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DESIGN FOR MICROGRAVITY - TOOLS FOR THE DESIGN OF HABITATS WITH NO GRAVITY

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1. Introduction

This paper illustrates the results of a doctoral thesis, due April 2004, on space "Habitability in space: design for microgravity" conducted by the author at the Industrial Design Department INDACO of the Politecnico di Milano. The results of the thesis are mainly based on a detailed survey of the habitability conditions on the International Space Station - the most recent and advanced orbital aircraft - and on a qualifying period at European Space Research Center ESTEC in the Microgravity Facilities for Columbus Division of the Microgravity and Space Station Utilisation Department (MSM-GF).

2. Aim

The outer space is the most challenging and dangerous place for man to live in because of its peculiar extra-terrestrial characteristics among which the most decisive are the extreme temperatures, the solar and space radiations, the lack of gravity and essential resources such as air, water, ect. Since human body is meant to live on Earth, an extreme effort must be pursued to guarantee living beings' survival beyond the atmosphere. Therefore, although great efforts have been done in order to offer astronauts a comfortable staying in space, the first requirements of manned spacecrafts have always been inevitably oriented to the crew's survival, so that, at the moment, the life on board spacecrafts is possible but tough. However, if considering the interest of today's space programs in implementing the long period missions such as the actual ISS and future mission to Mars or eventual Lunar Bases, the well-being of the crewmembers spending a long time aloft – from few to several months – becomes a key issue for assuring the success of such missions.
In this perspective the doctoral thesis is aimed at researching design solutions for a better life of crewmembers in outer space proposing the Industrial Design discipline as a promising integration to the future implementation of space projects.

3. State of the Art

3.1 Life aloft

The study starts from a general overview of the life condition on board the International Space Station which is an orbital laboratory that allows the running of different kinds of scientific experiments and the observation of the Earth and the outer space. In the final configuration the ISS should host up to seven astronauts living there for three to six months. The Station is provided with advanced and safe equipments that have been developed from both the Russian and American previous important space missions (SkyLab, Mir, Shuttle, and etc.).

The study has analysed the astronauts daily activities - working, cooking and eating, sleeping, relaxing attending daily physical training and personal hygiene needs, etc. – and the Station's equipments and habitat characteristics. It has been done from the point of view of the users, the astronauts, so that the observations collected give a reading of the life quality on board the Station and suggest several interventions and possible solutions to be studied more deeply. As results of the survey observations particular importance is put on: the need of comfort, the lack of gravity and centrality of the work activity.

Figure 1. Astronaut Daniel W. Bursch, Expedition Four flight engineer, in the Destiny laboratory on the International Space Station (ISS). The picture shows the different way of moving weightless in microgravity conditions with evident operability problems

Astronauts are requested to perform very well their tasks in very extreme conditions. The accuracy of their actions and the amount of time used are determinant for the success of any mission. They are therefore under constant performance stress to which must be also added the physical discomforts (mainly due to the adaptation to microgravity) and the psychological discomforts (confinement, solitude, melancholy, lack o privacy, etc) given by the space environment. Therefore, given these conditions, the thesis puts a stress on the crewmembers need of comfort considering it as key element for the success of long period space missions. Indeed it is agreed that the best comfort is offered to crewmembers during their tasks performance the less stress they complain and best result are achieved.

Spacecrafts are extraordinary habitats. They are shells that protect humans from the outside inhospitable environment - from extremely high and low temperatures, from meteorites and dangerous radiations - also they offer supplies for survival and escape for emergencies. Still, spacecrafts require astronauts' adaptation to confined spaces, lack of privacy and general discomfort. Thus the design of spacecrafts must deal with these difficult conditions and requirements among which the most peculiar and odd is certainly the almost total lack of gravity force, also called microgravity, "to which the crew members on board are subjected: the physiological conditions, the physical and psychological parameters, the posture assumed by the body, the movements necessary to go from one point to another and maintain one's balance and sense of direction, the perception of space, of volumes, and of colours and, consequently, operating efficiency and performance during the various human activities." [Dominoni, 2002].

This characteristic of space environment is the most challenging for designers because it distorts all terrestrial rules and criteria related to movements, weights and directions up to, generally speaking, the way of thinking, perceiving and relating to space, objects and other people. Moreover the microgravity can be considered as the most disturbing element of space activities especially because it can not be simulated on Earth with obvious further complexity for the operations' planning and equipment's design. On the other hand, in the thesis it is suggested that microgravity could be seen by designers as an extraordinary feature that could also be used in convenient unexpected ways.

3.2 Working activity

In this perspective the study is focused on the performance of work activity because it is the most important and demanding astronauts' activity. Work tasks are both those related to the maintaining and implementation of the ISS, to the mission realization (flight, boarding etc.) and to the running of scientific experiments. Among these work activities, this study focuses on the experiment performance with particular attention on the human physiological experiments because of their complexity and operational problems not yet completely solved.
The doctoral thesis, after the general overview on the ISS life conditions, has focused on the working conditions of the Columbus Laboratory of the International Space Station with particular regard to the utilization on orbit of the European Microgravity Facilities (EPM - European Physiology Module, BIOLAB and FSL - Fluid Science Laboratory). The EPM (European Physiology Module) is the facility designed for conducting research in human physiology under microgravity conditions. It is a multi-user facility consisting of a Carrier infrastructure that can support up to eight Science Modules, and includes storage volume for consumables and other items. The principal purpose of this survey was the optimization of astronauts' operations while running the scientific experiments through the improvement of the facilities' usability and crew's comfort.
For accomplishing this goal a first integrated design method was proposed and it was later partially reused and developed in MEEMM Operations Study (conducted by the SpaceLab INDACO Department's space design research center in 2003). MEEMM Multi-electrode ElectroEncephalogram Mapping Module is an experiment dedicated to the study of the central nervous system and muscle activity carried in the EPM.
The experiment MEEMM is considered to be very complex because of several reasons such as the wide range of equipments and items needed, the long time required, the kind of operational activities that involve two astronauts (the operator and the test-subject) and especially for the positioning and restraining of the test subject during the experiment performance.
The Operations Study of the MEEMM experiment has defined the best configuration for the Operator's activity and the Test Subject comfort during the preparation and performance of the experiment. Also, it proposed a concept design solution for the optimal layout of the operational scenario.

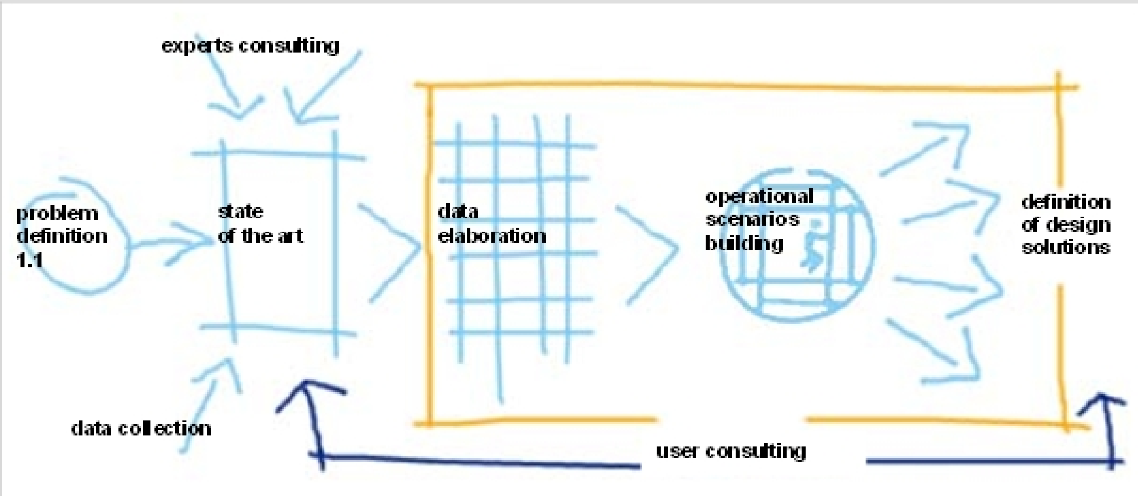
Figure 2. Columbus Laboratory, European Physiology Module, cap of the MEEMM (Multi-Electrode Electroencephalogram Mapping Module)

4. Design tools for microgravity

For the realization of the design research, such as the MEEMM mentioned, the author has evidenced the opportunity of an approach that integrates the typical engineering project and planning systems with the typical design tools such as the definition and visualisation of scenarios. In this paper the engineering project and planning systems are not deepened, although, it is necessary to mention that an effort has been pursued to understand them and take advantage of them. Generally speaking, the engineering approach is based on the meticulous and complete organization of data so that there is no room for misunderstanding. In particular it has been noticed the great usefulness of the data collection accuracy of and of the operational procedures' detailed compilation. This approach is extremely useful for the management of very complex plans as required by space missions. Still, when considering complex manned activities, such as the human physiological experiments, the wide amount of available data does not allow to picture the operational scenario while the possibility of a broad overview can be extremely useful.

Indeed it is suggested that the engineering approach can be successfully integrated by the design approach which is basically founded on the ability of resuming in a single vision the operational scenario and the complexity of a scene. This representation's techniques highlighs the user's needs and the design requirements.

Table 1. Scheme of the design approach applied to the study



The method used in this thesis is a linear approach based on five main steps:

1. the "Definition of the problem" to be solved might be given by the user, the purchaser or the designer; in the case of the mentioned studies for ESA the input came from the astronaut Guidoni's concerns and from the Responsibles of the Experiment Felicities.
2. in the "State of the art" are collected all the necessary data and knowledge. They might be taken by standard tools, such as handbooks, procedures, records, and from interviews to the users and to the experts of all disciplines involved in the study. In this phase the interdisciplinarity of the design approach is notably evident.
3. The data gained in the state of the art are elaborated in order to transform the knowledge into useful information for the design activity. This often means to transform quantitative data into qualitative data for a more generic but comprehensive reading of the operational situation. And also it is demonstrated the usefulness of applying visualisation techniques for the representation - in space and time - of realistic scenes.
4. For the study of the MEEMM the video recording of the experiment Crew Review has been analysed by the making of an Experiment Storyboard Analysis: a certain number of single images were selected from each video; this allowed obtaining storyboards of the experiment procedure steps. The making of storyboards with pictures or drawings is a typical visualization system adopted by designers to both check the good function/use of a design project and to show it to clients/users. The storyboard allow to obtain a qualitative perception of the operational problems such as the space organization; the layout of the experiment hardware and items; the operator's movements; the test subject positioning; the interaction of the operator with the hardware, the items and the test subject (see Figure 3).

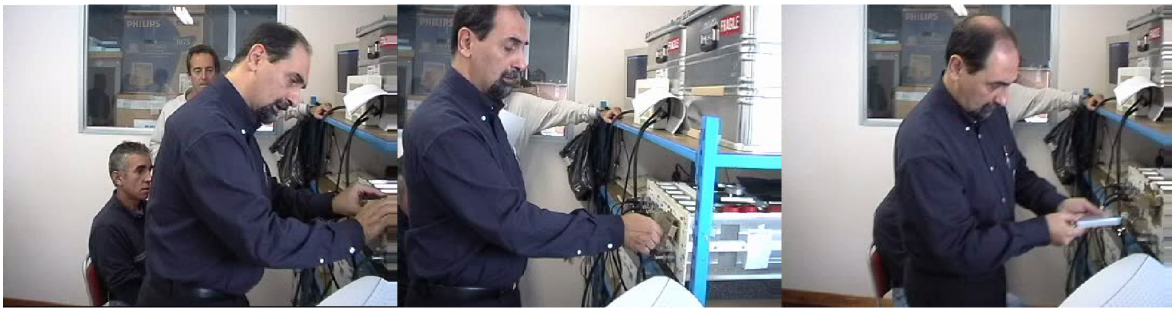


Figure 3. Storyboard of Astronaut Guidoni performing the MEEMM experiment preparation. The pictures are taken form the Crew Review held at EREMS, Toulouse in Nov. 2002.

5. When the operational situation is analysed a description and visual representation of the operational scenarios is given. The scenario building is optimal for highlighting the problems related to the microgravity conditions that cannot be simulated on Earth. This kind of analysis can be conducted visualizing the operational scenario of the experiment through synthetic drawings of the operator and the test subject interaction with relation to the facility in the Columbus Laboratory. All the considerations obtained by the previous study of the experiment performed on Earth are reconsidered in the conditions that characterise the space environment. The most concerning conditions are related to: the microgravity; the limited space; the availability of restraints; the organization of stowage on board of the ISS (see Figure 4). The drawing shows that the astronauts and the items do not have restraints for this kind of complex activities. They will therefore get tired and stressed. This discomfort could compromise the experiment performance and results. Also during the experiment they will take up a large area in the aisle thus the other experiment facility should not be used in the mean time of the EPM. This should be considered during the preparation of the mission schedule.

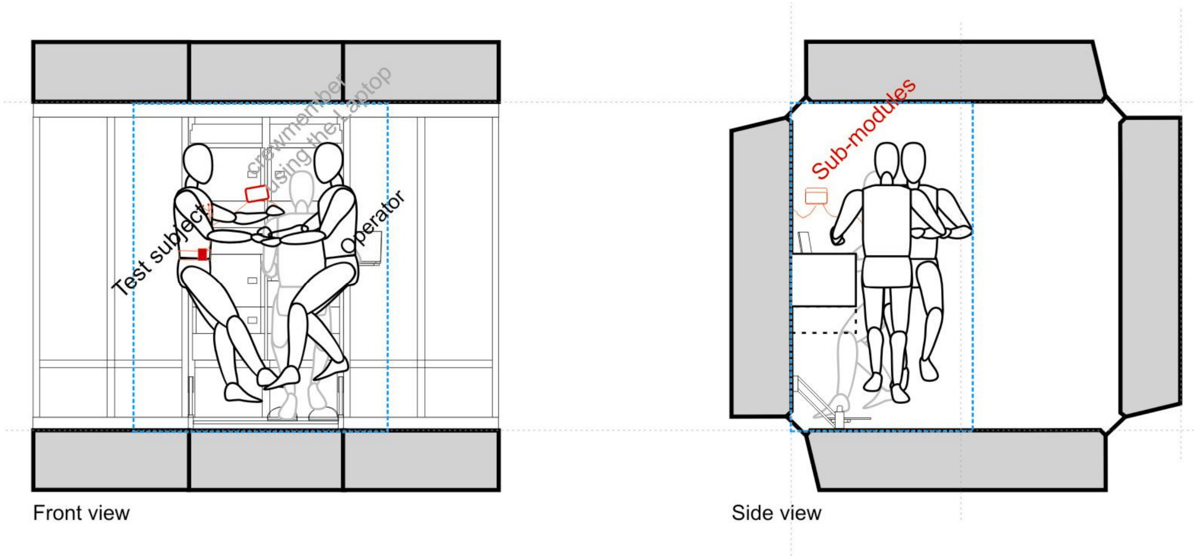


Figure 4. Scenario building of an experiment operational scenario of an EPM experiment inside the Columbus Laboratory

6. The study founded that the origin of the operational problems are partially traceable in a poor or lacking design (such as the restraints), thus possible solutions were suggested with a description of requirements and representation of design concepts.

In this kind of research activity particular importance has the opportunity of consulting the end user, in this case the ESA astronaut Umberto Guidoni, who has already been in the outer space and therefore can give is opinion on living and working aloft. His point of view is essential because only astronauts have actually experienced microgravity and are able to foresee and describe the real conditions in space. Thus the study has also an important user centred approach during all the steps of the designing process.

5. Conclusions

The study has shown how the use of visualization tools help to describe complex operational situations where two crewmembers are involved for a long period performing physiological experiments that require several items and submidules. The tools help to pucture the situation highlight eventual problems to be considered and solved. The storyboards are particularly useful to show the sequence of events giving importance to the progress and organization factors. The scenario building points out all concerns related to configuration and organization of space, users and objects.
The integration of these tools allows defining operational scenarios that can be interpreted and improved for proposing the best layout for space implementation. The generation of the operational scenario and the related best configurations lead to find out the requiremtns for new design concepts. However the study has had success especially as a tool to picture and preview the space activity, in microgravity condition, and its potential problems.
In light of these observations the doctoral thesis, as summarised in this paper, proposes a path for designing solutions for a more comfortable life and work in the outer space finding a promising integration of the Industrial Design discipline into actual design process of space missions.

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