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EARTH WATER ARCHITECTURE (UNDERWATER ARCHITECTURE)

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Abstract

In many books published so far, the Author often used the phrase 'architecture is the framework of life'. This is the most concise way of expressing his theory of architecture - Architecturally Defined Space (ADS), according to which architecture consists of four basic elements: Environment, Man, Boundaries and Perspectives. The content of the work UNDERWATER ARCHITECTURE was created and elaborated according to the mentioned theory of architecture. In addition to the books published so far, this work will further support and enrich the theory of Architecturally Defined Space (ADS), and will provide its readers with an insight into the special world of architecture that has not been officially studied at the Faculty of Architecture of the University of Sarajevo. As 'underwater architecture' has become an extremely attractive topic for businessmen (in the field of tourism) in the last decade, architects have found themselves in an unexpectedly wide field of activity. The 'underwater world' is a completely new natural environment, in many respects different from the 'environment on the surface of the planet Earth', which requires new concepts of spatial structures of architecture, the materialization of its boundaries (envelope) and the provision of the necessary conditions from the aspect of human comfort, which is treated by architectural thermodynamics, lighting, acoustics, security... The author is convinced that the subject of UNDERWATER ARCHITECTURE will soon be included in the curriculum of architecture studies, first as an 'elective subject', and then as a 'compulsory subject' where all the 'classical disciplines of traditional architecture teaching will be part of ': architectural constructions, constructive systems in architecture, design, theory and history of architecture and urban planning.

Keywords: *Architecturally Defined Space (ADS), Underwater architecture*

1. Introduction

„According to the author's understanding of architecture as an Architecturally Defined Space with its four basic elements - Environment, Man, Boundaries and Perspectives - a typology of architecture is also proposed according to the way its boundaries (envelope) are defined, and according to the specifics of global natural environments in with which man can realize his existence: on Earth (type E) in open space (type S) and on other heavenly bodies (type SB)“ [1], (Figure 1).

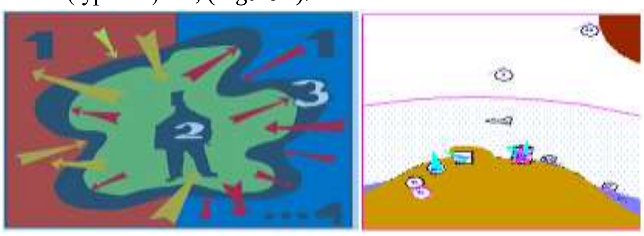

Figure 1. Architecturally Defined Space, ADS (A. Hadrovic, 1987), (left) and ADS Typology (A. Hadrovic, 2011), (right)

Everything that has been said and written about architecture to date is based on man's experience of life on Earth; since man has long since stepped into space, first with unmanned aircraft, and later with personal presence, new spaces for his existence have opened up, and therefore, completely new experiences in creating the boundaries of Architecturally Defined Space (ADS). These new experiences will also be transferred to the already known experiences of his life on Earth, where one can expect, until now, an unimaginable approach to defining the boundaries of the Architecturally Defined Space [1]. As already mentioned, type E (Earth) refers to architecture realized in the conditions of human existence on Earth. Here, as subtypes, we will observe architecture realized (mainly) on the surface of the Earth, in the field, with more or less significant digging into the ground (type EAG), architecture realized predominantly in the ground, but with an essential connection to the space above ground level (type EGA), architecture realized entirely in the ground, below ground level (type EG), architecture realized above water (type EAW), architecture realized entirely under water (EW), and architecture realized in the Earth's atmosphere, as flying bodies (type EA) [1]. In all analyzes of the aforementioned types of architecture, we will always have in mind, on the one hand, Man (in the spectrum of his clearly defined needs), and, on the other hand, the specific natural environment in which a particular architectural type is realized. In doing so, we want to see when, how and why the social environment appears as an input in defining architecture as well as the role of the architect (the immediate creator of architecture) with his knowledge, skill and subjective dimensions of his personality. As a special diopter of viewing architectural realizations, we could single out the way of achieving comfort within an architecturally defined space. At the same time, we understand comfort as a set of purely physical parameters (empirically measurable) that define the physiological and psychological comfort of a person. Considering their physical nature, we could classify these parameters into the following groups [2]:

1. Thermal comfort parameters,
2. Lighting comfort parameters,
3. Acoustic comfort parameters.

Thermal comfort parameters are: air temperature, relative air humidity, air flow speed, radiation (thermal radiation of surfaces and equipment inside the space), intensity of metabolism of people inside the space and clothing (level of drowning) of people inside the space. The parameters of lighting comfort are: level of illumination, intensity of illumination and brightness level (of luminous bodies and illuminated surfaces). Acoustic comfort parameters are: evenness of sound energy distribution in space, sound pressure level (intensity, power) in space and sound reverberation time. The mentioned parameters determine the basic dimension of the architecture, its expediency. Empirical analysis of architectural realizations throughout history, according to the mentioned parameters, we would find examples of anthologically important buildings that did not achieve optimal comfort, as well as architecturally unnoticed buildings in which supreme comfort was achieved; it is one of the most unacceptable controversies in architecture.

Type EAW (Earth-Atmosphere-Water) includes those ADS solutions that are realized above water (rivers, lakes, seas), with more or less complete contact with the atmosphere and, most often, specific contact with the ground [1]. The first EAW-realizations are generally related to vessels used by man as a means of transportation on water; later, borders were added to the floating platform of the vessel in order to protect people from various atmospheric influences (rigid or flexible roofs and walls), and more or less complex solutions for propulsion and management of vessels. In parallel with the vessels, man designed dwellings and various utilitarian architectural programs above the surface of the water, fixed in the ground, which were later included under the common name sojenica. While in the case of dwellings the main reason for such a situation was to ensure safety (against attacks by animals or people) and close contact with the source of food, in the case of purely utilitarian solutions (mills, for example) the situation above the water is a consequence of the technology of their functioning. It was the technology of functioning of utilitarian solutions of the EAG (Earth-Atmosphere-Ground) type that resulted in solutions suitable for the EAW (Earth-Atmosphere-Water) type. EAW-type architectural solutions are also common today, especially in those natural environments where water (river, lake, sea) is the basic source of food, the basis of existence, and the space for construction on land (next to water) is limited and expensive. Using the many benefits of direct human-water contact, on the one hand, and the mental strength of vernacular solutions (which remind man of his natural origins), modern hotels, restaurants and tourist resort complexes are often realized around the world. At the same time, the development of vessels reached a high technical-technological and architectural-design level, in a wide range of solutions for different functions (transport, entertainment, sports, economy...).

Type EW (Earth-Water) refers to those ADS solutions that are completely realized in water. The basic question related to this type of ADS is: what are the needs that lead people to build in a complete environment of water [2]? The environment of water, similar to the environment of the atmosphere and the environment of the soil (below the ground level), forms that part of the planet Earth that we call the biosphere. It is the framework of existence for many living beings, and as such, represents a special world with its specificities that make it special. Many parallels can be found between the underwater living world and the world of the Earth's atmosphere, many common properties that, in addition to their specificities conditioned by different environments, classify them into the same biological groups. Man is an exceptional living being that, among other things, despite his physiological-anatomical destiny for life in the Earth's atmosphere, wants to enter other worlds (under the ground, in water, in the open space of the Universe, on other heavenly bodies...). Sometimes he does it in the way of imagination, sometimes he steps into other worlds (with a longer or shorter stay) for reasons of curiosity, sometimes for reasons of reaching new knowledge about himself and the world that surrounds him, sometimes for reasons of mastering the resources that enable him to live more comfortably in his natural environment. environment, almost always for reasons of gaining an advantage over other people. Any stay of a person in a complete environment of water implies the establishment of those parameters of the environment in which he normally lives (atmosphere). As the physical parameters of the water environment are different, it is very often, technologically very demanding and limited to a certain period of time, to ensure the conditions for human existence in them. High rigidity (resistance to high hydrostatic pressure) and perfect sealing are the basic requirements that must be ensured by ADS borders in conditions of a completely watery environment (Figures 2, 3). Modern realizations of ADS in a completely water environment (or combined water-atmosphere) are mainly the result of exhibition efforts, with the ultimate goal of making money.

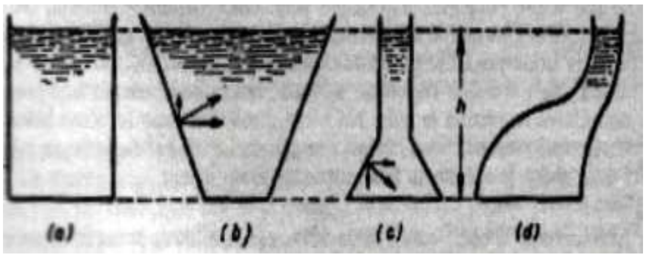

Figure 2. Hydrostatic pressure

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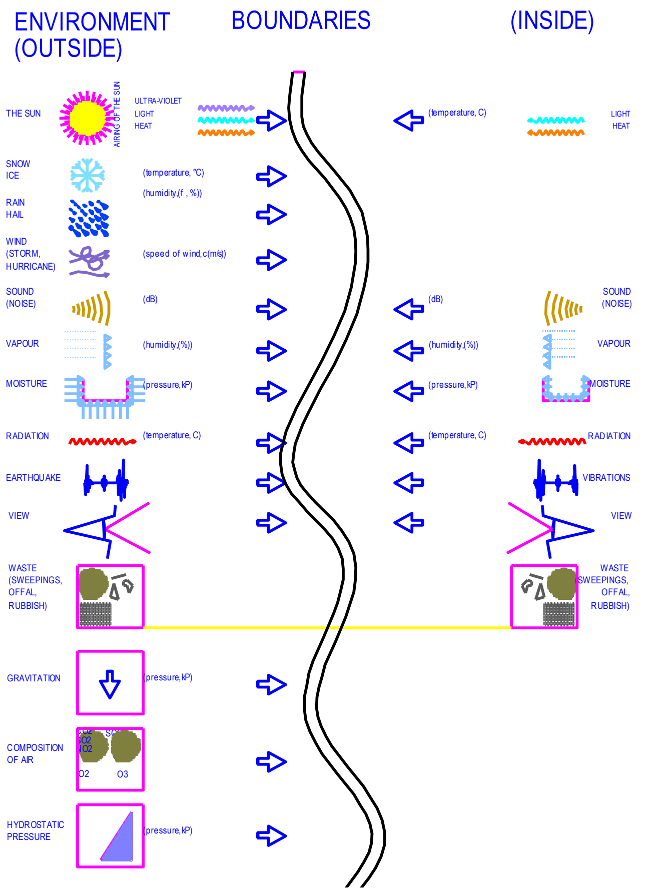

Figure 3. Environment-Boundaries of ADS-Man (A. Hadrovic, 2011)

2. Environment

"Environment is a fundamental feature of Architecturally Defined Space (ADS). As a complex expression of human struggle, architecture is simultaneously a strictly defined empirical phenomenon that is always realized in a concrete natural environment in which it must survive as a physical structure, resistant to more or less aggressive natural influences. At the same time, many inputs from the social environment give architecture the characteristics of a concrete society in the historical-time period Context" [3].

2.1. Natural environment

When we talk about the natural environment, we mean those parts of the visible world that were not created by man and that we can discern with our senses. The term 'nature' refers to all physical phenomena, from microscopic to macroscopic dimensions, from matter and energy to the Universe [2]. Without water there is no life. Water is the only common substance that exists as a solid, liquid, and gas under conditions normal for life on Earth. "The hydrosphere is a discontinuous layer of water on the Earth's surface. It includes all liquid and frozen surface water, underground water retained in the soil and rocks, and atmospheric water vapor" [4]. The abundance of surface water on Earth is a unique feature of the Solar System. The Earth's hydrosphere consists mainly of the oceans, but technically includes all of the world's water bodies, including inland seas, lakes, rivers, and groundwater down to a depth of 2,000 meters. The deepest underwater place is the Challenger Deep of the Mariana Trench in the Pacific Ocean, 10,900 meters deep. Conventionally, the Earth is divided into five separate oceans, but all these oceans connect into one world ocean. The mass of this world ocean is 1.35 × 10^{18} tons, or about 1/4400 of the total mass of the Earth. The world ocean covers an area of 3,618 × 10^8 km^2 with a mean depth of 3,682 m, resulting in an estimated volume of 1,332 × 10^9 km^3. If the entire surface of the Earth's crust were at the same elevation as a smooth sphere, the depth of the resulting world ocean would be about 2.7 kilometers. About 97.5% of the water on Earth is salty; the remaining 2.5% is fresh water. Most of the fresh water - about 69% - is present as ice in ice caps and glaciers. The average salinity of Earth's oceans is about 35 grams (1.2 oz; 1 oz = 0.035274 x g) of salt per kilogram of seawater (3.5% salt). Most of the salt in the ocean comes from weathering and erosion of rocks on land. Some salts are released from volcanic activity or extracted from cold igneous rocks. Oceans are a reservoir of dissolved atmospheric gases, which are essential for the survival of many aquatic life forms. Seawater has an important influence on the world's climate, and the oceans act as a large reservoir of heat. Changes in ocean temperature distribution can cause significant weather shifts, such as the El Niño-Southern Oscillation. Overall, the ocean occupies 71% of the world's surface, with an average depth of almost 3.7 kilometers. By volume, the ocean provides about 90% of the living space on the planet. However, water is found elsewhere in the solar system. Europa, one of the moons orbiting Jupiter, is slightly smaller than Earth's Moon. There is a strong possibility that there is a large ocean of salt water under the ice surface. It is estimated that the outer crust of solid ice is about 10-30 km thick, and the liquid ocean beneath it is about 100 km deep. This would make the European Ocean twice as large as the Earth's ocean. It has been speculated that Europa's ocean could support life and could support multicellular microorganisms if there are active hydrothermal vents on the ocean floor. Enceladus, a small icy moon of Saturn, also has a subsurface ocean that is actively releasing warm water from the moon's surface. The earth is about 4.54 billion years old. The earliest indisputable evidence of life on Earth dates back to at least 3.5 billion years ago, during the Eoarchean Era, after the geological crust began to solidify after the molten Hadean Eon. Fossils of microbial mats have been found in a 3.48-billion-year-old sandstone in Western Australia. Other early physical evidence of biogenic matter is graphite in 3.7-billion-year-old metasedimentary rocks discovered in western Greenland, as well as the remains of biotic life found in 4.1-billion-year-old rocks in Western Australia. All organisms on Earth are descended from a common ancestor or ancestral genetic pool. High-energy chemistry is thought to have produced a self-replicating molecule about 4 billion years ago, and half a billion years later the last common ancestor of all life existed. The current scientific consensus is that the complex biochemistry that makes up life arose from simpler chemical reactions. The beginning of life could have involved self-replicating molecules such as RNA and a collection of simple cells. In 2016, scientists reported 355 genes from the last universal common ancestor (LUCA) of all living things, including microorganisms, living on Earth [5]. Current species are a stage in the evolutionary process, with their diversity the product of a long series of speciation and extinction events. The common origin of organisms is first derived from four simple facts about organisms. First, they have a geographic distribution that cannot be explained by local adaptation. Second, the diversity of life is not a collection of completely unique organisms, but organisms that have morphological similarities. Third, the remains of traces without a clear purpose resemble the functional characteristics of ancestors and finally, that organisms

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can be classified into a hierarchy of nested groups using these similarities - similar to a family tree. However, modern research suggests that, due to horizontal gene transfer, this 'tree of life' may be more complicated than a simple branching tree as some genes have spread independently between distantly related species [6]. Past species also left records of their evolutionary history. Fossils, together with the comparative anatomy of present-day organisms, form a morphological or anatomical record. By comparing the anatomies of modern and extinct species, paleontologists can infer the lineages of those species. However, this approach is most successful for organisms that have hard body parts, such as shells, bones, or teeth.

2.1.1. Sea: bio-physical system

An ocean (also sea or world ocean) is a body of salt water that covers approximately 71% of the Earth's surface and contains 97% of the Earth's water. Separate names are used to identify five different areas of the ocean: Pacific (largest) Atlantic, Indian, Southern (Antarctic) and Arctic (smallest). Sea water covers approximately 361000000 km^2 of the Earth. The ocean is the main component of the Earth's hydrosphere, and is therefore an integral part of life on Earth. Acting as a large reservoir of heat, the ocean influences climate and weather patterns, the carbon cycle and the water cycle. Oceanographers divide the ocean into different vertical and horizontal zones based on physical and biological parameters. The pelagic zone consists of the water column from the surface to the ocean floor throughout the open ocean. The water column is further categorized into other zones depending on the depth and amount of light. The photic zone includes water from the surface to a depth of 200 m, where photosynthesis can take place. This is why the photic zone is the most diverse. Photosynthesis of plants and microscopic algae (free-floating phytoplankton) creates organic matter from water and carbon dioxide. This upper, sunlit zone is the source of the food supply that sustains most of the ocean ecosystem. Light penetrates only to a depth of several hundred meters; the remaining ocean below is cold and dark. The continental shelf where the ocean approaches dry land is shallower, with a depth of a few hundred meters or less. Human activity has a greater impact on the continental shelf [7]. The sea heats up by absorbing solar radiation, and cools down by emitting long-wave radiation, evaporation and conduction of heat between the atmosphere and the sea. The sea warms the most in the equatorial regions, and cools the most in the polar regions, so average surface temperatures decrease with increasing latitude. Surface isotherms show irregularities that arise due to the influence of currents on the temperature field. About 53% of the sea surface has an average temperature higher than 20 °C; the warmest surface is the Red Sea and the Persian Gulf (35 °C); the average annual temperature of the Pacific Ocean is 19.1 °C, the Indian Ocean 17.0 °C, and the Atlantic Ocean 16.9 °C. In the area of low latitudes, the temperature decreases towards the bottom (the first 1000 m in the thermocline layer by approximately 20 °C). All sea waters deeper than approximately 1000 m have a temperature of approximately 4 °C. At depths of 2000 to 3000 m, the temperature is lower, and at even greater depths it increases (adiabatic temperature increase due to increased pressure). The annual fluctuation of the surface temperature in the middle latitudes is 8 °C, and in the tropics and high latitudes it is about 2 °C; in shallow coastal areas, the temperature fluctuation is greater. The annual fluctuation of temperature in the open sea reaches a depth of about one hundred meters. The daily fluctuation of the surface temperature in mid-latitudes is about 0.3 °C, in tropical areas up to 1 °C in calm weather, and is felt to a depth of several tens of meters. Ocean water contains large amounts of dissolved gases, including oxygen, carbon dioxide, and nitrogen. This exchange of gases takes place on the surface of the ocean, and the solubility depends on the temperature and salinity of the water. The increased concentration of carbon dioxide in the atmosphere due to the burning of fossil fuels leads to higher concentrations in ocean water, which results in ocean acidification. The ocean provides important ecological services to society, including climate regulation. It also offers a means of trade and transportation, as well as access to food and other resources. Known as the habitat of 230,000 species, it may contain far more-perhaps more than two million species. However, the ocean is exposed to a number of environmental threats, including marine pollution, overfishing, ocean acidification and other effects of climate change. The continental shelf and coastal waters, which are most affected by human activity, are particularly sensitive. The world sea occupies a volume of 1368 million km^3; its mass is 1.44 trillion tons, or 1/420 of the total mass of the Earth. Compared to fresh water, seawater has a lower specific heat capacity (c) and a lower thermal conductivity (λ). The thermal conductivity coefficient is lower for seawater and increases with increasing temperature and pressure. Specific heat capacity and partial pressure of water vapor decrease with increasing salinity. The index of light refraction increases with increasing salinity and decreasing temperature; osmotic pressure increases with increasing temperature and salinity. The surface tension of the sea, which is 73 mN/m, is one of the highest surface tensions of liquids in nature. The coefficient of thermal expansion is higher than that of pure water, and increases with increasing pressure.

Water density depends on temperature, salinity and pressure; it decreases with increasing temperature, and increases with increasing salinity and pressure [8]. Pure water is densest at a temperature of 4 °C, and as salinity increases, the temperature at which water reaches its highest density decreases. Polar waters are the densest, and tropical waters are the thinnest. The density on the surface of the ocean is from 1021 to 1028 kg/m^3. Other values are possible in coastal areas. At depths greater than 1000 m, pressure affects density; surface density of 1028 kg/m^3 at a depth of 5000 m corresponds to a density of 1051 kg/m^3. The pressure in the sea is the sum of the pressure of the sea column above the observed depth and the atmospheric pressure.

Ice is more difficult to form in the sea than in fresh water, because the freezing point of water decreases with increasing salinity. At salinities higher than 24.7‰, cooling causes the water to freeze before it reaches its maximum density, and at lower salinities, the opposite is true [8].

Salinity is a term that defines the proportion of dissolved inorganic salts in the sea; it is expressed in grams per kilogram (g/kg), i.e. in parts per million (‰). Unlike fresh water, the composition of which has great differences, in the sea the ratio of ingredients is approximately constant. Salinity depends on the difference between the amount of water that left the ocean by evaporation and the amount of water that arrived in it through precipitation and inflow of land waters, on the formation and melting of ice, currents and mixing in the sea. The average salinity of the ocean is 35 ‰. In coastal seas, where the inflow of fresh water is greater than evaporation (Baltic, Black, East Siberian, Chukchi Sea, Arctic Sea, for example), the salinity is sometimes less than 10 ‰. In seas where evaporation is greater than freshwater inflow, salinity is

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higher than average and amounts to 38 to 41 ‰ (Mediterranean and Red Seas). The average depth of the world sea is 3794 m (average land height 875 m). The greatest depths are not in the middle of ocean slopes but in deep-sea trenches next to continents and some island groups. According to the latest measurements, the greatest depths are in the Mariana Trench in the Pacific Ocean (Challenger depth, 11033 m), in the Puerto Rico Trench in the Atlantic Ocean (Milwaukee depth, 8380 m), in the Java Trench in the Indian Ocean (Java depth, 7450 m) [8]. Seawater is primarily a solution of various inorganic salts, to a lesser extent gases and organic substances, and it also contains insoluble suspended particles. Evaporation of seawater leaves behind as sediment sea salt, a mixture of inorganic salts in which the main ingredients are chlorides and sulfates: sodium chloride (NaCl), magnesium chloride ($MgCl_2$), magnesium sulfate ($MgSO_4$), calcium sulfate ($CaSO_4$) and potassium sulfate ($K2SO_4$). . Dissolved inorganic salts are dissociated in water into ions. The pH-value of seawater, which ranges from 7.50 to 8.25, is affected by carbon dioxide and its buffering action, as well as salts and their hydrolysis processes. In the elemental composition of substances dissolved in seawater, the bulk is made up of 12 chemical elements. Chlorine is the most abundant, followed by sodium, magnesium, sulfur, calcium, potassium, bromine, carbon, strontium, boron, silicon and fluorine. This main group of elements makes up as much as 99.98% of all present elements, while in a very small proportion of 0.02% there are about fifty other elements [8]. Electromagnetic radiation in the sea is absorbed and scattered, which depends on the wavelength of the radiation, on the physical properties of seawater, dissolved substances and suspended particles. Ultraviolet and infrared radiation is quickly attenuated, and blue-green light reaches a depth of about a hundred meters. The transparency of the sea is traditionally determined by the depth at which a round white plate, 30 cm in diameter, disappears from view when descending into the depth. The Sargasso Sea has the highest transparency (66 m), in tropical and subtropical seas it is on average from 40 to 50 m, and in seas of subpolar latitudes from 15 to 20 m. In the Mediterranean Sea, transparency increases from west to east (the end of the Balearic Islands is 50 m, in the Ionian Sea 54 m, in the Levant 60 m). Transparency in the Red Sea is 60 m, in the Baltic Sea 13 m, and in the White Sea 8 m. The transparency of sea water also changes during the year, depending on the distribution of rainy periods (it is lower when rivers bring more detritus into the sea). Blue-green light penetrates the farthest into seawater, is scattered the most and is reflected the most, so it is most often perceived as the color of the sea. Blue is a typical color for temperate and warm parts of the world's seas, green prevails closer to the coasts, and along some coasts a brown or red color is observed (it is created by settlements of Trichodesmium algae and red bacteria). Deviations occur due to the color of dissolved substances and particles suspended in the sea or due to changes in insolation and the state of the atmosphere. The color of the sea water is also changed by the eruptions of underwater volcanoes. Some seas are named after their color (Red Sea, Yellow Sea, for example) [8]. Glowing or bioluminescence of the sea is caused by animals and bacteria that glow. Such a shimmer can be seen in the darkness on the tops of the waves, in the wake of the ship and on the rough surface. Glowing in the ocean depths is caused by animals with luminous organs [8].

In seawater, sound is absorbed less and spreads faster than in air. The speed of sound increases with increasing temperature, salinity and pressure; in the oceans it is between 1450 and 1570 m/s. Horizontal variations of sound speed are small, vertical variations in the surface layer depend primarily on temperature and salinity, and in deeper layers on pressure. These variations cause sound waves to refract. General circulation is the process of exchange of water of different temperature and salinity within individual oceans or between them. The speed of horizontal currents at the surface of the sea is 0.05 to 0.5 m/s, but in some places they can reach 4 m/s. These speeds decrease with depth. The direction of the current is indicated by the direction in which the current flows (opposite to the wind). Vertical currents are slower than horizontal currents, and can be ascending or descending. The general circulation on the surface of the ocean is determined on the basis of data on ship drifting and on the basis of temperature and salinity measurements, and in recent times also by satellite tracking of signal buoys (drifters). In the oceans, a circular current prevails - in the northern hemisphere clockwise, and in the southern hemisphere in the opposite direction. In the Atlantic Ocean, the North and South Equatorial Currents flow westward, and between them the Equatorial Countercurrent breaks in the opposite direction. The easternmost cape of South America is divided by equatorial currents. It directs the South to the Southwest, so it turns to the East as the Brazilian Current, then to the North, along the African coast, flows as the Bengvel Current and thus closes the great circular flow of the South Atlantic. The northern equatorial current (and part of the southern current) turns north. As the Guyana Current, it enters the Caribbean Sea and the Gulf of Mexico, exits the gulf between Cuba and Florida as the Florida Current and continues its journey to Newfoundland as the Gulf Stream, then as the North Atlantic Current enters the marginal seas of northwestern Europe and penetrates into the Arctic Ocean. One arm of the North Atlantic Current turns south, flows southwest as the Canary Current, and thus closes the great circular flow of the North Atlantic. In the middle of that stream, but shifted to the west, stretches the Sargasso Sea, where the waters are still, warm, blue and covered with seaweed. The Gulf Stream has a favorable effect on the climatic conditions of northwestern Europe. The cold Labrador Current brings the cold to the coasts of the USA and Canada. In the Pacific Ocean, the Gulf Stream corresponds to the warm Japanese Kuro-shio current, and the Labrador current to the cold Oya-shio. The Indian Ocean is landlocked to the north in the low latitude region. Its northern part is influenced by seasonal winds - monsoons and the currents change along with them. The general circulation in the deeper layers of the ocean is investigated with the help of current meters, which are placed on the bottom of the ocean, or with the help of drifters, which float at a certain depth and periodically come to the surface for communication with the satellite. There is still not enough data on the flow along the bottom (bottom flow), so general representations are based on theoretical assumptions. In the schematic depictions of the bottom current, there are two predominant areas to which water flows from the surface: one in the North Atlantic, from which the sea flows southward, close to the west coast, and the other in the South Atlantic, which is in the current that surrounds Antarctica. Branches separate from the latter into the Indian and Pacific oceans, and in their equatorial regions the water moves towards the surface. The causes of the general circulation of the ocean are wind (wind circulation) and surface heat and moisture flows, which affect temperature and salinity (thermohaline circulation). A change in one circulatory system can lead to a change in another. Wind circulation dominantly determines the surface current in the oceans; the thermohaline circulation is weaker, but it extends to the

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bottom of the ocean and thus regulates global dynamics. An example of a wind circulation is the subtropical gyre in the North Atlantic, bordered by the North Equatorial, Gulf, North Atlantic and Canary currents. It is driven by westerly winds, which prevail in areas of moderate latitudes, and trade winds, which prevail in the area of the equator. They create currents that are deflected to the right of the wind direction, due to the Coriolis force. Since the Coriolis force increases with increasing latitude, the subtropical gyre is asymmetric and shifted westward, and the poleward (Gulf) current is faster than the equatorward (Canary) current. Thermohaline circulation in the oceans is triggered by the sinking of high-density water, primarily in the extreme north and south of the Atlantic Ocean, and the rising of low-density water, primarily in the equatorial parts of the Indian and Pacific Oceans. Between these areas, a global thermohaline conveyor is created, whereby the surface flow is directed from the area of ascent to the area of sinking, and the flow in the bottom layer is in the opposite direction. Possible future disturbances in the thermohaline circulation regime could cause sudden changes in climate conditions on Earth. In the peripheral seas of the northern hemisphere, the general circulation is generally cyclonic (counter-clockwise). It also prevails in the Mediterranean Sea and the Adriatic Sea. Forced waves are the motion of the sea created under the influence of external periodic forces originating from the action of the Moon and the Sun (sea changes) and the action of the atmosphere (storm slowdowns, annual changes, for example) [8]. Sea tides are the periodic movement of the sea under the influence of the gravitational attraction of the celestial bodies, the Moon and the Sun, and are manifested as a vertical movement of the sea level (tide - rise, ebb - fall) and horizontal movement of water masses - tidal currents. The height difference between the highest and the lowest sea level is the range of sea changes. At the point on the Earth's surface that is closer to the celestial body, the gravitational force is greater than the centrifugal force that occurs due to the revolution, so the water rises towards the celestial body. On the opposite side of the Earth, the centrifugal force is greater than the gravitational one, the water rises in the direction opposite to the celestial body and two bulges appear on the Earth. The Earth rotates, but both bulges remain in the direction toward and away from the celestial body. On the surface of the Earth, two high and low waters are observed during the day. They can be of different heights if the celestial body is not in the plane of the equator. The Moon's (lunar) tides are about 2.2 times greater than the Sun's (solar) tides, because the gravitational force is proportional to the mass of the body, and inversely proportional to the square of the distance between the bodies. Since the sea changes are the result of the simultaneous action of the Moon and the Sun, their influences for the syzygy (new and full moon) constructively overlap (these are live sea changes), and for the quadrature (first and last quarter) they overlap destructively (they are significantly lower, dead sea minnows). The largest ranges of live minnows are: in Canada (Fundy Bay) 19.6 m, in England (Severn) 17.8 m, in France (Granville) 16.1 m. In the Adriatic Sea, these ranges are 0.3 (south) up to 1.1 m (north). Storm surges are slow motions in the sea caused by changes in air pressure and wind. An increase (decrease) in air pressure of 1 hPa leads to a decrease (increase) in the water level of 1 cm - this is the so-called the inverse barometer effect. The wind moves the sea level along the coast, and the amount of these shifts is greater the stronger the wind, the greater the area and the shallower the sea. The effects of air pressure and wind often add up (in the area of atmospheric cyclones, the drop in air pressure and winds contribute to the rise in water levels). A storm surge can cause the death of a large number of people and considerable property damage. In 1991, it killed 150,000 people in Bangladesh. Annual changes in sea level are partly caused by air pressure and wind, and partly by surface flows of heat and moisture. For example, warming the sea causes the water column to expand, and cooling causes it to contract. That is why surface heat flows in the area of moderate latitudes support a 10 cm higher water level at the end of summer than at the end of winter [8]. The atmosphere affects the sea, and it in turn affects the atmosphere, so the weather and climate in the atmosphere above the seas and oceans are significantly different from those above the continents. The sea surface heats up more slowly than the land surface and cools down more slowly, so its temperature does not rise as high and does not fall as low as the temperature of the land surface. That is why the surface of the land and the air above it are warmer during the day and summer, and colder at night and winter than the adjacent sea surface and the air above it. Due to corresponding changes in pressure, important meteorological processes take place along the sea coasts. In a small area, they cause the change of the daytime wind from the sea and the night wind from the land, and in a large area, they cause the appearance of the summer monsoon from the ocean and the winter monsoon from the continent. They also shape the paths that cyclones travel most often in a certain season (more over the land in the summer, over the sea in the winter). Due to the same processes, stationary anticyclones form over the central parts of the cooled continent in winter. Most of the moisture in the air comes from the evaporation of the seas and oceans, so the air masses over the oceans are wetter than those over the continents at a similar latitude. Cyclones are created in tropical areas due to intense evaporation - strong whirlwinds with a radius of several hundred kilometers, also known as typhoon, hurricane, hurricane. They develop above the sea, and quickly die off over land. Finally, the difference in the friction of the air on the ground over land and sea is important for atmospheric dynamics. The coast is an area where friction changes abruptly, so the large air current in the coastal area slows down if it comes from the sea, and speeds up if it is directed from the land. In the first case, the air accumulates and rises, so clouds can form, and in the second case, the air must descend from a height and then the clouds disintegrate. Due to less friction, wind speeds are generally higher over the oceans, and currents on a planetary scale – organized into the general circulation of the atmosphere – are more regular and freely developed. Parts of that circulation system, such as the trade winds and westerly winds, support the corresponding currents in the sea.

2.1.2. Atmospheric pressure

Atmospheric pressure, also known as barometric pressure, is the pressure in the Earth's atmosphere [9]. Standard atmosphere (symbol: atm) is a unit of pressure defined as 101325 Pa (1013.25 mbar), which is equivalent to 760 mm Hg (mercury column). The unit of atm is approximately equivalent to the mean atmospheric pressure at sea level on Earth, that is, the atmospheric pressure of Earth at sea level is approximately 1 atm. In most circumstances, atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of the air above the measurement point. With increasing altitude, the atmospheric mass becomes smaller, so the atmospheric pressure decreases with increasing altitude. Because the atmosphere is thin relative to Earth's radius-especially the dense atmospheric layer at low altitudes-Earth's gravitational constant as a function of height can be approximated

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as a constant and contributes little to this drop. Pressure is force per unit area, with SI unit pascal (1 pascal = 1 newton per square meter, 1 N/m^2). On average, a column of air with a cross-sectional area of 1 square centimeter (cm^2), measured from mean (mean) sea level to the top of the Earth's atmosphere, has a mass of about 1.03 kilograms and exerts a force or 'weight' of about 10.1 newtons, resulting in with a pressure of 10.1 N/cm^2 or 101 kN/m^2 (101 kilopascals, kPa).

2.1.3. Hydrostatic pressure

Hydrostatic pressure refers to the pressure exerted by any liquid in a closed space. If the liquid is in the tank, there will be some pressure on the wall of the tank. If we imagine a container in the form of a column, we can see that the pressure pressing on its wall is greater at the bottom than it will be at the top. This is partly related to the force of gravity. The air around us at sea level presses us with 101352.9 N/m^2. We do not feel this pressure since the fluids in our body push outward with the same force. But if we swim away and dive into the sea water just a few meters, we will notice a change. Namely, we will feel an increase in pressure on the eardrums. This is due to the increase in hydrostatic pressure, which represents the force per unit area with which the liquid acts on the object. The deeper we go into the water, the greater the pressure on our body. For every 10.06 meters of immersion in water, the pressure increases by 1 bar (100,000 N/m^2). Hydrostatic pressure is the pressure created by the action of a fluid in equilibrium at a certain point within the fluid, due to the force of gravity. Hydrostatic pressure increases proportionally to the depth measured from the surface due to the increasing weight of the liquid acting from above [10] (Figure 4). If the liquid is in a container, then the depth of the object placed in that liquid can be measured. The deeper the object is placed in the liquid, the more pressure it experiences. This is because the weight of the liquid is above it. The denser the liquid above it, the greater the pressure exerted on the submerged object, due to the weight of the liquid. The pressure due to the liquid alone (gauge pressure) at a given depth depends only on the density of the liquid, the acceleration of gravity, and the distance below the surface of the liquid (the height of the liquid column).

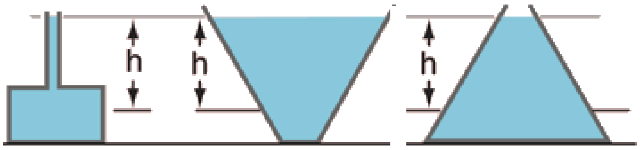

Figure 4. Hydrostatic pressure

If the tank is open to the upper atmosphere, the atmospheric pressure must be added if the total pressure on the object is to be found. The pressure at a given depth in a static fluid is the result of the weight of the fluid acting per unit area at that depth plus any pressure acting on the surface of the fluid.

2.1.4 Archimedes principle

Archimedes' principle confirms the fact that the buoyant force acting on a body immersed in a liquid, either completely or partially, is equal to the weight of the liquid displaced by the body. Archimedes' principle is a law of physics that is the basis of fluid mechanics. It was defined by Archimedes (Greek: Ἀρχιμήδης - Arkhimḗdēs, ca. 287-212 BC) of Syracuse. Archimedes' principle allows the calculation of the buoyancy of any floating object partially or completely immersed in a liquid. The downward force on an object is its weight. The upward force or upward force on an object is that stated in Archimedes' principle. Thus, the net force on an object is the difference between the magnitude of the buoyant force and its weight. If this net force is positive, the object rises, if it is negative, the object sinks, and if it is zero, the object is neutrally buoyant - that is, it stays in place without rising or sinking. Simply put, Archimedes' principle states that when a body is partially or completely immersed in a liquid, it experiences an apparent loss of weight equal to the weight of the liquid displaced by the submerged parts of the body. The weight of the displaced liquid is directly proportional to the volume of the displaced liquid (if the surrounding liquid is of uniform density). The weight of an object in a liquid decreases due to the force acting on it, which is called buoyancy. Simply put, the principle states that the buoyant force (Fb) on an object is equal to the weight of the fluid displaced by the object or the density (ρ) of the fluid multiplied by the submerged volume (V) times gravity (g). We can express this relationship with the equation:

$F_a = \rho g V$ (in newtons, N),

where F_a denotes the buoyant force applied to the submerged object, ρ denotes the density of the liquid, V represents the volume of liquid displaced and g is the acceleration due to gravity. Thus, among fully submerged objects of equal mass, objects with a larger volume have greater buoyancy. For a completely submerged object, Archimedes' principle can be reformulated as follows: apparent submerged weight = weight of object - weight of displaced liquid. When an object is immersed in a liquid, the liquid exerts an upward force, known as buoyancy, which is proportional to the weight of the displaced liquid. The net force acting on the object is therefore equal to the difference between the weight of the object (down force) and the weight of the displaced liquid (up force). Balance, or neutral buoyancy, is achieved when these two weights (and thus forces) are equal.

2.1.5 The flora and fauna of the ocean

The oceans are inhabited by groups of plants that are very different from the plant world on land (Figure 5). Marine flora plays an important role in the evolution and maintenance of life on Earth [11]. The oxygen produced by these plants is used by marine and terrestrial organisms. The flora in the sea consists of different types of lower plants (Thallophyta) and a smaller number of higher plants from the group of spermatophytes (Spermatophyta). Of the lower plants, a large number of forms are found in the sea, from microscopic, single-celled algae to huge, highly differentiated brown algae. These plants have adapted to life in the sea by acquiring the ability to float freely in the water, float on the open sea, or are permanently attached to the bottom or to other organisms in the sea.

Figure 5. General characteristics of a large marine ecosystem (Gulf of Alaska)

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Source: https://upload.wikimedia.org/wikipedia/commons/f/f6/General_characteristics_of_a_large_marine_ecosystem.jpg Accessed: July 9, 2023.

Among unicellular algae in the plant plankton, the most famous groups of photosynthetic algae are dinoflagellates, diatoms, coccolithophorids and silicoflagellates. Dinoflagellates (Pyrrophyta) have a cell wall (mostly) of cellulose, and two flagella that serve to propel them. Those known as zooxanthellae live in symbioses with corals, jellyfish and shellfish. Some dinoflagellates can glow, which is called bioluminescence. Others are harmful because they contain toxins dangerous to marine vertebrates and humans. Diatoms, coccolithophorids and silicoflagellates belong to the genus Chrysophyta and are also an important component of marine plant plankton. Diatom cells are informed by two flint (silicate) shells that bacteria cannot decompose, so after the death of the shell cells, they fall to the sea floor and create diatom mud. Coccolithophorids are planktonic algae, the cells of which are covered with calcium carbonate plates called coccoliths. They are moved using two whips, and the shells (plates) fall to the bottom after the death of the cells and form carbonate sludge. Silicoflagellates make up tiny plant plankton, particles in cold seas. The internal skeleton of the cells consists of silicates and forms appendages, which together with one or two flagella prevent the cells from sinking. In many species, drops of oil inside the cells also help them in this. Brown algae (Phaeophyceae) are multicellular inhabitants of the sea benthos [8] (Figure 6). They contain chlorophyll covered with a brown pigment, fucoxanthin. They are most abundantly developed in temperate and cold oceans, where some reach enormous dimensions, such as the Antarctic species called algae (Macrocystis pyrifera), whose stems are up to 60 m long.

Figure 6. Brown algae (Phaeophyceae)
Source: https://www.thoughtco.com/brown-algae-phaeophyta-2291972, Accessed: July 9, 2023.

Red algae is a type of algae that is identified by its unique pigment colors (Figure 7). They are red, blue and purple, and that pigment is called phycoerythrin. Many animals eat red algae as food, and it is used in different cultures as food for humans. This oceanic plant is able to survive in the deeper parts of the ocean because of its pigment structure. It is one of the oldest groups of eukaryotic algae. They are mostly attached to the rocky substrate, but also to shells very rarely as epiphytes attached to other algae [12]. Red algae or Rhodophyta (ancient Greek: ῥόδον – rhodon = rose and φυτόν – phyton = plant) are one of the oldest groups of eukaryotic algae. Rhodophyta also comprises one of the largest phyla of algae, containing over 7,000 currently recognized species with ongoing taxonomic revisions. The majority of species (6,793) are in the Florideophyceae (class), and are mostly composed of multicellular seaweeds, including many notable seaweeds.

Figure 7. Red algae
Source: https://www.formulatorsampleshop.eu/shop-product-ajax-page.php?id=294, Accessed: July 9, 2023.

Green seaweeds or Chlorophyta are characterized by chlorophyll a and b which give them their color [13]. They also have carotenoids and xanthophylls that protect their cells from sunlight (Figure 8). There are more than 7,000 known species of green algae, of which 800 are marine species. The rest are terrestrial and freshwater algae.

Figure 8. Green seaweed
Source: http://ourmarinespecies.com/wpcontent/uploads/2018/03/greenseaweed-16.png, Accessed: July 9, 2023.

Only 10% of all green algae (Chlorophyceae) live in the sea, and the rest are freshwater species. They are widespread in shallow coastal areas. They contain the same plant colors as several plants (chlorophyll a and b and carotenoids). Sea lettuce (Ulva lactuca) is well-known, and its stalk can be up to 30 cm long.

Kelp is an algae found in the shallow parts of the ocean (Figure 9). This plant tends to grow in groups, which creates kelp forests. The kelp forest serves as a source of food and protection from predators. Due to the density of the forest, fish, birds and other animals hide in the sea grasses of the forest where they escape from the enemy that is lurking for them. They usually grow in cold waters. Kelp is a type of large, brown algae that grows in shallow, nutrient-rich salt water near coastal fronts around the world. It's slightly different in color, taste, and nutrient profile than the kind you might see in sushi rolls.

Figure 9. Kelp
Source: https://theconversation.com/moveover-corn-and-soybeans-the-nextbiofuel-source-could-be-giant-sea-kelp-156728
Accessed: July 9, 2023.

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About 50 species of higher plants, monocotyledons, became secondary inhabitants of the sea. In these plants, the root, stem and leaf can be distinguished. Sea grass is a species that grows in shallow waters (Figure 10). It got its name because of the similarity of the long blades of grass in the shape of an eel [14]. Sea grass is a popular hiding place for crabs and other marine bottom dwellers in need of shelter. They are also used as a food source.

Figure 10. Seaweed
Source: https://ocean.si.edu/ocean-life/plantsalgae/seagrass-and-seagrass-beds, Accessed: July 9, 2023.

Mangroves grow in tropical areas above the surface of the sea, have aerial roots, and form real forests. They are also known for their viviparousness, when the seed develops on the parent plant, then separates and becomes an independent individual. Sea grasses grow in large 'meadows' below the surface of the sea, up to a maximum depth of 45 m. These species from the Potamogetonaceae family play an important role in retaining sediments on the seabed, which are normally blown away by surface sea currents.

Biodiversity of marine fauna, measured through several systematic groups, is greater than fauna on land [15] (Figures 11, 12, 13). Almost two-thirds of all types of single-celled protozoa (Protozoa) live in the sea. They are unicellular eukaryotes, and feed heterotrophically. Species from the chalk order (Foraminifera) have a calcium carbonate skeleton. They mostly live on the seabed, while the skeleton of plankton species is an important part of the sea sediment. The skeleton of the ray order (Radiolaria), built of silicon, covers large areas of the ocean floor as siliceous sediment. From the class of ciliates (Ciliata), the group Tintinnida is significant, which makes up a large part of the sea plan. Multicellular animals (Metazoa) in the sea are numerous. Sponges (Porifera) live attached to the substrate, are simple body structures, and their food is filtered by sea water. The most famous are the sponges of the genus Spongia, which are used for commercial purposes. Fireflies (Cnidaria) got their name from the glow cells found in their tentacles for catching prey. They are divided into fringes (Hydrozoa), lobed (Scyphozoa) and corals (Anthozoa). The most famous are corals, which are divided into gorgonians, moruzgva and stony corals, known builders of coral reefs. Ribs (Ctenophora) are offshore marine animals. Non-articulated, lower worm-like flatworms (Platyhelminthes) are only partially sea-dwellers. Vrpcari (Nemertina) are mostly marine inhabitants. Annelids (Annelida) live mainly in the sea. The most important class is Polychaeta, which includes almost 60% of all marine annelids, and they are found as sedentary, mobile and planktonic species. About 100,000 species of molluscs (Mollusca) live in the sea, and ten species of the class Monoplacophora live in the great depths of the ocean. From the class Polyplacophora, the most famous orders are Ischnochitonina and Acanthochitonina, which are found in tropical and moderately warm seas. Scaphopods (Scaphopoda) have a club-like house and live, mostly, buried in sand. Among marine molluscs, sponges (Gastropoda) are the most numerous. They are adapted to live at all depths, and some, planktonic Pteropoda, actively swim. Shellfish (Bivalvia) filter seawater. They live on hard and soft substrates or buried in sand. Some species, such as those of the genus Pecten, can swim actively by ejecting a stream of water. Species of the Teredo genus bore into wood and cause damage to wooden ships and structures in the sea. Cephalopoda, the most advanced class of molluscs, swim freely and are active predators. The most famous are cuttlefish (Sepia), squid (Loligo), octopus (Octopus) and sailfish. Arthropoda are the largest group in the animal world. In the sea, they are represented by crustaceans (Crustacea), which are divided into higher and lower. Branchiopods (Branchiopoda) have a primitive structure, the type of brine shrimp (Artemia salina) lives in salt pools by the sea. Shellfish (Ostracoda) live, mostly, along the seabed. Copepoda are the largest group among lower crustaceans. These mostly planktonic shrimps are important as a link between the plant plankton they feed on and higher groups in the food chain. Cirripedia (Cirripedia) as adults are sedentary or invasive. Among several crustaceans (Malacostraca) belongs the most famous red decapods (Decapoda), with species such as lobsters, pants or shrimps. Hunters (Lophophorata) are all sedentary and mostly marine species. Horseshoe crabs (Phoronida) live in the shallow coastal area on the sand. Brachiopoda (Brachiopoda) have shells like bivalves, while cooperative bryozoa (Bryozoa) are the most numerous of all hunters. Echinoderms (Echinodermata) with 6000 species are exclusively marine animals. They are divided into snakes (Holothuroidea), urchins (Echinoidea), stars (Asteroidea) and snakes (Ophiuroidea). Pogonophora are worm-shaped, bilaterally symmetrical animals that live mostly at great depths. Chaetognatha are planktonic animals with an arrow-shaped shape. The most common is the group of archers (Sagittoidea), ranging in size from a few millimeters to tens of centimeters. The tunicates (Urochordata or Tunicata) can be colonial or solitary, and sedentary or planktonic. Thus, molluscs (Ascidiacea) are sedentary animals, while barnacles (Thaliacea) are planktonic. Appendicularia are small planktonic animals that swim with the movements of their long tails. Acrania are marine animals to which the well-known spearfish (Branchiostoma lanceolatum) belongs. Many species of vertebrates are marine inhabitants. Roundmouths (Cyclostomata) are partly marine species, as well as bony fish (Osteichthyes). Cartilaginous fish (Chondrichthyes) – sharks, rays and sea rats – are all marine. Reptiles (Reptilia) in the sea are represented by turtles, snakes, crocodiles and one type of lizard, the sea iguana (Amblyrhynchus cristatus). Seabirds (Aves) are represented by a large number of species. They live along the shores of seas, oceans and on oceanic islands, where they nest and feed exclusively or predominantly from the sea. Some are excellent flyers or divers. There are: albatrosses, swifts, cormorants, petrels, terns, seagulls, sea swallows, minks, pelicans, penguins, terns, sailors, crows, terns, terns and terns. Marine mammals (Mammalia) include whales and dolphins (Cetacea), pinnipeds (Pinnipedia) and manatees (Sirenia).

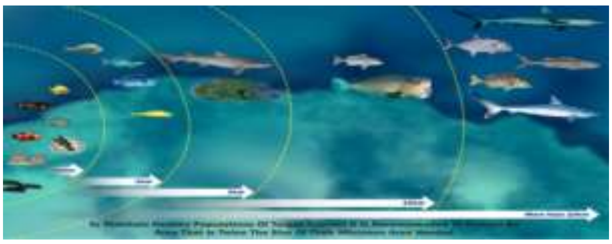

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Figure 11. Different species have smaller or larger 'homes' and therefore need marine reserves of appropriate size
Source: https://www.semanticscholar.org/paper/GUIDELINES-FOR-CREATINGEFFECTIVE-MARINE-RESERVES-%3A-Castagnino-Diaz/4ce0513f027cadd392928690763677906d1f8145/figure/2, Accessed: July 9, 2023.

Figure 12. Flocks of sea fish
Source: https://www.istockphoto.com/search/2/image?phrase=school+of+fish, Accessed: July 9, 2023.

Corals are marine invertebrates within the class Anthozoa of the phylum Cnidaria. They usually form compact colonies of many identical individual polyps. Coral species include important reef builders that inhabit tropical oceans and secrete calcium carbonate to form a hard skeleton. A coral 'group' - a colony is countless genetically identical polyps. Each polyp is a sac-like animal typically only a few millimeters in diameter and a few centimeters in height. A cluster of tentacles surrounds the central mouth opening. Each polyp secretes an exoskeleton near the base. During many generations, the colony thus creates a skeleton characteristic of the species, the size of which can be up to several meters. Individual colonies grow by asexual reproduction of polyps. Corals also reproduce sexually by spawning: polyps of the same species release gametes simultaneously overnight, often around a full moon. Corals support some of the most diverse marine wildlife on the planet, and unfortunately rising sea temperatures, driven by climate change, are threatening coral reefs worldwide through a phenomenon known as 'coral bleaching' [16]. Characterized by color bleaching, coral bleaching starves coral reefs of their dominant food source, algae. In some cases, corals can recover from bleaching, but recent research has shown that increased frequency of bleaching does not give them the chance to do so (Figure 13). As temperatures rise, mass coral bleaching has become more frequent, and the period between events has decreased fivefold since the 1980s.

Figure 13. Corals
Source: https://www.azocleantech.com/article.aspx?ArticleID=793, Accessed: July 9, 2023

2.2. Social environment

"A social environment (society) is a group of individuals involved in more or less permanent social interaction or a large social group sharing the same geographic or social territory, usually subject to the same political authorities and dominant cultural expectations. Societies are characterized by patterns of relationships (social relations) among individuals who share a distinctive culture and institutions. A given society can be described as the sum of such relationships between its constituent members. In the social sciences, the larger society often exhibits patterns of stratification or dominance in subgroups. Societies construct patterns of behavior by considering certain actions or speech as acceptable or unacceptable. These patterns of behavior in a certain society are known as social norms" [3]. It has already been said that the ocean (also sea or world ocean) covers approximately 71% of the Earth's surface and contains 97% of the Earth's water. The world ocean simultaneously separates and unites individual landmasses (continents) where great world civilizations have been created and developed throughout history. The military-political expansion of these civilizations took place mainly by land, but also by sea. Their spread by sea required the construction of specific vessels (various types of ships), the design of which involved immense knowledge and inventiveness. It was the water obstacles (rivers, lakes, sea straits, open sea) that were the generator for the development of science, technology and specific types of construction, which over time turned the water 'obstacles' into 'links'.

Each society is determined by several essential features:

1. Socio-economic relations,
2. Forms of consciousness (philosophy, religion, science, technique and technology),
3. Unprescribed forms of behavior and values (morality, tradition...).

Socio-economic relations represent the relationship between production forces and production relations, which are in a mutually dynamic relationship. The productive forces are made up of people with their knowledge and production experience and their means of work. The importance of productive forces is great because they drive the development of society. In addition, they also express the productive capacity of society. Whether a society will live in poverty or material well-being depends on the development of the productive forces. Production relations are relations between people in the process of social production. Production relations have several important levels of meaning:

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1. Property relations,
2. Relations between direct producers,
3. Production relations in the management process,
4. Relations between economic subjects i
5. Relationships in the distribution of production results.

Property relations significantly affect all other production relations. In one form of production relationship is dominated by private property, while in some other form state, social, cooperative or collective property may dominate in some other form. Relations between direct producers are a condition and an expression of their joint work in the production process. Production relations in the management process occur between direct producers and managers within a specific production unit. Relations between private entities occur between different economic entities, that is, between companies and individuals who opt for a certain type of production. The relations in the distribution of production results are determined by all the mentioned and some other similar relations. The central question of economic practice and theory is: 'For whom to produce and how to distribute the produced?' Modern society is characterized by the following features:

- Scientific and technological revolution,
- Connecting humanity, which is a consequence of the rapid development of science and technology, primarily electronic and computer,
- Reducing the difference between people, as a direct result of connecting humanity,
- Mass culture, created as a result of connecting humanity,
- Kitsch (anti-value, 'art junk'). According to Abraham Moles (1920-1992), there are five principles for the identification and classification of kitsch: the principle of inadequacy, the principle of accumulation, the principle of synesthesia, the principle of mediocrity, the principle of comfort,
- Environmental problems of modern society arise due to the rapid development of industry without environmental pollution control.

The economic importance of the sea. The sea is an inexhaustible source of salt, minerals and metals, a great source of food, the cheapest way of communication between nations and one of the oldest transport routes. Maritime trade is constantly increasing [17,18]. The transport of oil dominates, followed by the transport of oil derivatives, then ore, grain, coal, wood... The largest part of maritime traffic goes to the ports of the European continent, and then to the ports of both America, Asia, Africa and Australia. The following shipping routes stand out in terms of importance and intensity of navigation: North Atlantic west-east route (North America-Western Europe); Latin American route (from the coasts of Central and South America to Western Europe); maritime Atlantic route, from the coasts of Western Europe to the coasts of West Africa (Gulf of Guinea); American-West African route; South African route; American-Asian; American-Australian; Asian-Australian; maritime routes of marginal and Mediterranean seas; arctic route. Passages and sea channels are a special type of route: the English Channel or the English Channel, the Bosphorus and the Dardanelles, and Gibraltar. The dug sea canals, which shortened the long journeys around Africa and South America, are of great importance in world traffic: the Suez Canal and the Panama Canal. Sea routes in enclosed seas are also of great importance: the Caspian Lake, the Great Lakes, etc. The growth of world trade also conditioned the growth of the world's merchant navy. Maritime traffic is divided into coastal navigation and long-haul or oceanic navigation (liner, tramper or free navigation) based on the types of navigation. In contrast to goods traffic, passenger traffic is decreasing due to the increasing importance of air traffic. Today, the largest number of passengers are tourists - most often passengers on large cruises [8].

The sea as a source of food. One of the most important treasures of the sea is fish. They are a tenth of the world's total protein reserve. The fish stock is constantly replenished, so it also gives a high yield in case of large exploitation. Of the average catch of marine organisms, 80% is fish. Most fish are caught in the Pacific Ocean, followed by the Atlantic and Indian Oceans. The total fish catch in all seas is 130.4 million tons (2000). China (43.1 million), followed by Peru (10.7 million), Japan (5.7 million), India (5.7 million), USA (5.2 million), Indonesia (4.9 million) is in first place in terms of fish catch.), Chile (4.7 million), Russia (4.0 million), Thailand (3.6 million), Norway (3.2 million), Philippines (2.3 million), South Korea (2.1 million), Iceland (2.0 million), Vietnam (2.0 million) [8]...

The sea as a source of energy. Sea waves have enormous potential energy. Sea currents (tides) also provide sea water with great potential energy (in Brittany, France, the first power plant was built to exploit the energy of sea currents, November 1966). There are possibilities of exploiting the difference in the temperature of surface and deep water, from which a lot of energy could be obtained. Oil and natural gas found in the sea already have great economic importance today. Of the world's oil and gas reserves determined in 2003, about 20% of oil and natural gas was located under the seabed. Most of the oil is found along the coasts of the Middle East, and natural gas along the coasts of the Middle East and Europe. The richest oil and gas deposits are located in relatively shallow sea basins, which are accessible in terms of economic and technological possibilities. Oil is extracted from the seabed in the Gulf of Mexico, the Caribbean Sea, the Mediterranean Sea, the Black Sea, the Red Sea, the North Sea... It is predicted that oil exploitation technology will enable the extraction of oil from greater sea depths. As the depth increases, the costs of exploitation increase, and thus the price of oil. More than 80 countries are currently exploring for oil and natural gas in the sea, 40 of which are already producing oil and natural gas. Of the other mineral resources found in the seabed, the most valuable is manganese, which is widely exploited today. Manganese nodules also contain considerable amounts of copper, nickel, cobalt and molybdenum. Several hundreds of deposits have already been opened today. Among other substances that can be exploited from the sea are calcium carbonate, tin, magnesite, gold, platinum, diamonds, titanium, salts[8]...

Awareness of the fundamental importance of the World Ocean for life on Earth as a whole, on the one hand, and the threat of the World Ocean by the (irresponsible) actions of people-individuals, states and societies around the world, on the other hand, initiated the organization of the International Exposition Yeosu Korea 2012 (EXPO Yeosu 2012, May 12-August 12, 2012) [17] with the central theme:

- The Living Ocean and Coast. The accompanying themes of the exhibition were:
- Preservation and Sustainable Development of the Ocean and Coast, and:
- New Resources Technology,

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- Creative Marine Activities (Figure 14).

Figure 14. International Exposition Yeosu Korea 2012 (Central Street)

Source: Hadrovic, A. (2015). Great world exhibitions: architecture as a forerunner of the future, Sarajevo, Avicenna

2.2.1. Great sailors in history

History is full of personalities who, for various reasons (scientific-research expeditions, naval battles, adventures, piracy...) made a great contribution to familiarizing the public with the sea and thereby made a huge contribution to the development of humanity in every respect. In addition to sailors-historical figures, there are many fictional characters who entered the general perception of the sea (especially children). We give an overview of the most famous sailors in history. Christopher Columbus (1451-1506) was an Italian explorer and navigator. He completed four voyages across the Atlantic Ocean, paving the way for European exploration and colonization of the Americas. These expeditions were the first European contact with the Caribbean, Central and South America. Although he is known as the man who discovered America, Columbus always claimed that the countries he visited were part of the Asian continent. This refusal is one of the reasons why the American continent was named after the Florentine explorer Amerigo Vespucci, instead of Columbus.

Ferdinand Magellan (c. 1480-1521) was a Portuguese explorer who organized a Spanish expedition to the East Indies from 1519 to 1522, which resulted in the first circumnavigation of the Earth. This destroyed the belief that the Earth is a flat plate. Studying astronomy and cartography, the legendary explorer commanded the first expedition across the Atlantic Ocean to the Strait of Magellan and across the Pacific Ocean. Sam was unable to complete the first round trip as he was killed in a local dispute in the Philippines. However, the work was completed by Juan Sebastián Elcano (1486-1526) after his death [19].

Sir Francis Drake (c. 1540-1596) was an English explorer, sea captain, privateer, naval officer and politician. He is famous for his circumnavigation of the world in one expedition, from 1577 to 1580. This voyage made him the first English captain to circumnavigate the globe. During his voyage, Drake claimed a section of California, which at the time was still unexplored, for Queen Elizabeth I. Upon his return, the delighted Queen awarded him a knighthood in 1581. He is also known for his heroic role in the battle against the Spanish Armada in 1588.

Sir Henry Morgan (ca. 1635-1688) was a famous Welsh buccaneer (pirate), known for plundering Spanish Caribbean colonies at the end of the 17th century. The government hired him to protect British colonial interests in the Caribbean at all costs. For a total of 20 years, he attacked more than 400 ships - most of them Spanish - and caused chaos in the cities. He was accused of widespread torture and horrific acts. His greatest achievement was when he captured Panama City with more than 30 ships and about 2,000 men. Although he was arrested in 1672 as a result of his raid in Panama City, King Charles II (1630-1685) knighted him and appointed him deputy governor of Jamaica. With three plantations and 129 slaves, Morgan lived here until his death.

William Kidd (c. 1655-1701) was a Scottish sailor who was asked by King William III of England (1650-1702) to become the captain of a powerful ship and capture French ships as well as pirates from Madagascar. However, he soon turned into a pirate himself when he recruited a gang of bandits and set sail for Madagascar. In 1968, he made his biggest haul by taking the Quedagh Merchant, an Indian ship of 500 tons loaded with gold, silver, satin, muslin and various East Indian goods. Kidd was tried and executed for piracy after returning from a voyage to the Indian Ocean.

Commonly known as Calico Jack, John Rackham (1682-1720) was an English pirate captain who operated in the Bahamas and Cuba in the early 18th century. His nickname comes from the white clothes he wore. Two things that made Calico Jack very famous were that he designed the famous pirate flag (the Jolly Roger flag, which is a skull with two crossed swords) and that he had two female pirates (Mary Read and Anne Bonny) as his crew.

If there is one personality whose image has been distorted by time and popular culture, it is definitely Blackbeard (Edward Teach, 1680-1718). He was one of the (if not the most infamous) pirates to ever roam the high seas. However, contrary to how he is portrayed today, he allegedly never used violence in his relationships with his victims. Apparently, he would use his intimidating image (he had a long black beard and reportedly tied lit fuses under his hat) to strike fear into the hearts of those he was robbing. It was an effective way for people to remember you for the rest of history. Edward Teach (c. 1680-1718), better known as Blackbeard, was one of the most feared and possibly cruelest pirates of all time. He was known for fighting with two swords, several knives and guns at the ready, as well as a fearsome image with a thick, black beard that gave him his nickname. The Englishman became the captain of one of the ships he stole and began plundering ships traveling the American coast. In 1717, Blackbeard captured the colossal ship La Concorde, weighing 200 tons. He installed 40 guns on her, made her his flagship and renamed her Queen Anne's Revenge. With this boat, he ruled the waves of the east coast of North America and the Caribbean. He also defeated the famous warship HMS „Scarborough“ and its pirate army of 300 men in a naval battle. Blackbeard died in a battle with the British navy. Legend has it that he sustained 20 stab wounds and five gunshot wounds before finally succumbing.

Bartholomew Roberts (1682-1722) was a Welsh pirate who raided ships off America and West Africa between 1719 and 1722. He was the most successful pirate of the Golden Age of Piracy as measured by vessels captured. He captured and plundered over 400 ships. Although he never used this name while he was alive, he is also known as Black Bart. His biggest flagship was a ship with an arsenal of 40 guns and 157 men. The ship could fight any ship of the British Royal Navy at that time. Bartholomew Roberts is probably the inspiration for the character of Lord Bartholomew in the Pirates of the Caribbean series.

Captain James Cook (1728-1779) was a British explorer, navigator, cartographer and captain in the British Royal Navy, whose legacy of geographical and scientific knowledge influenced many scientists in the 20th century. He made the first recorded European

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contact with the east coast of Australia and the Hawaiian Islands, and the first recorded tour of New Zealand. The mapping of the Pacific, Australia and New Zealand, thanks to him, changed the Western perception of world geography. Before his three famous voyages across the Pacific and Australia, he also made detailed maps of Newfoundland. Cook was attacked and eventually killed by natives in the Hawaiian Islands, while attempting to kidnap a Hawaiian chief to recover a cutter stolen from one of his ships.

Admiral Horatio Nelson (1758-1805) was a British flag officer in the Royal Navy. He joined the navy at the age of 12 and became a captain at the age of 20. He was a spectacular leader and strategist. His unconventional tactics led to a number of decisive British naval victories, particularly during the Napoleonic Wars. Admiral Nelson was wounded in battle, losing the sight of one eye in Corsica at the age of 35, and most of an arm in an unsuccessful attempt to conquer Santa Cruz de Tenerife when he was 38. He was mortally wounded on the first day of the Battle of Trafalgar in 1805, which then became one of his greatest victories.

It is not so well known that Charles Robert Darwin (1809-1882) was a sailor as well as the guy who came up with the theory of evolution. But his five-year voyage on the HMS Beagle is legendary. Here he collected wild animals and fossils during his travels, and his findings made him a famous and popular scientist.
Jacques-Yves Cousteau (1910-1997) was, among other things, a naval officer, researcher, conservationist and scientist. He also co-developed the Aqua-Lung and was a pioneer in marine conservation. The man's dedication to the ocean and the vast amount of information he provided about it make him a maritime legend.

Jessica Watson (born 1993), when she was just 17, made headlines around the world for being the youngest person to sail around the world unaided (eventually earning her an Order of Australia Medal).

2.2.2. Exploring the underwater world

Oceans cover 71% of the Earth, but less than 5% of their depths have been explored to date. Although little progress seems to have been made, many new discoveries and inventions have been created just to see what lies beneath. Curiosity to see the bottom of the ocean led man to build ships to cross the water, develop sound technology, build submarines, and develop diving equipment to see for themselves the mysteries of the dark depths [20]. It was believed that life could not exist deep in the ocean. 200 meters below, the light scatters and fades. At 4,000 meters, the temperature drops almost to freezing, and the pressure rises to a level unbearable for humans. No light means no plant life, which ultimately implies no animal life. In 1868, the Scottish naturalist Sir Charles Wyville Thomson (1830-1882) convinced the Royal Society to support a deep exploration project in the North Atlantic. Thomson used a tool called a marine biology dredge, a net with a digging apparatus used to scrape the ocean floor and capture life forms. The original dredger, developed by Otto Friedrich Muller in 1830, had no locking mechanism, so samples often fell out, fueling the belief that there was no life on or in the ocean floor. Aboard HMS Lightning, Thomson modified the dredger so that it could be closed; this adaptation allowed him to collect many sponges, crustaceans, molluscs and other organisms 300 meters deep in the ocean. This discovery increased support for deep-sea exploration, and in 1872 HMS Challenger was sent to begin a three-and-a-half-year oceanographic expedition with Thomson leading the charge. Excavators were lowered to ever deeper levels, and by the end of the voyage in 1876, 4,417 new species of marine organisms had been discovered, and hundreds of samples of the ocean floor and seawater had been taken. Thomson died before all the results were compiled. Sir John Murray (1841-1914), another Scottish oceanographer, ended up in his place, publishing 50 volumes of Challenger's results and discoveries. In the eighth century, Vikings measured the depth of the sea by lowering lead weights attached to ropes from a ship and recording how far the rope was underwater when the weight reached the bottom. In 1872, Sir William Thomson (1824-1907) replaced the rope with a thinner piano wire and invented the Thomson sound machine. The machine still used a lead sinker, but the wire was freed by a tension wheel and brake, and a dial registered how much wire was used. Thomson's sounding machine enabled more precise measurements of ocean depth and was used for many other expeditions. From 1873 to 1874, George Eugene Belknap (1832-1903), a rear admiral in the U.S. Navy, aboard the U.S.S. Tuscarora, used Thomson's sounding machine on a telegraph cable to explore the Pacific Ocean. During this time he discovered the Juan de Fuca Ridge, the Aleutian Trench and the Japan Trench. Charles Dwight Sigsbee (1845-1923), rear admiral in the US Navy, in 1874 enlarged the Thomson sound machine and replaced the piano wire with steel. This new machine was called the Signsbee sounding machine and became the basic wireline surveying model for the next 50 years. After the sinking of the Titanic in 1912, an attempt was made to create an acoustic mechanism for detecting objects in the water. In 1914, Reginald Aubrey Fessenden (1866-1932) developed the Fessenden oscillator to use a technique called echo ranging, in which sound and its echoes from objects are used to determine distances in the air. The Fessenden Oscillator was a powerful underwater speaker that produced and detected sounds. With his new invention, Fessenden conducted echo range tests and managed to detect an iceberg 130 meters high, 137 meters long, 3.20 km away. During World War I, researchers further developed the Fessenden oscillator to detect underwater submarines. This improvement paved the way for the current Sound Navigation and Ranging (SONAR) system. Scientists today use two types of sonar: active and passive. Active sonar transducers emit a sound signal into the water. The sound then bounces off any object in its path and returns an 'echo' to the transducer, which then measures the strength of the signal. It can also calculate the range of an object by determining the time between the sound being emitted and the echo being received. Passive sonar systems are used to detect the noise of marine objects or animals; they detect the sound waves coming at them, but do not emit any sound. After figuring out how to map the ocean floor, scientists wanted to see the bottom for themselves. To achieve this feat, the Dutchman Cornelis Jacobszoon Drebbel (1572-1633) built the first submarine in 1623. His early machine consisted of an oiled leather outer hull over a wooden frame. Oars extending from the sides and sealed with tight-fitting leather covers provided propulsion. This early ship traveled to a depth of 3.7 to 4.6 meters. Since then, more and more improvements have been made in the design. In 1800, Robert Fulton (1765-1815) built a submarine named Nautilus with the support of Napoleon Bonaparte (1769-1821). The hull consisted of copper sheets over iron ribs; the most innovative parts of the vessel were the ballast tanks. The Nautilus would sink taking water into its ballast tanks and releasing water to rise. A horizontal rudder has been added for easier steering. The submarine contained enough air to keep four men alive and two candles that burned for three hours. During World

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War I, diesel engines were added to submarine designs for surface propulsion. Underwater, large batteries powered the electric motors that drove the submarines at a high speed of 15 knots (28 km/h) for two hours. In 1954, the USS Nautilus was commissioned as one of the first nuclear-powered submarines, a vast improvement over diesel and electric engines. Boarding a submarine for days required little uranium, and the engines were also much quieter. Basically, the heat from the uranium would boil water or metal to produce steam and spin turbines to propel the submarine forward. The innovation of submarines allowed man to travel deeper into the ocean without being affected by low temperatures and high pressure (inside the submarine). However, to get up close and personal, man had to figure out how to swim underwater for a long time. People have been swimming underwater for years using long reeds as breathing tubes. The concept of supplying oxygen from the surface to the diver inspired the original designs of underwater diving. In 1690, Edmund Halley (1656-1742) patented a diving bell (chamber) that was connected by tubes to weighted air barrels that supplied the diver with oxygen. Later, in 1788, John Smeaton (1724-1792) added a hand-operated pump for efficient oxygen supply and a check valve to prevent air from returning to the hose when pumping stopped. A fully functional suit, it was created in 1823 when Charles Anthony Deane (1796-1848) patented the smoke helmet. The helmet was originally intended for firefighters, but was later repurposed for divers. The helmet was weighted and connected to the oxygen hose, but the helmet itself was not connected to the suit and was only secured by straps. Therefore, the diver could not bend over because of the danger of drowning. Even so, the suit successfully salvaged cannons from the sinking Royal George in 1834-1835. For the next several decades, scientists worked to create a working oxygen tank that a diver could wear in the water. Frenchmen Benoit Rouquarol (1826-1875), a mining engineer, and Auguste Denayrouse (1837-1883), a naval lieutenant, developed and patented an underwater breathing apparatus in 1865. The tank was horizontal and made of steel and contained air at a pressure of 250-350 pounds per square inch (psi), or 1723.68932-2413.16505 kPa at the diver's back. A valve and mouth piece connected the diver to the tank. Known as "Aerofor", the device delivered air only when the diver inhaled thanks to a membrane that was sensitive to external water pressure. A hose supplying oxygen from the tank anchored the tank to the surface, but the diver was able to disconnect the tether and dive with only the tank for a few minutes. In 1933, French Navy Captain Yves Le Prieur (1885-1963) modified the Rouquayrol-Denayrouse invention by increasing the tank pressure to 1500 psi (10342.14 kPa). This increase allowed the diver complete freedom from moorings; in order to breathe, the diver had to open the tap, and air would enter. However, the continuous airflow actually made breathing difficult, limiting dives to short bursts. So in 1942, another French naval officer, Jacques-Yves Cousteau (1910-1997) and Emile Gagnan (1900-1984), an engineer for a Paris natural gas company, redesigned the car's regulator to provide compressed air to the diver only when he took a breath, and patented this design as an aqua-lung. The regulator revolutionized diving, as it allowed the diver to control breathing while carrying large oxygen tanks and ultimately extended the duration of the dive. A new era of ocean exploration began now that humans could travel to the deep dark depths of the sea to discover the mysteries hidden beneath. Armed with new equipment and technology, people managed to enter the depths. It was previously believed that life could not exist in the deep sea due to the lack of light, low temperatures and high atmospheric pressure. However, the discovery of thermal vents in 1977 changed that theory. These vents, which are connected to magma beneath the Earth's crust, provide light, heat and sulfur. Organisms like green bacteria thrive around these openings and actually feed on the sulfur. These microorganisms act as the bottom of the food chain; larger organisms, such as giant tube worms, feed on these bacteria and therefore must stay close to the vents. Many creatures on the sea floor are also bioluminescent, meaning they produce their own light. One such popular creature is the deep-sea kingfisher, which has a long dorsal stalk that contains a light-producing organ called a photophore. The deep sea fish waves this appendage back and forth to attract prey, which the fish devour with their rows of large teeth. Another popular creature in the deep sea is the giant squid, which can grow up to 18 meters. Not much is known about this large animal, because most scientists only come across their carcasses. Japanese researchers obtained a photo of a live giant squid in September 2004, and the same team recorded a live video in 2006. The development of sounding equipment and sonar not only allows scientists to map the ocean floor, but also enables the detection of objects in the water. This technology allows submarines to navigate dark deep waters. In turn, the submarines themselves not only provide transport and visualization of the deep sea, but are also a tactical tool. New and improved diving equipment allows people to experience for themselves the beautiful corals in the ocean and discover the mysteries of sunken ships that are seemingly lost to history. Only five percent of the ocean has been explored so far. As time goes on, technology will only improve and (perhaps) eventually 100% of the ocean will be explored [21].

2.2.3. Jacques Cousteau's underwater explorations

The French researcher Jacques-Yves Cousteau (1910-1997) made a particularly great contribution to the research of the underwater world and its presentation to the general public through books and films. Cousteau was a French naval officer, explorer, conservationist, filmmaker, innovator, scientist, photographer, author and researcher who studied the sea and all forms of aquatic life [22]. He collaborated with Aqua-Lung, was a pioneer in marine conservation and a member of the Académie Française. Cousteau described his explorations of the underwater world in a series of books, of which perhaps the most successful is his first book, The Silent World: A Story of Undersea Discovery and Adventure, published in 1953. Cousteau also directed films, most notably the documentary adaptation of the book, The Silent World, which won the Palme d'Or at the Cannes Film Festival in 1956. He remained the only person to win the Palme d'Or for a documentary film, until Michael Moore won in 2004 for Fahrenheit 9/11.

2.2.4. Legislation related to the World Sea

As the World Ocean concerns life on Earth as a whole, it has become the subject of attention of the umbrella world institution (United Nations, UN), but also of numerous organizations at the level of the Earth as a whole [23]. Maritime law is a set of customs and international treaties by which governments maintain order, productivity and peaceful relations at sea. In the development of maritime law, numerous international treaties signed in the second half of the 20th century were highlighted. The United Nations (UN) held its first Conference on the Law of the Sea (UNCLOS I) in 1956, which resulted in the 1958 Convention (Sea Convention,

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LOSC). The final conference, held in Montego Bay, Jamaica, in 1982, resulted in the 1982 Law of the Sea Convention (LOSC). The LOSC entered into force in 1994 when it received the required number of UN signatories. The National Oceanic and Atmospheric Administration (NOAA) is responsible for showing the boundaries on its nautical charts of the territorial sea limits of 12 nautical miles, the contiguous zone of 24 nautical miles and the 200 Exclusive Economic Zone (EEZ). Each of these marine zones is projected from what is called a 'normal baseline' and is derived from NOAA marine charts. 'Normal baseline' is defined under the Law of the Sea as the low water line along the coast as marked on officially recognized large-scale charts or the lowest charted datum, which is the mean value of lower low water (MLLW). in the USA. The method of arriving at this basis is described in the Convention from 1958 and in the Convention from 1982. The location of maritime zones and borders can have potentially far-reaching effects. Because of this, NOAA works with other federal agencies, particularly the US Department of State, to periodically update US maritime zones and boundaries as shown on NOAA navigational charts. The oceans have long been subject to the doctrine of the freedom of the seas - a principle put forth in the 17th century, which essentially limited national rights and jurisdiction over the oceans to a narrow strip of sea surrounding a national coastline. The rest of the sea was declared free for all and belonged to no one. Although this situation persisted into the twentieth century, by mid-century there was an impetus to expand national claims over offshore resources. Concerns grew over the toll that long-distance fishing fleets took on inshore fish stocks and the threat of pollution and waste from transport vessels and tankers carrying dangerous goods plying sea lanes around the world. The threat of pollution has always been present to coastal resorts and all forms of ocean life. The navies of naval powers competed for global presence in surface waters and even under the sea. The United Nations Convention on the Law of the Sea (UNCLOS). The United Nations works to ensure the peaceful, cooperative, legally defined use of the seas and oceans for the common good of mankind. Urgent calls for the effectiveness of the international regime over the seabed and the ocean floor beyond clearly defined national jurisdiction initiated a process that lasted 15 years and led to the creation of the United Nations Committee on the Seabed, the signing of the Treaty on the Prohibition of Nuclear weapons on the seabed, the adoption of the General Assembly's declaration that all resources of the seabed beyond the borders of national jurisdiction are the common heritage of mankind, and the convening of the Stockholm Conference on the Human Environment (Stockholm Conference on the Human Environment, 1972) [24]. The revolutionary work of the UN on the adoption of the Convention on the Law of the Sea from 1982 (1982 Convention on the Law of the Sea) represents a decisive moment in the extension of international law to the vast, common water resources of our planet. The convention resolved several important issues related to the use of the ocean and sovereignty, such as: established rights of freedom of navigation, set the territorial limits of the sea 12 miles from the coast, set exclusive economic zones up to 200 miles from the coast, set rules for expanding the rights of continental shelf up to 350 miles offshore, the International Seabed Authority was established, Other conflict resolution mechanisms were created (the UN Commission on the Limits of the Continental Shelf).

Protection of the marine environment and biological diversity. The United Nations Environment Programme, UNEP), particularly through its Regional Sea Programme, works to protect the oceans and seas and promotes the sustainable use of marine resources. Conventions and action plans on regional seas are the world's only legal framework for the protection of oceans and seas at the regional level. UNEP has also produced Governing the Global Program of Action [25] to protect the marine environment from land-based activities. It is the only global intergovernmental mechanism that directly addresses the connection between terrestrial, freshwater, coastal and marine ecosystems. The United Nations Educational, Scientific and Cultural Organization (UNESCO), through its Intergovernmental Oceanographic Commission, coordinates programs in marine research, observation systems, hazard mitigation and better management of ocean and coastal areas. The International Maritime Organization (IMO) is the key institution of the United Nations for the development of international maritime law. Its main task is to create a fair and efficient, generally accepted and implemented legal framework for the maritime industry. Maritime transport and pollution. In order to ensure that maritime traffic is cleaner and greener, the IMO has adopted regulations to address the emission of air pollutants from ships and has adopted binding energy efficiency measures to reduce greenhouse gas emissions in international shipping. These include the landmark International Convention for the Prevention of Pollution from Ships (MARPOL) of 1973 [26], as amended by the 1978 Protocol (MARPOL) and The International Convention for the Prevention of Pollution of the Sea by Oil (OILPOL) of 1954.

Polar code. In 2017, the International Code for Ships Operating in Polar Waters (Polar Code) came into force. The Polar Code covers the full range of design, construction, equipment, operations, training, search and rescue and environmental protection relevant to ships operating in the inhospitable waters surrounding the two poles. It was an important regulatory development in the field of transport and trade facilitation, alongside a number of regulatory developments relating to maritime and supply chain security and environmental issues. In recent years, there has been an increase in piracy off the coast of Somalia and in the Gulf of Guinea. Pirate attacks pose a danger to the well-being of seafarers and the safety of navigation and commerce. These crimes can result in loss of life, bodily injury or hostage taking of seafarers, significant disruption to trade and navigation, financial losses to ship owners, increased insurance premiums and security costs, increased costs for consumers and producers, and damage to the marine environment. Piracy attacks can have widespread consequences, including preventing humanitarian aid and increasing the cost of future deliveries to affected areas. The IMO and the UN have passed additional resolutions supplementing the rules of the Convention on the Law of the Sea to combat piracy. The United Nations Office on Drugs and Crime (UNODC) through its Global Maritime Crime Program (GMCP) fights transnational organized crime in Africa by focusing on combating piracy in the Horn of Africa and the Gulf of Guinea (Figure 15). The program has supported states in the region by conducting trials and arresting piracy suspects, as well as developing maritime law enforcement capabilities through facilitating training programs. From a model of piracy prosecution, prisoner transfer and training of members of the Atlantic and Indian Ocean justice system, to mentoring of coast guards and police units in Somalia, Kenya and Ghana, the UNODC GMCP has achieved many successes in a challenging environment. This was achieved through various programs aimed at promoting maritime security and strengthening the rule of law and judicial systems in countries.

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Figure 15. MONUSCO peacekeepers land on a beach to protect themselves from piracy in the Democratic Republic of Congo
Source: UN Photo/Sylvain Liechti, Accessed: July 9, 2023

3. Man

„On the life scale of each person, the image of the 'objective world' changes, and he himself, his 'software and hardware', with which he perceives objective reality and forms his judgments about it, changes as well. It is the result of the 'natural' default of the world". This is a quote from the Author's book Man, Something or Nothing [27], which is philosophical in content, but is suitable as a pretext for this chapter of the book, the content of which is of an empirical-scientific nature.

3.1. Comfort assurance requirements

When it comes to humans, it is very important to know that there is an exact and measurable range of external influences (elements of the natural environment) that humans experience as physiologically pleasant. Outside of that (optimal) range, a person feels more or less discomfort, which sometimes rises to, for him, a deadly level. At the global level, the issue of human thermal comfort is regulated by appropriate standards. The following standards are the most relevant:

- ISO 7730:1994 Moderate Thermal environments - Determination of the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices and specification of the conditions for thermal comfort. This standard has been revised: ISO 7730: 2005,
- ASHRAE 55 (2007), including a calculation methodology based on the PMV/PPD ratio,
- CEN 15251(2005): Criteria for indoor conditions including thermal conditions, indoor air quality, lighting and noise.

The CEN standard defines minimum ventilation requirements, minimum and maximum indoor air temperatures that are included in the energy calculation. PMV (Predicted Mean Vote) index – evaluates the level of (dis)pleasure → predicts the subjective evaluation of the pleasantness of being in the environment by a group of people (determined from complex mathematical expressions according to ISO 7730). PPD (Predicted Percentage of Dissatisfied) index → predicts the percentage of dissatisfied people (determination from a simple mathematical expression, function of PMV). Knowledge of the 'defining areas of human physiological comfort' is of elementary and essential importance for architecture. The basic task of architecture, in fact, is to ensure the physiological comfort of man within the limits that he himself designs and builds. Only after fulfilling this requirement, we can continue to search for the realization of other dimensions of architecture. This elementary dimension of architecture was more or less understood throughout its entire past, but it was often neglected, at the expense of some other architectural values. It could even be said that the biggest internal conflict in architecture has always been between its elementary purpose and the architects' desire to communicate that purpose in a beautiful way. It seems that the just-mentioned conflict was at the same time the greatest internal strength of architecture, which led it towards the realization of new values. Man paid the highest price for this internal antagonism in architecture through energy costs (heating and cooling), or, as we have already seen, by endangering the natural environment in the last instance. Architecture necessarily had to turn to the principles of bioclimatic organization, and that path in the 21st century became global. Definitional areas of human physiological comfort within the boundaries of the Architecturally Defined Space have been well researched, and as given values, they have been translated into national, regional and world standards. The most important dimensions of the environment whose intensities determine human comfort can be classified into three basic areas:

1. The field of thermodynamics in architecture,
2. The area of lighting in architecture and
3. The field of architectural acoustics.

In the field of thermodynamics in architecture, the most important quantities whose intensity determines the area of human comfort are: the temperature of the outside air (t_e), the temperature of the air inside the room (t_i), including the vertical gradient of the air temperature inside the room, the temperature of the inner surfaces of the outer enclosure surfaces (υ_j) , relative humidity of the outside air (φ_e), relative humidity of the air inside the room (φ_i), air flow velocity (c_z), CO_2 concentration and odor concentration [2].

In the area of lighting in architecture, the most important quantities whose intensity (quality) determines the area of human comfort are: Spectral composition of light. Light color climate, Light color temperature (T, in K), Luminous flux (luminous flow, W/s), Luminous intensity (intensity, cd), Illuminance (lx). Evenness of illumination, Brightness (luminescence, cd/m^2). Brightness distribution. Glare limitation, Phototechnical properties of materials and surfaces: reflection (ρ), absorption (α), transparency (τ), refraction (index of refraction, n) [2].

In the area of architectural acoustics, the most important quantities whose intensity (quality) determines the area of human comfort are: intensity (W/m^2), power (W) and density of sound energy (Ws/m^3), level of sound pressure, intensity and power of sound (Db), types of sound impulse, sound resonance, sound interference, directional characteristics of a sound source, Doppler effect, phenomena that threaten sound propagation (reflection, diffraction, absorption, refraction), reverberation and flutter-echo in the room, reverberation of the room. reverberation time (s), volume of the room (m^3) and specific acoustic volume of the room (m3/person), Noise [2]. The speed of sound is the distance traveled by a sound wave per unit time during propagation through an elastic medium. At 20 °C, the speed of sound in air is about 343 meters per second. It depends a lot on the temperature, as well as on the medium through which the sound wave propagates. In colloquial speech, the speed of sound refers to the speed of sound waves in air. However, the speed of sound varies from substance to substance: usually sound travels slowest in gases, faster in liquids and fastest in solids. For example, while sound travels at a speed of 343 m/s in air, it travels at a speed of 1481 m/s in water (almost 4.3 times faster) and 5120 m/s in iron (almost 15 times faster). In an extremely rigid material, such as diamond, sound travels at 12,000

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meters per second - about 35 times the speed of air and about the fastest it can travel under normal conditions.

3.2. Aesthetic and psychological requirements

For now, all underwater architectural realizations are created as 'unusual architecture' that should attract (mostly) wealthy clientele to enjoy the environment of the underwater sea world, day and night. A stay in underwater architecture will provide a certain impression for each individual, depending on his profession, social status, general knowledge of the 'structure of the world', philosophy, religion... It is absolutely certain that it will not be long before UNDERWATER ARCHITECTURE, similar to the usual architecture on land, to be governed by standards in all its dimensions - as a physical structure, by individual functions, location...

3.3.Communicating by sound underwater

Although sound travels quickly in water[1], our vocal cords are not designed to create underwater sound. So how can humans use sound to communicate underwater? The development of the technique of communicating using sound in water was based on research into the communication of aquatic animals, especially dolphins and whales [28]. Scientists around the world have been studying dolphins for years, learning about the way they communicate with each other (Figure 16). In Hawaii, an experiment was conducted between a mother dolphin and her calf. Placed in two separate water tanks and connected by a special telephone, the two dolphins communicated clearly. This means that each dolphin has a distinctive 'voice'. Dolphins are mammals and have many similarities with humans. Like humans, dolphins are social creatures, swimming and hunting together with other dolphins. They also seem to communicate with each other. Beginning at birth, dolphins vocalize using squeaks, whistles, clicks, and other sounds. Researchers often observe dolphins 'chattering' and being responded to by another dolphin, indicating that they are engaged in some sort of dialogue. From time to time, dolphins in the same group make the same sounds in unison, further indicating a communication link. In addition to vocalizations, dolphins appear to communicate nonverbally through body language, blowing bubbles and rubbing their fins. Humans produce sound by pushing air through our larynx, which vibrates our vocal cords. Researchers believe that dolphins vocalize by moving air in their nasal passages. Dolphin sounds have a whole range of frequencies, volumes and patterns, including trills, clicks, hums and squeaks. One very unique form of dolphin communication is the whistle. Each dolphin appears to have a signature whistle that is uniquely theirs and is used to identify them. A mother dolphin constantly whistles her own pattern to her young, perhaps to help him remember her whistle. Each dolphin's whistle is so unique that dolphin researchers have been able to measure specific sound waves on a sonogram. This shows how each individual dolphin's whistle takes on a different pattern. Another fascinating form of dolphin communication is their use of echolocation. Echolocation is still a very complex area of study, as is the entire field of dolphin communication. What we have is that dolphins use high frequency clicks while in the water. These clicks create sound waves that travel outward from the dolphin and bounce off nearby objects, sending information to the dolphin about the location, size, shape, and more of surrounding objects. Echolocation provides the dolphin with the ability to gauge its location and assess the presence of nearby structures, including potential predators or food sources. Echolocation helps dolphins learn what sound patterns are coming back from their common prey, effectively aiding them in their future search for food. Just like dolphins, whales use different sounds to communicate. There are two primary types of whales that emit different sounds, the toothed whales and the hook whales. Toothed whales communicate using high-frequency clicks and whistles. Single-click sounds are mainly used for echolocation, while multiple clicks are used to communicate with other whales and even dolphins in the area. When in a large group, each whale has a different pitch to identify who is 'speaking'. Baleen whales use low-frequency sounds that can be heard over long distances. Some species, such as humpback and blue whales, produce melodies that scientists call whale songs. Whales also use spying to alert other whales to their surroundings and flap their tail fins to show aggression or warn other whales of potential threats.

Figure 16. People often think that the underwater world is 'silent'. In fact, many marine organisms use sound to communicate, reproduce and search for prey. The hydrophone shown here is located within the Gray's Reef National Marine Sanctuary in Georgia. This is one of four sites where hydrophones are used to collect soundscape data within the National Marine Sanctuary system.

Source: https://oceanservice.noaa.gov/facts/hydrophone.html, Accessed: July 9, 2023

Underwater acoustic communication is a technique for sending and receiving messages underwater. There are several ways of using such communication, but the most common is using a hydrophone [29]. A hydrophone is an underwater device that detects and records ocean sounds from all directions (Figures 17,18,19). Underwater communication is hampered by factors such as multipath propagation, temporal channel variations, low available bandwidth, and severe signal attenuation, especially over long distances. Compared to terrestrial communication, underwater communication has low data rates because it uses sound waves instead of electromagnetic waves.

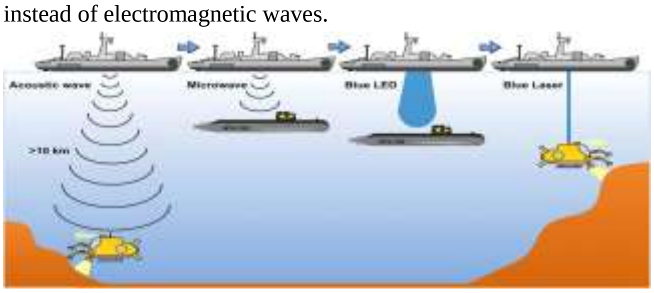

Figure 17. Scheme of the underwater communication system. Scheme of underwater communications based on acoustic waves, microwaves, blue LED and blue LD

[1] For example, while sound travels at a speed of 343 m/s in air, it travels at a speed of 1481 m/s in water (almost 4.3 times faster than in air).

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Source: https://oceanservice.noaa.gov/facts/hydrophone.html, Accessed: July 9, 2023

Figure 18. NATO establishes the first (in history) digital standard for underwater communications

Source:https://www.navyrecognition.com/index.php/naval-news/naval-newsarchive/2017/april-2017-navy-navalforces-defense-industry-technologymaritime-security-global-news/5158-nato-establishes-the-first-ever-digitalunderwater-communicationsstandard.html

Accessed: July 9, 2023

Figure 19. JANUS applications are unlimited

Source:https://www.navyrecognition.com/index.php/naval-news/naval-newsarchive/2017/april-2017-navy-navalforces-defense-industry-technologymaritime-security-global-news/5158-nato-establishes-the-first-ever-digitalunderwater-communicationsstandard.html

Accessed: July 9, 2023

In an operational context, CMRE has already successfully tested the delivery of Automatic Identification System (AIS) data consisting of identification, position, course and speed of ships at sea and meteorological and oceanographic (METOC) information to underwater assets using JANUS-standardized acoustic communications. Pictured: the schematic shows the AIS data (upper right frame) and METOC information (lower right frame) delivered to the submarine using JANUS sound communication. In the early 20th century, some ships communicated with underwater bells as well as navigation systems. Submarine signals at that time were competitive with the primitive maritime radionavigation service [30]. The later Fessenden oscillator enabled communication with submarines. Types of modulation used for underwater acoustic communications. In general, modulation methods developed for radio communications can be adapted to underwater acoustic communication (UAC). However, some modulation schemes are more suitable for a unique underwater acoustic communication channel than others. Some of the modulation methods used for UAC are: Frequency-shift keying, FSK, Phase-shift keying (PSK), Frequency-hopping spread spectrum (FHSS), Direct-sequence spread spectrum (DSSS), Frequency and pulse-position modulation (FPPM an PPM), Multiple frequency-shift keying (MFSK), Orthogonal frequency-division multiplexing (OFDM). Frequency Shift Keying (FSK) is the earliest form of modulation used for acoustic modems. Underwater acoustic communication (UAC) before modems was by hitting different objects under water. This method has also been used to measure the speed of sound in water. Phase-shift keying (PSK) typically uses two different frequencies to modulate the data; for example, frequency F1 to indicate bit 0 and frequency F2 to indicate bit 1. Therefore, a binary string can be transmitted by alternating these two frequencies depending on whether it is a 0 or a 1. The receiver can be as simple as having analog matched filters at the two frequencies and a level detector to decide whether a 1 or a 0 was received. This is a relatively simple form of modulation and is therefore used in the earliest acoustic modems. However, more sophisticated demodulators using Digital Signal Processors (DSP) can be used today. The biggest challenge FSK faces in UAC is multipath reflections. With multipaths (especially in UAC) several strong reflections may be present at the receiving hydrophone and the threshold detectors become confused, thus strictly limiting the use of this type of UAC to vertical channels. Adaptive equalization methods have been tried with limited success. Adaptive equalization attempts to model the highly reflective UAC channel and subtract the effects from the received signal. Success is limited due to rapidly changing conditions and difficulty adapting in time. Phase-shift keying (PSK) is a digital modulation scheme that transmits data by changing (modulating) the phase of a reference signal (carrier wave). The signal is imprinted in the magnetic field x, y region by changing the input sine and cosine at a precise time. It is widely used for wireless Local area network LAN), Radio-frequency identification (RFID) and Bluetooth communication. Any digital modulation scheme uses a finite number of different signals to represent digital data. PSK uses a finite number of stages, each assigned a unique pattern of binary digits. Usually, each phase encodes an equal number of bits. Each bit pattern forms a symbol that is represented by a certain phase. A demodulator, which is specifically designed for the set of symbols used by the modulator, determines the phase of the received signal and maps it to the symbol it represents, thus restoring the original data. This requires that the receiver can compare the phase of the received signal with the reference signal - such a system is called Coherent Phase Shift Keying (CPSK). Alternatively, instead of operating relative to a constant reference wave, the broadcast can operate relative to itself. Changes in the phase of a single broadcast waveform can be considered significant items. In this system, the demodulator determines changes in the phase of the received signal, and not in the phase itself (relative to the reference wave). Since this scheme depends on the difference between successive phases, it is called differential phase-shift keying (DPSK). DPSK can be significantly simpler to implement than regular PSK because there is no need for the demodulator to have a copy of the reference signal to determine the exact phase of the received signal (it is a non-coherent scheme). In return, it produces more erroneous demodulation. Orthogonal frequency-division multiplexing (OFDM) is a digital modulation scheme with multiple carriers. OFDM transmits data on several parallel data channels by including closely spaced orthogonal carrier signals. OFDM is a favorable communication scheme in underwater acoustic communications due to its resistance to frequency-selective channels with large delay spacing. Compared to a scalar pressure sensor, such as a hydrophone, which measures a scalar acoustic field component, a vector sensor measures vector field components, such as the velocities of sound-generating particles. Vector sensors can be classified into inertial and gradient sensors. Vector sensors have been widely researched in the last few decades. Many algorithms have been designed for vector sensor

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signal processing. Applications of underwater vector sensors are focused on sonar and target detection. Their use as an underwater multi-channel communication receiver and equalizer has also been suggested. Other researchers have used arrays of scalar sensors as multi-channel equalizers and receivers. The underwater telephone, also known as the UQC, AN/WQC-2 or Gertrude, was developed by the US Navy in 1945. The UQC (Unique Quantity Code) underwater telephone is used on all manned submarines and many ships at sea in operation. Voice or audio tone (morse code) communicated via UQC is heterodyned to high pitch for acoustic transmission through water [31]. Divers are trained to use hand signals to communicate with their friends (Figure 20). They also use underwater writing boards that allow for better communication. However, both of these techniques require light. But what if the water is cloudy? Or if it's night? Or if the divers are too far away to see each other clearly? Is it possible to use sound instead? Special underwater communication systems have been developed that allow divers to talk to each other underwater. A transducer is attached to the diver's face mask, which converts his voice into an ultrasound signal. The fellow diver has an ultrasonic receiver, which receives the signal and converts it back into sound that the diver can hear, enabling communication. The same system can be used for communication between a diver and a surface ship.

Figure 20. Divers use hand signals and writing boards to communicate with their buddies. Acoustic communication systems allow divers to talk to each other underwater
Source: https://dosits.org/people-andsound/communication/how-is-soundused-to-communicate-underwater/, Accessed: July 9, 2023

US Navy submarines use a specialized telephone system for underwater communication (Figure 21). It works similar to an AM radio, except that it transmits and receives sound waves instead of transmitting and receiving radio waves. Similar to land-based systems, underwater telephone systems use microphones and audio amplifiers.

Figure 21. The US Navy submarine USS Key West is conducting surface operations
Source: https://dosits.org/people-andsound/communication/how-is-soundused-to-communicate-underwater/, Accessed: July 9, 2023

These systems are designed for voice communication. More advanced systems have been developed for the transmission and reception of digital data (e-mail, surfing the Internet...). The Popoto modem is a compact, inexpensive, high-power, general-purpose underwater communication device (Figure 22). With digital modulation schemes (FH, M-ary PSK) enabled, the modem will accommodate a relative speed of at least ± 5 kts (± 2.5 m/sec) on a standard carrier frequency of 26 kHz and allows tracking through all payload packet headers. The Popoto Modem software is designed to allow customization. The environment includes many common signal processing tools, such as fast correlation and convolution, FFT, and data storage. Popoto connects seamlessly with external processing tools, such as MATLAB or Python.

Figure 22. Modem Popoto
Source: https://www.popotomodem.com/bundle-kits-page/, Accessed: July 9, 2023

Unlike classic modems, Modem-M64 is completely omnidirectional (Figure 23). Omnidirectional means that the modems can rotate around all axes and maintain their robust data connection. This is particularly important for ROV/AUV applications where the modems are in constant motion.

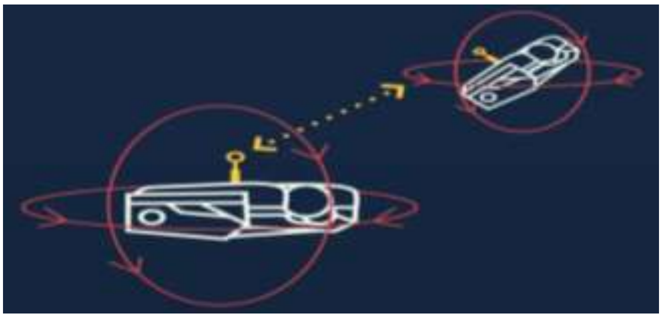

Figure 23. Modem-M64
Source: https://www.popotomodem.com/bundle-kits-page/, Accessed: July 9, 2023

4. Boundaries: architecture as a framework of life

In accordance with the previously mentioned concept of architecture as Architecturally Defined Space (ADS, Figure 1), Boundaries (3) are the one (of the four basic) elements of ADS that, with its concept and materialization, reflect the result of harmonizing the requirements of Man (2), on the one hand and conditions of the specific Environment (1), on the other hand. As man is a very complex being, and as the possible combinations of conditions of the concrete environment are practically unlimited, the possible physical appearance of the boundaries of ADS is also unlimited. The boundary that demarcates the complex system of needs in the environment is also built by other living beings, sometimes with such skill that not even humans can achieve

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(termite mounds, bee combs, bird's nests, cobwebs...). However, despite their perfection, we do not consider such borders to be architecture, since architecture is the exclusive creation of man. According to the presented definition of borders, one could carelessly conclude that borders are created 'automatically' by matching the demands of man and the input of the environment. Some examples of vernacular (traditional) architecture around the planet Earth almost confirm this. However, since architecture is created by humans, and each one is different from the other in a population of several billions, the 'solutions to the same architectural task' obtained by any number of architects will be different. Moreover, the same architect, at different times, will give different answers to the same architectural task. The just-mentioned complexity and controversy characteristic of architecture are those specificities that distinguish architecture from the world of other sciences, arts and philosophy and make it a total human creation [32].

4.1. Engineering and construction works under water

People have been researching underwater construction for years, and construction techniques already exist to create underwater structures and underwater buildings. Although the only underwater cities are those that have been submerged over time, plans are already being considered for the underwater cities of the future. Construction on land can be difficult, but construction under water presents even more unique challenges [33]. Some of these challenges include: finding suitable materials (many of the materials we often use on land - like wood - are simply not suitable for long-term underwater use), dealing with water pressure both during construction and during the life of the structure, the effects of water pressure play a key role , corrosion management (subsea projects in a coastal environment must take into account the corrosive effects of salt water). Some ancient civilizations figured out how to overcome these obstacles by using appropriate materials and simple underwater construction methods to build support columns for bridges across rivers.

Materials used in underwater construction. When building in water, materials must be used that can withstand various complications, including water pressure, corrosion and erosion. The most common materials used in underwater construction are: concrete (a special type of concrete used underwater can set quickly despite water currents and has a high resistance to the effects of salt water), steel (steel, usually sealed with concrete, forms a strong structure for underwater buildings), acrylic glass (resistant to sunlight, durable and quite strong, acrylic plastic is well adapted to underwater construction. Because it is transparent, acrylic glass is used for underwater windows, i.e. most of the envelope of the underwater structure).

Methods of underwater construction. Over the years, several main techniques have developed that allow construction companies to install large and small water bodies. Some of the most important underwater construction methods include: Caissons, Cofferdams, Driven piles and Off-site building, float and lower.

All of these underwater construction methods have the same basic goal: to avoid construction under water. Instead, water is diverted or avoided in various ways during construction. So building underwater is more about finding creative ways to bypass the water and create structures that could withstand it after construction is complete.

Caissons are watertight constructions that can be lowered into water, while maintaining a dry environment in them (Figure 24). Inside the dry interior of an open caisson, workers can dig to reach a solid surface on which to rest the caisson. Eventually, the caissons become part of the foundation of a building, often a bridge or dam. Although bridges and dams are not considered 'underwater structures', it is true that many of their important elements are underwater. Many massive bridges would not be possible without large support structures, often founded underwater. In the construction of the Brooklyn Bridge, for example, the construction of which began in 1870, two large caissons were used to excavate the foundation beds in the load-bearing soil under water on which the bridge tower is based. Although they use the same basic principles, there are several different types of caissons: open caisson, pneumatic caisson and box caisson. An open caisson has no bottom and contains only vertical walls, allowing workers to dig through the bottom. A pneumatic caisson is similar to an open caisson, but compressed air is pumped in to prevent water ingress. Unlike other caissons, the caisson in the box contains a floor, so it descends on already laid foundations. While caissons are still used today, their usefulness is limited, so many situations call for the use of rubber dams.

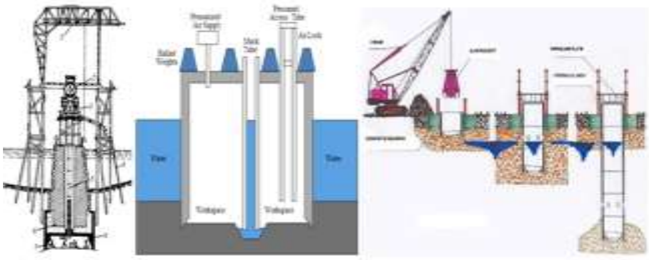

Figure 24. Caissons
Source: https://upload.wikimedia.org/wikipedia/commons/e/ef/Caisson_Schematic.svg, Accessed: July 9, 2023
Source: https://www.pinterest.com/pin/373446994077808152/, Accessed: July 9, 2023

Cofferdams are temporary enclosures that allow water to be pumped out, creating a dry environment for construction (Figure 25). As the name suggests, cofferdams act similar to dams, preventing the flow of water from a certain area. A fully constructed ark looks like a large walled pit with water surrounding it. Cofferdams can be constructed from a variety of materials, including steel and rock. The most basic type of cofferdam is made by simply piling large amounts of dirt. However, these types of cofferdams often require some type of reinforcement to prevent erosion. Cofferdams can be used to build a variety of structures, from docks and piers to partially or fully submerged buildings.

Figure 25. Cofferdams
Source: https://projects.arcelormittal.com/foundationsolutions/applications/underground_construction/cofferdams/language/EN
Accessed: July 9, 2023

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Source: https://eddypump.com/education/cofferdam-construction-using-dredge-pumps/, Accessed: July 9, 2023

Cofferdams are also used in the construction of permanent dams (for example, several cofferdams were erected to divert water from the Colorado River to build the Hoover Dam). During the construction of foundation elements under water, driven piles with power enable crews to create solid structures without the need to remove water (Figure 26). Pylons, which look like long, vertical posts, can be driven into the ground with a powerful hammer, creating stable foundations for underwater or above-water structures. In the case of underwater construction, pylons are driven into soil or rock layers.

Figure 26. Driven piles
Source: https://theconstructor.org/geotechnical/methods-of-driving-piles-overwater/20669/, Accessed: July 9, 2023

In underwater construction, pylons are most often made of steel, although they have a partially hollow interior. After placing the pylon, a pipe is used to fill its inner cavity with concrete, which displaces the water that was previously there. Concrete can set even when surrounded by water, and what remains at the end of this process is a reinforced concrete column. For example, driven piles were used to anchor Apple's partially submerged store at Marina Bay Sands in Singapore. As already mentioned, the main goal of underwater construction is to avoid having to build under water. As a result, one of the most common practices in underwater construction is off-site building, float and lower (Figure 27). The structures are built and assembled off-site, sometimes using modular construction, and then transported to the site.

Figure 27. Off-site building, float and lower
Source: https://www.architecturaldigest.com/gallery/floating-architecture-around-theworld-slideshow, Accessed: July 9, 2023

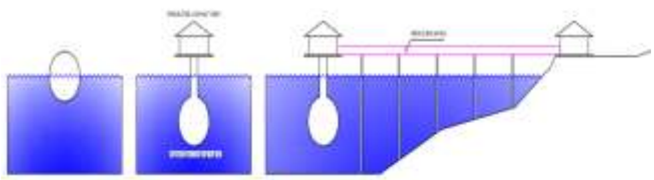
Structures or building parts are often set afloat or towed by tugboats and then lowered into place. Some pieces descend under their own weight, while other pieces are weighted down to help them reach the seabed. If necessary, water is pumped out of the structure after it is lowered into place. One structure that was built this way is the Utter Inn, a small hotel in Sweden that was built on the shore and then later sunk in the middle of a lake (Figure 28). Entrance to the hotel is only available by boat.

Figure 28. Utter Inn
Source: https://www.uniqhotels.com/utter-innfloating-house-on-the-lake, Accessed: July 9, 2023

Although this method of construction can be expensive, it is significantly more cost-effective than building directly underwater, which involves complex tools, skilled divers and high risks. All these construction methods - caissons, cofferdams, piles and off-site construction - enable the creation, quite often, of beautiful and useful underwater structures.

4.2 Concepts of creating boundaries of underwater architecture

Underwater habitats are underwater structures where people can live longer and perform most of the basic human functions during 24 hours, such as work, rest, nutrition, personal hygiene and sleep. In this context, habitat is generally used in a narrower sense to mean the interior and immediate exterior of a structure and its elements, but not the surrounding marine environment. Most early underwater habitats did not have regenerative systems for air, water, food, electricity and other resources. Recently, however, some new underwater habitats allow these resources to be delivered by pipe or created within the habitat rather than by hand. The underwater habitat must meet the needs of human physiology and provide suitable environmental conditions, the most critical being breathing air of adequate quality. Others concern the physical environment (pressure, temperature, light, humidity), the chemical environment (drinking water, food, waste, toxins) and the biological environment (dangerous sea creatures, microorganisms...). Numerous underwater habitats have been designed, built and used around the world since the beginning of the 1960s, either by private individuals or by government agencies [34]. They were used almost exclusively for research, but in recent years there have been more underwater habitats for recreation and tourism. The research was devoted especially to physiological processes and the limits of gas breathing under pressure for aquanauts. The term 'underwater habitat' is used for a range of applications, including some structures that are not exclusively underwater during operation, but all include a significant underwater component. There may be some overlap between underwater habitats and submersibles and between fully submerged structures and those whose part extends above the surface during operation. In the underwater habitat, observations can be made at any time to study the behavior of diurnal and nocturnal organisms. Shallow water habitats can be used to accommodate divers from greater depths for much of the required decompression. Saturation diving provides the ability to dive at shorter intervals than is possible from the surface, and the risks associated with diving and boat operations at night can be minimized. In the La Chalupa habitat, 35% of all dives took place at night. To perform the same amount of useful work diving from the surface instead of from La Chalupa, it was estimated that eight hours of decompression would be required each day. Concepts of underwater habitats are shown in (Figure 29).



Floating Access pane on the surface

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Semi-autonomous Autonomous

Figure 29. Concepts of underwater habitats (A. Hadrovic, 2021)

Floating. The habitat is in the underwater hull of a floating structure. In the Sea Orbiter example, this part should reach a depth of 30 meters. The advantage of this type is horizontal mobility.

Access window on the surface. The habitat is accessible through a shaft above the water surface. The depth of immersion is quite limited. However, internal atmospheric pressure can be maintained so that visitors do not have to undergo decompression. This type is generally used on land, such as the underwater restaurant Ithaa in the Maldives or the Red Sea Star in Eilat, Israel.

Semi-autonomous. The habitats of this species are accessible only by diving, but energy and breathing gas are supplied by an umbilical cord. Most stations are of this type, such as Aquarius, SEALAB I and II and Heligoland Autonomna. The station has its own reserves of energy and breathing gas and can be maneuvered (at least in the vertical direction). This type is similar to submarines or atmospheric diving suits, but avoids complete separation from the environment. Examples of this type include Conshelf III and Bentos-300.

Underwater habitats are designed to work in two basic ways. Open to ambient pressure across the lunar basin, meaning that the air pressure inside the habitat is equal to the underwater pressure at the same level as SEALAB (Figure 39). This makes entry and exit easier as there is no physical barrier other than the surface of the water in the moon pool. Living in pressurized habitats is a form of saturation diving, and returning to the surface will require adequate decompression.

Closed towards the sea by openings, with an internal air pressure lower than the ambient pressure and at or near atmospheric pressure. Entry or exit to the sea requires passing through openings and an air chamber. Decompression may be required when entering the habitat after diving. This would be done in the air chamber.

The third or composite type has compartments of both types within the same habitat structure and are connected by air chambers.

Habitat components are: habitat, life support buoy (LSB), personnel transfer capsule (PTC), deck decompression chamber (DDC), diving support vessel (Diving Support Vessel, DSV) and shore base station (Shore base station).

Habitat: Air filled underwater structure where occupants live and work.

Life Support Buoy: A floating structure attached to a habitat that provides power, air, fresh water, telecommunications and telemetry. The connection between Habitat and LSB is made with a multi-conductor umbilical cable in which all hoses and cables are connected.

Personnel Transfer Capsule: Closed diving bell, submersible decompression chamber that can be lowered into the habitat to transfer aquanauts back to the pressurized surface, where they can be transferred while still under pressure to a decompression chamber on a support vessel for safer decompression (Figure 30).
Deck Decompression Chamber: A decompression chamber on the support vessel.

Diving Support Vessel: A surface vessel used to support diving operations.
Coastal base station: a coastal facility where operations can be monitored. This may include a dive control base, workshops and accommodation.

An excursion is a visit to the environment outside the habitat. Diving trips can be done on diving or umbilical supply, and are limited upwards by decompression obligations during the trip, and downwards by decompression obligations when returning from the trip. Open-circuit or rebreather diving has the advantage of mobility, but it is critical to the diver's safety from saturation that he can return to habitat, as emerging directly from saturation is likely to cause severe and possibly fatal decompression sickness. For this reason, most programs have signs and guidelines posted around the habitat to prevent divers from getting lost. Umbilical or air hoses are safer because the supply of respiration is unlimited and the hose is a guide for returning to the habitat, but they limit freedom of movement and can become tangled. The horizontal extent of excursion is limited to the supply of diving air or the length of the umbilical cord. The distance above and below the level of the habitat is also limited and depends on the depth of the habitat and the associated saturation of the divers. The open space available for exits thus describes the shape of a cylinder with a vertical axis centered on the habitat.

Figure 30. Divers ride on a stage to an underwater workplace
Source: https://en.wikipedia.org/wiki/Underwater_diving, Accessed: July 9, 2023

The history of underwater habitats follows from the previous development of diving bells and caissons, and as long exposure to a hyperbaric environment leads to saturation of body tissues with inert gases from the environment, it is also closely related to the history of saturation diving. The original inspiration for the development of underwater habitats was the work of Captain George Foote Bond (1915-1983), who investigated the physiological and medical effects of hyperbaric saturation in Project Genesis between 1957 and 1963. Edwin Albert Link (1904-1981) began the Man-in-the-Sea project in 1962, which exposed

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divers to hyperbaric conditions underwater in a diving chamber, culminating in the first aquanaut, Robert Pierre André Sténuit (1933), who spent more than 24 hours at a depth of 61 m. Inspired by George Foote Bond's Genesis, Jacques-Yves Cousteau (1910-1997) conducted the first Conshelf project in France in 1962, where two divers spent a week at a depth of 10 meters, and in 1963 it was followed by Conshelf II at 11 meters for a month and 25 meters for two weeks. In June 1964, Robert Sténuit and Jon Lindberg (1932-2021) spent 49 hours at 126 meters in Link's Man-in-the-Sea II project. The habitat was an inflatable structure called a SPID. This was followed by a series of underwater habitats where people stayed for several weeks at great depths. Sealab II [35] had a useful surface of 63 m^2, and was used at a depth greater than 60 meters. Several countries built their own habitats at the same time and mostly started experimenting in shallow waters. In Conshelf III, six aquanauts lived for several weeks at a depth of 100 meters. In Germany, the Heligoland UWL was the first habitat used in cold water, the Tektite stations were more spacious and technically advanced. The most ambitious project was Sealab III, a renewal of Sealab II (Figure 31), which was supposed to be in operation at 186 meters. When one of the divers died in the preparation phase due to human error, all similar projects of the US Navy were stopped. Internationally, apart from the La Chalupa research laboratory, large projects were carried out but not expanded, so the following habitats were smaller and designed for shallower depths. It seems that the race for greater depths, longer missions and technical progress has come to an end.

Figure 31. Sealab II

Source: https://perezcope.com/2019/10/19/sealab-2-rolex-submariners/, Accessed: July 9, 2023

Due to reasons such as lack of mobility, lack of self-sufficiency, a shift in focus to space travel, and the transition to surface saturation systems, interest in underwater habitats declined, resulting in a noticeable decrease in large-scale projects after 1970. In the mid-1980s, the Aquarius habitat was built in the style of Sealab and Heligoland and is still in operation (Figure 32).

Figure 32. Heligoland Underwater Laboratory (UWL) in Nautineum, Stralsund (Germany)

Source: https://pbase.com/wintermeer/image/161389901, Accessed: July 9, 2023

Conshelf, short for Continental Shelf Station, was a series of underwater living and research stations undertaken by Jacques Cousteau's team in the 1960s [36]. The original design was that five of these stations would be submerged to a maximum depth of 300 meters over a decade. In reality, only three were completed with a maximum depth of 100 meters. Much of the work was partially financed by the French petrochemical industry, which, along with Cousteau, hoped that such colonies could serve as base stations for future exploitation of the sea. Such colonies did not find a productive future, since Cousteau later withdrew his support for such exploitation of the sea and devoted his efforts to its preservation. It was later discovered that industrial tasks underwater could be performed more efficiently by underwater robotic devices and humans working from the surface or from smaller suspended structures, made possible by a more advanced understanding of the physiology of diving. Nevertheless, these three underwater live experiments did much to advance human knowledge of undersea technology and physiology and were valuable as proof-of-concept constructs. They also did much to publish oceanographic research and, ironically, ushered in an era of ocean conservation by building public awareness. Together with Sealab and others, he spawned a generation of smaller, less ambitious, but long-term underwater habitats primarily for marine research purposes. Conshelf I, built in 1962, was the first inhabited underwater habitat (Figure 33). Developed by Cousteau to record basic observations of underwater life, Conshelf I was submerged in water to a depth of 10 meters near Marseille, and the first experiment involved a two-man team spending seven days in the habitat. The two Oceanauts, Albert Falco (1927-2012) and Claude Wesly (1930-2016), were expected to spend at least five hours a day outside the station and were subjected to daily medical examinations. Conshelf II, a starfish-shaped habitat, the first ambitious attempt by men to live and work on the seabed, was launched in 1963. Six oceanauts lived in it for 30 days in the Red Sea near Sudan at a depth of 10 meters. The submarine experiment also had two other structures, a submarine hangar that housed a small two-man submarine called the SP-350 Denise, often called a diving saucer because of its resemblance to a science fiction flying saucer, and a smaller deep cabin where two oceanauts lived at a depth of 30 meters for seven days. They were among the first to inhale heliox, a mixture of helium and oxygen, avoiding the normal nitrogen/oxygen mixture, which, when inhaled under pressure, can cause narcosis. The deep cabin was also one of the first attempts at saturated air diving, in which the aquanaut's body tissues were allowed to become completely saturated with the helium in the breathing mixture, the result of breathing gases under pressure. The necessary decompression due to saturation is accelerated by the use of oxygen-enriched breathing gases. They suffered no obvious adverse effects. The underwater colony was supported by air, water, food, power, all the essentials of life, from a large support team above. The men on the bottom performed numerous experiments designed to determine the practicality of working on the seabed and were subjected to constant medical examinations. The Conshelf II was a seminal effort in the study of diving physiology and technology and attracted widespread public attention for its dramatic „Jules Verne“ look and feel. The feature film about the effort, World Without Sun, directed by Jacques-Yves Cousteau, won the Academy Award for Best Documentary the following year (1956). Conshelf III was launched in 1965. Six divers lived for three weeks in a habitat at a depth of 102.4 meters in the Mediterranean Sea near the Cap Ferrat lighthouse, between Nice and Monaco. In this effort, Cousteau was determined to make the station self-sustaining, severing most connections to the surface. An underwater oil platform has been placed under water, and divers have successfully completed several industrial tasks.

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Figure 33. CONSHELF I, II & III
Source: https://www.cousteau.org/legacy/technology/conshelf/, Accessed: July 9, 2023

SEALAB I, II and III were experimental underwater habitats developed by the US Navy in the 1960s to demonstrate the viability of saturation diving and people living in isolation for long periods of time [37] (Figure 34). The knowledge gained from SEALAB's expeditions has helped to advance the science of deep sea diving and rescue and has contributed to the understanding of the psychological and physiological stresses that humans can endure. The three SEALABs were part of The United States Navy Genesis Project. Previous research work was undertaken by Captain George Foote Bond (1915-1983). Bond began research in 1957 to develop theories about saturation diving. Bond's team exposed rats, goats, monkeys and human beings to various gas mixtures at different pressures. By 1963, they had collected enough data to test the first SEALAB habitat.

Figure 34. US NAVY SEALAB I, SEALAB II and SEALAB III
Source: https://www.cousteau.org/legacy/technology/conshelf/, Accessed: July 9, 2023

The Tektite underwater habitat was built by General Electric and financed by NASA, the Office of Naval Research and the United States Department of the Interior [38], (Figure 35). On February 15, 1969, four scientists from the Department of the Interior (Ed Clifton, Conrad Mahnken, Richard Waller and John Van Derwalker) descended to the ocean floor in Great Lameshur Bay in the US Virgin Islands to begin an ambitious diving project under named Tektite I. By March 18, 1969, four aquanauts had set a new world record in saturated diving by a team. On April 15, 1969, a team of aquanauts returned to the surface after 58 days of marine scientific studies. It took more than 19 hours of decompression to safely bring the team back to the surface. Inspired in part by NASA's upcoming Skylab program and an interest in better understanding the effectiveness of scientists working in extremely isolated living conditions, Tektite was the first saturation diving project to employ scientists rather than professional divers.

The Tektite II missions were carried out in 1970. Tektite II consisted of ten missions lasting 10 to 20 days with four scientists and an engineer on each mission. One of those missions included the first female aquanaut team, led by Dr. Sylvia Earle (1935-). Other scientists participating in the mission included Dr. Renate True of Tulane University, as well as Ann Hartline and Alina Szmant, graduate students at the Scripps Institution of Oceanography. The fifth crew member was Margaret Ann Lucas, an engineering graduate from Villanova University, who worked as a habitat engineer. The Tektite II missions were the first to undertake deep environmental surveys.

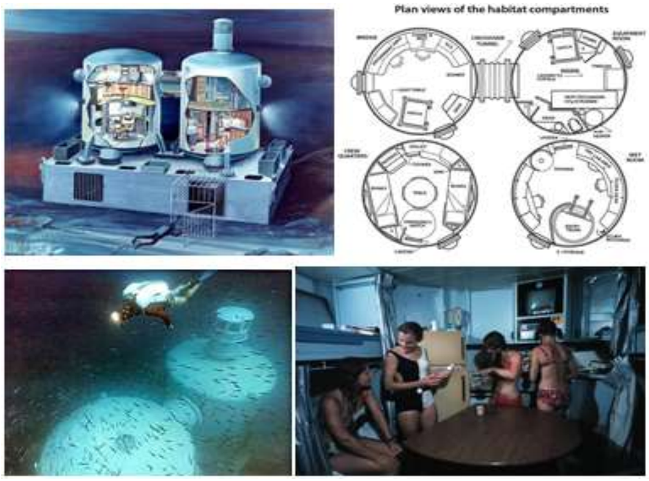

Figure 35. Tektite underwater habitat
Source: https://tektitedocumentary.wordpress.com/, Accessed: July 9, 2023

Hydrolab was built in 1966, and has been used as a research station since 1970. The project was partially funded by the National Oceanic and Atmospheric Administration (NOAA) [39]. Hydrolab could accommodate four people (Figure 36). Approximately 180 Hydrolab missions were conducted-100 missions to the Bahamas from the early to mid-1970s, 80 missions to Saint Croix and the US Virgin Islands from 1977 to 1985. These scientific missions are documented in the Hydrolab Journal [40]. dr. William Fife spent 28 days in saturation, performing physiological experiments on researchers such as Dr. Sylvia Earle. The habitat was decommissioned in 1985 and is on display at the Smithsonian Institution's National Museum of Natural History in Washington, DC (The National Museum of Natural History, The Smithsonian Institution). As of 2017, the habitat is located at The NOAA Auditorium and Science Center at the National Oceanic and Atmospheric Administration (NOAA) in Silver Spring, Maryland.

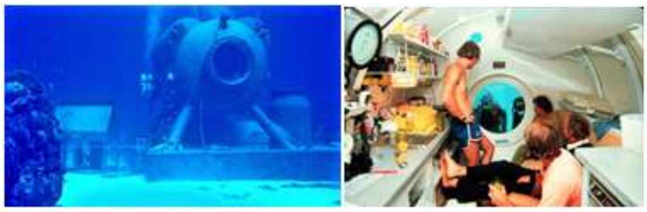

Figure 36. Hydrolab
Source: https://www.noaa.gov/heritage/stories/how-noaas-first-undersea-lab-helped-scientists-study-corals, Accessed: July 9, 2023

The Bentos-300 (Bentos minus 300) was a Soviet diver-blocking maneuvering submarine that could be deployed on the seabed (Figure 37). He managed to spend two weeks underwater at a maximum depth of 300 meters with about 25 people on board. Although it was announced in 1966, it was deployed for the first time in 1977. There were two vessels in the project. After the Bentos-300 sank in the Russian Black Sea port of Novorossiisk in 1992. In November 2011, it was cut down and returned to scrap within the next six months.

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Figure 37. Bentos-300
Source: http://www.deepstorm.ru/DeepStorm.files/45-92/cda/bentos/list.htm, Accessed: July 9, 2023

The MarineLab underwater laboratory is the longest-running seabed habitat in history, operating continuously since 1984 under the leadership of aquanaut Chris Olstad in Key Largo, Florida [41] (Figure 38). The seabed laboratory has trained hundreds of individuals in that time, with an extensive range of educational and scientific research from US military investigations to drug development.

Figure 38. MarineLab
Source: https://www.marinelabmuseum.org/, Accessed: July 9, 2023

Designer Lloyd Godson's Biosub was an underwater habitat, built in 2007 for the Australian Geography competition [42] (Figure 39). The Biosub generated its own electricity (using a bicycle), its own water, using the Air2Water Dragon Fly M18 system, and its own air, using O2-producing algae. Algae were fed using a Cascade High School Advanced Biology Class Biocoil.

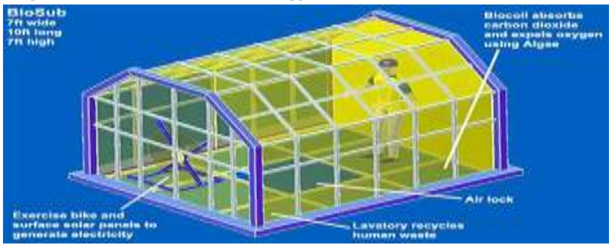

Figure 39. Biosub (designer: Lloyd Godson)
Source: http://www.lloydgodson.com/underwater-projects.html, Accessed: July 9, 2023

Hippocampe is an underwater habitat, created by the French architect Jacques Rougerie (1945), launched in 1981 to act as a scientific base suspended in the middle of water [43] (Figure 40). Hippocampe can accommodate 2 people on saturation dives to a depth of 12 meters for periods of 7 to 15 days and is also designed to act as a subsea logistics base for the offshore industry.

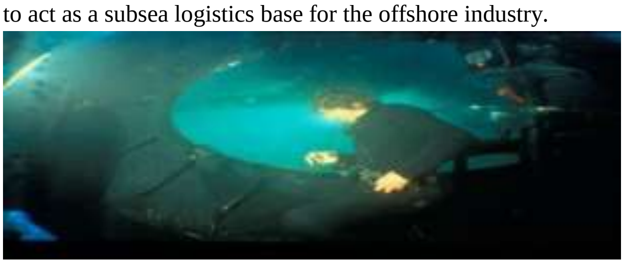

Figure 40. Hippocampe
Source: https://architizer.com/idea/1608982/, Accessed: July 9, 2023

Ithaa is the world's only fully glazed underwater restaurant located at the Conrad Maldives Rangali Island [44] (Figure 41). It is accessible through a corridor above the water and is open to the atmosphere, so there is no need for compression or decompression procedures. Ithaa was built by M.J. Murphy Ltd and has an unballasted mass of 175 tonnes.

Figure 41. Restaurant Ithaa, Hotel Conrad Maldives Rangali Island, Republic of Maldives
Source: https://www.flickr.com/photos/suraark/5473968139, Accessed: July 9, 2023

The Red Sea Star restaurant in Eilat, Israel consisted of three modules (Figure 42); an entrance area above the water surface, a restaurant with 62 panoramic windows 6 m under water and a lower ballast area [45]. The entire construction weighs about 6,000 tons. The restaurant had a capacity of 105 people. It was closed in 2012.

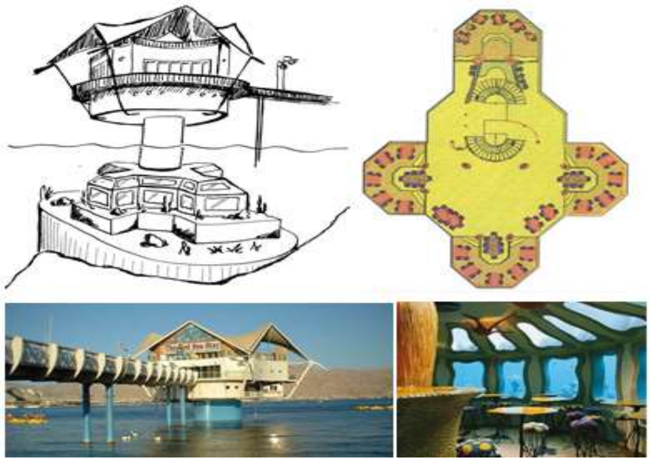

Figure 42. Restaurant Red Sea Star (Red Sea Star) in Eilat, Israel (architects: Kiriaty Architects)
Source: http://www.kiriatyarchitects.com/Info.aspx?txtParam=CT_PROJECTS&txtItemID=1, Accessed: July 9, 2023

The first part of the Coral World underwater observatory in Eilat, Israel, was built in 1975, and was expanded in 1991 by adding a second underwater observatory connected by a tunnel [46] (Figure 43). The underwater complex is accessible by a pedestrian bridge from the shore and a shaft above the water surface. The observation area is located at a depth of approximately 12 m.

Figure 43. Coral World Underwater Observatory in Eilat, Israel, 1975-1991.
Source: https://www.shutterstock.com/sv/video/clip-13920266-eilat--israel---november-20-2014, Accessed: July 9, 2023

The brainchild of designer and futurist Phil Pauley, Sub-Biosphere 2 is originally a self-sustaining underwater habitat designed for aquanauts, tourism and oceanographic life sciences, and long-term

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human, plant and animal habitation [47] (Figure 44). SBS2 is a seed bank with eight living biomes that allow humans, plants and fresh water to interact, powered and controlled by a central support biome that oversees the life systems from its own drives.

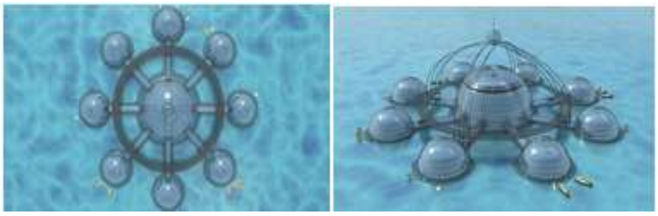

Figure 44. Sub-Biosphere 2, conceptual solution (designer: Phil Pauley)
Source: https://inhabitat.com/futuristic-subbiosphere-2-provides-self-sufficienthome-for-100-people-under-thesea/phil-pauleysubbiosphere2-1/, Accessed: July 9, 2023

4.3 Diving suit and equipment

A diving suit is a piece of clothing or a device intended to protect a diver from the underwater environment. A diving suit may also contain a breathing gas supply (a standard diving suit or an atmospheric diving suit), but in most cases it only refers to the environmental protection worn by the diver. The supply of breathing gas is usually treated separately. There is no general term for the combination of only suit and breathing apparatus. It is generally referred to as scuba gear with any other equipment required for diving.

Diving suits can be divided into two classes: 'soft' or pressurized diving suits, dry suits, semi-dry suits and diving skins, and 'hard' or atmospheric pressure suits, armored suits that keep the diver at atmospheric pressure at any depth within areas of the suit.

Charles C.-J. Le Roux has created a waterproof and windproof fabric that can be used to make a diving suit. The first diving suit designs appeared at the beginning of the 18th century. Two English inventors developed the first pressure-resistant diving suits in the 1710s. John Lethbridge (1675–1759) built a fully enclosed suit to aid in rescue [48] (Figure 45). It consisted of a barrel filled with pressurized air with a glass viewing hole and two watertight sealed shells. This suit gave the diver more maneuverability to perform useful underwater rescue work.

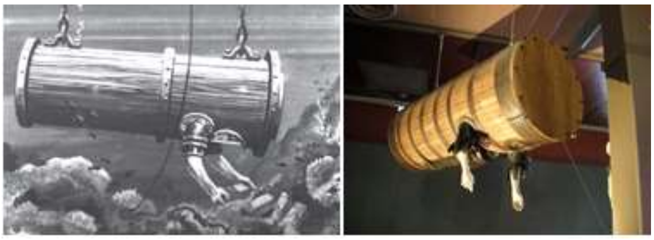

Figure 45. John Lethbridge's diving machine
Source: https://www.amusingplanet.com/2018/12/john-lethbridges-divingmachine.html, Accessed: July 9, 2023

After testing this machine in his garden pond (specially built for the purpose), Lethbridge dived a number of wrecks: four English warships, one East Indian (English and Dutch), two Spanish, and numerous other galleons. Because of his rescues, he became very rich. One of his more famous recoveries was on the Dutch Slot ter Hooge, which sank off Madeira with more than three tons of silver on board. At the same time, Andrew Becker created a diving suit [49] (Figure 46). Becker used a tube system to inhale and exhale, and demonstrated his suit in the River Thames in London, during which he remained submerged for an hour.

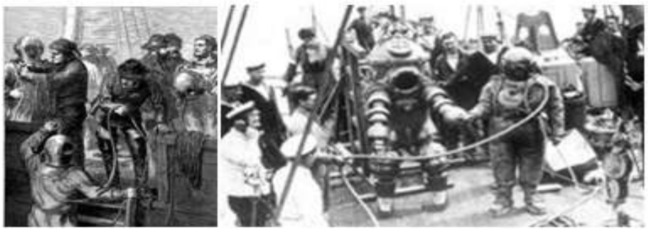

Figure 46. A diving suit created by Andrew Becker
Source: https://gratefulamericanfoundation.com/who-created-the-first-diving-suit/, Accessed: July 9, 2023
Source: https://www.pinterest.com/pin/46161964911603075/, Accessed: July 9, 2023

German-born British engineer Augustus Siebe (1788-1872) developed the standard diving dress in the 1830s. Expanding on improvements already made by another engineer, George Edwards, Siebe produced his own design: a helmet built into a waterproof canvas wetsuit. Later suits were made of waterproof canvas invented by Charles Rennie Mackintosh (1868-1928). From the late 1800s and throughout most of the 20th century, most standard dresses were made from a sheet of solid rubber laminated between layers of twill.

The oldest preserved suit called “Wanha herra” (Old Finnish, meaning 'old gentleman') can be found in the Raahe Museum, Finland (Figure 47). It is made of calfskin and dates from the 18th century. His exact origin is unknown, but parts of his feet indicate a Finnish origin. The suit, which was used for short underwater work, such as checking the condition of the ship's bottom, was donated to the Raahe Museum by Captain Johan Leufstadius (1829-1906), who was a master mariner, merchant and ship owner. The conservator of the Raahe Museum, Jouko Turunen, made a perfect copy of the old suit in 1988. The copy has been successfully tested several times under water.

Figure 47. “Wanha herra” diving suit (18th century)
Source: https://www.raahenmuseo.fi/en/tietolaari/old-gentleman, Accessed: July 9, 2023

Dry suits made of latex rubber were used by Italian frogmen in World War II. They were patented and manufactured by Pirelli in 1951 (Figure 48).

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Figure 48. Left: Pirelli dry suit (1951). Right: Pressure suits
Source: http://www.therebreathersite.nl/Zuurstofrebreathers/Italian/pirelli_diving_suit.htm, Accessed: July 9, 2023
Source: https://www.wikiwand.com/en/Pressure_suit, Accessed: July 9, 2023

External pressure suits are a form of exposure protection that protects the wearer from the cold. They also provide some protection against abrasive and sharp objects, as well as potentially harmful underwater life. They do not protect divers from the pressure of the surrounding water or the resulting barotrauma and decompression sickness. There are five main types of ambient pressure diving suits; diving skins, suits and their derivatives semi-dry suits and suits with warm water and dry suits. In addition to warm water suits, these types of suits are not only used by divers, but are also often used for thermal protection by people engaged in other water sports such as surfing, sailing, motor boating, windsurfing, kitesurfing, water skiing , speleology and swimming.
Diving skins are used when diving at water temperatures above 25 °C. They are made of spandex or Lycra and provide little thermal protection, but protect the skin from jellyfish stings, abrasions and burns. This type of suit is also known as 'Stinger Suit' (Figure 49). Some divers wear diving skins under their wetsuits, which makes dressing easier and (for those with skin problems due to neoprene) provides extra comfort. The 'diving skin' was originally invented to protect divers in Queensland, Australia from the „Box" jellyfish (Chironex fleckeri).

Figure 49. Stinger Suit
Source: https://www.whitsundaydiscountmarine.com.au/stinger-suit-complete-whood-mittens, Accessed: July 9, 2023

Diving suits. Proper fit is key for warmth. A suit that is too loose will allow a large amount of water to circulate over the diver's skin, absorbing body heat. A suit that is too tight is very uncomfortable and can impair circulation in the neck, a very dangerous condition that can cause fainting. For this reason, many divers choose to have their suits made to measure. Suits are limited in their ability to retain heat due to three factors: the wearer is still exposed to water, the suit is compressed by ambient pressure, reducing effectiveness at depth, and insulating neoprene can only be made to a certain thickness. The thickest commercially available suits are usually 10 mm thick. Other common thicknesses are 7 mm, 5 mm, 3 mm and 1 mm. A 1 mm suit provides very little thermal insulation and is usually considered a diving skin rather than a suit. Suits can be made with more than one thickness of neoprene, to place the greatest thickness where it will be most effective in keeping the diver warm. A similar effect can be achieved with layered suits of different coverage. Some neoprene products are softer, lighter and more compressible than others for the same thickness and are more suitable for non-diving suits as they will compress more quickly under pressure and lose their insulating value. Semi-dry suits are efficient thick suits with nearly waterproof neck and ankle seals and zippers (Figure 50). They are usually used where the water temperature is between 10 and 20 °C. Seals limit the volume of water entering and leaving the suit, and the tight fit minimizes pumping action caused by limb movement. The wearer gets wet in a semi-dry suit, but the water entering it soon heats up and does not leave the ready suit, so the wearer stays warm. A trapped layer of water does not contribute to the insulating ability of the suit, and any circulation of water past the seals still causes heat loss, but semi-dry suits are cheap and simple compared to dry suits and do not deteriorate quickly. They are made of dense neoprene, which provides good thermal protection, but loses buoyancy and thermal protection because trapped gas bubbles in the neoprene foam are compressed at depth. Semi-dry suits are usually made as a full suit with one-piece neoprene wrists, cuffs and neck with a smooth inner surface. Two-piece suits are usually a full-length one-piece suit, sometimes described as 'long pants', plus accessories to be worn over, under or with the one-piece suit, such as a short tunic, which can be worn separately in warm waters but has no seals to limit flushing to openings. Semi-dry suits usually do not include hoods, boots or gloves, which are worn separately.

Figure 50. Semi-dry suits
Source: https://www.diverightinscuba.com/wetsuitssemidry-waterproof-sdcombatsemidry-p-3409.html, Accessed: July 9, 2023

Hot water suits are used in commercial surface cold water supplies (Figure 51). A hose in the diver's umbilical line, which connects the diver to the surface mount, carries warm water from the heater on the surface to the suit. The diver controls the flow of water from a valve near the waist, allowing him to vary the heat of the suit in response to changes in environmental conditions and workload. Tubes inside the suit distribute water to the limbs, chest and back. Special boots, gloves and a hood are worn to extend the warming to the extremities. Heating of the breathing gas on the helmet is available by using a hot water blanket over the helmet inlet pipe

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between the valve block and the regulator. These suits are usually made of foam neoprene and are similar in construction and appearance to wetsuits, but are not as close fitting in design and do not need to be very thick as their primary function is to temporarily contain and direct the flow of heating water. The wrists and ankles of the suit are open, allowing water to drain out of the suit as it is replenished with fresh warm water from the surface.

Figure 51. Hot water suits
Source: https://www.divehive.com/dui-hot-water-suit.html, Accessed: July 9, 2023

Warm water suits are often used for deep dives when breathing mixtures containing helium are used. Helium conducts heat much more efficiently than air, meaning that a diver will lose large amounts of body heat through the lungs when inhaling. This increases the risk of hypothermia that is already present in the low temperatures at these depths. In these conditions, a wetsuit is a matter of survival, not comfort. Loss of heated water supply to hot water suits can be a life-threatening event with a high risk of debilitating hypothermia. Just as an emergency backup source of breathing gas is needed, a backup water heater is also an essential precaution whenever diving conditions require a hot water suit. If the heater fails and the backup unit cannot be brought online immediately, a diver in the coldest conditions can die within minutes. Depending on decompression obligations, taking the diver directly to the surface could prove just as deadly. The heated water in the suit forms an active insulating barrier to heat loss, but the temperature must be regulated within fairly close limits. If the temperature drops below about 32 °C, hypothermia can occur, and temperatures above 45 °C can cause divers to burn. A diver may not notice a gradual change in inlet temperature, and in the early stages of hypo- or hyperthermia, may not notice a worsening condition. The suit is loosely attached to allow the water to flow freely. This causes a large transient volume of water (13 to 22 liters) to be retained in the suit, which can hinder swimming due to additional inertia. When properly controlled, a hot water suit is safe, comfortable and effective and allows the diver adequate control of thermal protection, however interruption of the hot water supply can be life-threatening. A diver will usually wear something under the warm water suit for protection against burns, chafing and personal hygiene. Hot water is supplied by a surface heating system, which is usually heated by burning diesel fuel, although electric versions are also available. The hot water supply hose to the umbilical is usually a 13 mm diameter opening and is connected to a supply manifold on the right side of the suit, which has a set of valves that allow the diver to control the flow to the front and rear of the torso, arms and legs, and to discharge supplies into environment if the water is too hot or too cold. The distributor distributes water through the suit through perforated pipes. The warm water suit is usually a one-piece neoprene suit, quite loose, to fit over a thin neoprene undersuit, which can protect the diver from burns in the event of a temperature control system failure, with a zipper on the front of the torso and on the lower part of each leg. Gloves and boots are worn that receive hot water from the ends of hoses for hands and feet. If a full face mask is worn, the hood can be supplied with a tube at the neck of the suit. Helmets do not require heating. The heating water escapes through the neck and cuffs of the suit through overlapping with gloves, boots or hood.

Dry suit in ice water (Figure 52). Dry suits are generally used where the water temperature is between -2 and 15 °C. Seals at the neck and wrists prevent water from entering the suit, and the opening for putting on and taking off the suit is usually closed with a waterproof zipper. The suit insulates the wearer by maintaining an insulating layer of air in the undersuit between the body and the suit shell (exactly the way thermal insulating clothing works above water) or by using the suit's waterproof expanded neoprene shell, which is inherently insulating in the same way as a wetsuit and which can usually be worn with additional insulating underwear.

Figure 52. Dry suit in ice water
Source: https://blueoctopusscuba.com/courses/dry-suit-diver, Accessed: July 9, 2023

Both laminated fabric and neoprene drysuits have advantages and disadvantages: a fabric drysuit is more adaptable to changing water temperatures because different clothing items can be placed underneath it. However, they are quite bulky and this causes increased towing and swimming effort. Woven materials are relatively inelastic and limit joint mobility unless inflated to a fairly loose fit. Additionally, if a dry suit malfunctions and floods, it loses almost all of its insulating properties. A neoprene drysuit is relatively fashionable like a wetsuit and is more elastic, but in some cases it does not allow for clothing to be placed underneath and is therefore less adaptable to different temperatures. The advantage of this construction is that even if completely flooded, it essentially becomes a clothing suit and will still provide a significant degree of insulation. Special dry suits made of strong outer rubberized fabric. They are worn by commercial divers who work in polluted environments, such as sewage or hazardous chemicals. The hazmat dry suit has integral boots and is sealed to the diving helmet and dry gloves to prevent any contact with hazardous material. Constant volume drysuits have a system that allows the suit to be inflated to prevent compression of the suit caused by increased pressure and to prevent excessive compression of the insulating underwear. They also have vents that allow excess air to escape from the suit during ascent. For added warmth, some dry suit users inflate their suits with argon, an inert gas that has superior thermal insulation properties compared to air. Argon is carried in a small cylinder, separate from the diver's breathing gas. This arrangement is often used when the breathing gas contains

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helium, which is a very poor insulator compared to other breathing gases.

When diving, gloves are often worn, as thermal protection, as protection from environmental and occupational hazards, or both. Both dry and wet gloves are available. Foot protection is usually worn when diving, either under the fins, or as foot protection during heavy diving, where the diver moves mainly by walking. In this case, the boots can be weighted for better stability when standing. Boots are an integral part of most dry suits, unless completed with integral socks. Boots that are not waterproof can be worn over integral boots or neoprene socks to protect against workplace hazards. Hoods are generally worn for thermal protection if the diver is not wearing a helmet. Dry hoods are available, but relatively rare, and the usual arrangement is a neoprene hood that is a separate unit or part of the suit.

Atmospheric diving suit is a small articulated submarine with one man of an anthropomorphic shape that resembles a suit of armor, with elaborate pressure joints that enable articulation while maintaining an internal pressure of one atmosphere (Figure 53). They can be used for very deep dives for extended periods without the need for decompression and eliminate most of the physiological hazards associated with deep diving. Divers don't even have to be skilled swimmers. Mobility and dexterity are usually limited by mechanical limitations, and the ergonomics of movement are problematic.

Figure 53. Atmospheric diving suit
Source: https://divermag.com/the-case-for-oneatmosphere-diving-exosuit/, Accessed: July 9, 2023

4.4 Bathysphere and bathyscaphe

The Bathysphere (Greek: βαθύς – bathus = 'deep' and σφαῖρα – sphaira = 'sphere') is a unique spherical deep-sea submarine that was unpowered and lowered into the ocean by cable, and was used for a series of dives off the coast of Bermuda from 1930 to in 1934 (Figure 54). The bathysphere was designed in 1928 and 1929 by the American engineer Otis Barton (1899-1992), which was used by the naturalist William Beebe (1877-1962) to study the undersea. Beebe and Barton dived together in the bathysphere, the first time a marine biologist had observed deep-sea animals in their authentic environment. Their dives set several consecutive world records for the deepest dive ever performed by a human. The record set by the deepest of them on August 15, 1934, at a depth of 923 m, lasted until Barton broke it in 1949. In 1928, American naturalist Charles William Beebe received permission from the British government to establish a research station on Nonsuch Island, Bermuda. Using this station, Beebe planned to conduct an in-depth survey of the animals that inhabit the ocean's 21 km^2 surface, from a depth of 3.2 km to the surface. Although his initial plan called for him to conduct this study by diving, Beebe soon realized that these methods were inadequate for a detailed understanding of deep-sea animals, and began making plans to observe them in their native habitat.

At the end of the 1920s, people who could safely descend only a few meters in diving helmets. Submarines then descended to a maximum of 117 meters, but had no windows, rendering them useless for Beebe's goal of observing deep-sea animals. The deepest in the ocean that any man had descended at this time was 160 m in an armored suit, but these suits also made movement and observation difficult. What Beebe hoped to create was a deep-sea vessel that could descend to a much greater depth than any human had ever descended, and would also allow him to clearly observe and document the animals of the deep ocean. Beebe's initial design called for a cylindrical vessel, and articles describing his plans were published in The New York Times. These articles attracted the attention of engineer Otis Barton, who had his own ambition to become a deep-sea explorer. Barton was certain that the cylinder would not be strong enough to withstand the pressure of the depth to which Beebe intended to descend, and sent several letters to Beebe proposing an alternative design. So many unqualified opportunists tried to join Beebe in his endeavors that Beebe ignored most of his mail, and Barton's first attempts to contact him were fruitless. A mutual friend of Barton and Beebe eventually arranged a meeting between the two, allowing Barton to present his design to Beebe in person. Beebe approved Barton's design, and the two struck a deal: Barton would pay for the vessel and all the other equipment that would go with it, while Beebe would pay other expenses, such as chartering a boat to raise and lower it, and as the owner of the vessel, Barton would follow Beebe at his dives in it. Barton's design called for a spherical vessel, as a sphere is the best possible shape to withstand high pressure. The sphere had openings for three 76 mm thick windows made of fused quartz, the strongest transparent material then available, as well as a 180 kg entrance hatch which had to be bolted before lowering. Initially, only two windows were mounted on the sphere, and a steel plug was mounted instead of the third window. Oxygen was supplied from high-pressure cylinders carried inside the sphere, while containers of lime and calcium chloride were mounted inside the sphere's walls to absorb exhaled CO_2 and moisture. The occupants of the Bathysfera were to circulate the air through these drawers by means of fans made of palm leaves. Casting of the steel sphere was handled by the Watson Stillman Hydraulic Machinery Company of Roselle, New Jersey, and ropes for raising and lowering the sphere were provided by John A. Roebling's Sons Company. General Electric provided a lamp to be placed just inside one of the windows to illuminate the animals outside the sphere, and Bell Laboratories provided a telephone system by which divers inside the sphere could communicate with the surface. The telephone and lamp power cables were sealed inside a rubber hose, which entered the Bathysphere body through the charging body [50].

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Figure 54. Bathysphere
Source: https://www.amusingplanet.com/2020/03/bathysphere-worlds-first-deepsea.html, Accessed: July 9, 2023
Source: https://www.pinterest.co.uk/pin/741405157383296584/, Accessed: July 9, 2023

After the initial version of the sphere was cast in June 1929, it was found to be too heavy to be lifted by the winch used to lower it into the ocean, so Barton needed to have the sphere melted down and cast again. The final, lighter design consisted of a hollow sphere of cast steel 25 cm thick, 1.45 m in diameter. It weighed 2.25 tons above water, although the buoyancy was reduced by 1.4 tons when submerged, and 910 meters of steel cable weighed an additional 1.35 tons. The first Bathysphere dives were carried out from the deck of a former British Navy ship called Ready, towed by the tug Gladisfen. The winch used to raise and lower the sphere was salvaged from a third ship, the Arcturus, on which Beebe had led two previous expeditions. One of Beebe's assistants, John Tee-van, was in charge of operations on the two ships, while Gloria Hollister was tasked with communicating with the two divers via telephone line and recording all observations they relayed to her.

A bathyscaphe is a deep underwater system consisting of a crew cabin similar to a bathysphere, but suspended below a float rather than from a surface cable, as in the classic bathysphere design (Figure 55). The float is filled with gasoline because it is readily available, buoyant, and, for all practical purposes, incompressible. The incompressibility of gasoline means that tanks can be constructed very easily, since the pressure inside and outside the tank is equal. In contrast, the crew cabin has to withstand a large pressure difference and is massively built. Buoyancy on the surface can be easily reduced by replacing gasoline with water, which is denser. Auguste Piccard (1884-1962), the inventor of the first bathyscaphe, coined the name bathyscaphe using the ancient Greek words βαθύς - bathys = deep and vessel - skaphos = vessel/ship. Descent of the bathyscaphe is done by overflowing the air tanks with seawater, but unlike a submarine, the water in the flooded tanks cannot be forced out with compressed air for ascent, because the water pressures at the depths for which the vessel is designed are too great. For example, the pressure at the bottom of the Challenger Deep is more than seven times the pressure in a standard "H-type" compressed gas cylinder. Instead, ballast in the form of iron shot is released for the bathyscaphe to ascend, and the shot is lost on the ocean floor. Iron shot containers are in the form of one or more containers that are open at the bottom throughout the dive, and the iron shot is held in place by an electromagnet on the neck. This device is safe to operate as it does not require power to climb; in fact, in the event of a power failure, the bullet disappears by gravity and the ascent is automatic. The first bathyscaphe was called FNRS-2, named after the Fonds National de la Recherche Scientifique, and it was built in Belgium from 1946 to 1948 by Auguste Piccard. (FNRS-1 was the balloon used for Piccard's stratospheric ascent in 1938). The drive was provided by battery-powered electric motors. There were 37,850 liters of aviation gasoline in the float. There was no access tunnel; the orb had to be loaded and unloaded while on deck. The first trips are described in detail in Jacques Cousteau's book The Silent World (1953).

Figure 55. Bathyscaphe FNRS-III, Toulon, France
Source: http://www.picture-worl.org/bateauboat-bathyscaphe-trieste-fnrs-iiitoulon-france.html, Accessed: July 9, 2023

Piccard's second bathyscaphe was actually the third ship Trieste, which the US Navy bought from Italy in 1957. It had two ballast water tanks and eleven buoyancy tanks that held 120,000 liters of gasoline (Figure 56).

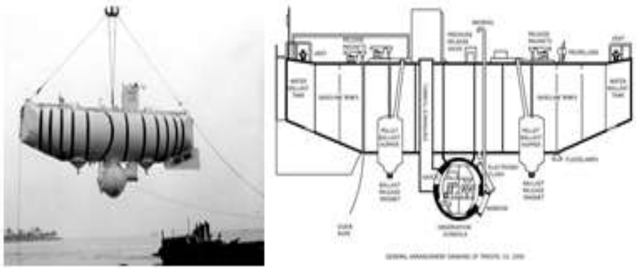

Figure 56. Bathyscaphe - ship Trieste
Source: https://www.britannica.com/technology/bathyscaphe, Accessed: July 9, 2023
Source: https://upload.wikimedia.org/wikipedia/commons/3/31/Trieste_nh96807.svg, Accessed: July 9, 2023

In 1960, Trieste, with Piccard's son Jacques Piccard and Don Walsh, reached the deepest known point on the Earth's surface, the Challenger Deep, in the Mariana Trench in the Pacific Ocean (Figure 57). The crew of the Trieste, who were equipped with a powerful light, noticed that the seabed was composed of diatomaceous fluid and reported observing a type of flat fish, similar to a sole, lying on the seabed.

Figure 57. Auguste Piccard on his bathyscaphe Trieste
Source: https://bertrandpiccard.com/3-generations/jacques-piccard, Accessed: July 9, 2023

4.5 Submarine

A submarine is a vessel capable of independent action under water (Figure 66). It is also sometimes used historically or colloquially to refer to remotely controlled vehicles and robots, as well as medium or smaller vessels, such as midget submarines.

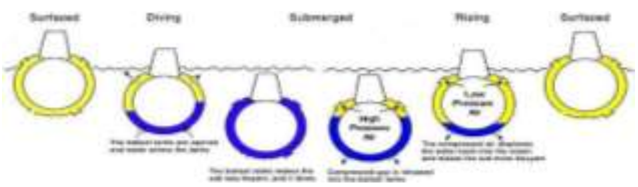

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Figure 58. Submarine operation
Source: https://www.quora.com/How-can-asubmarine-float, Accessed: July 9, 2023

Although experimental submarines had already been built, submarine design took off during the 19th century, and several navies adopted them (Figures 59,60,61). Submarines were first widely used during World War I (1914-1918) and are now used by many navies large and small. For military purposes, they are used to attack enemy surface ships (merchant and military) or other submarines, protect aircraft carriers, blockade, nuclear deterrence, reconnaissance, conventional land attack (for example, using a cruise missile) and covert insertion of special forces. Civilian uses of submarines include marine science, rescue, research, and facility inspection and maintenance. Submarines can also be modified to perform more specialized functions such as search and rescue missions or repairing submarine cables. Submarines are also used in tourism and underwater archaeology. Modern deep-diving submarines are descended from the bathyscaphe, which originated from the diving bell. Most large submarines consist of a cylindrical body with hemispherical (or conical) ends and a vertical structure, usually located amidships, that houses communication and sensing devices, as well as periscopes. On the back side there is a propeller (or pump jet) and various hydrodynamic control fins. Smaller, deep-diving and specialty submarines can deviate significantly from this traditional look. Submarines have one of the widest ranges of types and capabilities of any vessel. They range from small autonomous examples and one- or two-man submarines that operate for a few hours to vessels that can stay underwater for six months - like Russia's Typhoon class, the largest submarines ever built. Submarines can operate at greater depths than are survivable or practical for human divers.

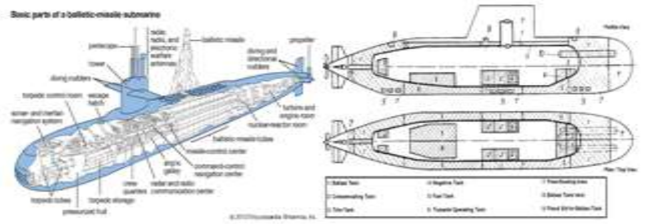

Figure 59. Design of a typical submarine
Source: https://www.britannica.com/technology/naval-architecture/Generalarrangement, Accessed: July 9, 2023
Source: https://www.marineinsight.com/navalarchitecture/submarine-design-uniquetanks-submarine/, Accessed: July 9, 2023

Figure 60. Construction of a typical submarine (DIY 1/350 German U-boat U-BOAT TYPE VIIC, model MX003)
Source: https://www.aliexpress.com/item/1892981002.html, Accessed: July 9, 2023

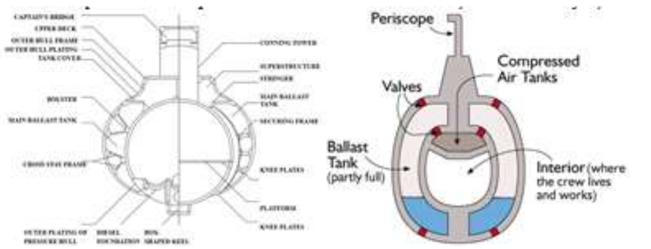

Figure 61. Submarine construction
Source: https://www.marineinsight.com/navalarchitecture/submarine-designstructure-of-a-submarine/, Accessed: July 9, 2023
Source: https://www.quora.com/How-dosubmarines-go-up-and-down-in-thewater, Accessed: July 9, 2023

While the main meaning of the term 'submarine' is an armed, submersible warship, the more general meaning is any type of submarine. According to naval tradition, submarines are still commonly referred to as 'ships', regardless of their size. In other navies with a history of large submarine fleets, these are also "boats"; in German it is Unterseeboot or U-Boot (underwater boat), and in Russian it is podvodnaya lodka (underwater boat). Although unofficially called 'boats', American submarines use the designation USS (United States Ship) at the beginning of their names, such as the USS Alabama. In the Royal Navy, submarines are still officially called 'boats', despite the markings 'Her Majesty's Ship'. In 1578, the English mathematician William Bourne (1535-1582) recorded in his book Inventions or Devises [51] one of the first plans for an underwater navigation vehicle. The first submarine whose construction has reliable information was designed and built in 1620 by Cornelis Jacobszoon Drebbel (1572-1633), a Dutchman in the service of James I (James Charles Stuart, 1566-1625). It was propelled by oars [52]. By the middle of the 18th century, dozens of patents for submarines had been issued in England. In 1747, Nathaniel Symons patented and built the first known working example of using a ballast tank for submergence. His design used leather bags that could be filled with water to sink the vessel. A mechanism was used to draw water out of the bags and cause the vessel to surface. In 1749, the Gentlemen's Magazine reported that a similar design had initially been proposed (1680) by Giovanni Borelli. Further design improvement stagnated for more than a century, until the application of new propulsion and stability technologies [53]. The first military submarine was the Turtle (1775), a manually operated acorn-shaped device designed by the American David Bushnell (1740-1824/1826) to accommodate one person. It was the first proven submarine capable of independent underwater steering and movement, and the first to use propellers for propulsion [53]. In 1800, France built a human-powered submarine designed by the American Robert Fulton (1765-1815), the Nautilus [53]. The French eventually abandoned the experiment in 1804, as did the British when they later considered Fulton's submarine design. In 1864, late in the American Civil War, the Horace Lawson Hunley (1823-1863) of the Confederate Navy became the first military submarine to sink an enemy vessel, the Union USP Housatonic [53]. In 1866, the Sub Marine Explorer was the first submarine to successfully dive, cruise underwater and surface under crew control. The design by the German-American Julius Hermann Kroehl/Kröhl (1820-1867) contained elements still used in modern submarines. The first submarine that did not rely on human power for propulsion was the French Plongeur (diver), launched in 1863, which used compressed air at 180 psi (1,200 kPa). Narcís Monturiol i Estarriol (1819-1885) designed the first

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air-independent combustion submarine, the Ictíneo II, which was launched in Barcelona, Spain in 1864. Military submarines first had a significant impact in the First World War. Forces such as German U-boats saw action in the First Battle of the Atlantic and were responsible for the sinking of the RMS Lusitania, which was sunk as a result of unrestricted submarine warfare and is often cited as one of the reasons for the US entry into the war. At the outbreak of war, Germany had only twenty U-boats available for combat, although these included the diesel-powered U-19 class vessels, which had a sufficient range of 8,000 km and a speed of 8 knots (15 km/h) to made it possible to operate effectively all over the British coast. In contrast, the Royal Navy had a total of 74 submarines, albeit of mixed effectiveness. In August 1914, a German flotilla of ten U-boats sailed from their base in Heligoland to attack Royal Navy warships in the North Sea in the first U-boat war patrol in history. During World War II, 314 submarines served in the US Navy, of which nearly 260 were deployed in the Pacific. When the Japanese attacked Hawaii in December 1941, 111 ships were operating; 203 submarines of the Gato, Balao and Tench classes were ordered during the war. During the war, 52 American submarines were lost to all causes, and 48 directly to hostilities. American submarines sank 1,560 enemy ships, with a total tonnage of 5.3 million tons (55% of the total number sunk). The first launch of a cruise missile (SSM-N-8 Regulus) from a submarine occurred in July 1953 from the deck of the USS Tunny, a World War II Navy ship modified to carry a nuclear warhead missile. Tunny and her sister ship, Barbero, were America's first nuclear deterrent patrol submarines. In the 1950s, nuclear power partially replaced diesel-electric propulsion. Equipment for the extraction of oxygen from seawater has also been developed. These two innovations gave submarines the ability to stay submerged for weeks or months. Most naval submarines built since then in the US, Soviet Union, Great Britain and France are powered by nuclear reactors. In 1959–1960, the first ballistic missile submarines were commissioned by both the United States (George Washington class) and the Soviet Union (Golf class) as part of a Cold War strategy for nuclear deterrence. During India's intervention in the Bangladesh Liberation War, Pakistan Navy's Hangor sank the Indian frigate INS Khukri. This was the first sinking of a submarine since World War II. During the same war, the Indian Navy was sunk by Ghazi, a Tench-class submarine on loan to Pakistan from the US. It was the first combat loss of submarines since World War II. In 1982, during the Falklands War, the Argentine cruiser General Belgrano was sunk by the British submarine HMS Conqueror, the first nuclear-powered submarine sunk in the war. Military submarines use several systems to communicate with remote command centers or other ships. One is the VLF (very low frequency) radio, which can reach a submarine either on the surface or submerged at a fairly shallow depth, usually less than 76 meters. ELF (extremely low frequency) can reach a submarine at greater depths, but has a very low bandwidth and is generally used to call a submerged submarine at a shallower depth that VLF signals can reach. The submarine also has the ability to float a long wire antenna to a shallower depth, allowing VLF transmission by a deeply submerged boat. By extending the radio mast, the submarine can also use a 'burst transmission' technique that lasts only a fraction of a second, minimizing the risk of the submarine being detected. A system known as Gertruda is used to communicate with other submarines. Gertrude is basically a sonar phone. Voice communication from one submarine is transmitted by low-power speakers into the water, where it is detected by passive sonars on the receiving submarine. The range of this system is probably very short, and it radiates sound into the water, which the enemy can hear. Civilian submarines can use similar, though less powerful, systems to communicate with support ships or other submarines in the area. With nuclear power or air-independent propulsion, submarines can remain submerged for months. Conventional diesel submarines must periodically resurface or snorkel to recharge their batteries. Most modern military submarines generate breathing oxygen by electrolysis of water (using a device called an 'electrolytic oxygen generator'). Atmospheric control equipment includes a CO_2 scrubber, which uses absorbent amines to remove the gas from the air and diffuse it into the waste pumped from the ship. It also uses a machine that uses a catalyst to convert carbon monoxide to carbon dioxide (removed by a CO_2 scrubber) and binds hydrogen produced from the ship's storage battery with oxygen in the atmosphere to produce water. The atmospheric monitoring system samples air from various areas of the ship for nitrogen, oxygen, hydrogen, R-12 and R-114 refrigerants, carbon dioxide, carbon monoxide and other gases. Toxic gases are removed and oxygen is replenished using an oxygen bank located in the main ballast tank. Some heavier submarines have two oxygen discharge stations (forward and aft). Oxygen in the air is sometimes kept a few percent less than the concentration in the atmosphere to reduce the risk of fire. Fresh water is produced either by an evaporator or a reverse osmosis unit. The primary use of fresh water is to supply feed water for reactor and steam plants. It is also available for showers, sinks, cooking and cleaning after the needs of the drive system are met. Seawater is used to flush toilets, and the resulting 'black water' is stored in a sanitary tank until it is blown off the ship using pressurized air or pumped overboard using a special sanitary pump. The black water discharge system is difficult to operate and the German Type VIIC boat U-1206 was lost with casualties due to human error while using this system. Water from the showers and sinks is stored separately in 'grey water' tanks and is discharged overboard using drainage pumps. Trash on modern large submarines is usually disposed of using a pipe called a Trash Disposal Unit (TDU), where it is compacted into a galvanized steel bucket. There is a large ball valve at the bottom of the TDU. An ice cap is placed on top of the ball valve to protect it, and the cans on top of the ice cap. The top shutter door is closed and the TDU is flooded and equalized with sea pressure, the ball valve is opened and the cans fall out with the help of scrap iron weights in the cans. The TDU is flushed with seawater to ensure it is completely empty and the ball valve is clean before closing it.

4.6 Selected examples of underwater architectural realizations

Today in the world there is a relatively large number of realizations of underwater constructions: research stations, railway and road tunnels, hotels, resorts, residences, nightclubs... Regardless of the differences between these structures, they have one thing in common - remarkable creativity in engineering and architecture. The results vary from the practical, like the Transbay tube connecting San Francisco and Oakland, to the particularly pronounced aesthetic, like the underwater suites at the Atlantis Dubai hotel. Below we give an overview of some particularly inspiring underwater constructions. Built in 1971, the underwater Ashizuri underwater observation tower is a perfect example of the Japanese idea of the future in the 70s (Figure 62). Designed by

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architect Yoshikatsu Tsuboi, Located in the heart of Ashizuri-Uwakai National Park, Tatsukushi Marine Park, Kochi Prefecture, the observatory stands out for its vibrant red color. It had a visible influence on Japanese architecture and engineering. The observatory is accessed by a bridge that stretches over the water at a height of 24 meters. The Ashizuri underwater observation tower offers a view of the seascape and the undersea. The structure consists of two levels - one above the water and one below. The underwater level can be reached by a spiral staircase that descends 7 meters below the water level. Once inside, visitors can hear the sound and echoes of the water while spotting tropical fish, colorful corals and exotic creatures. Different animals change in season from season to season. Girela, porcupine and butterfly fish can be seen all year round, while mass migrations of sardines and horse mackerel occur in winter. Barracudas, sea turtles and rays can be spotted in autumn. Architect Yoshikatsu Tsuboi's design is heavily influenced by Metabolism - the post-war Japanese architectural movement that fused ideas of architectural megastructures with those of organic biological growth. It also takes cues from the pavilions built at the EXPO '70 World Exhibition held in Osaka in 1970. The observatory is the fourth oldest existing underwater tower in Japan.

Figure 62. Ashizuri Underwater Observation Tower, Tatsukushi Marine Park, Kochi Prefecture, Japan, 1971 (Architect: Yoshikatsu Tsuboi)
Source: https://www.designboom.com/architecture/ashizuri-underwater-observationtower-japan-04-07-2021/, Accessed: July 9, 2023

The Transbay Tube is an underwater rail tunnel that carries four Bay Area Rapid Transit transbay lines under the San Francisco Bay between the cities of San Francisco and Oakland, California. The pipe is 5.8 km long. Including approaches from the nearest stations (one of which is underground), it is 10 km long. The greatest depth is 41 m below sea level. Built using the submerged pipe technique, the pipe is built on land, transported to the site, then submerged and attached to the bottom - primarily by packing the sides with sand and gravel.

The Transbay Tube was opened in 1974 (Figure 63). It was the last segment of the opening of the original BART (San Francisco Bay Area Rapid Transit District) plan [54]. All BART lines except the Berryessa-Richmond line run through the Transbay tube, making it one of the busiest sections of the system in terms of passenger and train traffic. During the longest journeys, over 28,000 passengers per hour travel through the tunnel. BART trains reach top speeds in the tube of nearly 130 km/h, which is twice the average speed of 58 km/h common elsewhere in the system. Seismic research began in 1959, including drilling and testing programs in 1960 and 1964, and the installation of a seismic recording system on the bottom of the bay. The pipe route was changed after preliminary surveys failed to identify a continuous bedrock profile, requiring more precise drilling and sounding of the bay floor. The route was chosen to avoid bedrock as much as possible, so that the pipe could bend freely, avoiding concentrated bending stresses. Design concepts and route alignment were completed by July 1960. A 1961 report estimated the cost of the Transbay Pipe at $13,272,000 (equivalent to $1,149,400,000 in 2020). The construction of the pipe began in 1965, and the construction was completed after the last part was lowered on April 3, 1969. Before it was equipped, the tube was opened for visitors to walk through a small section on November 9, 1969. The tracks and electrification needed for the trains were completed in 1973, and the tube opened for service on September 16, 1974, five years after the originally scheduled completion date, after the California Public Utilities Commission's concerns about the automatic dispatch system were allayed. The first test journey was performed by a train under automatic control on August 10, 1973. Train no. The 222 traveled from West Oakland to Montgomery Street in seven minutes at speeds of 109 to 113 km/h and returned in six minutes at a full speed of 130 km/h, carrying approximately 100 passengers, including BART officials, dignitaries and reporters. The tunnel was placed in a trench 18 meters wide with a gravel foundation 0.61 meters deep. Lasers were used to guide the direction of the trench and lay the gravel foundation, maintaining route accuracy within 76 mm for the trench and 46 mm for the foundation. The construction of the trench required the excavation of 4,300,000 m3 of material from the bay. The structure consists of 57 separate sections that are built on land at the Bethlehem Steel shipyard at Pier 70 and hauled out into the bay by a large catamaran tug. After the steel shell was completed, watertight bulkheads and poured concrete were installed to form the inner walls and the 0.70-meter-thick track. They were then moved into position (placed above where they were supposed to sit) and the barge was moored to the floor of the bay, acting as a temporary tension platform. The section was ballasted with 450 tonnes of gravel before being lowered into a trench filled with soft soil, mud and gravel to level the bay bottom. After the part was installed, divers connected it to the parts that had already been placed under water, the partitions between the installed parts were removed, and a protective layer of sand and gravel was packed on the sides. Cathodic protection is provided to resist the corrosive action of salt water in the bay.

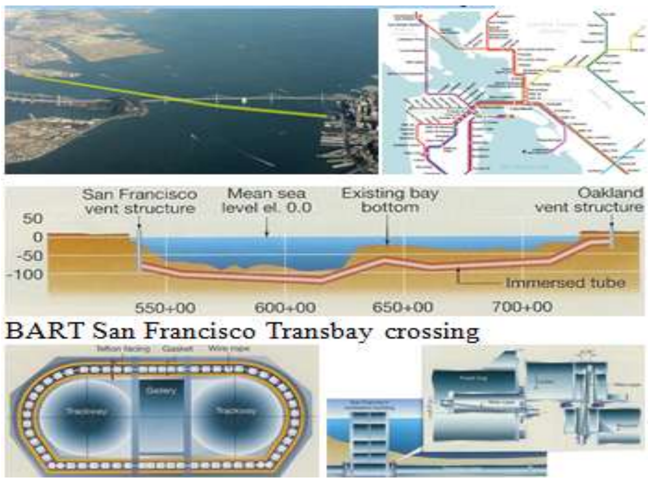

Figure 63. Transbay Tube, 1974
Source: https://www.thetransportpolitic.com/2010/01/06/crossing-the-bay-again-but-not-necessarily-with-bart/, Accessed: July 9, 2023

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Source: https://www.bart.gov/about/projects/eqs/retrofit, Accessed: July 9, 2023

Underwater restaurant Ithaa (Dhiwehi: mother-of-pearl), located on the island of Maldives, on the atoll of Alif Dhaal in the Republic of Maldives, is an acrylic construction located at a depth of 5 meters below sea level [55] (Figure 64). Built almost entirely from transparent acrylic, the restaurant offers its guests a panoramic view of the marine life that surrounds the restaurant. The restaurant, with an area of about 500 m^2, was built using the floating method and below. After being assembled in Singapore, Ithaa was transported on a barge and then lowered with sandbags onto the steel piles that form its foundation. The mainly acrylic structure measuring 5 x 9 meters has a capacity of 14 people, it is enclosed in R-Cast acrylic with a transparent roof that offers a panoramic underwater view of 270 °. The restaurant was designed and built by M. J. Murphy Ltd - a New Zealand-based design consultancy - and opened in April 2005, as the world's first underwater restaurant. The Ithain restaurant is accessed via a spiral staircase in a thatched pavilion at the end of the pier. It is interesting that the Tsunami that followed the earthquake in the Indian Ocean in 2004 had a peak of 0.31 meters below the entrance to the staircase and did not cause any damage to the restaurant. The restaurant is also used for private parties and weddings. In April 2010, at the celebration of Itha's fifth anniversary, the restaurant could be booked as a place to stay overnight. Promotion of the underwater apartment continued until April 2011. In February 2004, the Crown Company in the Maldives approached M. J. Murphy Ltd. in order to create a unique underwater restaurant. Initially, Crown envisioned an underwater restaurant with flat walls and glass windows. Later, they began to favor Mike Murphy's (M.J. Murphy Ltd.) R-Cast acrylic tunnel, a product of Reynolds Polymer Technology, Inc. in the USA. This tunnel was also designed for The Kuala Lumpur National Science Centre, the world's largest aquarium tunnel. Work on technical projects and drawings for Itaha began in March 2004. Murphy initially planned to build the structure on Rangali Beach. After building on land, Ithaa would be winched into the water. Technical challenges, limited resources, and quality control issues were anticipated in building the 175-ton structure. So the decision was made to build Ithaa in Singapore instead. In May 2004, the construction of Ithae in Singapore began. In October 2004, construction work was completed, including the installation of 5-meter wide acrylic arches, air conditioning and electrical ducts. On November 1, 2004, Ithaa was lifted onto an ocean barge for transport to the Maldives, which took 16 days to get there. At that moment, Ithaa weighed 175 tons. On November 19, 2004, Ithaa was sunk with the help of 85 tons of heavy sand ballast loaded into her belly. It was accurately maneuvered onto four steel piles that were vibro-hammered 4 to 5 meters into the seabed, and then the structure was attached to the steel piles with concrete. The estimated lifespan of the restaurant is 20 years.

Figure 64. Ithaa Underwater Restaurant, Maldives Island, 2005 (Architects: M. J. Murphy Ltd)
Source: https://trends.archiexpo.com/project-212533.html, Accessed: July 9, 2023

The Atlantis Hotel in Dubai is located on Palm Jumeirah in the United Arab Emirates, a man-made island in the shape of a palm leaf. Although most of the building is above ground, the hotel has several underwater suites 20 meters below sea level [56] (Figure 65). After taking the elevator down to the apartments, guests are greeted by floor-to-ceiling windows with a view of sea animals, even from the bed and bathtub. Although details of the construction of the underwater suites are scarce, the above-ground construction involved modular units, which could also be used for subsea. Atlantis The Palm in Dubai was the first resort built on the island, and is themed around the myth of Atlantis. It also includes various Arabic elements. The resort was opened on September 24, 2008 as a joint venture between Kerzner International Holdings Limited and Istithmar. The resort with 1,548 rooms has two accommodation wings, consisting of the east and west towers, connected to each other by the Royal Bridge suite. It is complemented by the Aquaventure water park and the Lost Chambers aquarium, home to over 65,000 marine animals. Underwater apartments Poseidon and Neptun at Atlantis Palm regularly appear on lists of the most unique accommodation units in the world. The upper, entrance floor is on the ground floor, while the master bedroom and bathroom are submerged. Almost floor-to-ceiling windows in the bedroom and bathroom face the Ambasador Resort lagoon, home to a multitude of exotic sea creatures. In March 2012, Istithmar bought Kerzner's 50 percent stake in the property for USD 250 million. The property continues to be managed by Kerzner International Resorts. Atlantis The Palm was designed by Wimberly, Allison, Tong and Goo (WATG), an international company specializing in luxury hotels. The main contract for the project was awarded to Laing O'Rourke, a UK-based multinational construction company. Laing O'Rourke was responsible for the design and construction phases of the 23-story hotel and water park. After Laing O'Rourke built the hotel, it was officially opened on September 24, 2008. In October 2007, the hotel received a shipment of 28 bottlenose dolphins from the Solomon Islands, to be used as part of their aquarium exhibit, called Dolphin Bay. The move has been condemned by several environmental groups, particularly due to the fact that the Solomon Islands government has previously banned the export of dolphins (following a similar controversial shipment to Mexico). Hotel managers said that while the dolphins are trained to interact with guests, they will not appear in any shows or circus acts. They also stated that the health of the dolphins is paramount, and since these dolphins are not an endangered species, their delivery was not a

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problem. The agreement was reached with the approval of the governments of the United Arab Emirates and the Solomon Islands, through the Solomon Islands Marine Mammal Education Center and Exporters Limited.

Figure 65. Hotel Atlantis, Dubai, 2008 (architects: Wimberly, Allison, Tong and Goo - WATG)

Source: https://www.forbestravelguide.com/hotels/dubai-united-arab-emirates/atlantisthe-palm, Accessed: July 9, 2023

Source: https://www.agoda.com/atlantis-thepalm-dubai/hotel/dubaiae.html?cid=1844104, Accessed: July 9, 2023

Source: https://www.breakingtravelnews.com/news/article/new-underwater-yogaclass-at-atlantis-the-palm/, Accessed: July 9, 2023

Subsix is located off the coast of the private island of Niyama in the Maldives (Figure 66). It is the only underwater nightclub in the world, and it was opened in 2010 [57,58]. Submerged 18 meters underwater and with floor-to-ceiling windows, Subsix nightclub offers its guests a view of vibrant coral and marine life during the night of dancing. The Subsix structure was built off-site and then brought and lowered into place Subsix Nightclub has a complex structure due to its size and distance from the coast (about 500 meters) and is only accessible by boat.

Figure 66. Subsix Nightclub, Niyama Island, Republic of Maldives, 2010.

Source: https://www.themilliardaire.com/en/restaurants/subsix-per-aquum-niyamamaldives-15018/, Accessed: July 9, 2023

Source: https://www.pooleassociates.com/Niyama-Maldives%20PhaseII-SUBSIX.htm, Accessed: July 9, 2023

Source: https://www.niyama.com/en/dining/subsix, Accessed: July 9, 2023

Located on the island of Pemba in the Tanzanian archipelago of Zanzibar, the Manta resort was built in 2007 according to the project of the Swedish design firm Genberg underwater hotels (Figure 67). It has an extraordinary jewel in its crown of luxury, the underwater sea room [59,60]. Manta Resort's underwater suite is a floating platform with an above-ground and underwater part, and both parts are assembled off-site. After construction, the platform was towed into place and then anchored by attaching steel cables to the four corners of the building as well as to the seabed. There are three levels: the landing deck is where visitors disembark from the ship and the living and bathroom area. The platform has beds and sunshades for relaxing during the day and stargazing at night (due to the lack of light pollution, the Milky Way and planets can be seen). Below the sea level is a submarine room, a 'bubble', from where you can see the fish next to the glass, from the side of the water. There are even fish that have settled around the structure. The room is located in the 'blue hole' in the middle of a living coral reef, so it is a perfect place for diving enthusiasts.

Figure 67. Manta Resort, Pemba Island in the Tanzanian Zanzibar archipelago, 2007 (architects: Genberg underwater hotels)

Source:https://themantaresort.com/https://www.facebook.com/themantaresort/photos/pcb.2057548157627831/2057548010961179/?type=3&theater, Accessed: July 9, 2023

Source: https://www.bbc.com/travel/article/20131119-an-underwater-hotel-opens-inafrica, Accessed: July 9, 2023

”We believe that the future can be found under the sea. Reefs cover less than one percent of the ocean floor, but support twenty-five percent of all marine life. More than fifty species of native coral live in the Arabian Gulf, where our science-based initiatives are helping coral reefs recover from some of the serious challenges they face today, including climate change and more acidic oceans. Our Coral Institute strives to find new ways to reconstruct and restore damaged coral reefs as part of our commitment to sustainability. Our underwater lifestyle ventures brought us the iconic Floating Seahorse, the first luxury marine-style retreat to come complete with its own natural coral reef. Designed and developed by one of our companies based in Dubai, the Floating Seahorse has received worldwide media attention and investor interest on a global scale” [61]. The underwater level is spacious, with two bedrooms and an en-suite bathroom, and is equipped with two panoramic floor-to-ceiling glass windows offering stunning views of the colorful coral reefs teeming with marine life from the Arabian Gulf - including bright striped clownfish, elegant deep blue angelfish, majestic purple tang, peaceful seahorses, lovely pink anemones and black ink sea urchins. The sea-level deck offers a large living area with privacy windows that allow natural light to enter, panoramic sliding doors that open onto the deck, a ladder for seawater access and a smart and sustainable recreational area - a hammock. The sky deck features panoramic views of the Dubai skyline and seascape, an alfresco dining area with privacy shades, a Jacuzzi and a sunbathing area. The deck is surrounded by a

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transparent fence that allows an unobstructed view of the outdoors. The structure of the Floating Seahorse consists of marine-grade concrete below surface level and a super-lightweight aluminum skeleton above water and a Glassfiber Reinforced Plastics (GRP) cladding with a premium yacht gloss finish. The Floating Seahorse villas have a 100-year guarantee, thanks to the robust waterproof concrete mix of the Kleindienst Group. This exclusive and protected concrete also allows corals to grow on it, which will eventually cover the underwater area with marine life (Figure 68). The project is part of the vision of Mr. Josef Kleindienst who wanted to see underwater treasures, marine life sightings and stunning underwater scenery without getting wet in the ocean. His passion for creating an unsuspected experience made him travel globally and study underwater projects.

Figure 68. Floating Seahorse, Dubai, UAE, 2020 (architects: Kleindienst Group)
Source: https://www.kleindienst.ae/, Accessed: July 9, 2023
Source: https://inhabitat.com/breathtakingunderwater-villas-let-you-sleep-withthe-fishes-in-dubai/floating-seahorsesby-kleindienst-group-7/
Accessed: July 9, 2023

In the summer of 2012, Sergio Gamberini, founder of the diving equipment company Ocean Reef Group, enjoyed a vacation at sea on the Italian Riviera (Figure 69). Resting between dives, he enjoyed walking along the edge of the sea talking with friends. One day the conversation turned to his other passion: gardening. He wondered, would it be possible to create the perfect conditions for growing basil, the most popular local herb and an essential ingredient for pesto? Like most plants, basil prefers sheltered, sunny locations with well-drained soil and a constant, stable temperature. Glancing at the sea, Gamberini had an unusual idea: why not try to grow basil underwater? Bizarre as it may seem, the idea made perfect sense because it came from a diving fiend and an innovation-oriented entrepreneur. In fact, it would allow Mr. Gamberini to combine two of his passions: diving and gardening. He made a few phone calls and, with the help of a team from the Ocean Reef Group, began experimenting, sinking transparent biospheres 6 meters below the sea surface and filling them with air. Nemo's Garden is not only a technological enterprise, the goal of which is to make underwater farming an economically profitable, long-term alternative form of agriculture, but above all it is an ecological and self-sustaining project. The use of renewable energy obtained from the Sun and fresh water obtained from seawater desalination make Nemo's garden a self-sustaining system. Microclimates and thermal conditions within biospheres are optimal for plant growth and crop yields, unlike conventional greenhouses, but do not require additional energy sources [62].

Figure 69. Ocean Reef's Nemo's Garden underwater farming concept, 2012 (architect: Sergio Gamberini)
Source: https://inhabitat.com/welcome-to-nemos-garden-where-plants-grow-under-the-sea/, Accessed: July 9, 2023

The underwater restaurant Under in Norway was built in 2019 according to the project of the renowned Norwegian design firm Snøhetta (Figure 70). Unlike the majority of underwater restaurants built so far, in 'warm seas', Under will not host guests with a tropical climate and fantastic seascapes of the Indian Ocean, but the rugged coast of Lindesnes in Norway [63]. The Norwegian coast dwells in such beauty, and the client's ambition is to attract more people to experience the Norwegian nature and rough coast up close. The client, or rather clients, the Gaute brothers and Stig Ubostad, actually approached Snøhetta with preliminary sketches at another nearby location. The underwater restaurant building is designed as a concrete tube that brings people from the land to the sea and is a perfect harmony of physical (food) and intellectual understanding and visualization of marine life at the southernmost tip of Norway. Architecture is the key that brings these elements together. The striking auditorium-like form descends below the water's surface ready to display a robust underwater world for 80-100 guests at any given time. The view from the restaurant will be framed by a huge 11m x 4m acrylic window and dimmed lighting that will be used to observe the wildlife and seabed outside as they change through the weather conditions and seasons. The designers consulted with marine biologists to avoid disturbing marine life. The architects used a kind of theatrical approach to lighting in their design, of course trying to hide the lights and being very careful with it. It will be possible to change the intensity of the light as well as the color to match the landscape outside the window. Guests will learn about the context of the site through info boards on the path leading to the restaurant, providing a story about marine biodiversity and the Norwegian coast. When they arrive, they will enter the top of the three levels, the cloakroom area. They will then move down, through a passage that bridges the waterline crossing, above-below. This will be accentuated by a tall window that conveys a sense of depth and space bathed in muted, coastal colors of shells, stones and sand. From the bar, guests will look down into the restaurant at the level of the seabed, where the tables will naturally be oriented around a large window. Here, the aesthetic will blend darker blues and greens inspired by the seabed, seaweed and rough seas, with warm oak details that help foster a cozy, intimate atmosphere. Oak will also be used elsewhere, contrasting with the building's concrete envelope. The heat pump will use the stable temperature of the seabed to heat and cool the building throughout the year. The building itself covers 600 m2, weighs 1,500-2,000 tons and, at restaurant level, sits five meters below the surface of the water. It was crucial that the final shape

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could coexist with the force of the ocean, so the concrete shell is half a meter thick, and the acrylic windows are about 25 cm. The slightly curved shape allows the volume to better withstand water pressure and the impact of waves, with the design said to be able to withstand a hundred years of waves. The concrete shell of the restaurant was cast in the town of Mandal in southern Norway, and the building was built on a barge so that it was lowered into the sea after completion. It was in July 2018, when the structure was attached to steel rods to guide it as it descended to the seabed. Now in situ, it is designed to become part of the marine environment, with a rough concrete shell an ideal surface for holding mussels. The building will become an artificial mussel reef, with the added benefit of the mussels purifying the seawater, thus attracting more marine life and giving guests a better view outside the restaurant. In addition to opening its doors to guests, serving local specialties inspired by the water and under the water, Under will also function as a research center for marine life. Interdisciplinary research teams will study marine biology and fish behavior, and researchers will also work to optimize living conditions for marine life in the restaurant.

Figure 70. Underwater restaurant Under, Norway, 2019 (architects: Snøhetta)
Source: https://www.cladglobal.com/architecture-designfeatures?codeid=33510&source=home&p=12, Accessed: July 9, 2023

Hurawalhi Maldives Island is home to a range of overwater villas and bungalows as well as beachfront rooms. They have several restaurants and bars overlooking the crystal clear water.

One of the unique things to do in the Maldives is to dine at the underwater restaurant 5.8 at Hurawalhi Maldives. 5.8 Undersea Restaurant (the world's largest underwater restaurant made of glass) in Hurawalhi Maldives fascinates with the extravagance of the choice of dishes and top equipment (Figure 71). It is also a place of art. It seems that the best way to see and experience the 5.8 underwater restaurant in its best light is dinner, when the visitor can observe the surroundings in (still) daylight with a change of scenery during sunset [64]. Located on Lhaviyani Atoll in the Maldives, this five-star luxury resort was designed by Japanese architect Yuji Yamazaki of YYA New York and is owned by Crown & Champa Resorts. It is a 40-minute seaplane flight from Male International Airport. It consists of 90 spacious, modern villas. Sixty villas are above the water, and 30 are on the beach. Some of the villas have swimming pools.

Figure 71. 5.8 Undersea Restaurant, Hurawalhi Resort, Maldives (architect Yuji Yamazaki of YYA New York)
Source: https://www.withhusbandintow.com/underwater-restaurant/, Accessed: July 9, 2023
Source: https://www.hurawalhi.com/dining/, Accessed: July 9, 2023

Muraka is a luxury vacation home in the Maldives that has a suite and underwater bedrooms in the shape of an aquarium where guests can watch marine life while resting, washing and dressing [65]. The rooms and bathrooms are at a depth of about 6 meters below the surface of the water (Figure 72). Local architect Ahmed Saleem teamed up with the New York firm of architects Yuji Yamazaki to design Muraka as a private vacation villa at the Conrad Maldives Rangali Island Resort. The villa consists of a slender upper floor above the water, which contains a kitchen, living room and dining room, and three bedrooms. The additional bedroom is submerged in water and enclosed in 18 cm thick curved acrylic walls. Guests arrive at the villa by private seaplane and enter along the wooden jetty that leads to the upper floor. A spiral staircase that has windows facing the sea on the way or an elevator, then descends to the 100 m^2 underwater apartment. A passage between two smaller rooms for a bathroom and a built-in wardrobe with windows to the water leads to the bedroom, with a portal to the adjacent sitting area. Yuji Yamazaki, who was responsible for designing all the interiors throughout Muraka, chose a dark and moody aesthetic for the room, including lots of leather flooring and carpets. Inside the bedroom, he integrated long benches and a headboard into the walls. The interior design and many finishing details are inspired by the luxurious airplane cabin. The blackout curtain was custom-made to allow for total blackout-a feature Saleem described as one of the most challenging aspects of the project. Saleem, who previously owned Rangali Island Conrad Maldives, launched the Muraka project to follow the resort's Ithaa underwater restaurant. He enlisted Mike Murphy, an engineer and expert in aquarium technology, to build a heavy suite and submerge it. The island's isolated location, accessible only by boat or seaplane, was also a key issue. The solution was to build the apartment as three parts that could be fabricated on land and then transported by barge to the site, where it was then welded. The 600-ton structure was lifted by a crane and placed in the water, where it was attached to concrete piles. Divers were on hand to help get the suite into place. Unlike the lower level, the main level is decorated in a light palette, including white painted walls, gray, marble floors and dark wood. It has an open plan kitchen, living room and dining room. Long, spacious sliding glass doors offer a view of the water and open onto a wooden deck, where you can jump straight into the sea. The outdoor space is completed by an infinity pool, a shower, a dining table and an open-air living room.

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Accessed from the living room, the master bedroom is joined by its own bathroom where guests can relax in the bathtub and enjoy the view of the sea through the large windows. There are two additional bedrooms designed to accommodate children and a nanny and a small gymnasium. Muraka, which translates to coral, was completed in 2018 and is available to rent for $22,000 per night during peak season. The price includes a chef who prepares meals for guests and a private boat to explore the island. The high level of service (private butler and private chef available 24 hours a day, on-call fitness trainer and spa treatments, private jet skis, dedicated tunnel viewing theater) make Muraka one of the most luxurious residences in the world. Villa Muraka was designed by the Japanese architect Yuji Yamazaki.

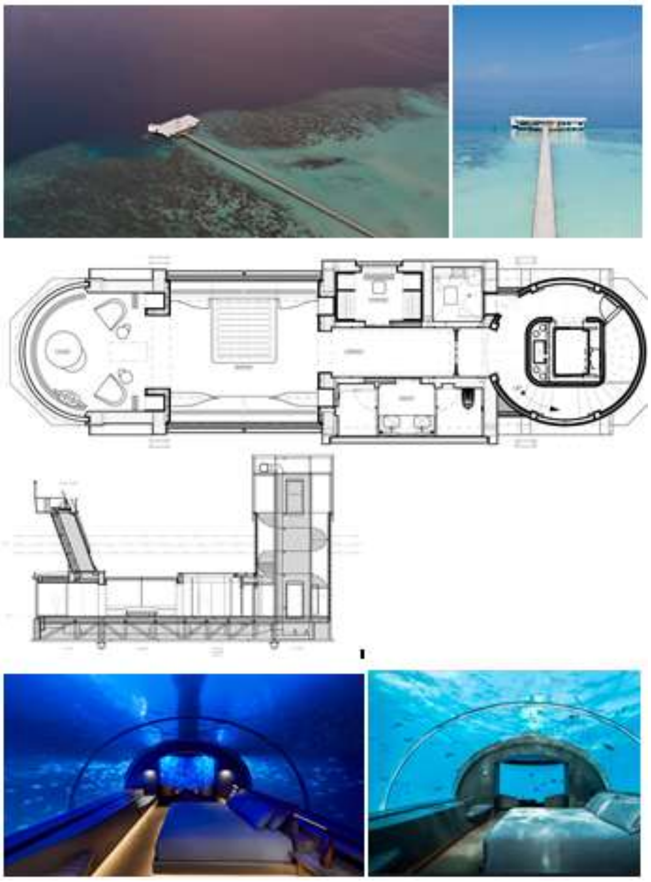

Figure 72. Muraka Villa at Conrad Maldives Rangali Island, 2018 (Architects: Ahmed Saleem and Yuji Yamazaki)
Source: https://www.cladglobal.com/architecture-designfeatures?codeid=33510&source=home&p=12, Accessed: July 9, 2023
Source: https://www.conradmaldives.com/stay/the-muraka/, Accessed: July 9, 2023
Source:https://www.dezeen.com/2019/11/21/the-muraka-underwater-bedroom-conradmaldives-rangali-island-resort-yujiyamazaki-ahmed-saleem/, Accessed: July 9, 2023

5. Conclusion (Perspectives)

Perspectives of underwater architecture can be seen in the light of perspectives of architecture in general [1,66,67]. However, perspectives in architecture, regardless of the historical period, have their constant as well as a number of more or less variable dimensions appropriate to the specific time and space, that is, to the natural and social environment. The constant perspective in architecture is related to man, that is, confirmation of his true values. At the same time, some requirements of architecture according to human needs are universal and timeless and, as such, are prescribed by standards at the world, regional or national level. It is about the so-called definition area of human comfort in the field of thermodynamics, acoustics and lighting [1,66,67]. Perspectives of underwater architecture are based on the principles discussed in chapters 2. Man and 3. Limits. Actual realizations will be conditioned by the progress of technique and technology, that is, they will be dictated by the social environment. According to the author's typology of architecture [1,66,67], for the perspectives of architecture in general, the following types are particularly interesting: S-type (architecture in the free space of the Universe), SB-type (architecture on other celestial bodies) and EW-type (underwater architecture). Exactly ten years after the publication of this typology, humanity experienced the first stay in space in a private arrangement, the flights of businessman Richard Branson (July 12, 2021) and Jeff Bezos (July 20, 2021), (Figure 73).

Figure 73. Left: Richard Branson (July 12, 2021) and Jeff Bezos (July 20, 2021) are the first visitors to space in a private arrangement. Right: Jeff Bezos' flight into space (July 20, 2021)
Source: https://www.aljazeera.com/news/2021/7/20/jeff-bezos-flight-to-edge-of-spacekey-questions-answered, Accessed: July 9, 2023

Richard Branson became the first person to fly into space on a rocket he financed (Fig. 4.2). The supersonic space plane, developed by his company Virgin Galactic, took off early Sunday (July 12, 2021) into the skies above New Mexico, carrying Branson and three crew members. Branson—along with Virgin Galactic employees Beth Moses, Colin Bennett, and Sirisha Bandla, and pilots Dave Mackay and Michael Masucci-boarded SpaceShipTwo, the winged, single-rocket engine the company has been developing for nearly two decades. Attached beneath a massive twin-hulled mother ship, named WhiteKnightTwo, the vehicle took to the skies at 8:30 a.m. MT and climbed about 15 km into the air. Jeff Bezos, the richest man in the world, aboard his company Blue Origin's New Shepard, made (July 20, 2021) a suborbital flight as part of a history-making crew-another milestone in the new era of private space travel. The American billionaire and founder of Amazon took off from a desert site in West Texas on a trip nine days after British rival Richard Branson took off on the successful maiden suborbital flight of his rival Virgin Galactic from New Mexico. In addition to all that has been practically realized so far in terms of underwater architecture, we should remember the 'visions of the underwater world' that have long been presented by artists - writers of science fiction novels and creators (and screenwriters) of science fiction films. It was the works of this type that 'paved the way' for concrete architectural realizations. The Deep South, directed by Bret Haaland, written by Joseph Stewart Burns, is the 12th episode in the second season of the American animated television series Futurama (Figures 74,75). It originally aired on the Fox network in the US on April 16, 2000.

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Figure 74. Futurama undersea city
Source: https://www.imdb.com/title/tt0584462/, Accessed: July 9, 2023
Source: http://theinfosphere.org/File:Time_keeps_on_slipping.png, Accessed: July 9, 2023

Figure 75. Futurama undersea city
Source: https://www.rethinkingthefuture.com/designing-fortypologies/a2442-history-and-futureof-underwater-architecture/ Accessed: July 9, 2023

The way people breathe underwater and the depth of the structure are linked, dictating the way the structure should be created as well as the air mix people will need to breathe in their underwater city. It seems that humans should not build colonies deeper than 300 meters, and ideally at much shallower depths. This is because the pressure at these depths would not only require very thick walls, but would also require long periods of decompression when returning to the surface. At these depths, people need to take extra measures to ensure a healthy ratio of oxygen to other gases in the air, as the body requires different levels of different components of air when under pressure. Plants and artificial light could be used to supply oxygen, but nitrogen or helium will also be needed. On the bright side, living at the bottom of the ocean could give humans easy access to seafood and sea plants. There are aquanauts currently living under water, who can subsist in part by spearfishing, combined with canned food. More traditional meals and even fresh water could be transported through tunnel or hose systems connected to the surface. The paradox is that scientists and explorers today have better maps of Mars than the ocean floor on Earth. To date, humans have explored only 3% of the ocean. Life under water could help scientists better understand the planet and the evolution of life on Earth. In addition, there are likely a number of yet-to-be-discovered resources on the ocean floor. Experts predict that there could be an immeasurable amount of minerals and metals that could be used to improve humanity and even help further build underwater cities. Architects of the design firm Shimizu Corporation from Tokyo have already designed a project worth 26 billion dollars to create an underwater city (Figure 76). Their project would enable thousands of people to live very comfortably underwater. Although most of it is still just a concept, Ocean Spiral City would be located below sea level off the coast of Tokyo. With its massive turbines, the city would be powered by the power of waves, tides and ocean currents, supporting those who would live within the structure. The structure could support 5,000 people and would include laboratories, schools and residential areas. An underwater city could become a reality around 2030.

Figure 76. Ocean Spiral City (proposal of Shimizu Corporation architects)
Source: https://interestingengineering.com/7-things-you-should-know-about-thefuture-of-underwater-cities, Accessed: July 9, 2023

Currently, humans have the ability to create underwater colonies that could support more than 100 people. As Stanford University biology professor Ian Koblick states: "There are no technological barriers. If you had the money and the needs, you could do it today" [68,69]. Hydropolis Underwater Hotel and Resort is an underwater hotel in Dubai for which the project was proposed by architect Joachim Hauser (Figure 77). It would be the first multi-room underwater hotel in the world. Announced in 2005, plans were put on hold until 2014. The hotel is planned on a location in the Persian Gulf near Dubai with the mediation of Hans Peter Pesenhofer according to the plans of Siemens IBC (Professor Roland Dieterle) in collaboration with the German designer Joachim Hauser and with the approval of the Dubai Development & Investment Authority (DDIA). The original plan of the hotel was to be located 20 meters underwater along the coast of Jumeriah Beach. The hotel plan covers an area of 260 hectares, which is equivalent to the area of Hyde Park in London. The cost of building Hydropolis would be around 600 million euros, which will make Hydropolis one of the most expensive hotels ever built. The hotel was designed by Joachim Hauser and Professor Roland Dieterle, and it is planned to consist of three segments: a land station, a connecting train and an underwater hotel. The idea of architecture represents the connection between man and water. The initial planned opening year was 2006, but due to financial reasons and disagreements with the DDIA, the project was canceled by the DDIA as early as October 2004. Hydropolis Holdings LLC Dubai had the original intellectual property rights to Hydropolis. The underwater hotel will be similar in structure to a jellyfish. To withstand underwater pressure, the main structure of the hotel is a dome made of Plexiglas, reinforced with concrete and steel. The underwater hotel will consist of 220 underwater suites priced at $5,500 per night. In addition to the underwater suites, Hydropolis plans to have many other underwater accommodation facilities, including restaurants, a spa, a cinema, a ballroom and bars. It is planned that the underwater hotel will not only be a place for permanent guests, but also a place for visitors-researchers.

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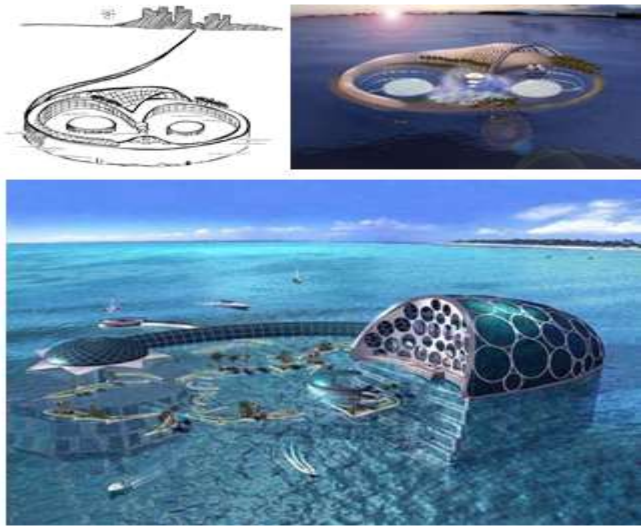

Figure 77. Hidropolis, Dubai, UAE (Project, 2005-2014). (architect: Joachim Hauser)

Source: https://gcaptain.com/6-incredibleunderwater-hotels/dubai-hydropolisunderwater-hotel/, Accessed: July 9, 2023

Life underwater could help save the human race in the event of a major apocalyptic event. Philip Pauley, founder of London-based visual communications consultancy Pauley, designed a self-sustaining habitat that could save 50-100 people during a disaster scenario (Figure 78).

Figure 78. Self-sustaining habitat, project (author: Philip Pauley)

Source: https://interestingengineering.com/7-things-you-should-know-about-thefuture-of-underwater-cities, Accessed: July 9, 2023

One way to combat the growing threat of war, limited resources, or global warming may be to settle the population underwater (Figures 79,80). There are already restaurants and hotels popping up around the world that allow people to experience limited underwater life.

Figure 79. A floating underwater ecopolis for climate refugees. Source: Vincent Callebaut Architects

Source: https://interestingengineering.com/7-things-you-should-know-about-thefuture-of-underwater-cities, Accessed: July 9, 2023

Figure 80. Floating/underwater city project (architects: AT Design)

Source: https://interestingengineering.com/7-things-you-should-know-about-thefuture-of-underwater-cities, Accessed: July 9, 2023

The project proposal of an underwater structure (2009) by architects from Grupo HCR (Higinio Llames, Ifigeneia Arvaniti) understands the need to live in a sustainable way in harmony with nature (Figure 81). There is a close connection between the building and its surroundings. It could be described as a surface that holds an inverted skyscraper under the sea. Living spaces under the sea are independent units with living and working areas, while gathering spaces, agricultural lands and recreational areas are located at sea level. The skin of the building interacts with the sea and produces tidal energy with a double membrane. Solar panels and wind turbines are located in a dome-shaped pool topped with rainwater collectors.

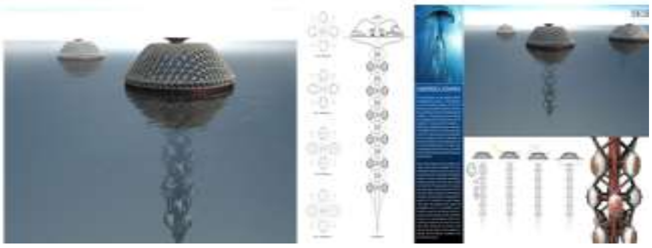

Figure 81. Underwater skyscraper, 2009 (architects: Grupo HCR - Higinio Llames, Ifigeneia Arvaniti)

Source: https://www.evolo.us/underwaterskyscraper/, Accessed: July 9, 2023

Trilobis is a 20-meter eco-yacht for six people, ideal for bays, atolls and marine parks (Figure 82). It was designed by Giancarlo Zema for SemiSubGeneration. The main goal of this project is to enable everyone to live in a fantastic, unusual environment in a self-sufficient habitat that does not pollute the environment. It consists of four levels connected by a spiral staircase. The highest level is 3.5 meters above sea level. From here, thanks to sophisticated technology, Trilobis can be controlled with a joystick that allows it to rotate 360 ° on its own axis. At 3 meters below sea level, completely submerged, there is an underwater observation globe. Encased in high-strength acrylic, there are six seating areas connected to computers and special software that allow residents to personalize the exterior lighting and get real-time information about the seabed and fish below. The hull and superstructure of the Trilobis are made of aluminum, which means that 80% can be recycled. This is very important from an ecological point of view. Glass windows are electrochemical, in other words, they change their opacity thanks to a sophisticated electrochemical system. This can be done manually or automatically depending on the light outside. Photovoltaic panels on top capture and store the solar energy needed for the instruments inside. Electric motors are powered by hydrogen fuel cells that produce potable water as a waste material only through an electrochemical process. It is obvious that it is a project that does not pollute the environment.

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Thanks to the shape of Trilobis, it is possible to assemble several modular units into a ring, thus creating floating colonies. The project was named Trilobis after Trilobita, small creatures that lived in the sea 500 million years ago [70].

Figure 82. Trilobis 65 (2001). (architects: Giancarlo Zema Design Group)
Source: https://www.giancarlozema.com/project/trilobis/, Accessed: July 9, 2023

The world's largest underwater hotel is planned to be built in Dubai with rooms both on the sea floor and on stilts above the surface. The Water Discus Hotel was designed by Polish company Deep Ocean Technology (DOT), whose other ventures include designing underwater vehicles and equipment for seabed research (Figure 83). The hotel will consist of two main discs, one above water and one below the surface, connected by five columns and a vertical shaft for stairs and an elevator. Smaller circular volumes above the surface will contain additional facilities, with a helicopter landing gear mounted on one of them. The lower disk will contain 21 hotel rooms with underwater views, an underwater diving center and a bar. Each of the surrounding discs will be able to detach from the main upper disc to be used as a floating life raft in the event of an emergency or flood. The diving center will be accessed through an underwater air chamber, leading divers straight into the ocean. There will also be a decompression chamber for training purposes, while guests will also be able to take a course in piloting an underwater vehicle. The modular construction of the hotel will allow it to be expanded or even moved to a new location [71].

Figure 83. Water Discus Hotel, Dubai, 2013 (architects: Deep Ocean Technology, DOT)
Source: https://www.dezeen.com/2013/01/29/worlds-largest-underwater-hotelplanned-for-dubai/, Accessed: July 9, 2023

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