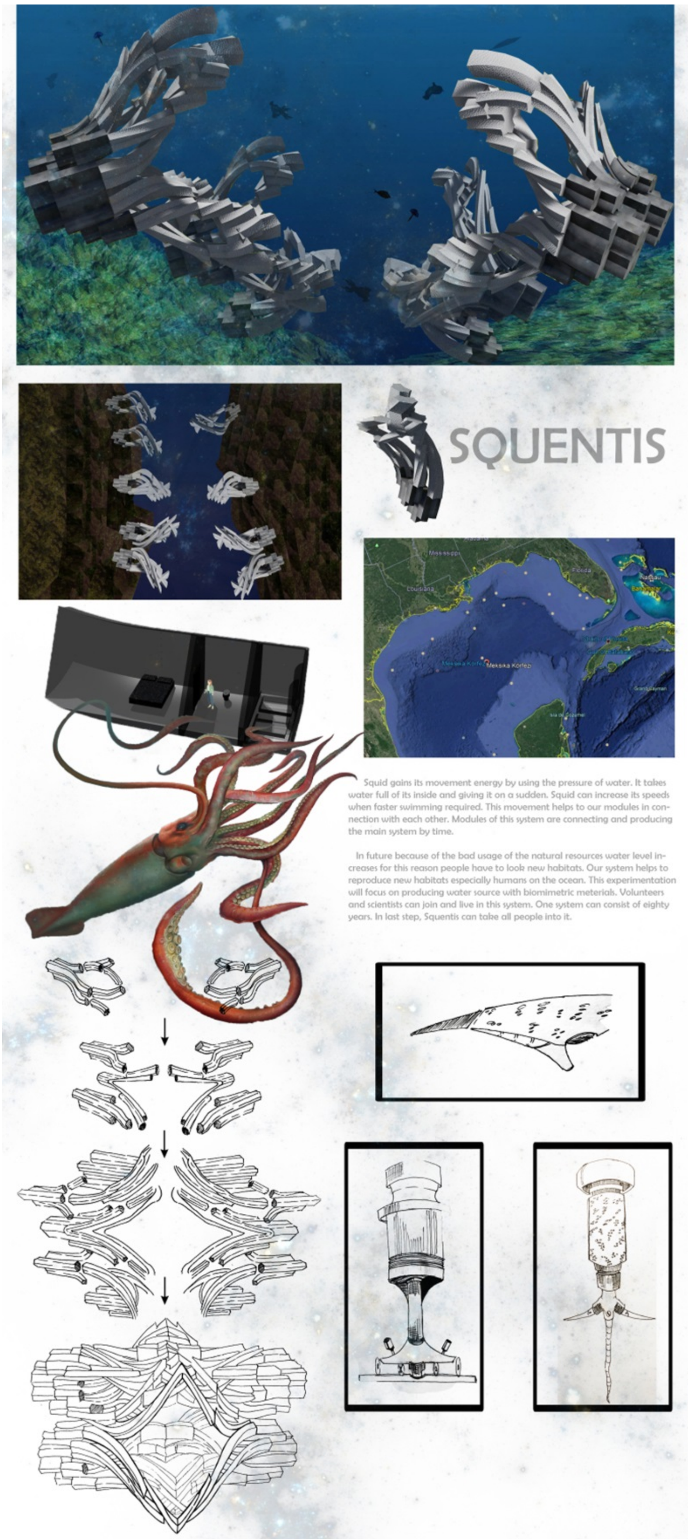

Figure 4. Presentation Board of Team 10

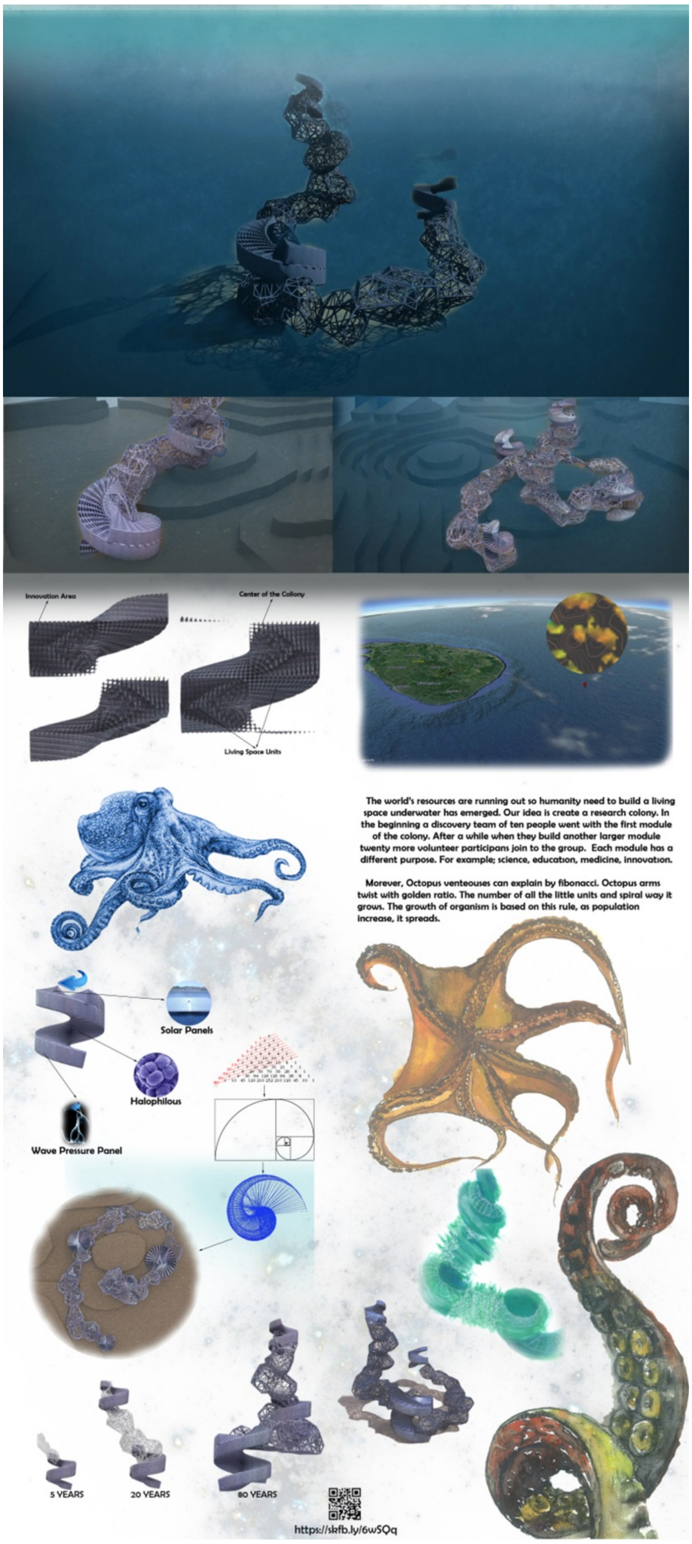

Figure 5. Presentation Board of Team 15

Figure 6. Distribution Map of the selected sites on Earth

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