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Extreme Living Solutions: Self-sufficient habitat for extreme environments based on space technology

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ABSTRACT

This paper presents the first research phase of a system based on space technology that is capable of increasing habitability in extreme environments on earth. In this scenario, this research aims to support the establishment of a self-sufficient and minimum habitat from consulting to construction based on minimum space, time and costs.
Extreme environments are places for which human beings are not fully suitable, such as an environment where the water is contaminated because of a natural disaster. To support habitability in such conditions, this paper approaches research on autonomous habitats based on space technology, such as the water recycling system used today on the International Space Station. But what happens in such isolated habitats from a psychological side? In an extreme situation, the habitability project needs to be approached from a multidisciplinary dimension, considering all the different aspects as part of holistic (Holos: all) research. Indeed, space research can be applied both to technology transfer and to research transfer, including, for example, psychological research.
This project would start by providing consultancy services for users who want to improve extreme habitability projects and later on evolve towards building minimum habitats for extreme environments, to be used in isolated conditions, disaster situations or even in urban settings. The investigation (capturing space dimensions, volumes, people, traffic, and interaction flow) will serve users in terms of the quantitative assessment of habitability and ergonomics for habitats in extreme or stressed environments. The research will be validated using data from the Mars Desert Research Station and other cases.

Keywords: self-sufficient system, architecture, sustainability, technology transfer, space architecture, Melissa.

1. INTRODUCTION

1.1 Space Technology

High-tech technology transfer is the concept at the base of the project of autonomous habitats for extreme environments. The idea is to transfer the technology and the know-how from high-tech habitats to applications in autonomous habitats in extreme environments.
Space stations are the most highly developed high-tech habitats, which are intended to support human life under the most extreme and isolated conditions (NASA, 2010a[1]). Their purpose is to enhance human progress and knowledge of the extreme environment surrounding our planet (Huntress et al., 2006[2]; Ehrenfreund & Foing (Eds) 2006[3]; Foing & Ehrenfreund, 2008[4], COSPAR PEX report 2010[5]). Because of the extreme and isolated conditions, a Space habitat needs to be as much as possible a sustainable system, a closed-loop system with autonomy from Earth. To help us understand the artificial closed-system concept, we can imagine an aquarium where each single element has a direct influence on the equilibrium of the overall system. In the aquarium, the equilibrium between fish, plants and water is fundamental. As in the aquarium, in a closed-loop habitat all the factors are closely interrelated and influence each other, and therefore necessitate a design that focuses not only on elements of human-machine environments, but also on interdependencies and interactions between them (Bandini Buti, 2008[6]; Schlacht, 2010[7]). Indeed, an artificial closed system is a highly complex and expensive project, in particular in the case of a space station, which is extremely isolated.
While the high-tech of habitats in space (and their terrestrial analogues) aims to support the life and work of astronauts outside the Earth environment, they also

offer an invaluable chance to test concepts and technology that could be applied to any other human habitat on our planet, solving problems and improving the life of the inhabitants and the impact on the environment. Space habitats as integrated high-tech test platforms have great potential benefits when adapted to the needs of human beings.

1.2 Technology needed on Earth

Minimum self-sufficient habitats have been developed during many years of high-tech research for the most extreme context: Space. Such technology has enormous potential for our everyday lives. ESA (European Space Agency), DLR (German Space Agency) and ILEWG are now working on high-tech transfer from Space to domestic environments.

Nowadays, the creation of self-sufficient habitats is necessary not only for Space and other extremely isolated and expensive habitats without access to supplies, but also in much more common contexts. One example are megacity areas with limited access to resources (Quantius et al., 2012 a[8],b[9]).

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[10]; Quantius et al., 2012 a[11],b[12]; Karga & Schlacht, 2012[13]). Moreover, such habitats are also interesting for environmentally sensitive people who want to experience living with self-sufficient technology. Those are the reasons why the expensive high-tech technology may be transferred in order to be accessible for the benefit of the Earth population of both trained and common[I] people (ESA, 2002[14]).

Fig.1: Schema of high-tech transfer from space to daily life (Image © NASA)

2. STATE OF THE ART

On the basis of these considerations, one of the authors (Schlacht) has been previously co-operating with members of the Technology Transfer Programme of ESA and DLR to develop the first European closed-loop habitat (ESA, 2009; Karga & Schlacht 2012; Quantius et al., 2012a,b; Schlacht, 2012a; Schlacht et al,. 2012a,b).

2.1 Challenges 1

One main problem of high-tech transfer to domestic environments is low usability and habitability because the interface design and the human factors design are not integrated from the start of the project (ECSS, 2008).

Table 1: Habitability investigation (Schlacht, 2012, p.73)[15]

Habitability is relevant	Habitability is low
14 out of 14 astronauts consider the topic of habitability as a relevant matter for mission success	13 out of 14 astronauts suggested that habitability factors need improvement. Only the astronaut "I" found habitability not to be relevant (X); however, he agreed that in long duration missions, habitability needs to be improved.

In a questionnaire developed by Irene Schlacht, one of the author, and based on a literature review (Table 1), it was revealed that the level of habitability in the current high-tech Space station has low quality. This will be a problem if applied for common contexts where the users have not undergone any survival training. At the European Space Agency, the human factors missions are supported by different members of the team; however, there is no centralised human factors person and there is no user-centred design approach (ESA, 2007; Bandecchi et al., 2000). The problem is that the design approach used in the Space environment is the same for unmanned satellite missions and for human missions.

Today an important assertion can be found in the European Space standard: "The customer's total cost of ownership will be dramatically reduced if HFE (HF Engineering) practices are well integrated into all project phases, from the very beginning" (ECSS, 2008, p. 8). In conclusion, the lack of human factors applications extends from the very preliminary phase of the design process and is problematic not only in terms of supporting the user's autonomy in view of remote distances and prolonged mission duration, but also with regard to the actual technology transfer projects.
Qualitative dimensions of human factors, such as sensations and feelings, can be designed and planned on the basis of the users' needs, which in this research are considered to be a fundamental part of habitability.

[I] Designing the interaction with trained and selected users, such as astronauts, is a different approach than applying a "design for all" for common people. As a consequence, the need has emerged for integrating the design right from the start of the technology transfer process in order to support interaction with common users.

Those dimensions, which constitute a typical approach in human-centred design and in the humanities, are not part of mission design today. To design habitability, we need all the knowledge available, such as psychology and design, and as a consequence, a multidisciplinary approach ought to be the first step in mission design. Humanities and science disciplines need to be just as involved as engineering disciplines in order to support both the quantitative and qualitative dimensions of mission design (Schlacht, 2010; Schlacht & Ono, 2009).

2.2 Solution 1

Those problems were dealt with during the PhD, developed by Irene Schlacht, through tests and experiments based on cognitive psychology in high-tech self-sufficient habitats, such as during Space mission simulations. The results show that in those contexts the interface design is one of the key factors for interaction with high-tech. Moreover, living in direct contact within a self-sufficient system establishes an awareness attitude regarding the optimisation of resource utilisation (Schlacht, 2012a*;* Hendrikse et al., 2011). Based upon this experience, Irene Schlacht successfully developed and tested a design model called Integrated Design Process (IDP) for improving the usability of complex high-tech habitats by integrating human factors design from the start of the habitat project (Schlacht, 2012a). The model was personally applied by Irene Schlacht as a human factors team specialist during the FLasH project. FLaSH is an interdisciplinary DLR study of a terrestrial Facility of Laboratories for Sustainable Habitation. Various products like higher plants (e.g., vegetables, fruits, crops), animal husbandry (e.g., fishery, insects), fuel gases (e.g., hydrogen, oxygen), building materials (e.g., structural and isolation materials), but also consumables (e.g., clothes) as well as base maintaining services (e.g., water or waste recycling) and power supply will be provided and, where applicable, recycled in such a system.
The first DLR habitat design workshop was held at DLR's Concurrent Engineering Facility (CEF) of the Institute of Space Systems. "By the help of domains such as Air, Water, Waste, Greenhouse, Animal, Food Processing, Human Factors, Living, Sickbay, ISRU, Workshop, Design and Configuration, a scenario of selected habitat modules with input and output relationships has been set up" (Quantius et al., 2012b, p. 1).
The system consists of twelve modules, which are linked together via a connecting passage through locks. The modules are arranged in a circle around a dome-shaped agglomeration. With this arrangement, all modules are distributed at the same distance from the centre of the system (see Figure 4), (Quantius et al., 2012b, p. 5).

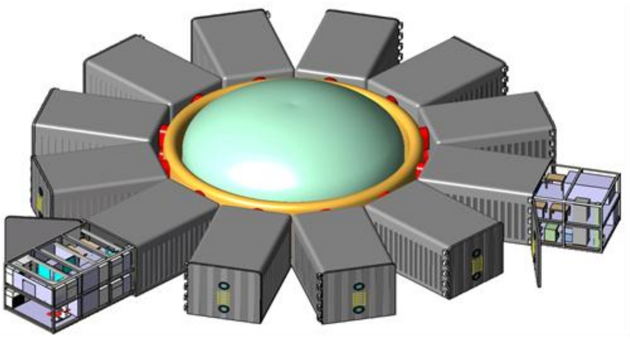


Fig. 1: Overall layout of the Habitat Module Complex

In such a closed environment, "Isolation and user-system interaction are some of the many human factors challenges that strongly affect the level of habitability" … and consequently human performance, safety, and well-being" (Quantius et al., 2012b, p. 3). As a means for dealing with these needs, the FLaSH study, with the support of Irene Lia Schlacht as a Human Factors specialist, incorporated human factors principles already in the preliminary design phase. The main issues were the following:

• Safety and quality of life (e.g., health, performance, privacy, motivation)
• Human system interactions (e.g., system usability and work load in normal and emergency situations)
• Psycho-physiological, operational, socio-cultural and ethical factors (e.g., anthropometric, nutrient, ergo-nomic, and ethical requirements) (Quantius et al., 2012b, p. 3).

This project resulted in a positive approach towards the integration of design into Space high-tech transfer projects as well increased interest in the development of self-sufficient habitats.

2.3 Challenge 2

The FLaSH study is a successful example of dealing with the problem of habitability; however, the time and cost related to this project are really high.
One big discussion, always proposed by the media and Internet blogs, focuses on the cost of space exploration, in particular during this time of crisis (Debate.org, 2012[16]). The idea is that space exploration may "create important new technologies to advance our economy" (Dubner, 2008[17]). However, the resulting technology still needs a lot of time and money to become applicable and sellable on earth, and for this reason most of the time it is not reflected in economic progress.

2.4 Solution 2a

The solution may lie in translating Space technology into low-budget systems that are easy to build.
"Machine for sustainable living is a system that converts a house into a small energy production plant (Karga, 2010[18]; Karga, in press[19]). It is not a product but a manual for a Do-It-Yourself (DIY) product that can be adapted to needs, budget, time and climate. 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)" (Karga & Schlacht, 2012, p. 5)[20].

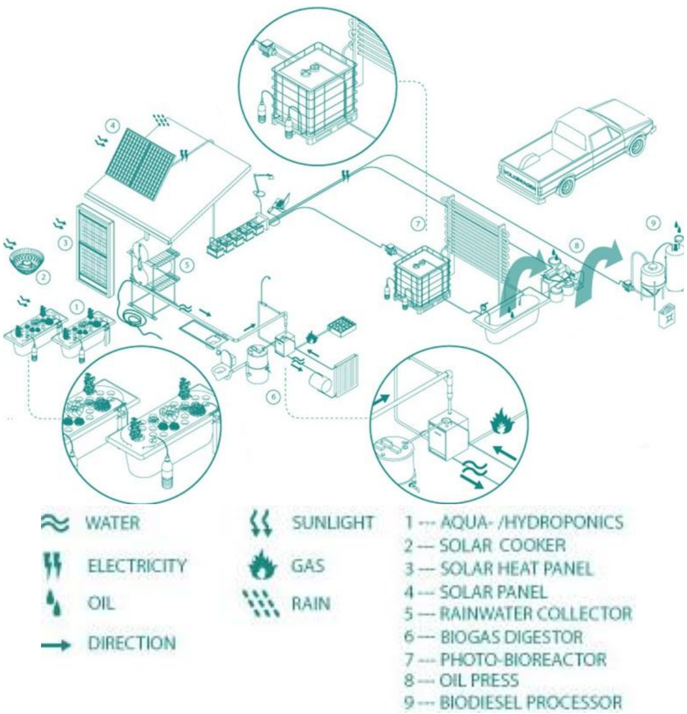


Fig. 2: Machine for sustainable living

"The Berlin Farm Lab is an application of "Machine for sustainable living" to fit one person's requirements. Valentina Karga is building a small prototype using herself as the centre of the experiment. So far an aquaponic system of 600l has been built, which is mobile and can be used indoors in the winter and outdoors in the summer.

She has also created 15m^2 of garden, where she grew a variety of 20 vegetables and herbs, according to square foot gardening and companion planting.
For cooking, a solar cooker is used on sunny days, while on non-sunny days, biogas from the biogas digester is used. If there is a lack of biogas, a rocket stove is used, which is a fuel-efficient stove that burns wood leftovers from the garden. For waste management she uses a compost toilet that converts human waste to fertile Earth for next year's cultivation.
Moreover, there is a rainwater collector for watering the garden and washing the dishes. Next year she is planning to complete the system with solar cells and a water purification system." (Karga & Schlacht, 2012, p. 6)[21].

Fig. 3: Aquaponic system outdoors in summer and indoors in winter (© V. Karga, 2012)

Another 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. At MDRS, "every two weeks exchanging crews of six members come to the station to perform a new mission to establish the knowledge and the equipment necessary for future successful planetary exploration viewed also from a Human Factors perspective" (Schlacht, et al., 2010, p. 1)[22]. 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.

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

2.5 Challenges 3

The Berlin Farm Lab still had to face a major problem, as it needed a trained person to be maintained: "Someone has to be constantly there. If I need to ever leave again I should find someone who is responsible and really teach him how live there" (Karga & Schlacht, 2012, p. 8)[23].
A similar system, also based on Space technology, was tested by architect Graham Caine with his Eco-House in 1972 in South London (Kallipoliti, 2012)[24]. When

the architect needed to leave the House system to his most trusted student, the system broke down.

At the MDRS in 2010, 2011 and 2012, different crews were requested to analyse the issues experienced in the habitat with a debriefing. During the debriefings listed below (Table 2) with crews 91, 200a and 103, which were organised by the authors, system management, maintenance and design emerged as problems, mainly related to the unusability of the interface.

Table 2: MDRS Habitability debriefing 2010-12 (Schlacht et al., 2012)[25]

Problems at MDRS
System management (e.g., potable tank water level, diesel and propane tank level, grey water level, storage system
System maintenance (e.g., toilet and green house system)
Space design (e.g., small quarters, cold environment, low air quality, environmental noise, overloading of tasks, low-quality radio, uncomfortable bathroom…)

2.6 Conclusion

As a conclusion, it was found that after dealing with habitability (challenge 1), the next problem that emerged was that of technology accessibility (challenge 2). Once the problem of accessibility had been dealt with, the issue of usability arose (challenge 3).

3. INNOVATIVE METHODOLOGY

3.1 Technology transfer feasibility

Considering the previous chapter on the state of the art, many projects have been developed for self-sufficient habitats based on technology transfer from Space to Earth. However, the result has been low feasibility of this project for common people on Earth.
The reasons are:

1. The system does not have habitability: it does not support the quality of life level assessed by human factors requirements.
2. Space technology is not accessible: it needs a long time to be developed and transferred, and it is too expensive.
3. The interface is not usable: it is highly complex and needs a highly trained person or expert to be used.

The goal of this research is to use the Space technology and know-how transferring process to support the feasibility of a self-sufficient habitat project.
To do this, first we need to reduce the cost, the time and the volume of the habitat to the minimum needed in order to achieve accessibility. But we need to balance the accessibility of the technology with habitability. In other words, we need to reduce the cost, time and volume but still consider the human factors requirements in order to achieve habitability. Finally, the system needs to be evolved further to also make it usable by common people on Earth.
Only if accessibility, habitability and usability can be provided will the high-tech applied to Space also become applicable for Earth application in the near future.

3.2 Habitability requirements

Human Factors is defined "as the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance" (IEA, 2000).
"Habitability is defined as the quality of life in an environment" (AA.VV, 1999)[26]. This is the concept addressed by the human factors discipline when it is applied to living and working environments for long-term activities[II] (Messerschmid & Bertrand, 1999).
Human factors applied to habitability need to support the following human-habitat system qualities:

- Usability (user friendly: e.g., equipment)
- Livability (living space quality: e.g., privacy)
- Flexibility (variability of the place: e.g., personalisation)
- Innovation (solutions to unsolved problems: e.g., application of technology transfer) (Häuplik-Meusburger, 2011[27]; Schlacht, 2012a[28])

Those qualities need to be considered in the interaction with humans and the following factors:

- Operational factors: activities
- Psychological factors: mental reaction
- Socio-cultural factors: group interaction and personal background
- Physiological factors: body interaction
- Environmental factors: local environment (Schlacht, 2012a[29])

Those requirements support a human-centred design approach that sees the human quality of life as its main goal.

3.3 Multidisciplinary methodology

A multidisciplinary methodology is the basis for creating highly habitable living spaces following human factors requirements. Unlike in a working context, in a living context a person needs to not only be healthy and productive but must also be able to feel joy and experience development. This is why the habitat project needs to have a sound interdisciplinary basis in order to support humans from the cultural and the technical perspective. Therefore, a multidisciplinary approach is a particular focus of the methodology suggested. The multidisciplinary methodology consists of the utilisation of an interdisciplinary panel of experts in the design process with the aim of supporting the habitability and quality of life (Schlacht et al., 2008[30]). Following this multidisciplinary logic, both humanities and scientific disciplines (such as architecture, human factors, cognitive psychology, anthropometry, and cultural anthropology), and engineering disciplines (such as

[II] Long term is considered more than two weeks.

system engineering, civil engineering and human factors engineering) will be integrated into the design of the human-machine systems. With this multidisciplinary team, the project will support the user both in performing quantitative tasks and in acquiring quality of life.

3.4 Integrated Design Process

The main objective is to develop the human-machine system of the minimum domestic self-sufficient living unit based on high-tech transfer. This objective will be accomplished by designing concurrently in a multidisciplinary team and integrating with a user-centred approach the human factors discipline "into all project phases, from the very beginning" (ECSS, 2008, p. 8[31]). This kind of design is called "Integrated Design Process".

The application of the IDP is based on:

- Multidisciplinary team: to support the project from different perspectives
- Design concurrently with user-centred approach: to support interrelationships among all disciplines and interaction constraints within the human
- Human-machine-environment interactions: operational, physiological, socio-cultural, physiological and environmental factors.
- Support of the human-habitat qualities: usability, livability, flexibility, innovation

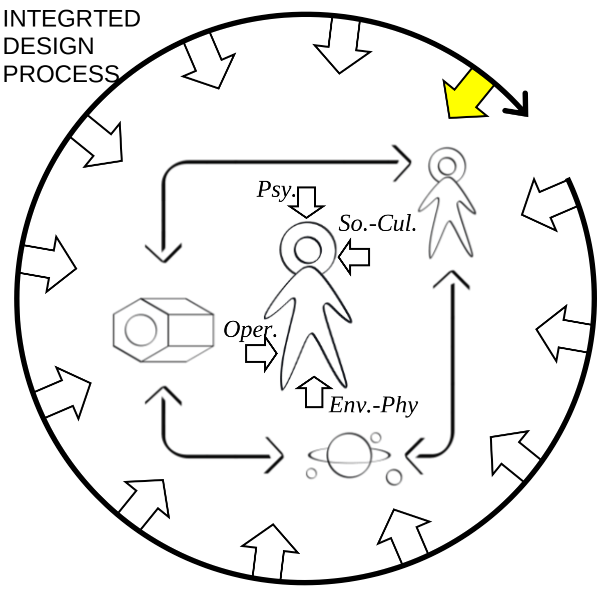


Fig.1: The Integrated Design Process is based on a multidisciplinary team (the different arrows starting from the circle are the different disciplines that together cover all the different perspectives in 360°) working concurrently (the circle joins all the disciplines together) considering the human-machine-environment interactions (the 3 elements connected around the user) to support the human factor requirements (the 4 arrows that point to the user) with a user-centred design approach (the user is in the centre).

3.5 Design Steps

On the basis of the Integrated Design Process, the project should be consistent with the following steps:

1. Acquisition of lessons from exploration field tests

In analogue and Space environments, consider and select the high-tech and know how to be transferred from Space and extreme environments to domestic application;

2. Development of requirements

Set the interface requirements, verifying the standards in anthropometrics, cognitive psychology, human-machine interaction, quality of life, etc.;

3. Coordination of workshop with scientific users

Adapt the selected technology using human-machine R&D principles to optimise for habitability and performance.

Apply the concept for the development of the habitat project within the IDP strategy (human factors, concurrent design, multidisciplinary team, user-centred).

4. Development of prototype

Build the prototype of a minimum habitat interface to be tested (e.g., Connors et al., 1999[32]; ECSS, 2008[33]; NASA 2010b[34])

5. Execution of tests and validation

Finally test the man-machine system and the human factors parameters selected within the standards and requirements selected to reach autonomy and self-sufficiency

6. Exploitation

Set the habitat up for production and utilisation

4. FIRST PROPOSALS

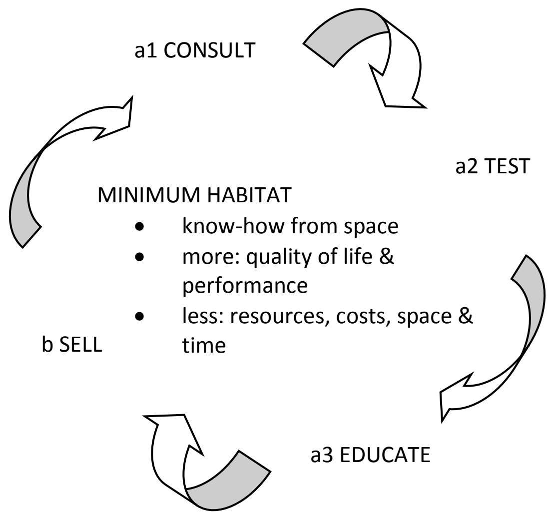
After considering the problems related to the state of the art and how to solve those, a first proposal has been developed, approaching also the economic side with a complete business plan.

4.1 Mini Hab

Mini Hab is a project that aims to increase habitability on Earth using sustainable technologies and know-how from the Space habitat where resources are very limited and are constantly recycled. The strategy will be not to build expensive and complex habitats, but to do so with a minimum of space, time and costs. In particular, this concept needs to be applied in extreme environments where habitability is really low today.

4.2 Development phases

To build this facility as a pilot system to transfer Space technology to Earth application, the concept has been integrated into the development of a company. The company development is based on different phases.



The a1 phase is related to consultancy. The goal will be to offer consulting to companies that build commercial habitats such as caravans, yachts, refugee shelters, etc. in order to determine which Space technology could be applied to their products.

The a2 phase is related to testing. The idea is to offer a minimum habitat facility for testing the transfer of technology and knowledge from Space industries as well as industries that work with extreme environments.

During the a3 phase, whose purpose is education, the market will also be opened to schools and educational entities related to resource utilisation and environmental impacts, which may also increase the number of partners or clients in the future (e.g., schools, educational services in developed countries).

The second phase (b) will be to produce, on a large scale, minimum and autonomous habitats[III]. The clients will be companies that can deploy the habitat in areas where no housing and supplies (energy and water) are available. For example, aid agencies that need to work in extreme environments for long times, e.g., following floods, or in disaster areas with epidemics, or scientific research institutions studying extreme environments such as polar areas, jungles, deserts and underwater areas, as well tourism entities.

4.3 Customers

The clients during the first phase will be the human resource departments of different entities as well as educational entities. During the second phase, services will be open to a large variety of clients, from enterprises to private individuals.

The point of entry to each market is described with the following list.

- Space technology and research

Benefit: Earth application

- Mobile homes, sustainable houses and domotics, alternative resource technologies

Benefit: extreme environment application

- Extreme environments user

Benefit: increase of well-being and performance

- ESA and entities related to Space

Benefit: increase the market and the awareness regarding the relevance of Space research, and, as a consequence, investments in this area.

- Aid agencies, tourism agencies and research entities active in extreme environments

Benefit: provide an easy-to-access and easy-to-build working and living station from where to operate in extreme environments such as natural disaster areas or isolated environments that are of interest to tourists or scientists

- Private individuals

Benefit: optimise resources for ethical purposes, personal purposes and/or to save costs

- Educational entities

Benefit: increase awareness related to resource consumption and the environmental impact of human life

Considering that ESA has a scientific and not a defence purpose, the military market is not considered to be consistent with the ESA approach.

Customers have also been studied in relation to the SWOT analysis (Table 3).

Table 3 SWOT Analysis

	POSITIVE	NEGATIVE
INTERNAL	Strengths Minimum cost, time and space. Know-how in the field PhD research on the topic Developed prototype Unique selling context Customised product	Weakness Clients' contacts to be set Client, supplier and co-operator are spread all over the world, not in the same nation, so they have different norms and regulations and difficulty to meet personally
EXTERNAL	Opportunities Need for small places There is no society that offers this service The suppliers and the partners are already aquired on the first phase of the proect as clients	Threats Competitors that have similar products but with a developed network of clients Military will not be supported and may be a competitor

[III] With b1, the market will expand to large-scale production of habitats for entities that need to work in emergencies and extreme situations. Habitats for the construction of megacities will also be supported. With b2, the markets approached will also be expanded to include non-extreme fields covering private consumers. Finally, b3 will support the possibility of goods implementation resulting from the production of equipment for the self-sustainable habitat. This will be offered to everyone who may have an interest in self-sufficient habitats and living behaviour.

4.4 Technology applied

The technologies applied in the minimum habitat system aim to increase the autonomy of the habitat in terms of resource utilisation. The habitat system is supposed to be as regenerative as possible to reach maximum autonomy. Such technology will refer to the ISS's Space habitat systems, such as Thermal Control System (TCS), Electrical Power System (EPS) and Crew Health Care System (CHeCS). In particular, the Environmental Control and Life Support System (ECLSS), which provides and controls air, water, pressure, temperature and humidity, but also detects and suppresses fire. Recycled wastewater, including water from air humidity condensation and urine, is converted into "drinking water, oxygen for breathing and hydrogen" (NASA, 2010 p. 82)[35].
Initially those technologies will be provided by companies that want to test their product in the habitat; indeed, the construction of the first habitat will serve as a testing facility. As a test, a company that produces minimum wind turbines has been contacted and has offered a turbine model to be tested on the habitat.
Particular attention will be given to support the possibility to update the technology applied. If, after a certain period of time, one component needs to be substituted, removed or updated, it should be possible to do so without compromising the entire system.
Not only the technology will be transferred from Space, but also the knowledge and the research done by the human factors, ergonomics, design, psychology as well as architecture disciplines. This will provide a multidisciplinary approach to a living solution in an extreme context.
An example of this field is the research carried on in isolation by Mars 500, as well as the one at the Mars Desert Research Station in Utah. In those isolated habitats, a multidisciplinary approach has been applied as a methodology for building the habitat as well as for testing the habitability of the place.

4.5 Structure selected

The structure needs to be easy and cheap to transport in each location, also in extreme environments that cannot be reached easily. The structure needs to be composed by an easily movable, easy-to-build and affordable analogue facility for testing technologies, architectures and procedures applicable from Space to Earth.

Fig. 2 Mini Hab at La Reunion Island, Europe (Indian Ocean)[IV]

The ISO container proposal supports the possibility to develop a specific field project with high fidelity. Indeed, the container structure is very similar to the interior structure of a modular Space habitat. The habitat needs to be planned and designed from the start and fitted out with services such as toilet, shower, cooking facilities, beds, office, laboratory, EVA air lock facilities and internal partitions. Possible adaptation of the container shell will support any required configuration. This option draws heavily on the existing and prevailing architecture employed in the design of Space habitats.

Advantages:

- Easily transportable
- Self-contained
- Robust
- Weather- and transportation-proof
- Does not require additional storage facility for transportation
- Pre-qualified for shipping

Although it is envisaged that this approach will require the largest initial time and financial budgets, (because of the fidelity as an analogue of Space architecture design), it is also likely that it will have the highest scientific yield and therefore the highest return on investment. The proximity of this design to any design eventually deployed in Space will give more scientific yield for the design and fabrication costs.

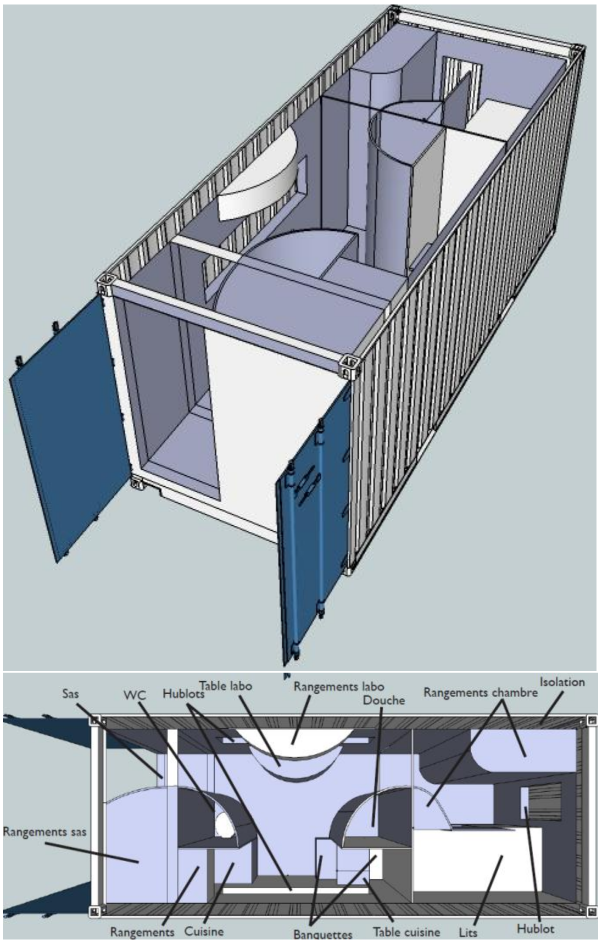
ISO containers are currently in use in a variety of different environments and fulfill a number of different functions, such as regenerative energy applications as in the case pictured below. They are sturdy, easily transportable and open to a wide range of manipulation and augmentation.

Fig.3 ISO Container application [V]

[IV] Image reference: http://www.panoramio.com/photo/59593879
http://twotimestwentyfeet.com/download_container
[V] Image reference:
www.architecturelist.com/2011/09/09/sustainable-architecture-containers-by-luis-de-garrido/

This habitat needs to provide the basic requirements for living: bathroom, sleeping accommodation, kitchen, refrigerator and storage. The habitat must also function in a basic manner, as a facility for a Space mission: laboratory, storage, equipped EVA air lock.

Fig. 4 Mini Hab Zoning (© Fabian Watelet)



4.6 Pricing

The pricing strategy will be studied in relation to the kind of clients that will approach the company. During the first stage, the main goal will be to gain clients and to support the affordability of the project in relation to the clients.

a1. Consultant: Extreme environments as well as domotics
400 euros per day x 10 consultant services x 5 days for each = 20,000 euros
On the basis of know-how

a2. Test: During the test phase, consulting services will also be offered on the habitat prototype
20,000 euros per habitat prototype

a3. Education: 150 euros per class, 40 classes per year = 6,000 euros

b1. Market: Each LES habitat 30,000 euros

b2. Sector: Each LES habitat 30,000 euros

b3. Product: Each product from 10 to 2000 euros

4.7 Impacts

The design and construction of a prototype of a minimum self-sufficient habitat has a very strong potential impact on research, on social and environmental progress, as well as on the economic growth of high-tech industries.

1. Social and Environmental Progress
   The utilisation of the minimum self-sufficient habitat will bring social and environmental progress, including:
   - Energy, resource and monetary savings
   - Awareness regarding energy and resource consumption
   - Different attitude towards the environment
2. Economic Growth
   The production of the minimum self-sufficient habitat will bring economic growth:
   - Increase the market of application and the work capability of high-tech production (e.g., Space field) to low-cost domestic environments
   - Increase sensitivity to Space research investments
3. Research Impact
   In particular, within the two years of the research timeframe, the prototype will lead to progress in research in the following areas:
   - Development of the Habitability field of research (quality of life and usability of the habitat) and technological innovation
   - New interdisciplinary co-operation

4.8 Benefits

The benefit to the Space field will be to create awareness regarding the importance of Space research and its applicability for human well-being on Earth.
There are many benefits for the non-Space sector:

- Increase of habitability for workers in extreme environments
- Increase of performance in minimum habitat facilities
- Expansion of the sector for companies working in the Space field
- Application of technology and knowledge from Space to improve living conditions on Earth
- Social benefits provided by the changes in human attitudes and behaviours, reducing aggregate consumption of unsustainably managed ecosystem services

A concrete example of application will be habitats in disaster areas, shelters for humanitarian or emergency operations, and cultivation areas.

5. CONCLUSION

After considering the current needs of creating a self-sufficient habitat based on technology transfer from Space, the state of the art has been analyzed and the major challenges have been approached with a new methodology.
As a result, a Mini Hab project proposal has been presented.

The innovation of this project can be found in three main focal points:

1. Technology accessibility: high-tech transfer from Space and extreme sectors to minimum self-sufficient habitats for earth
2. Support of habitability: new design methodology and approach (IDP) that integrates human factors and human-centred design
3. Usable interface: development of smart systems of interface (including communication, power, data management, environmental control)

Having the project based on these focal points will assure better feasibility of the project for large-scale Earth applications.

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