A Holistic Space Experience on Earth Through Architecture

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Abstract—**With the popularization of space exploration and the rapid development of technology to push us further into space, it is no surprise that the general public is becoming more intrigued by the day and wishes to visit outer space sometime. Creating a holistic experience through architecture can be the answer that enables people to feel space without physically going there. This relatively new and experimental design approach is examined through the case study of ‘Mars Science City’, designed by the Bjarke Ingels Group. A similar case study for The Mars Desert Research Station is studied as well. This concept's main strategies and elements are highlighted through exploring the design approaches used in the case study. The results of this study indicate the importance of learning context, extraterrestrial building methods, and achieving sustainability through design.**

Keywords— **celestial bodies, holistic experience, space architecture.**

I. INTRODUCTION

Humans have always been fascinated by the natural world and have wanted to understand more about it. Ancient peoples such as the Greeks and Romans, among others, devoted vast resources in order to learn about destinations and phenomena outside their direct lines of sight [1]. Except for a brief period of human exploration on the Moon, most planetary investigations in the past have been conducted utilizing unmanned spacecrafts and planetary land rovers [2]. Current plans call for the first human expeditions to Mars to start sometime around 2035 since the necessary technologies are not yet available, and the missions would be far too risky and costly without significant technological improvements [3]. NASA mission developers have studied numerous exploration tactics ranging from fast "flags and footprints" missions to field stations, to more efficient operational outposts and even colonies since its start. These research ideas have covered a variety of destinations, with the majority focusing on the Moon, Mars, and occasionally near-Earth asteroids [4]. The development of permanent human homes outside of Earth, or space colonization, has long been the subject of scientific and public discussion. The concept of colonizing space has a poetic air to it: space is the next big territory, the next great leap for humanity, which we aspire to one day conquer by our willpower and inventiveness [5]. Space colonization is a field yet to be delved deep into and studied, as it comes with a risk of unjustified exploitation of Earth’s resources due to doubts about its technological impracticalities. This birthed the idea of replicating a controlled environment on Earth to test out the stability and functionality of those ecosystems before introducing them to outer space [6].

II. OBJECTIVES

This research aims to reinvent the means for learning through creative and innovative architectural designs. Here, the user becomes the subject and the architecture is simply a vessel through which we enhance experiences. Through design and architecture we can create a place where visitors may learn about outer space, live through the lens of an astronaut, and participate in other enjoyable learning activities through an entire holistic experience.

III. RESEARCH METHODS

This research mainly relies on qualitative methods including literary review and analyzing case studies to highlight key concepts and review architectural approaches used to achieve the concept of creating a holistic experience of outer space. The two case studies that were selected: ‘Mars Science City Project’ and ‘The Mars Desert Research Station’ represent examples of architecture used as a tool to help develop technology to colonize Mars. An emphasis was placed on extraterrestrial building techniques and suggested habitat models.

TABLE I: RESEARCH STRATEGY

Research method	Databases	Type	References
Literature review	- Google Scholar - Science Direct - Research Gate - Aerospace Research Central - NASA - ASCE	Journals	Kovic, 2021; Falk, 2020;Varinlioğlu et al., 2018; Leach, 2014; Vellinga, 2013; Moore, 2010; Madhavan et al., 2008; Cliffton, 1990; Kennedy and Cerimele, 1990; Namba et al., 1988.

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		Conference papers	Enç and Basarir, 2020; Zhu et al., 2020; Connolly et al., 2018; Stavrev, 2011; Wong, 2003; Benaroya, 2002; Ceccanti et al., 2009; Schroede r et al., 1994; Vanderbilt et al., 1988.
		Books	Howe and Sherwood, 2009; Launius, 2004.
		Organizations	European Space Agency, 2017; Granath, 2015.
		Special Publications	Johnson and Holbrow, 2004.
		Thesis	Happel, 1993.
Case studies	- Google Scholar - Google News	News outlets	CNN, 2020; WIO News, 2020; Universe Today, 2019.
		Journal articles	Grove, 2021.
		Organizations	World Architecture, 2017; MDRS, n.d.

IV. LITERATURE REVIEW

A. *Defining Holistic Architecture*

According to the Cambridge dictionary, the word 'holistic' means addressing the entire matter or person rather than simply a portion of it [7]. A holistic, integrative, and analytical approach is required if the goal is to actually learn from vernacular architecture. This approach should also look at the building's social, political, and economic ramifications in addition to its environmental features and performance [8].

Holistic design was created by structural architects as a superior alternative to construction for a single application. Examining perspectives of human occupation from all directions was the plan (e.g., energy consumption, mental health). As a result, they could create structures that were specifically suited to the needs of the people who would utilize them [9]. Designers strive to have a deeper understanding of all the human factors that affect how people interact with a given design while creating user experiences. If they concentrated just on accommodating a few parts of what the users feel, they could not realistically examine the many viewpoints [9].

B. *Outer Space architecture*

Space architecture is an area of research that focuses on creating livable homes in harsh settings, such as space and other planets [10]. As space architecture advances, we will eventually be able to "live off the land" on the surface of the Moon and other worlds, fabricating homes, outfitting, and supplies from what we find. This innovative technique is known as in situ resource use (ISRU) [11]. New types of human life and behavior patterns are expected to emerge both inside and outside the living unit in an extraterrestrial setting where time flow, sun orientation, physiological stimulation, ergonomics, and regional climate context are quite different from those on Earth [12]. The functional, formal, physical, and chemical characteristics of organic life forms on Earth have frequently been disregarded during the design process of extraterrestrial habitats, despite the fact that Earth is the only known natural environment where the human species can survive and offers a wide range of biomimetic resources and references for extraterrestrial colonization [12]. The generalization of terrestrial architecture can be recognized as space architecture. Its theoretical and philosophical foundation ought to be valid across the cosmos and may perhaps be applied again on Earth. Learning from space architecture's technologies and methods might result in a far more effective and environmentally friendly design on Earth [13].

C. *Achieving a holistic experience*

1. Physical context

Vernacular architecture is characterized as being built using local materials to fit its native environment, indigenous climate, and distinct local necessities [14]. The study of vernacular architecture focuses on the links between the built environment and the individuals who interact with it, focusing on the two-way nature of those connections [11].

Space habitats are intended to support human existence in the harsh environment of space. The main aspect that all habitats have in common is that they are pressure vessels under the vacuum conditions of orbiting space and the lunar surface [15]. Studying the physical context is one of the main factors that will shape the final design, as it can influence form, function, and the accommodation of any necessary spaces. The physical context can include air pressure, topographical build, temperatures, and so on.

The intricacies of the outer space environment must be studied in order to access the resources of space securely, efficiently, and with minimal impact on the productive capacity of colonists and Earth [5]. When compared to terrestrial architecture, outer space architecture has significantly different program needs, limitations, and loading conditions. This huge shift would need modifications in traditional schooling and methods [14].

2. Sustainability

The concept of sustainability is inevitable when we look into long-term existence on an extraterrestrial body. Humans need to be able to build, eat, harvest energy, and carry out other activities without being dependent on obtaining the necessary resources back from Earth.

The University of Arizona has developed potential greenhouse models to be used on planet Mars and the Moon. The goal is to utilize materials and resources that are already present or grown in that location. This practice known as in-situ resource usage (ISRU) is being researched by scientists at NASA's Kennedy Space Center in Florida as it is an essential principle for deep-space exploration [16].

In-situ resource utilization (ISRU) in space has emerged as a practical option to save shipping costs and time and break free from the reliance on building materials obtained on Earth [17].

Long-duration missions will need the recycling of waste products owing to payload constraints.

The ESA recommends utilizing sustainable materials to construct aircrafts, which may later be processed into usable biological and technical nutrients. It was shown that if materials could be recycled and processed on-site, a large number of support flights might be spared for the construction of greenhouses, shelters, or other facilities [18].

3. Design and Construction

To reduce local manufacturing for first structural colonies, construction components must be efficient and, in some ways, modular [19]. The design of a space colony incorporates all of the subsystems necessary to offer and maintain a living and working environment in space, as well as to serve the mission of the colony [15]. The components of the space colony - transportation, mining, the habitat, manufacturing, agriculture, and so on - must interact and interrelate in such a way that the total system can meet the demands of each for energy, raw materials, personnel, transportation, and waste removal [5].

3.1. Inflatables

Inflatable enclosures provide new options for habitat forms and sizes, redefining how we create habitats, labs, hotels, and space resorts [15]. The fundamental geometry of the pressure vessel around which these designs are created may be divided into two categories: forms that more or less mimic terrestrial analogs and generic inflated shapes. Among general forms, the sphere (figure 1) and the torus seem to be the most popular [20].

As a potential proposal for a permanent lunar base, Vanderbilt et al. (1988) proposed a pillow-shaped structure. The suggested foundation is made up of quilted inflated pressurized tensile structures made of fiber composites. Similarly, Chow and Lin (1988, 1989) envisioned a permanent lunar base with a pressurized membrane framework, as shown in figure 2.

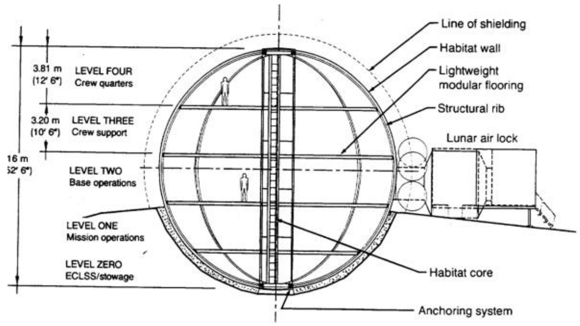
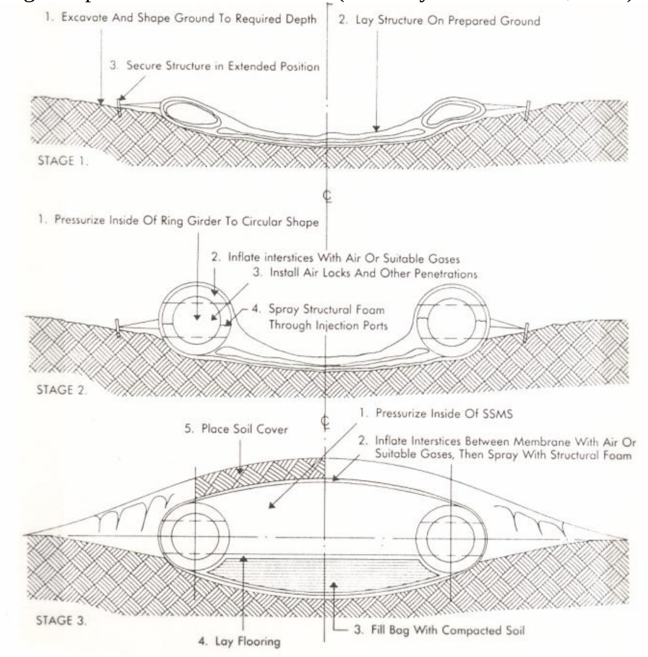


Fig. 1. Spherical 16 m dia. habitat (Kennedy and Cerimele, 1990).



Inflatable membrane structure – construction sequence. [p. 372 Chow & Lin in Johnson & Wetzel 1988]

Fig. 2. Inflatable membrane structure—construction sequence (Chow and Lin, 1988).

3.2. Erectables

Cliffton, E.W. (1990) advocates utilizing fused regolith as an example of utilizing some sort of lunar regolith for building purposes. Cliffton's structure, as demonstrated in figure 4, adopts the shape of an inverted truncated pyramid and is modular, allowing numerous modules to be linked for increased use.

Zhu et al. (2020) suggested an erectable truss structure composed of a several truss bay. A pre-assembled component comprises four short struts, four long struts and four nodes. They have considered the working ability of humans and robots in the space environment in order to give full play to their advantages and complete space assembly tasks safely, quickly and efficiently.

3.4. Modular

One of the primary sources of morphological inspiration in the formal approach to design modularity is the construction of complex structure out of basic pieces [20]. As a flexible way to build a range of structures for the lunar surface, Schroeder et al.

(1994a) offer a modular approach to lunar base design and construction.

Shimizu Corp. researchers in Japan have proposed utilizing prefabricated, prestressed concrete modules to build massive structures on the moon's surface. Each module has a floor space of roughly 15 square meters. The concrete is loaded in compression because the floor and ceiling panels are curved. During casting and assembly, steel prestressing tendons are threaded through the side panels. The tendon force is estimated to be under 50 tons when the modules are compressed to 1 atmosphere. The modules are intended to be combined in a wide range of ways. Once the module factory is up and operating, the design's exceptional flexibility allows for continual structural extension [35].

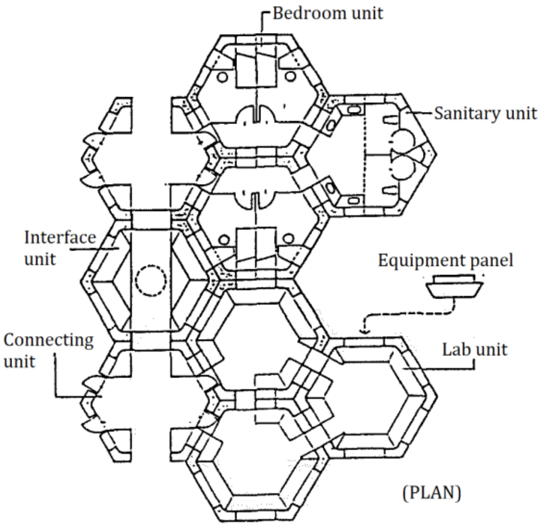


Fig. 3. An example of a small base layout using concrete modules (Namba et al.,1988).

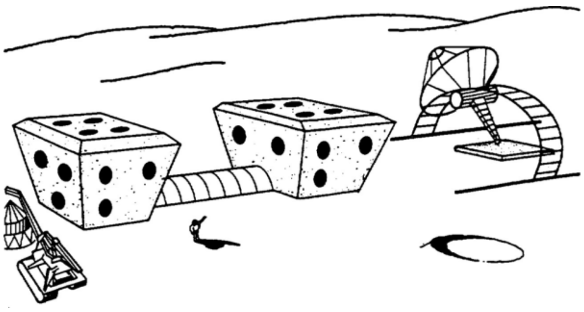


Fig. 4. Fused regolith habitat (Cliffton, 1990).

The ability to design goods that can be customized to fit specific needs and the ability to produce those products at costs that are comparable to those of mass producing a single product design are two reasons to build a massive structure out of modules [20].

4. Materials

Alternative sources seem more reasonable since transporting materials from planets requires such a high level of effort. If a planet is close and dense in resources, a colony may consider the endeavor worthwhile. As a result, the Earth might be a key supply of material for a colony in its neighborhood, particularly of the elements hydrogen, carbon, and nitrogen, which are not abundant elsewhere near Earth [5].

5. Technology

The development of technology capable of using in-situ materials, like lunar dust, is critical to the future of extraterrestrial architecture [21]. 3D-Printing technologies have captured the attention of the architecture world in recent years due to their promise of allowing direct production of structures of nearly any shape. Some of these methods can use a special "ink" to agglomerate inert elements like sand [22].

V. CASE STUDY: MARS SCIENCE CITY PROJECT

A. *Background*

The Mars Science City was designed to be a testing ground for Dubai's Mohammed Bin Rashid Space Centre (MBRSC) in order to develop the technologies required to colonize Mars. Bjarke Ingels Group was then tasked with designing a prototype of a metropolis fit for maintaining life on Mars – and then adapting it for usage in the desert [23]. The project intends to mimic a practical and accurate model to mimic living on the surface of the red planet, covering a total area of 176,515 square meters [24].

B. *The Design*

Mars 2117 is based in part on a comparable design appeal to a vernacular asset. In presentations regarding the UAE's vision for post-Earth futures, comparisons between the UAE's desert climate and high heat and circumstances on Mars that are unfriendly to human existence - including a lack of viable atmosphere and mineral resources for planet life - are prevalent [25].

The infrastructure for Mars Science City is to be 3D printed using "local sand," according to B.I.G., demonstrating the ideal fusion of using "indigenous" resources with borrowed technology. In the Gulf, traditional aesthetics are sought in a way that expressly accentuates their contribution to "sustainability," and such climates are envisioned as a "natural" byproduct of land, temperature, and culture. However, this desire for traditional aesthetics is not restricted to the Gulf [25].

The martian metropolis would consist of a group of pressurized biodomes enclosed with transparent polyethylene membranes, each maintaining suitable thermal conditions as well as breathable air pressure. The oxygen for these pressurized domes will come from applying electric current onto ice found underground [24, 26].

Sand from the Emirati desert will be used to 3D print the museum's walls. A chosen crew will spend a year inside the experimental module as part of the project in order to create and test various Red Planet conditions. It is intended that the experience would serve as a crucial benchmark for future research on how to support life in a harsh planetary environment. It is necessary to design a variety of trials that will spur innovation in the areas of self-sufficiency in energy, water, and food.

Fig. 5. Showing a render of the food laboratories

C. The Program

These domes will contain a museum which will exhibit humankind’s greatest space accomplishments, as well as greenhouses to grow food, laboratories for energy and water along with research concerning food security, as envisioned in figure 5. Other than the various laboratories and experimental areas, the museum will have educational spaces to connect young people with space and awaken in them a desire for exploration and discovery. Adding to the many recreational amenities, the designs include an amphitheater to improve scientists' mental health and improve their quality of life in this isolated location [24].

VI. CASE STUDY: THE MARS DESERT RESEARCH STATION

A. Background

The Mars Society owns and runs the Mars Desert Research Station also known as MDRS. The site is located at an elevation of 2500 meters above sea level in a dry, rocky environment that is very cold and receives very little precipitation. MDRS is a space analog facility in Utah that promotes Earth-based research in an effort to develop the operations, technology, and science necessary for human space exploration [27]. MDRS provides an equivalent for the harsh and unique working conditions that will be faced by men and women who hopefully one day will be exploring Mars. During the mission a selection of quantitative and qualitative psychological tests were administered to the international, multidisciplinary team [28].

Fig. 6. Showing Mars society exterior (Mars Society MRDS, 2019).

B. The Design

There are six buildings on the MDRS campus. A two story, 8 meter in diameter cylindrical building, seven crew members can reside simultaneously in the habitat. In recent years, the building has been undergoing renovations. The EVA preparation room with the spacesuit simulators, an outdoor airlock, a shower room, a toilet room, and a rear airlock leading to tunnels providing access to other structures are all located on the lower deck. The living quarters are located on the upper deck and consist of seven bunk rooms, a shared work/living area, and a fully functional kitchen. Seven staterooms are in all; six are on the main floor and one is in the loft [27].

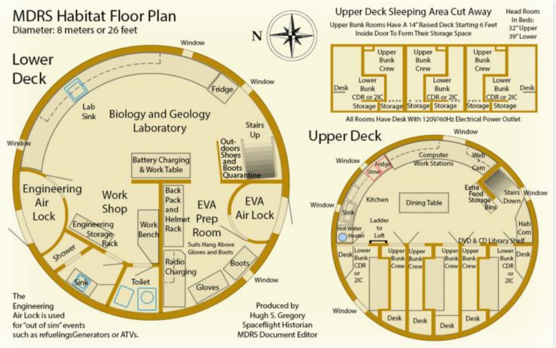


Fig. 7. Showing floor plans of Mars Desert Research Society habitat (Mars Society MRDS, 2019).

C. The Program

There are two observatories on campus. The first is the Musk Observatory, which was once the sole observatory on campus, but has been turned into a solar observatory for crew use. The second is the telescope is housed in a 7.5-foot automated dome that may be operated from the habitat module or on-site. There is one GreenHab containing conventional and aquaponic growing systems, as well as room for agricultural research investigations. And finally the Science Dome is a 7-meter-diameter geodesic dome that houses the control center for our solar system as well as a working microbiological and geological laboratory [27], [28].

VII. DISCUSSION

After looking at these case studies, we can notice a repeating pattern in function and purpose of this typology of architecture.

A. Educational and research innovations

Not only can these spaces house museums and exhibitions, but they can also give rise to research developments, new techniques and build on existing experiences. Research amenities like laboratories, greenhouses, energy harvesting plants, etc, can help scientists prototype a suitable framework for a potential outer space colony.

B. Trial and development

Before establishing an existence on an extraterrestrial body, scientists need to further study and evaluate possible strategies for constructing colonies, ensuring a sustainable life cycle, and means for coexistence in a harsh, foreign environment. Without testing out the possibilities and likely outcomes, there is a greater risk factor and reduced chances of success. Not only does trial and error help scientists come up with more well-rounded solutions, but it can also trigger the birth of innovative technologies.

C. Construction techniques

New construction methods are required to account for the various differences in atmosphere, surrounding environment and foreign landscape. The new structure needs to be able to withstand the outer air pressure, gravitational pull, harsh solar flares and dust, and other factors present in an extraterrestrial space. A sustainable and reliable approach is recommended in order to ease the process of construction and make use of available materials, which in turn reduces costs. Ensuring the safety of the built structure is essential and can be done through assessing risk factors of different constructed habitat models.

D. Social, economical and political milestones

A number of projects have arised over the last few decades regarding plans to colonize outer space with nationalist-based visions to create the first ever settlements. Such projects are aimed to create and direct populations favorably toward technical solutions in times of political and environmental crises. Establishing a presence on an extraterrestrial body is crucial to the political eye as it puts into work the technological advances, global collaborations, and use of crucial resources.

VIII. CONCLUSION

This emerging area of study and concept could potentially be the next big revolution, not just architecturally, but scientifically as well. The case studies in the paper are great examples that showcase how such projects could potentially have great political, economic, sociological and scientific impact. Afterall, it is the idea of returning to our vernacular ways to build and create within the existing environment and make the best of the resources on hand. Both of these case studies implement building an extraterrestrial habitat and mimicking its respective environment on Earth as a gateway to new discoveries and technologies. The architecture typologies were based on extraterrestrial habitat concepts as well as the architectural programs inside of these structures. The challenges of colonizing outer space go beyond practicality and economics, as there are physiological and psychological components that also need to be addressed. This style of architecture can act as a test bed for future plans to invade outer space and solve the challenges that come up with it.

Additionally, through implementing holistic architecture, new strategies are learned that can be further improved and later implemented in outer space

This paper investigated a new approach for space research and ways to achieve a holistic experience by implementing key elements of outer space architecture.

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