Autonomous reserve housing in the aquatic environment: designing a self-sustainable floating module

S A Kizilova

Moscow Architectural Institute (State Academy), Fundamentals of Architectural Design Department, 11/4 Rozhdestvenka st., 1-4, 107031, Moscow, Russia

E-mail: kizilovasvet@mail.ru

Abstract. The article is devoted to the study of design aspects of the innovative housing of the future: an autonomous reserve floating module. The leading approach to the study is the analysis of implemented and conceptual precedents and experimental modeling. The analysis of precedents revealed the main parameters that an autonomous floating home in the aquatic environment should possess. The identified parameters affect the structure of the dwelling at three levels: layout, operational and technological infill, and the outer shell of the building. The layout parameters are flexibility, versatility, transformability. Operational and technological parameters are the production of resources, water purification, recycling, computerization of production and tracking systems. Shell parameters are: sealed, capsular, biomorphic. The identified parameters were combined within the experimental design model, which can be implemented at the present stage of the development of society. The experimental model has an additional parameter: the ability to connect individual modules into an autonomous network. The research material may be useful for theoretical and practical developments in the field of designing autonomous dwellings for extreme environments.

1. Introduction

The creation of innovative types of dwellings for long-term residence in extreme environments is one of the priority areas of research in modern architecture. Due to the irreversible effects of climate change in recent years, there has been growing interest in the construction of settlements on floating platforms and artificial islands.

Prospects for the design of habitable structures in the extreme aquatic environment as well as its scientific and philosophical interpretation are presented in theoretical studies by N.A. Saprykina [1], [2], R. Barker and R. Coutts [3], P. Steinberg and K. Peters [4], M. Jue [5]. The potential for energy-efficient construction of floating facilities is reflected in research by C. Moon [6], S. Habibi [7], L. Piątek [8]. Aspects of the development of “seasteading”, the concept of autonomous living within floating architectural spaces in the ocean, are described in studies by P. Friedman and B. Taylor [9], V. Tiberius [10]. Some technical features of designing multifunctional architectural objects on floating bases are described in the works by T. Kim et al. [11], Y-H. et al. [12], H. Stopp et al. [13], C.M. Wang et al. [14].

The purpose of this study is to identify the parameters for designing an autonomous housing in the aquatic environment according to the principles of sustainable development with the subsequent implementation of these parameters in the design of an eco-sustainable model of a floating unit.
2. Materials and Methods
To establish the parameters for the contemporary autonomous floating home, it is necessary to examine the implemented and conceptual precedents.

2.1 Analysis of the implemented innovative floating dwellings
The outer shell of the “Exbury Egg” capsular houseboat, designed by artist S. Turner, is made of waterproof reclaimed cedar. The overall shape of the compact dwelling was inspired by nesting seabirds. During the year, the inner space served as a research station for monitoring the flora and fauna of Beaulieu river, UK. With the influence of the sun, tides and rains the moisture-resistant shell retained strength but changed color. The dimensions of the house are 6 m by 2.8 m (figure 1). The interior is equipped with a bed, a desk, an oven, a wet area with a shower and a portable toilet. Electricity for the operation of a telephone, a digital camera, and a computer comes from solar panels [15].

Figure 1. “Exbury Egg” by Steven Turner, SPUD and PAD Studio Ltd (Source: https://divisare.com/projects/262392-pad-studio-spud-nigel-rigden-stephen-turner-s-exbury-egg).

In 2018, in Japan, Huis Ten Bosch implemented a floating capsule project for an amusement park. According to the authors, visitors get to the park overnight, moving downstream in a floating house. The two-story sealed capsule includes recreation space, a small open deck, a bathroom, and a toilet.

The “Survival Capsule” project was developed by aeronautical engineers D. Sharp and S. Hill as part of the NASA 2011 competition. Spherical, waterproof capsules made of aircraft aluminum will provide necessary protection against the primary effects of a natural disaster: sharp objects, heat, shock, and emergency braking.

Sealed capsule dwellings can be used in case of tsunamis, tornadoes, hurricanes, earthquakes and storm waves when evacuation is not possible. The “Survival Capsule” was developed as a response to
the effects of the 2004 Indonesian tsunami, which claimed the lives of more than 225,000 people. Access inside was made through the sea door hatch. Capsules are equipped with seats and storage for food and water for 5 days. Engineers provided capsules of five different sizes. Smaller objects will be used by families in private homes, while larger capsules are for municipal buildings, enterprises, hospitals, airports, schools, and public shelters. The first capsule sales took place in the USA, Western Australia, and Japan.

2.2 Analysis of the conceptual designs of floating dwellings

Presented by architect P. Lazzarini in 2019, floating mobile homes “U.F.O. 2.0 - unidentified floating object” are designed as spherical capsules with 12.5 diameter surface decks. In the 2.3 m high underwater part there is a bedroom and a bathroom. In the deck part, there are water storage tanks, ballast weights and solar panels. The implementation of the project is planned in 2021. Floating capsules will be equipped with engines for movement at speeds up to 3.5 knots and 4 anchors. During the parking period, the motor can be used to charge energy batteries (figure 2).

Figure 2. “U.F.O. 2.0” by Lazzarini Design (Source: https://www.designboom.com/technology/pierpaolo-lazzarini-ufo-unidentified-floatng-object-05-07-2019/)

The houseboat “Waternest 100”, designed by Italian architect G. Zema and EcoFloLife, is equipped with solar power cells mounted on the roof of the building. The area of photovoltaic panels is 60 m². The living space occupies 100 m². The frame and the shell are made of glued timber. An aluminum pontoon serves as the floating foundation for a wooden superstructure. The houseboat is 98% recycled and reusable. The diameter of the structure is 12 m².

The house is designed for simultaneous accommodation of 1 to 4 people. “Waternest 100” has a flexible interior design that can be adapted for various functions. If the owner does not intend to live in the house, the floating capsule can be transformed into an office, restaurant, shop or exhibition space (The WaterNest: An Eco-Friendly Floating House. Source: https://www.alternative-energy-news.info/waternest-floating-house/).

The project of the bioclimatic building named "Ark" designed by Russian architect A.N. Remizov (Remistudio) has fully autonomous life support systems. Designed for the areas of natural and technological disasters, the building has the shape of a torus segment of 30 m high and 40 m by 60 m in the plan.

The shape of the shell allows the economical use of materials and energy for the functioning of an autonomous system. The dome shell makes it possible to place photocells at different angles according to the movement of the sun. The form also helps to raise warm air upward, where it is captured by heat pumps that store energy to cool the building (figure 3).

Sheath material is a self-cleaning transparent ETFE (ethyl tetrafluoroethylene) foil, resistant to extreme weather conditions. Wooden arches supporting the shell are fastened together by metal cables,
which reduce vibration during earthquakes. The ribs extending beyond the enclosure are gutters for collecting rainwater used for watering plants and heat collectors.

Figure 3. “Ark” by Remistudio (Source: https://www.remistudio.ru/blank-uiyxd).

Inside the central support column, main engineering communications are located. The upper part houses a wind generator, while the lower level has a power unit that converts thermal energy into electricity. Waste is processed within the building using explosive boiling and oxygen-free pyrolysis. The building has a multifunctional layout and can be used as housing, hotels, research centers, healthcare facilities. The set of engineering measures ensures the autonomous existence of the inhabited structure for an indefinitely long period [16].

3. Results

The analysis of the implemented and conceptual projects allowed us to identify the necessary parameters for autonomous housing at the level of technological organization, the layout structure, and form-finding.

3.1 Parameters for designing a self-sustaining floating home

The following parameters are set.

Technological and operational infill parameters:
- raw material extraction;
- water purification;
- energy production;
- recycling and disposal;
- computerized control systems.

Form-finding parameters:
- capsular;
- biomorphic;
- sealed.

Layout parameters:
- versatile;
- flexible;
- transformable.

3.2 Architectural modeling of an autonomous self-sustaining floating home

The designed modular object is intended for the formation of a network floating settlement. Within the proposed floating structure of an autonomous aquatic village numerous marine farms, research laboratories, residential buildings, and hotels could be located (figure 4).
The module has three variations - A, B, C, where A is “large” with four exits (20 m height, 50 m width), B is “medium” with three exits and C is “small” with two exits. Modules can be freely connected by junction passages to form a network structure of various patterns.

In the underwater part, there are production facilities: aquaponics and hydroponic farms, biogas and desalination plants, water storage tanks. Hydraulic energy turbines are integrated into the underwater part of the building and have non-linear funnels to increase the pressure of the water flow and generate more energy. Engines in the lower level provide mobility of the structure in case of off-network operation (figure 5).

**Figure 4.** General view and the section of the module. Drawing by the author. Measurements are in meters.

**Figure 5.** The internal structure of the module. Axonometry and plans. Drawing by the author. Measurements are shown in meters.
Multifunctional residential and public spaces are concentrated on the upper above-surface levels. Energy-efficient heat-saving glazing in the form of a parametric pattern provides uniform illumination of the interiors. In this case, smart glazing techniques described by A. Ghosh et al. could be applied [17]. Climate and lighting control systems will create a comfortable environment inside the habitable module.

The module could be manufactured using 3D printing technology and delivered anywhere in the world. The presence of systems for generating energy and resources, waste treatment, desalination, along with the dynamic characteristics of the module, provides an autonomous living for an indefinitely long period.

The model was designed using the Rhinoceros 3D software and the Grasshopper plugin. Through the design process, an additional form parameter was obtained: the ability to connect and form a spatial network. The shape of the floating module allows energy accumulation by glazing, which indicates a direct relationship between the shape and technological parameters. The developed project of the floating module can be implemented in various climatic latitudes.

4. Discussion
The identified parameters can be used in the field of generative design and serve as guidelines for creating reserve floating dwellings and autonomous infrastructure. The established parameters of the form, layout and technological equipment could be initially provided for in the universal design model.

5. Conclusion
The parameters obtained as a result of the analysis and project modeling can be used in the design of autonomous dwellings in the aquatic environment at the current stage of the technological development of society. These parameters are differentiated by layout, function, and form, but are in close interconnection and mutual influence. Formulated components can potentially become universal and necessary in the design of an autonomous and adaptive reserve home of the near future.

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