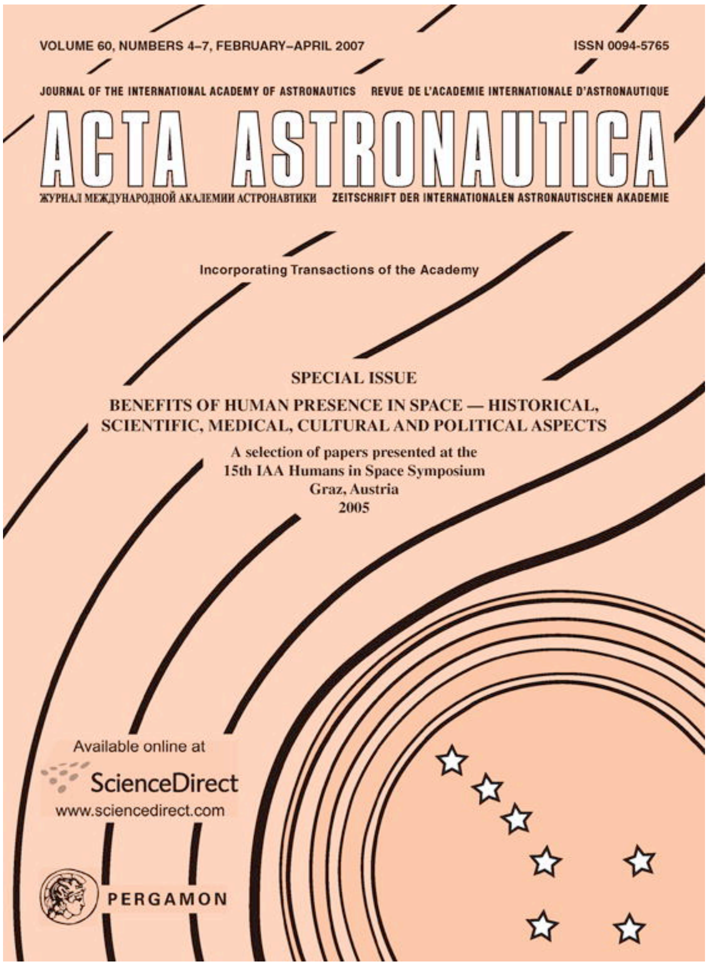
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Transformation: Structure/space studies in bionics and space design

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Abstract

This paper discusses the architectural design project "Transformation Structure Space", which was carried out at the Department of Building Construction HB2 in 2004. The goal of the study was to find innovative solutions for space system design through the application of bionic (biomimetic) approaches. Using specific research both fields as the foundation, five different architectural projects based on a scientific-technological concept were developed. The introduction of natural role models into the design process and the development of the application in space and the respective setting proved to be a difficult task within the timeframe of a design program, nonetheless all of the projects show very innovative aspects.

Keywords: Bionics; Biomimetics; Space architecture; Space system design; Technologized space; Transformation

1. Introduction

Engineers, designers and architects often look to nature for inspiration. Nature has perfected its designs through billions of years of evolution, so mimicking its creations is a sure way of producing technologies that are both efficient and reliable. There is nothing new about borrowing design ideas from nature, but now this has received a new name bionics or biomimetics.[1] As a scientific discipline, bionics (biomimetics) deals systematically with the technical execution and implementation of constructions, processes and developmental principles of biological systems. This also includes various forms of interaction between living and non-living elements and systems.[2]

Present and future robotic missions to the Moon [SMART-1 (ESA), SELENE (Japan), Chandrayaan-1 (India), CHANG'E-1 (China), South Pole-Aitken Basin Sample Return (USA)] and Mars [Mars Express (ESA), Beagle-2 (ESA), Rovers Spirit and Opportunity (USA), Mars Odyssey (USA)] will serve as precursors to future human missions to our planetary neighbors. Future long-duration human missions will have direct implications for the architecture of the space habitats. Therefore, it is timely to explore this field and also to look for the overlaps in terrestrial and extra-terrestrial architecture for possible spin-ins and spin-offs.

The architectural design project "Transformation Structure/Space", which was carried out at the

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[1] The term "biomimetics" is in the englishspeaking world equivalent for the german "bionik".

[2] Definition according to Nachtigall, Werner, *Bionik*, *Grundlagen und Beispiele für Ingenieure und Naturwissenschaftler*.

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Department of Building Construction in the summer term of 2004, was announced as a set of experimental concepts to investigate the overlapping areas of the two architectural fields, representing the authors' respective expertise: Bionics and Space System Design.[3] External experts working in scientific and engineering fields of institutions and organizations supported the project.[4]

In the project approach described in this paper, transformation could signify, for example:

- transformation of concepts from nature, science, art, etc. into architecture;
- transformation of methodologies from one professional field into the other;

and finally, also

- transformation of an idea into a built space.

Bionics was used as the topic for conceptual translation into project design: learning from nature for technological applications, using an interdisciplinary approach. Space was seen not only as space for observations to be incorporated in architectural designs, but also as space for projections from Earth.

2. Problem statement

In the current architecture discussion, the topics of performative architecture, animate form, augmented reality, technologized spaces (spaces which have a highly technical infrastructure and are defined in their character through this) as well as issues of construction, material development and others have been of predominant interest. Recently, through the efforts of a few European architects space and architecture have come onto the architectural discourse platform and thus become a media issue, which serves the entire space industry.

The theme of transformation seems to be quite prominent in the current architectural discourse of performative space and animation but is also emerging in the space industry. Looking at new concepts of intelligent robotics, ESA's new ExoMars rover or the United States Mars rovers Spirit and Opportunity, we see that models from other sources (e.g. nature) have successfully come into play.

3. Project structure and methods

A design studio approach was taken. Pre-studies in specific areas and lectures of invited speakers served as preparation for the project. A visit with of all the participating students to Alenia Spazio in Torino (Italy) enhanced the students' knowledge. Frequent reviews with invited guests and telephone conferences with experts from the European Research and Technology Center of the European Space Agency (Noordwijk, Holland) and the industrial firm Alenia Spazio were important inputs for the discussion.

The pre-studies included research topics for each student, which were presented to everyone for reciprocal learning. Through these investigations the students embarked upon their projects and concept developments. In this way, different mission scenarios were developed according to previous research. Amongst these mission scenarios were the following:

- Case study 1: space loggia.
- Case study 2: lunar base telescope.
- Case study 3: augmented lunar base: a habitat for one person.
- Case study 4: spaceship Mars+.
- Case study 5: mobile Mars habitat—triangle-flex Mars Rover.

Each of the case studies will be explained and discussed in the following sections.

The start of the design project was an extended research phase. Several themes were offered to the students for research. The entirety of the collected, processed and exchanged information was intended to form the basis of the development of architectural concepts.

The themes included basic information on space system design, such as living and building in zero-gravity (ISS/MIR), or on Mars/Moon, spin-in and spin-off between technologies used on Earth and technologies used in space, and another concept used in interpreting space: augmented reality. The themes were:

- Living and working in space: what are the boundary conditions, how to build in space, what does everyday life look like.
- Augmented realities: an approach to architecture in space, the current discussion in architecture, its implications and implementations, technologized space.

[3] Architect Barbara Imhof has worked on space design projects in various organizations and is currently acting as a consultant for ESA in human factors and habitability for the Human Mars Mission. Architect Petra Gruber has been teaching the course "Bionics (Biomimetics)—Natural Construction" at the TU Vienna for five years and is a freelance architect. Both currently work as Assistant Professors to architect Prof. Helmut Richter, Institute of Architecture and Design, Department of Building Construction, Vienna University of Technology (TU Vienna).

[4] The project was supported by experts of Alenia Spazio, Italy, European Space Agency and The Institute for Biomimetics, Great Britain.

The "natural" themes were selected among the most promising approaches of the course "Bionics—natural constructions"[5] :

- Folding techniques and inflatable habitats for space.
- Materials from nature for extreme conditions.
- Locomotion in nature.
- Propulsion methods of nature.
- Robotics—functional morphology and sensors.
- The principle of self-organization and possible technical applications.

The findings of the analysis were projected onto current themes in space architecture:

- Inflatable habitats.
- Human factors for long-duration missions and incorporation into the design of a space habitat.
- Human–machine interface.
- Spin-in/off—bringing Earth's building technologies into space (indigenous search for water, minerals, living off the land) and space technology into Earth's building industry (disaster relief).

The design included the respective concept. Five case studies are briefly introduced to give an overview of the outcome of the project and to highlight the findings and conclusions.

3.1. Case study 1: space loggia

3.1.1. Brief description

The project "space loggia" is the design of an astronaut's lounge serving as a relaxation area in the spaceship (Figs. 1–4). The feeling of being in space is stronger than in a conventional module of the ISS. Earth is the object of reference, watching the Earth gives orientation and produces feelings of affiliation.

The project's challenge is to create a transparent skin, which resists the harsh environment, e.g. micrometeoroids, radiation and temperature change. The concept suggests a multilayered skin containing gelatinous and glass or plastic structures. In the opening scenery, the windows (biological membrane) of the loggia will be "nourished" by a liquid, which keeps this kind of multilayered membrane viable.

[5] Gruber, Petra, *Bionik—natürliche Konstruktionen*, lecture book, Department HB 2 of Building Construction, Vienna University of Technology, 2001.

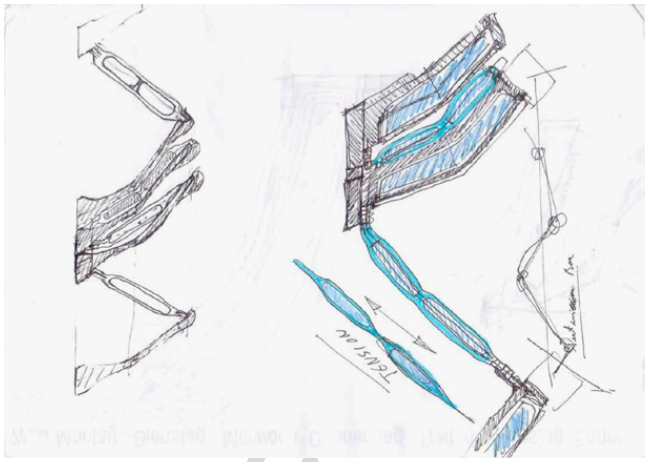

Fig. 1. Concept sketch of the expansion of the space loggia 1.

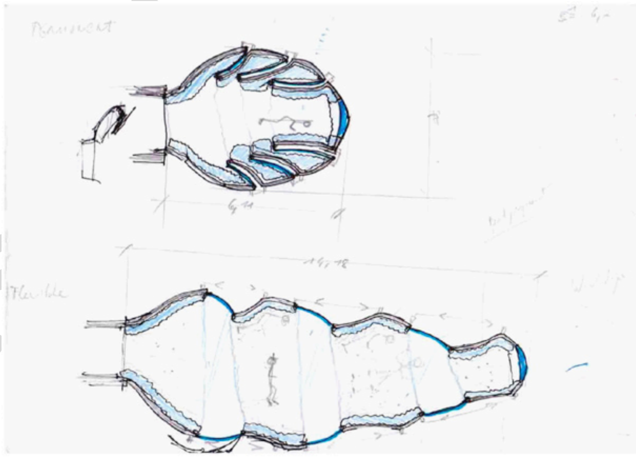

Fig. 2. Concept sketch of the expansion of the space loggia 2.

3.2. Case study 2: lunar base telescope

3.2.1. Brief description

The project takes a NASA contract study for a lunar telescope as a conceptual basis.[6] An astronomical observatory, including a habitat connected with a cable car, is to be built at the Moon's South Pole. The telescope is to be placed inside the Shackleton Crater, where it would never be exposed to sunlight. On the crater rim a solar power factory would be situated, and a habitat for maintaining the telescope would be placed on the other side of the crater. The habitat section was the focus of the project (Figs. 5 and 6). The human blood circulation system served as a model for the layout of the whole area.

Along the cable car track, a zone of infrastructure including several habitats can be built. Easy access to

[6] Colorado School of Mines by Mike Duke and Paul van Susante.

the telescope can be guaranteed. Cargo from the Earth lands a few kilometers from the habitation zone and can be transported by cable car to the base or directly

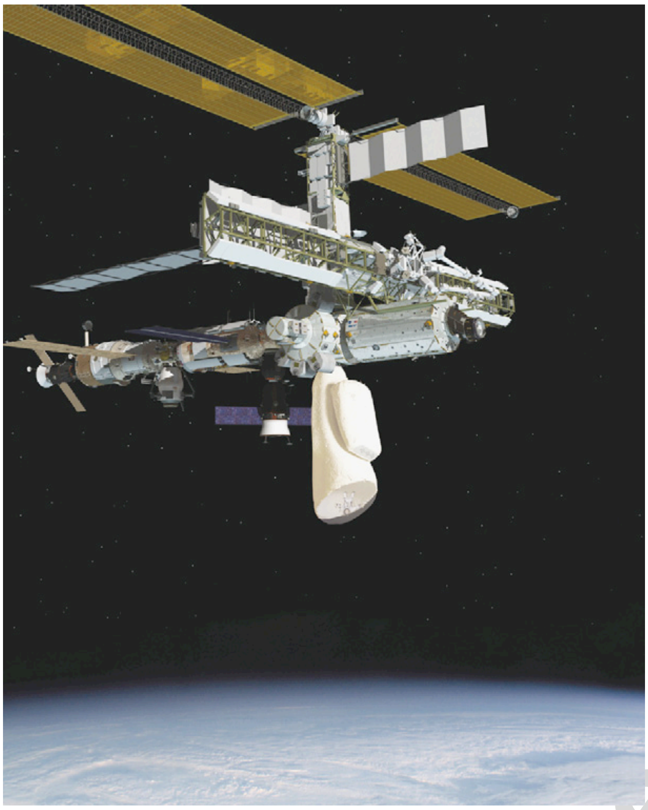

Fig. 3. Space loggia attached to the ISS.

to the crater. The initial human lunar base houses 7–8 crewmembers. The functional program of the habitation zone includes social and private areas, zones for laboratories and working, and storage facilities. The social and private areas are divided into the crew's quarters, training and hygiene facilities, and the galley with the areas for socializing and recreation. The life support systems would be incorporated into the whole structure, with a focus on easy access for maintenance. For scientific reasons and to supplement the diet, a greenhouse was added. Emergency infrastructure and system contingency has been incorporated.

3.3. *Case study 3: lunar base, augmented: a habitat for one person*

3.3.1. *Brief description*

This project starts with an extreme assumption: one person lives and works in full autonomy for six months on his/her own on the lunar surface. This one-human crew lives in a mobile base with relatively low power consumption, little resource management, simple base organization, radiation protection and an excellent system for communication. The mission is to search for water ice, helium 3 and other lunar resources with the support of robotic systems such as an unmanned rover. This mission scenario is to be seen in a highly experimental context focusing on socio-psychological issues for further findings for long-duration missions.

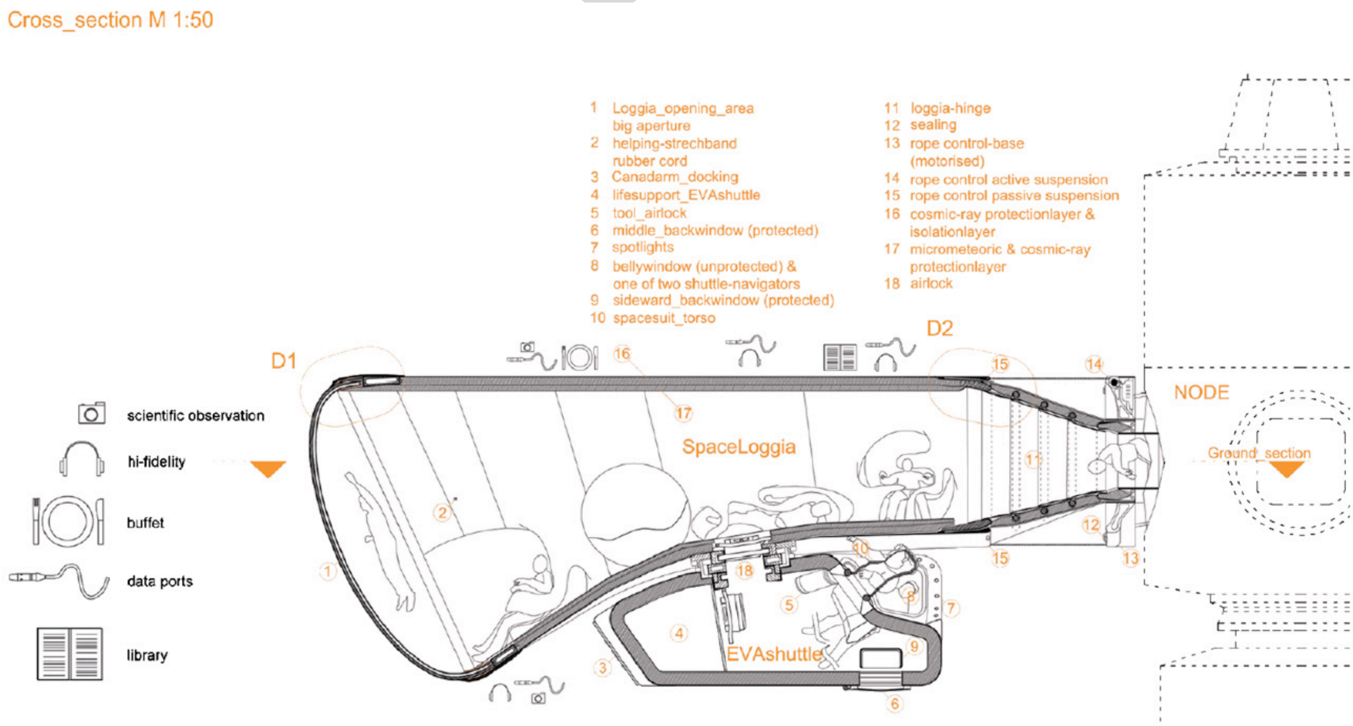

Fig. 4. Section of the space loggia.

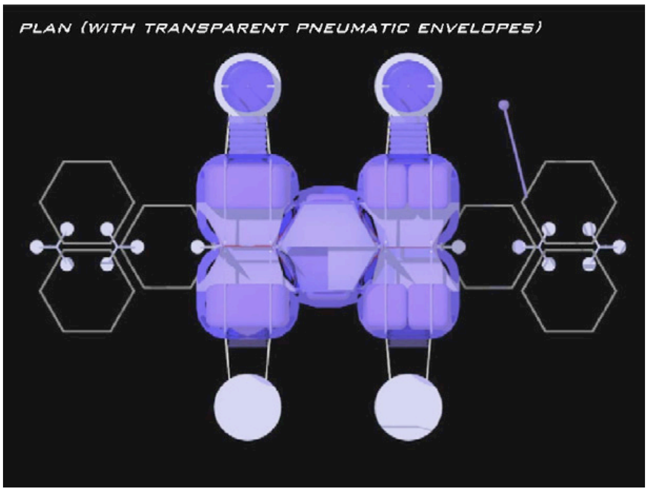

Fig. 5. Schematic of one habitat module viewed in plan.

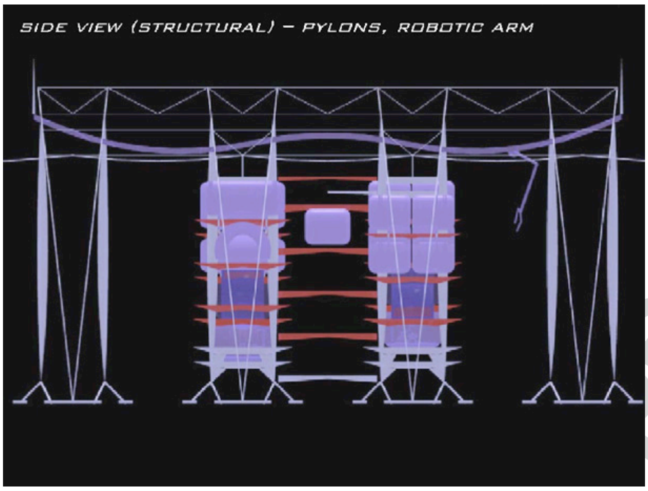

Fig. 6. Schematic of a habitat module in section, including the cable car track above the buildings.

Isolation, deprivation and psychological stressors such as claustrophobia, insomnia and depression have occurred in similar missions in extreme environments in space and on Earth. The need for a highly effective interpersonal communication system with virtual reality facilities to augment the perception of the confined space has to be added to the program of the base so that the single person can withstand a 6-month period.

For this reason, a communication system for teleoperation, navigation and for the human physiological and psychological constitution will have to be implemented. The real habitat space will be enlarged through a virtual space. The real physical space is formed by a flexible skin, which on its inside is changeable and allows different interior configurations where possible and useful. The virtual space has its technical interface with count-

Fig. 7. Concept of the flexible skin of the single lunar base, being adaptable to different activities.

less LED and lCD panels which are immersed in the flexible skin.

The skin (Fig. 7) adapts to host any type of contact that is needed or allowed to answer the user's movements or moods. It offers a full communicative environment. The user is wearing gear, which defines his/her exact position within the habitat space and allows the system to react to and interact with the user's position and emotional condition.

Not only the user or the automated system would be able to transform the environment, but also remote persons from Earth, such as family members or friends. Real time images, speech and skin movement form the communication habitat and allow the user's integration into a larger societal world. Seen from our home planet, the augmented habitation space of a spaceship or a planetary surface enables the same degree of active participation of the user in three-dimensional space as it provides in connecting the space farers with home (Earth).

3.4. *Case study 4: spaceship Mars+*

3.4.1. *Brief description*

This design and research project is based on three main ideas:

> To create an architecture using new paradigms, derived not only from specific mission objectives and environmental conditions but also from experimental forms of architecture, leaving Earth-stereotypes.

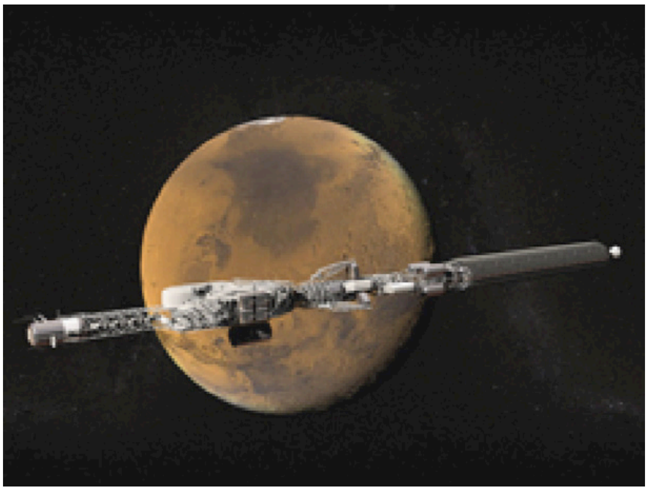

Fig. 8. Overview of the spaceship MARS+ (left = front: Mars excursion vehicle/Lander, left-middle: the heart/habitation module, right-middle: centrifuge and laboratories, right = back: propulsion).

Fig. 9. Spaceship MARS+—detailed view (left: centrifuge with the tiny laboratory modules/white cubes, middle right: induction for radiation protection, upper right: cold fusion as propellant).

> To identify and make use of the advantages of living in zero gravity, incorporating artificial gravity facilities for long-duration missions.

> To create an interior space for human necessities inside a machine—the spaceship—for an environment that continuously stimulates its inhabitants, with the object of creating a living and emotional space, as well as a space to live in.

The project described uses the following future mission scenario: the Moon has been colonized since 2045 and its resources are mined to be processed directly on the surface. In 2075, Mars exploration has reached the next step and humankind has managed to build a permanent Martian research outpost. Therefore, new transportation technologies are of essence in order to exchange crews and supplies. The required spaceship parts are produced on the Moon's surface and assembled in the lunar orbit. From there the spaceship takes off towards Mars with a crew of eight astronauts.

Gravity is a necessity for the human biological physiology. Life without gravity can, therefore, be seen as a problem but also as a great opportunity. The perceptional effects of zero gravity completely redefine interior spaces and dimensions and challenge the architecture of a spaceship.

The proposed design assumes advanced propulsion and radiation protection technologies and deals with an architecture that interlinks the spaces of the habitat in a functional circulation like a biological system of cycles (Figs. 8 and 9).

The primary technical drivers are incorporated into the architectural layout in the same way as other equally important drivers (e.g. socio-psychological stressors), including:

- The human desire for socializing, communicating and being close to others as well the direct contrast to this, i.e. the desire for privacy, meditation and individuality.
- Spatial qualities derived from the research, evaluation and interpretation of the fact that the journey to Mars takes several months, a long time, which, far away from Earth, might seem like an eternity.
- The seemingly unnoticed physical moving of the spaceship—time and distance.
- The absence of external influences, such as weather or the change of time of day.

Biorhythm and the change of the architectural setting (change of atmospheres) are suggested by the possibilities of an ongoing succession of interior rearrangements, based on a form of communication between the crew and the ship (Figs. 10 and 11). These should be induced by the crew's living necessities, and not only include the adjustment of space volume, depending on the number of attendees, but should also reflect the conditions of every day life.

3.5. Case study 5: mobile Mars habitat—flex-triangle Mars Rover

3.5.1. Brief description

The scenario defines a small Mars base existing on a Martian plateau in 2040. The explorers start from this base to venture into regions of scientific interest—mountains and valleys of Mars. For these

Fig. 10. Interior configuration next to the crew's quarters; orientation as in ISS.

Fig. 11. Interior configuration in the social area, the main zero-gravity area—the heart of the spaceship—recognizing the potential of zero-gravity, introducing an orientation system with significant markers (objects).

excursions into the extreme topography of Mars, the new mobile base is used. In contrast to conventional rovers, where only a limited number of wheels are responsible for the movement, here the whole structure moves like a unicellular organism (Figs. 12–14).

The structure of the mobile habitat consists of triangular positioned struts, which change their length to move. The connecting nodes allow deformation by a change of angles in order to always provide the best contact with the planet's surface while moving through extremely rough regions.

The first important idea taken from nature is the manner of moving through deforming of the flex-triangle-structure. Every part of the structure can change its length like the muscles of a snake or grub. A second bionic idea is the attachment of the inner structure (life support systems, cockpit, storage, experiments) as compact parts on the deforming flex-triangle structure (Fig. 13). In some ways this is similar to the positioning and attachment of organs in the human body.

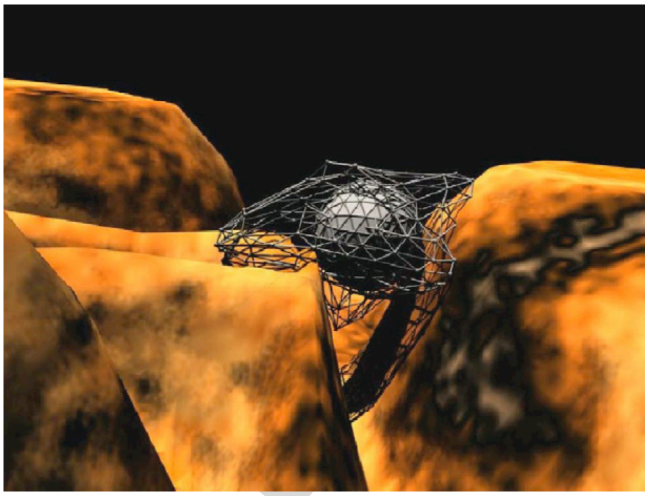

Fig. 12. Movement of habitat in the Martian terrain.

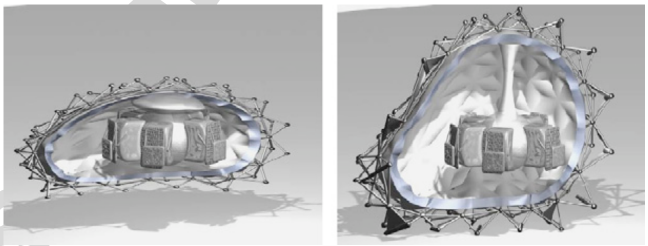

Fig. 13. Studies of the deformation and skin.

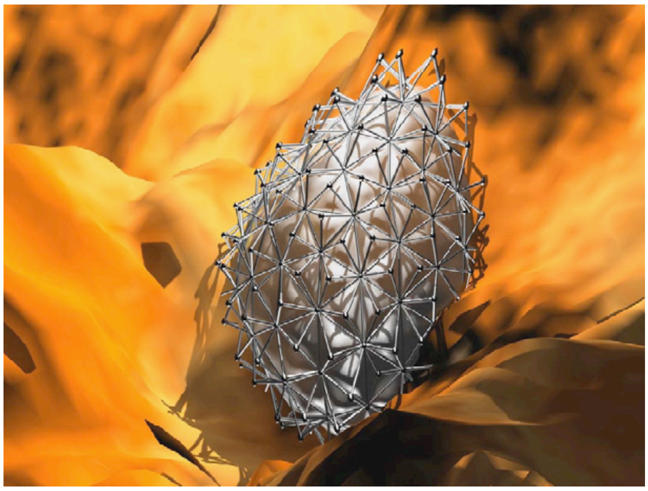

Fig. 14. Close-up of a study of the rover skin.

And third, it is also a natural strategy to change form as efficaciously as possible in order to achieve best performance.

4. Discussion

The process carried out in the "Transformation" project showed significant differences to conventional architectural project design:

A long search on the part of the students for logical scenarios was observed, because the general setting had to be positioned in a future time frame. The question of available technologies became apparent. Which assumptions can be made about relevant future technologies used for space travel? What might be the criteria for making correct choices with regard to certain technologies, which will define the further mission scenario and the design project? With assistance from experts of ESA's advanced concepts team, it was possible to answer most of the emerging questions.

With projects such as "Transformation", interdisciplinary project development is essential. To enhance this approach, scientific information should be more easily accessible and ready for interdisciplinary use. This would help other disciplines to transfer special knowledge from any discipline into a technical application.

Another interesting observation was made during the design process: the originally researched topics of bionics and biomimetics, such as materials from nature for extreme conditions, locomotion or propulsion methods, were taken as a starting point. After the main concept development was completed and elaboration began, different and new problems arose—interestingly, together with bionic approaches to their solution—which in turn required further research. Thus, new investigation commenced. In this iterative process, the mission scenario and the design projects developed.

The process of constant search without expectations of a particular result is a known one in architectural design development, but rarely applied. Our attempt with the "Transformation" project led to unforeseen and unconventional concepts, although the method of proceeding at first appeared to be purposeless and undirected. The designs developed in the interface of scientific research, experimental architectural approach and concrete program.

The five case studies focused on several aspects, of which the most important are exemplarily described in the following:

1. *Interpretation of a model from nature, e.g. an interpreted analogy of natural skin implies technologized, intelligent material*: In the case study *space loggia*, a large earth-viewing window made of a multilayered membrane refers to natural transparent skin. Only the specifications of the window materials are known. The scenario assumes that in future such materials will be developed, due to the fact that glass, plexiglass, aerogels and their composites are already undergoing major advances.

2. *Overall concept of a complex system*: In the *spaceship Mars+* project, the biorhythm of the crew plays an important role, being translated into the "behavior" of the spaceship. This also implies that the skin of the transporter has to be adaptive and reactive. The absence of external influences, such as weather or the change of time, of day and night, is re-interpreted and incorporated into the technology of the spaceship. The layout of the entire spacecraft is subjected to an organism-like interpretation, influencing space, arrangement of functional organs, distribution and circulation systems.

Another interpreted analogy is shown in the concept of *lunar base telescope*. The masterplan is determined by the cable car system serving as the vital connecting infrastructure, analogous to any grid supplying a living system.

3. *Visibility of technology*: In the project *augmented lunar base*, technology becomes perceivable by the human senses instead of staying invisible. Technology becomes interpreted and thus more apparent. Communication with humans and robots develops and expands an external environment, which, conventionally experienced, lacks the Earth's complexity. New enlarged real and virtual spaces, which overlap, emerge and serve the survival of humans in isolated and confined environments.

4. *Movement*: In the last case study, the *mobile Mars habitat—flex-triangle*, movement and the way structure deforms is directly taken from natural models and transformed into a habitable Mars rover concept. The structural parts evidence analogies with animal skeletons and moving joints, but as far as construction is concerned the project remains remarkably mechanical.

With further more intensive investigation into the scientific, technological and material aspects, more themes for discussion would emerge. The transformation project is an ongoing architectural research project, which has the potential to lead to many more important findings.

5. Conclusion

Future habitats, whether on Earth or in space, will incorporate the technological advancements of their time.

Thus the structure and form and the way of inhabiting such "buildings" will change radically. Therefore, innovative input and new concepts are needed.

Incorporating the field of bionics gives the end-user many advantages in the designed systems. Pre-found and evolutionary approved conditions, processes and principles serve as models for technologized interpretations and implementations. Especially in robotics, a number of renowned institutions, such as MIT, are currently developing exploration rovers using concepts from nature. Finally, the bionic approach will lead to more economic solutions, as one of nature's most important goals is energy efficiency.

In this context the "Transformation" project was the first of its kind with regard to architecture and space habitat development. The general approach and concepts of future structures for space settlements have to rely on new paradigms regarding the main management of space projects, the interest and support of the general public (commercialization), the economic conceptual approach, general willingness to engage in experimentation and many other factors, as well as, finally, the greater vision. The "Transformation" project is definitely a small step in the direction of a paradigm shift.

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