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PRACTICAL DESIGN EXAMPLES FOR HUMAN HABITATS IN SPACE, OFF-GRID, AND IN LOW-IMPACT COMMUNITIES

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ABSTRACT

All human habitat problems fall into three major categories- the environment, the habitat itself, and the occupants. By breaking these problems down into common themes and addressing them directly, we can build a common knowledge base for all three challenges faced by humanity. A crew living in space has the new problems of coping with radiation, microgravity, and vacuum. All the while, they are dealing the usual issues of eating, sleeping, and getting along with the rest of the occupants. By isolating the differences between space and earth habitats, we can create common architectural styles for each human habitat challenge where commonality is appropriate. We can then examine the differences, then isolate and modularize the secondary systems where possible. This simplifies experimentation and testing of the physical and psychological design of a structure on Earth prior to attempting use in space. It also allows spin-off architectures for extreme environments, off-grid settlements, research bases, and low impact communities on Earth. By isolating and testing each attribute of the system in parallel with control groups, we can scientifically refine the systems for human shelter regardless of environment. This paper will show numerous examples of architectures designed for space or space analog research bases. These designs can be both de-scoped to off-grid sustainable architecture, and scoped up for space habitat applications. Concepts such as internal greenhouses, enclosed permaculture, thermal protection, energy management, and radiation shielding are included for both minimal habitats and large bases. These systems can then be applied for disaster first responders, research bases in extreme environments, o-grid homes, and low-impact communities.

I. INTRODUCTION

Space stations are the highly developed high-tech habitats, which are intended to support human life under the most extreme and isolated conditions (NASA, 2010a[1]). Because of the extreme and isolated conditions, a Space habitat needs to be as much as possible a sustainable system, a closed-loop and off-grid system with autonomy from Earth. Those characteristics are the base for the creation of concepts and technology that could be transfered to any other human habitat on our planet, solving problems and improving the life of the inhabitants and the impact on the environment. (Schlacht et al., 2012)[2]

Figure 1: Knowledge transfer between Space and Earth (©Schlacht 2014)

Considering the ever growing population and the ever decreasing resources available, self-sufficiency and sustainability have become important issues today. We are faced with habitat problems in our everyday common reality, too, e.g. in megacities with their exploding populations and their need for room and resources; when catastrophes occur; as a consequence of limited access to resources; as well as for scientific research or tourism in isolated contexts that require self-sufficiency (Schlacht, 2012a[3]; Quantius et al., 2012 a[4],b[5]; Karga & Schlacht, 2012[6]). (Quantius et al., 2012 a[7],b[8]).

II. OBJECTIVES

Architectures designed for space or space analogue research bases can be used as test facilities for spin-in/spin-off [9] innovation in habitats to optimise performance, safety and comfort (Schlacht, 2012 [10] ; Schlacht et.al, 2012[11]).

The innovation is aim into:

- To test the degree of habitability within spin-in/spin-off innovations.
- Increase of safety, efficiency and performance for operation in extreme environment conditions
- Optimised use of resources and autonomy for water, energy and communication
- Smart remote operations

- Development of a safe, self-sustainable, smart habitat and lab concept with high-tech, green and social development content.

III. PAST PROJECTS

BIOS-3 (Russian)

315 cubic meter habitat located at the Institute of Biophysics, Krasnoyarsk, Siberia.

The Bios-3 facility has conducted a number of long duration two-people and three-people CELSS experiments for periods of up to six months. Their only contact with the outside world was via telephone, television and the windows.

Bios-3 is divided into four equal quarters. One quarter provides the housing for the crew -- three single cabins, a kitchen, a toilet, and a control room with various equipment for food processing, measurements, and repairs, as well as systems for additional purification of air and water when necessary. The other three quarters of the facility are where the wheat, vegetables, and other food plants are grown, as well as the cultures of chlorella.

The crews plant the food, cultivate it, and harvest it -- managing the entire system and processing the harvest.

In these experiments, natural air and water recycling met most of the crew's needs, and the crops produced over 50% of the food needs of the crews. (Gitelson et.al, 1989[12]; Prado, 2002[13])

Figure 2: Bios3 © Michael Daugaard from http://scienceillustrated.com.au/blog/in-the-mag/dreaming-of-mars-part-1/

CELSS ´80 (American)

Controlled Environmental Life Support System (CELLS) are a type of scientific endeavor to create a self-supporting life support system for space stations and colonies

In CELSS, air is initially supplied by external supply, but is maintained by the use of foliage plants, which create oxygen in photosynthesis (aided by the waste-byproduct of human respiration, CO2). Eventually, the main goal of a CELSS environment is to have foliage plants take over the complete and total production of oxygen needs; this would make the system a closed, instead of controlled, system. CELSS studied means of breaking down human wastes and, if possible, integrating the processed products back into the ecology. For instance, urine was processed into water, which was safe for use in toilets and watering plants. (Fitch, 2003[14], Wheeler et.al., 1996[15])

There is also a Chinese version called CELSS-Experiment Facility (Guo et.al, 2008)[16] and a Japan one called Japanese Closed Ecological Experimental Facility (CEEF) (Nitta eta., 2000)[17]

BIOSPHERE2 90´ (American)

Biosphere 2, the large glass closed life facility in the mountains of southern Arizona, USA. Plans used concepts of systems ecology and biospherics from the early writings of V.I. Vernadsky, work of the Russian space program on closed ecological life support systems and other leading proponents of a total systems approach to ecology. Mission one was the first experimental closure of Biosphere 2 with eight crew members for 2 years, 1991–1993. The capability to sustain closure was demonstrated over a period of ∼3 years with human inhabitants reflecting one of the most unique and sophisticated structural features of the facility distinguishing it from large greenhouses and phytotrons. (Bruno, 1999 [18], Dempster et.al, 2004[19])

Figure 3: Biosphere2 from http://3.bp.blogspot.com/_-lmw6mzLegs/TAybUzGJt_I/AAAAAAAAAGc/Pg7wXTDg-QA/s1600/IMG_1077.JPG

CESRF (Canadian)

The Controlled Environment Systems Research Facility (CESRF) is an essential part of Canada's contributions to plant research and development for space and closed environment related activities. The CESRF provides a complete research venue suitable for measurement of plant growth, gas exchange, volatile organic compound (VOC) evolution, and nutrient remediation in a precisely controlled environment. The facility is comprised of 24 sealed environment chambers including 14 variable pressure plant growth hypobaric chambers capable of sustaining a vacuum. CES's personnel have extensive experience in the fields of plant physiology, environment analysis and sensor technology.

Figure 4: CESRF © University of Guelph http://www.ces.uoguelph.ca/facility.shtml

MARS 500

MARS 500 was not based on closed loop but on study and operation related to human isolation. The purpose of the Mars500 was to gather data, knowledge and experience to help prepare for a real mission to Mars. Obviously there has not been effect of weightlessness, but the study was helping to determine key psychological and physiological effects of being in such an enclosed environment for such an extended period of time: such as stress, hormone regulation and immunity, sleep quality, mood and the effectiveness of dietary supplements. (ESA, 2012[20])

Figure 5: Virtual tour of the Mars500 © SSC RF IBMP RAS http://www.pano360.ru/vtours/mars-500/station/tour.html

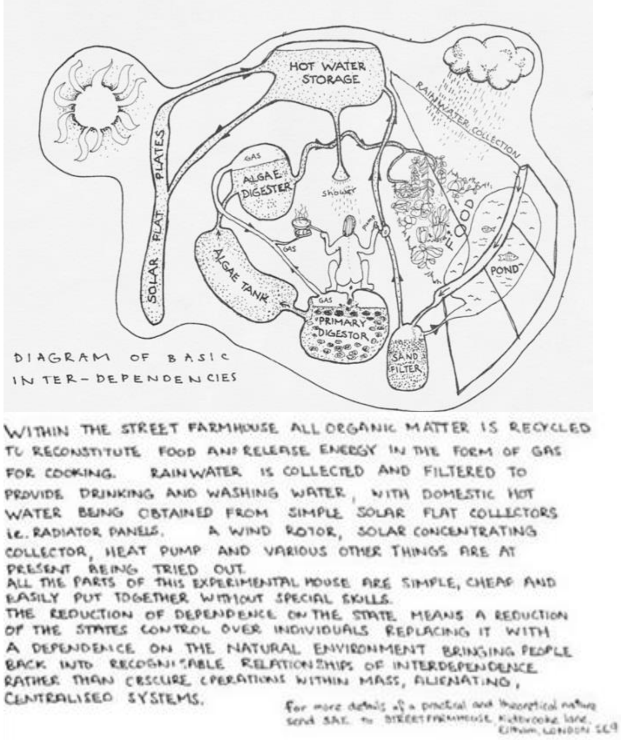
MDRS

One example is the Mars Desert Research Station (MDRS), built by the Mars Society. The MDRS is a terrestrial settlement in Utah, which simulates a base on Mars (Schlacht, et al., 2010, p. 1)[21]. Each person receives a brief manual on the system maintenance and through this and the remote support of experienced persons, each crew is able to let the system run. The system works as a semi-autonomous system; it needs re-fuelling and provisions, but it can work in isolation for two weeks.

Figure 6: The Mars Desert Research Station.
© I.L. Schlacht 2010 (MDRS, Utah)

ECO-HOUSE 70´

Onether example is the one of architect Graham Caine and his Eco-House in 1972 in South London. He lived there for two years with his family until he was asked to demolish it. The Eco-House was a fully functional integrated system that converted human waste into methane for cooking, as well as maintained a hydroponic greenhouse with radishes, tomatoes and even bananas" (Kallipoliti, 2011, *pp. 32-33)*[22].



WITHIN THE STREET FARMHOUSE ALL ORGANIC MATTER IS RECYCLED TO RECONSTITUTE FOOD AND RELEASE ENERGY IN THE FORM OF GAS FOR COOKING. RAINWATER IS COLLECTED AND FILTERED TO PROVIDE DRINKING AND WASHING WATER, WITH DOMESTIC HOT WATER BEING OBTAINED FROM SIMPLE SOLAR FLAT COLLECTORS i.e. RADIATOR PANELS. A WIND ROTOR, SOLAR CONCENTRATING COLLECTOR, HEAT PUMP AND VARIOUS OTHER THINGS ARE AT PRESENT BEING TRIED OUT.
ALL THE PARTS OF THIS EXPERIMENTAL HOUSE ARE SIMPLE, CHEAP AND EASILY PUT TOGETHER WITHOUT SPECIAL SKILLS.
THE REDUCTION OF DEPENDENCE ON THE STATE MEANS A REDUCTION OF THE STATES CONTROL OVER INDIVIDUALS REPLACING IT WITH A DEPENDENCE ON THE NATURAL ENVIRONMENT BRINGING PEOPLE BACK INTO RECOGNISABLE RELATIONSHIPS OF INTERDEPENDENCE RATHER THAN OBSCURE OPERATIONS WITHIN MASS, ALIENATING, CENTRALISED SYSTEMS.

For more details of a practical and theoretical nature send SAE to STREET FARMHOUSE, Kidbrooke lane, Eltham, LONDON SE9

Figure 7: Graham Caine's diagram for the Eco-house from Kallipoliti, *2012, p. 97*

MACHINE FOR SUSTAINABLE LIVING
The Berlin Farm Lab is a system based on the manual "Machine for sustainable living" that converts a house into a small energy production plant (Karga, 2010[23]). It is an assemblage of a rainwater collector, an aquaponic system, a biogas digestor, photovoltaics, a solar cooker, a solar heat panel, an algae photo-bioreactor and a biodiesel processor. When all these systems are combined together in a "nothing is wasted" concept, they could produce a semi-closed loop system with the only inputs being solar energy, rainwater and human (energy and outputs) to fit one person's requirements. (Karga & Schlacht, 2012, p. 5)[24].

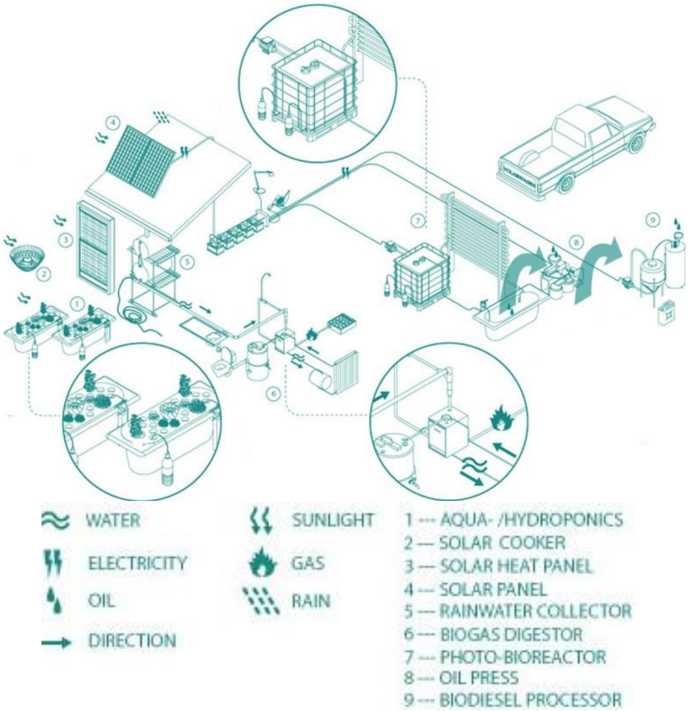


Figure 8: Machine for sustainable living © Valentina Karga

MELiSSA
The driving element of MELiSSA is the recovering of food, water and oxygen from waste (feces, urea), carbon dioxide and minerals. Based on the principle of an "aquatic" ecosystem "MELiSSA goes further than other recycling systems used on Mir or the International Space Station, which purify water and recycle exhaled carbon dioxide but do not attempt to recycle organic waste for food production." ESA (2007)[25]

Figure 9: Melissa © ESA http://www.bbc.co.uk/blogs/legacy/thereporters/jonathanamos/2010/08/bugs-and-humans-will-team-up-t.shtml

SOUTHBASE

it is an experiment of regenerating life from scratch in a dead place, such as the desert. They use photovoltaic panels for electricity, to run refrigerators, lights, heaters, and other equipment. They have a rainwater collector and a greywater treatment facility, and for waste management they use a compost toilet from where they generate soil in order to create plant life and "link the end and the beginning of the life cycle" (Center for Land Use Interpretation). The system is called Clean Livin' because it "is cycling the waste generated by its users back into the system" (Center for Land Use Interpretation) (Karga & Schlacht, 2012[26]).

Figure 10: The Southbase (Image from http://fopnews.wordpress.com/2010/06/, Retr. date: 09/03/12*)*

IV. NEW PROJECT: BASED ON THE ENVIRONMENT

Any habitat functions as a moderator between the occupants and the environment. A modular structure can be reconfigured to deal with many environments. If designed well, it will also draw resources from the environment, such as solar power, rainwater, or consistent ground temperature. In the case of a space structure, the lack of habitability is a negative, but the presence of consistency (constant sunlight, predictable conditions) is a positive. In either case, using solar panels as sunshades, ground temperature as a heat sink, or local materials as insulation is a logical move.

Designs can start with off-grid systems internally, that can then be encapsulated in structures that can withstand the local range of conditions. This is true in any environment. However, not all environmental challenges can be isolated with thicker walls, such as earthquakes.

The new projects focuses on the definition of spin-in/off variable from space research to develop a shelter for disaster first responders, research bases in extreme environments, off-grid homes, and low-impact communities.

The new habitats system need to start by providing a facility for bench technology for testing the technology/knowledge spin-in and spin-off from entities that work for space and outside the space sector. The facility will be used to test procedures and technologies for living and working in extreme environments. The goal of this phase is the finalisation and optimisation of the shelter (minimum space, time and costs) for the different applications.

Table 1: Exohab1 Space and Earth benefits (©Schlacht 2014)

EXOHAB1 **SPACE BENEFITS**	**EXOHAB1** **EARTH BENEFITS**
GOAL Easy-to-build test bench for Space technology transfer	GOAL facility for operations in extreme environment
IMPACT Create awareness on space technology utilisation, e.g. sustainability	IMPACT Manage disasters quickly and safely
APPLICATION Private companies that like to expand their technology application	APPLICATION Agencies and governments that provide disaster management

TEST (Bench Technology): Operational habitat for testing and researching the application of space technology and knowledge for Earth use.
USE: Facility for operations during disasters. Providing the Extreme Operational Habitat to disaster management organisations for disasters requiring minimum space, time and costs, which can be quickly set up immediately after a disaster as a safe location from where to operate in autonomy from, for example, contaminated areas.

V. CURRENT PROJECTS

EXOHAB1

Earthquakes, floods, cyclones as well as human made disasters are all hazards which kill thousands of people and destroy billions of euros of infrastructures every year[27]. The rapid growth of the world's population and its increased concentration often in hazardous environments[28] has escalated both the frequency and severity of disasters[29]. As it has been underlined by the European Commission (EU) in 2011[30], this situation is increased by poor or no budgetary allocation for disaster assessment and management[31]. To face the problem the EU has been encouraging funding to support development of adequate technology[32]. As pointed out by the ABS head of catastrophes management, what is needed is an immediate and safe access to experts for in-situ disaster assessment and management that at the moment is performed without equipment and without possibility for a safe in-situ working location[33].
Exohab1 is an Extreme Operation Habitat based on Space Technology for immediate disaster assessment and management. It is a safe, self-sufficient, smart shell to support geological and medical experts with equipment for immediate and in-situ assessment.
Disaster may create break-down of water, communication, and electricity access, contamination and infrastructure damage. Thanks to the space technology and know-how transfer, Exohab1 is able to support experts for operation in very devastated and extreme environments. In particular, the space technologies used, focus on energy, communication, and water self-sufficiency applied for the optimized autonomy of the International Space Station: the habitat that is undoubtedly suited for the most extreme environments.
Finally under the EU guideline and the needs pointed out by disaster management associations, Exohab1 provide a key innovative step providing a sound disaster assessment with immediate and equipped in-situ disaster screening, optimizing the specialists' safety and performance. Moreover it is business planned to supports the maximum feasibility with minimum cost, time, and space.

Figure 11: Exohab1 in Rotterdam (©3Develop & Schlacht 2014)

HOPES

EXOHAB1 is conducted in close cooperation with the team working within the HOPES project (in French: Habitat Opérationnel pour Essais de Systèmes). The aim of that project is threefold. First, it is to provide to companies working in the habitat domain an experimental platform (a space hab) in order to test new systems of the habitat and new interfaces in presence of the users. Interfaces, behaviors and attitudes play an important role in the use of the systems (O'Connor, 2012[34], Urbina and Charles 2014[35]). Human systems interactions will be observed in an operational and instrumented environment. Second, the same platform can be exploited in the space domain to test new systems related to the planetary habitat and life support. The application context of the second objective implies very strong constraints in terms of energy independence, clean air, water, robustness of systems or monitoring (Lange et al, 2003[36]). These constraints should lead to efficient and innovative technology solutions, which may also have applications for the terrestrial habitat. The third goal, which derives directly from the second, is to work on the transfer of technology from the space domain to the terrestrial habitat.

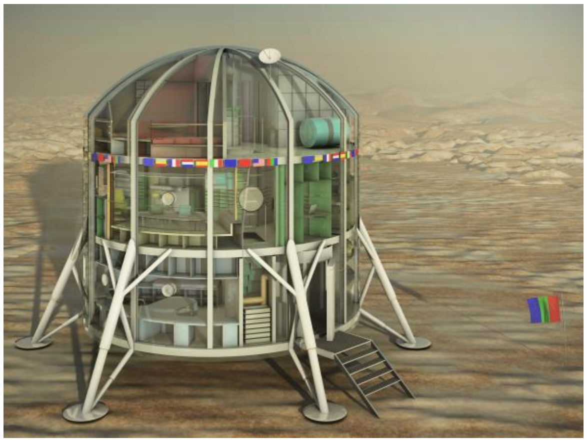


Figure 12: Euro-M.A.R.S interior © Frans Blok/3Develop

EURO-M.A.R.S.

The European Mars Analogue Research Station, or Euro-M.A.R.S., is a collaborative project of several chapters of the Mars Society. The proposed location in the Krafla region in Iceland offers a very Mars-like terrain, together with geological features similar to those already imaged on Mars. The area is also the home to a range of extremophile life of the kinds that may be encountered while exploring Mars. The core element of the station is the tuna-can shaped habitat unit, 8.6 metres in diameter and 8.4 metres tall, which provides room for up to 6 people at a time. It provides a realistic environment in which teams of volunteers can perform research into living and working on Mars. The habitat is similar to earlier Mars Society stations in the Canadian arctic and in Utah, but experiences from those predecessors have strongly influenced the interior design. Euro-M.A.R.S. has a three floor layout, with airlocks, laboratories, a workshop, a sickbay and EVA preparation room on the lowest level, living spaces, a galley, an exercise area, sanitary spaces and a solar flare shelter on the middle level and private quarters for the crew members on the upper level. Storage space and equipment voids are located through the entire structure which will allow for further expansion of the facility in the future with the inclusion of items such as waste management systems, water recycling systems, etc.

Figure 13: Euro-M.A.R.S © Frans Blok/3Develop

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