TECHNISCHE UNIVERSITÄT WIEN
VIENNA UNIVERSITY OF TECHNOLOGY

DISSERTATION

A methodical approach to the transfer and the integration of design knowledge from terrestrial extreme environment structure designs to inhabited space structure design concepts

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines Doktors der technischen Wissenschaften unter der Leitung von

O.Univ.Prof. Dipl.-Ing. William Alsop

E253
Institut für Architektur und Entwerfen
Abteilung Hochbau und Entwerfen

eingereicht an der Technischen Universität Wien
Fakultät für Architektur und Raumplanung

von

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Barmherzigengasse 16/30, 1030 Wien

Wien, im Januar 2009

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D I S S E R T A T I O N

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Abstract

This work proposes a methodical approach to the transfer and integration of design concepts, which are originally developed for terrestrial extreme environments to inhabited space structure design concepts. Like all the new frontiers in the terrestrial human exploration history (i.e. polar expeditions, underwater research, geographical discovery expeditions etc.), planetary exploration enterprises will also be built up on the past human experience in extreme environments alongside technological progress. The ongoing design and development activity, concerning the human exploration of the Moon and the Mars requires extensive networking of many disciplines, as well as the effective use of human knowledge on extreme environments. The utilization of the previous experience not only in the space missions but also in the terrestrial extreme environments can provide vast benefits in exploration architecture design. However, the design transfer attempts without an extensively applicable structure are likely to stay inconsequent and not repeatable in means of character and method. Therefore a transfer system, featuring a literature search on terrestrial extreme environment designs, basic evaluations and clear transfer processes is needed. The proposed design transfer method is expected to enhance the planetary exploration infrastructure designers with a practical tool, enabling them to do systematic and efficient design transfer from terrestrial extreme environments.

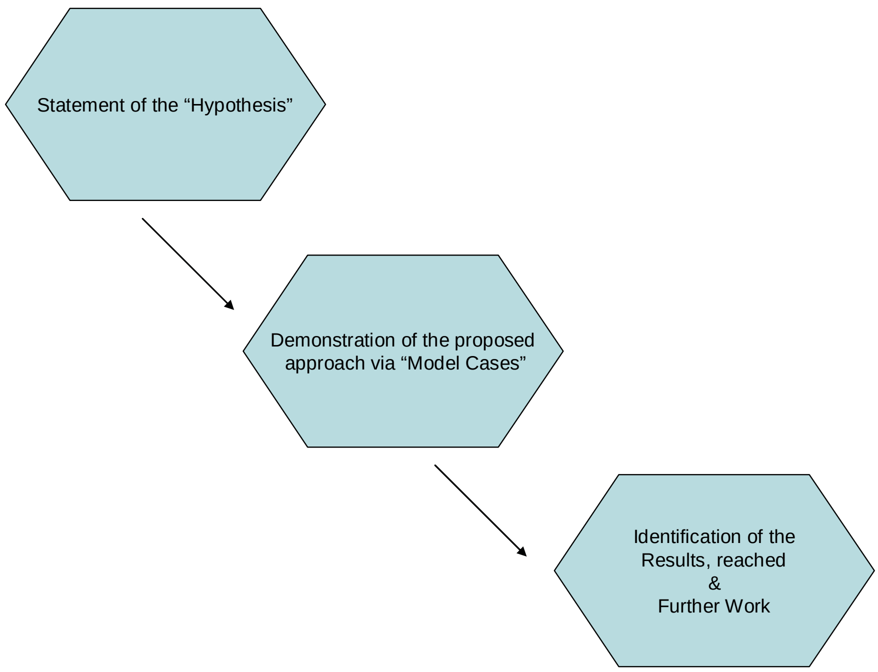

Figure 0-1: Scheme, depicting the basic study logic

Kurzfassung der Dissertation

Die vorliegende Arbeit beschäftigt sich mit dem Thema des „Design Transfers“ zwischen extremen terrestrischen Umgebungen und dem Weltraum. Ziel ist, eine systematische Behandlung des Themas aufzuzeigen und Ansätze für eine Transfer-Strategie (Methode) zu entwickeln.

Große und einflussreiche Expeditionen der Geschichte, die von Menschen in Extremumgebungen der Erde (z.B. Polarexpeditionen) oder in den Weltraum unternommen wurden, zeigen, dass der jeweilige technische Fortschritt eine kritische Rolle bei der erfolgreichen Umsetzung spielt. Die aktuelle Planung der Infrastruktur, die für die bemannte Erforschung des Mondes und des Mars verwendet werden soll, benötigt eine intensive Vernetzung von vorhandenem Wissen über das Leben von Menschen in extremen Umweltumgebungen und deren Ressourcen. Erkenntnisse aus dieser Vernetzung können dazu beitragen, die Konzeption und den Bau von Weltraumhabitaten effizienter innovativer und besser geeignet für das Leben und Arbeiten der Menschen unter Weltraumbedingungen werden zu lassen. Die bisherigen Forschungsprojekte in diesem Bereich des „Design-Transfers“ zwischen terrestrischen und Weltraumumgebungen waren nicht in eine methodische Herangehensweise eingebunden. Deshalb wird in dieser Arbeit der Versuch unternommen anhand von exemplarischen Designprojekten einen strukturierten und methodischen Ansatz zu finden, der als Vorbild für zukünftige Studien und Projekte in dieser Richtung, Weltraumdesign und -architektur, dienen kann.

Fünf Musterfälle, denen jeweils eine Mondstation als Grundlage dient, werden anhand von zwei Projekten entworfen. Es handelt sich hierbei um die „Kopernikus 2 Mondstation“, die ursprünglich im Rahmen des *Lunar Base Design Workshop (2002)* konzipiert und nachträglich vom Autor weiterentwickelt wurde; Sie beinhaltet vier Komponenten, die mit der vorgeschlagenen Vorgehensweise eines „Design Transfers“ als Entwurf umgesetzt wurden:

- **Eine ausfahrbare Reparaturwerkstatt mit dem terrestrischen Vorbild einer „Tauchglocke“**

- **Eine Rettungskapsel, die wie ein „Freifall-Rettungsboot“ funktioniert**

- **Die Konfiguration der Station, die in ihrer räumlichen Organisation einem militärischen U-Boote ähnlich ist**

- **Die „Container Terminal“ Komponente der Station, die auf terrestrischen Kontainerhafensystemen beruht**

Der fünfte Musterfall bezieht sich auf ein Konzeptdesign eines „Pressurized Rovers“, eine erst kürzlich (Januar 2009) abgeschlossene Studie für die European Space Agency ESA. Er behandelt eine Minimallösung für einen Kurzausflug auf dem Mond oder Mars in einem druckbeaufschlagtem Gefährt. Der Autor war designführend an diesem Konzept.

Executive Summary

Hypothesis

The hypothesis of this PhD work is:

Design transfer cases from terrestrial extreme environment designs to space structure design concepts can be handled, using a methodical approach to find and to process the relevant terrestrial knowledge efficiently.

This PhD work proposes a practical methodical approach for the to the transfer and integration of design features from terrestrial extreme environments into the inhabited space structure design concepts, to be used by designers that are dealing with extreme environments.

This type of systematic approach, constructed on a standard processing method for the design transfer cases that are related to extreme environments, has not been done yet. Therefore, this PhD work presents a new way of dealing with the design transfer between terrestrial and space extreme environments. The presented design cases that are developed with the mentioned transfer method and the identification of the further work to be done on this subject is the contribution of this PhD work to the academic system of architectural knowledge.

The main goal of the mentioned approach is to identify the terrestrial extreme environment design and technique role models to be used in space structure design concepts. The system is designed to be used by space infrastructure planners, involved in space exploration programmes. The proposed approach is demonstrated in this PhD work in the following steps:

- Following a detailed and analytical assessment of the transfer target, a literature search reveals the relevant design concept role models from the terrestrial extreme environments.
- An evaluation of the search results indicates the applicable features of the acquired role model concepts for the design transfer.
- The integration of selected features of the terrestrial role models into the target design concludes the proposed design transfer process.

This sequence of processes can be visualized schematically as follows:

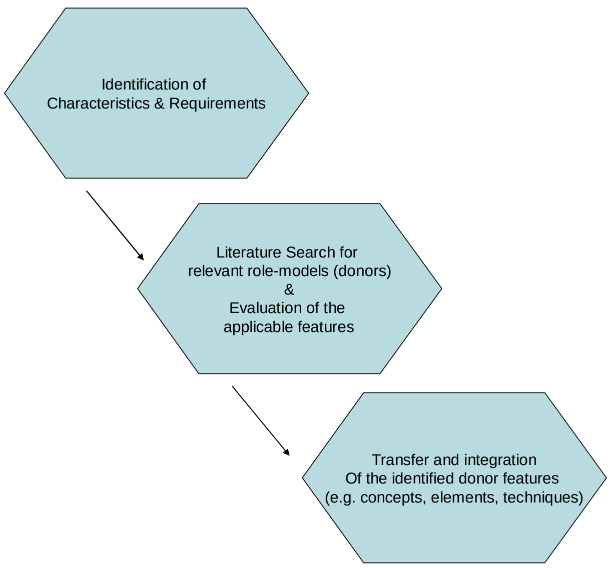

Figure 0-2: Flowchart diagramme of the proposed approach

Research

The research work contains five design model cases, through which the proposed approach to design transfer cases is explained. These model cases are grouped under two space related research projects, in which the author was involved and used the mentioned methodical approach. The model cases, transfer process, acquired final design concepts and benefits of the transfer for the overall design are explained in detail. Two main groups of the design model cases are as follows:

- Four elements of a lunar logistics station, at single element and system levels, are designed using terrestrial role models (i.e. diving bells, free-fall lifeboats, submarines and container terminal systems). The proposed designs use proven operational techniques, adapted to the lunar environment. A comparison with other design concepts, developed for the lunar and terrestrial environments reveal the benefits in design, development and the operation of the acquired design concepts through the demonstrated transfer approach.

- The application of the approach for design transfer in an actual design study for the preliminary planning of infrastructure for planetary explorations, conducted by ESA (European Space Agency), is presented with its results. The model case for the design transfer involves the design of an integrated one-person habitat for planetary surface vehicles. Terrestrial role models like camping tents and sleeping pods are used in the transfer process.

Findings

The proposed methodical approach to design transfer cases is observed to enable the systematic transfer of concepts in element, system and technique scales. The role models used in the design transfer cases are originally developed for terrestrial applications in extreme environments. These are transferred and integrated into the space structures, which are designed for humans to live and work on other planets and in space. The benefits of this course of action are presented via improvements in design model cases that also contain actual research work, done for an on-going space exploration programme.

The most significant drawbacks, experienced in the research is the lack of a common and united database for extreme environment structures and the premature categorization of the search criteria, to be used to reach the relevant role-models. These are expected to be cured by the construction of a common database system, which is proposed as the future work to be done in the last section. The construction and further expansion of a database can enhance the design transfer process with a high degree of efficiency besides involving students in an educational network.

Acknowledgements

I would like to express my gratitude to my doctoral advisor, Prof. William Alsop for his guidance and especially for giving a chance to my research work to be integrated into the “Architecture level” of academic studies. His supervision provided valuable guidelines and a high degree of motivation to progress with my work.

I want to thank Mr. Stephen Ransom for his kind support. The final supervision and reviews that I received from him enhanced my work with qualities from his vast experience in aerospace structures design and development.

I also thank Dr. tech. Barbara Imhof for her extensive technical and motivational support. Her experiences, as a space architecture PhD candidate, helped me to navigate through the entire process of my PhD research work.

Finally, as an acknowledgement of my gratefulness to my family, my friends and to my patient companion Dipl. Ing. Mim. Zeynep E. Talayer for their tolerance, love and support, I would like to quote the following from Cherry-Garrard of Robert Falcon Scott’s Terra Nova Expedition team:

“The history of the human race is a continual struggle from darkness towards light. It is, therefore, to no purpose to discuss the use of knowledge; man wants to know, and when he ceases to do so, he is no longer man.”

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1. Introduction

1.1 Extreme environments

Extreme environments are settings that possess extraordinary physical, psychological, and interpersonal demands that require significant human adaptation for survival and performance

Taking this type of definition into consideration space, high-altitudes, Polar Regions, deserts, underground, open ocean, and underwater can be regarded as extreme environments. Furthermore, a number of extreme activities and occupations occur in these environments such as spaceflight, aviation, mountaineering, military operations, fire fighting, emergency services, search & rescue, hazardous materials handling, mining, diving, and a variety of extreme sports.[1]

Various terrestrial extreme environments are listed below:

Desert:

Desert regions are characterized by:

- Extreme temperature ranges, varying between 0°C and 50°C over a 24-hour period.
- Changing visibility conditions.
- Minor levels of precipitation
- Long periods of drought, interrupted by sudden rains that bring flash floods.
- Shortages of suitable ground water and virtually no surface water.
- Large areas for mobility, interspersed by ravines, bogs, and sand seas.

Polar Regions:

Polar Regions are characterized by

- Extreme low temperature levels
- Heavy glaciations
- Extreme lighting angles, durations and levels
- Extremely low humidity

High seas / offshore environment:

High sea environments are characterized by

- Rough sea conditions (high waves)
- Rough atmospheric conditions (wind, temperature, rain, humidity levels)
- Remoteness to support infrastructure

Underwater:

Underwater environment is characterized by

- Extremely high pressure levels
- Low temperature levels
- Limited communication possibilities (mostly acoustic based)

[1] Definition of the extreme environments retrieved from The Society for Human Performance in Extreme Environments website, www.hpee.org.

1.1.1 Human presence in terrestrial extreme environments

The human presence in extreme environments has various reasons, which are often enough to convince humans to take high levels of risks during their activities. The main categories of these motivations can be listed as:

Exploration:

Though defined as “to investigate, to learn about, to study”, exploring bears the act of travelling over to discover Peter Eckart, in his *The Lunar Base Handbook*,[Eckart, 99] introduces exploration as a movement outward into a larger whole system, feeding off the richer information content of that system and pumping it back into the subsystem as evolutionary energy.[2]

Exploration, as the act of travelling over new territory for adventure or discovery of the unknown, has been one of the main motivations of the terrestrial expeditions and is yet the main driver of the human space flight effort. Space, as an extreme environment for the humans, will be the main exploration environment for the explorers in the future.

Terrestrial polar expeditions were among the major daring human enterprises, which did not instantly found acceptance and political support besides the harsh conditions of the expedition environment. The need to discover and learn was often opposed by a pragmatic and short-sighted way of thinking throughout the history of human exploration effort. A purely scientific exploration was constantly under pressure in regard to commercial and political perspectives. Blunted by a such mentality, the human exploration endeavour, with all its hurdles, was not easily comprehensible for the public. What the explorers took as a matter of course, the painfully long and dangerous journeys to the polar caps for example was a waste of time and resources for many, as Cherry-Garrard, a member of Robert F. Scott’s last expedition to Antarctica, notes:

“It is really not desirable for those who do not believe that knowledge is of value for its own sake to take up this kind of life. The question constantly put to us, in civilization was and still is: “What is the use? Is there gold? Is there coal?” The commercial spirit of the present day can see no good in pure science. The members of this expedition believed that it was worth while to discover new land and new life, to reach the South Pole of the Earth, to make elaborate meteorological and magnetic observations and extended geological surveys with all the other branches of research for which we were equipped.”[3] [Stutster, 96]

Nearly a century past since the Scott’s expedition to Antarctica, the sceptic public view on polar exploration is replaced by extensive scientific research, being done in numerous research stations in both poles of the Earth. Even space habitats are being tested and developed under the harsh conditions of the Polar Regions. An example is presented below:

ILC Dover Antarctic Habitat Demonstrator

Location: Antarctica

Type of Structure: Inflatable habitat demonstrator

Motivation: Technical Demonstration & Development for Exploration

In January of 2008, ILC Dover, in partnership with NASA and the NSF Office of Polar Programmes, successfully erected an analogue Lunar Habitat structure at McMurdo Station, Antarctica. Setting up the structure in this particular environment provided a technology test for the study of inflatable structures in the harsh environment of Antarctica (as an analogue for the Lunar environment).

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[2] Eckart refers here to the continuous exploration of the land by the first water creatures as the beginning of the evolution-exploration duality.

[3] Quoted from the personal notes of Cherry-Garrard, these words reflect the scientific oriented character of Scott’s polar expedition. Ironically, this type of vision was probably among the factors, which were not favourable for Scott in case of the race to reach the South Pole first.

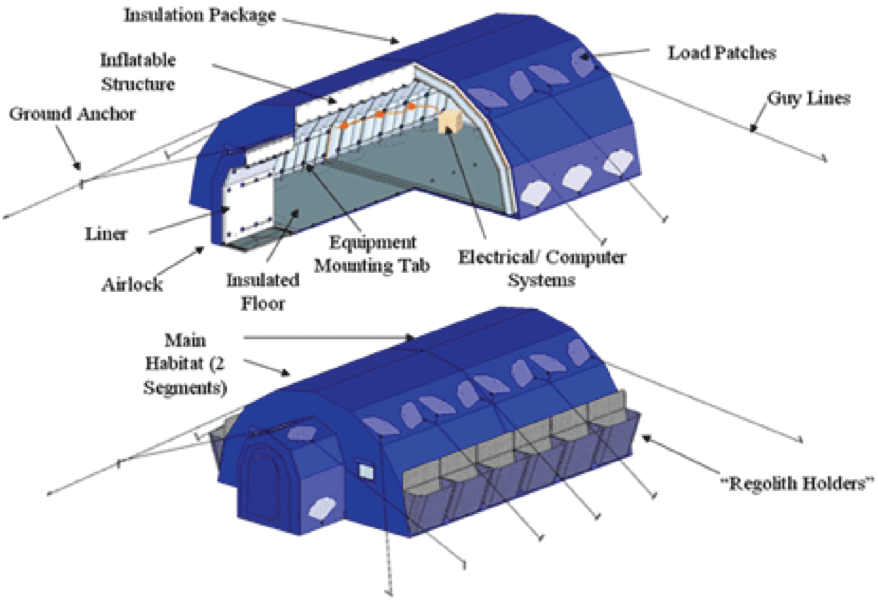


Figure 1-1: ILC Dover Antarctic Habitat Demonstrator (Credit: ILC Dover)

The habitat (and airlock) system consist of a tubular inflatable structure, an insulation blanket, a guy wire package, power and lighting systems with outlets, two quartz resistance heaters, a pressurization system, and a protective floor. The integrated sensors track pressure, temperature, CO2, smoke and power consumption. The system can be packed in a small volume and weighs approximately 45 kg. The small, packed volume makes for efficient transport which not only reduces the size of launch vehicles for NASA, but its transportability supports the NSF charter by allowing large structures to be transported to remote sights on small aircraft such as twin-Otters or helicopters. The habitat can be erected by 4 people in under an hour, and can be packed and redeployed many times. The habitat can be erected almost anywhere including over uneven terrain, and can sustain 160 km/h winds. The capabilities of the light weight and inflatable habitat structural systems allow adaptability to many sizes by simply connecting additional sections.

Figure 1-2: The packaging sequence of the demonstrator habitat[4]. (Credit: ILC Dover)

The analogue structures and systems tested in terrestrial extreme environments provide the development of space applications and the direct transfer of human knowledge, gained in these environments. Materials, systems and techniques are tested and redeveloped under similar-to-planetary conditions, considering the design-shaping factors ranging from packaging efficiency to dust mitigation.

[4] The packaging efficiency, achieved in this test was 15:1. Source: ILC Dover

Extreme environment design transfer related aspects of the ILC Dover Antarctic Demonstrator:

The following aspects of the Antarctic Habitat Demonstrator can be listed as applicable for design transfer processes between extreme environment concepts:

- Structural system, materials
- Packaging, deployment technique
- Thermal and radiation isolation system

Military:

Military organizations are systems formed by armed forces, including their operation, command and support structures. Military activities happen in and/or generate their own extreme environments. Basic factors of a military related extreme environment can be listed as:

- Hostile and friendly fire
- Need for and execution of uninterrupted logistic support
- Need for high level of manoeuvrability in extreme physical environments
- Need for and execution of uninterrupted communication and coordination
- Extreme atmospheric and terrain features of the battlefield
- Human interaction with the combat equipment

The systems, hardware and techniques used in military applications provide valuable design transfer material to be used in space environment, in regard to their high operational survivability and reliability levels.

Figure 1-3: Military actions create their own extreme environment, where survivability is a key factor. (Credit: US Airforce)

Commercial:

Driven by the contest for acquiring the natural resources, commercial institutions establish systems in various extreme environments. The offshore platform concept is a good example for the commercially motivated human presence in an extreme environment, where harsh atmospheric and sea conditions challenge the operations constantly.

An example for a commercially motivated extreme environment structure is presented below, together with the applicable design features for other extreme environment designs.

Offshore Oil / Gas Platforms

Motivation: Commercial

Type of structure: Inhabited, utility

Oil and gas platforms are offshore structures built to house workers and machinery needed to drill and/or extract oil and natural gas through wells in the sea bed. Oil and gas platforms are inhabited extreme environment structures operating mostly in high seas and responsible for the extraction of volatile substances sometimes under extreme pressure in a hostile environment.

Structurally, oil and gas platforms may be made of steel, reinforced concrete or a combination of both.

Figure 1-4: Oil platforms are isolated remote-duty structures operating in extreme environments (Source: http://ie-invest.net)

Offshore oil/gas exploration (and drilling) platforms may have different structural systems, ranging from towable floating platforms to fixed tower structures. The type of an oil/gas platform structure is chosen primarily due to water depth considerations, and secondarily due to the intended service and quantity of deck equipment necessary to perform its service.

All the habitable spaces and working stations of an oil platform are located in the superstructure, called topsides. The topsides, generally, consists of modules, which are pre-fabricated structures, for accommodation, production and drilling zones. The only regular transportation on an oil platform is done with helicopters. The helicopter landing pad, called the heli-deck is located on the top of oil platforms.

Figure 1-5: Two images from two zones of an oil platform. The dirty and highly technical working environment has little in common with the isolated and conventional nature of the crew quarters. (Credits: Suau/EIA)

Oil platforms feature a number of sub-systems that might present suitable design transfer role-models. As oil platforms operate under extreme conditions, the level and complexity of safety measures are high. Various maintenance, transportation and crew rescue systems are installed at the oil platforms with a good level of structural and operational integrity. The emergency escape systems, in particular, present interesting role models for design transfer to the space structures:
The integrated emergency escape systems are responsible for the quick and safe evacuation of the oil platform personnel in emergencies. Emergency escape systems include deployable on-board structures like evacuation chutes, lifeboats and escape pods; or external rescue systems like ESVs (emergency support vessels). As the basic purpose of these systems is the safe and fast evacuation of an extreme environment structure crew, some features can also be applied to the planetary exploration infrastructures.[5]

[5] Please see the emergency escape system of the lunar logistics station, Kopernikus 2 in the research section for a possible design transfer option. The evacuation of the endangered personnel is highlighted as the common function of the systems in two different environments.

Figure 1-6: An escape pod mounted on an oil platform. Escape pods resemble advanced lifeboat type self-rescue measures (Raw image source: Flickr, Edit: Özdemir)

- An emergency escape pod is an enclosed structure that can sustain a number of personnel under extreme conditions in the high sea environment for a certain amount of time. They are designed to be deployed rapidly from the oil / gas platforms in an emergency situation. The escape pods may be self propelled, in order to get clear of the endangered main structure or be just water tight, designed to float or even stay submerged[6] until the search and rescue teams arrive.

- Platform integrated life-boats[7] have similar features to the escape pods. They are mostly self-propelled and capable of reaching a rendezvous point for the collection of the crew further than just moving clear off the oil platform. This feature determines a hydro dynamically efficient vessel shape.

- The emergency escape chute systems are based on a tubular soft structure, deployed from the platform to the sea level. With this system, the endangered personnel can be evacuated one by one from the offshore structure. Escape chutes are mostly combined with a floating unit, a life raft, in order to collect the evacuated crew members. (See Figure x-x). This system provides the platform crew with a fast emergency egress from the offshore structure. One important drawback is the need to collection of the crew at the sea level and the safe departure from the danger zone.

[6] A submersible escape pod design for offshore oil platforms was patented in the USA in 1989 by J.W. Doerffer et. Al. The design could sustain 70 people with the on-board life support systems including food, fresh air and communications. US Patent Number: 4,822,311

[7] One of the most critical issues for platform integrated lifeboats is the rapid and safe deployment of the unit from the platform. Free-fall boats or lowerable boats are among options.

Figure 1-7: The Hibernia Oil Platform can be evacuated via escape chute / raft systems in an emergency case. Escape chutes have to be used in combination with surface rescue units. (Source: CHHC)

Extreme environment design transfer related aspects of off-shore platforms:

The crew rescue systems of the offshore platforms resemble applicable features for the rescue systems of space stations. Lifeboats, escape-chutes and personal escape outfits can be adapted for space use. Furthermore, the transportation, maintenance and the drilling zone systems of these platforms may provide suitable concepts for a design transfer to space structures. The interaction of the offshore structure with the supply and maintenance units, for example, can be studied in the frame of a planetary logistic base design concept, as there is a certain level of similarity between the operation profiles and conditions.

1.2 Space as a new extreme environment

Space is a new frontier in the human exploration of unknown territories. Space travel is focused on the search for life outside the Earth and establishing a human presence outside the physical environment of the Earth, thus extending the force projection range of the humankind. A similar type of behaviour to terrestrial exploration can be expected and is also viable, in regard to the utilization of human experience in extreme environments to serve for planetary exploration efforts. The terrestrial experience has to be used to form a solid and practicable planetary exploration infrastructure design attitude. Concerning the utilization of the knowledge on the human behaviour in terrestrial extreme environments, following points were brought forward by Jack Stutster [Stutster, 96]:

- Future space expeditions will resemble sea voyages much more than test flights, which served as the models for all previous space missions.

- Many lessons can be learned from the experiences of military and scientific remote-duty personnel and from previous explorers that are extremely relevant to the planners of future expeditions and to others, as well.[8]

[8] Especially, early polar expeditions were planned and equipped similar to the space missions of today, resembling a solid parallelism between human polar and space explorations.

Planetary exploration plans for the Moon and the Mars:

Driven by the motivation to explore the solar system and the universe and stimulate new technologies, improving space flight as well as inspiring humans to explore, space faring states set their near term goals as the exploration of the Moon, Mars and later Asteroids, respectively. Having identified the human landing and exploration on Mars surface as the main target, permanent human presence on the Moon [Marsiske, 2005] is the first step to be taken, in order to consolidate the plans to fly to Mars. Mars was chosen as the ultimate goal of the foreseeable exploration, because it is the most Earth-like of the eight planets that make up the solar system and recent indications of the presence of water raise the likelihood of being able to find traces of life. As for the moon, the quotation from an ESA scientist describes the situation: “If space is an ocean, then the Moon is our nearest island." A return of humans to the Moon, after Apollo missions of the early 1970s, is expected to start around 2020. American NASA, European ESA, Russian ROSKOSMOS, as well as Indian and Chinese space agencies, are already working on implementation programmes for lunar exploration visions. For this purpose a number of studies are announced and executed recently.

The infrastructure, required for the human missions to the Moon and Mars are being studied mainly in three segments, being:

- Transport segment, where transport vehicles (e.g. launchers) are designed
- In-space segment, where options for orbital and lagrange location stations are evaluated
- Surface segment, where all the infrastructure needed for the surface activities, ranging from habitats to field-work tools, are designed at preliminary level

The ongoing studies of the major space agencies will provide a basis for the exporation infrastructure concepts and designs. In this early phase of infrastructure planning, first ideas in system and element design scale are produced. Innovative design concepts, which can enhance the capabilities of the planned infrastructure, are especially favoured by the space agencies. Therefore an option to incorporate design transfer processes in the planning work is considered as important.

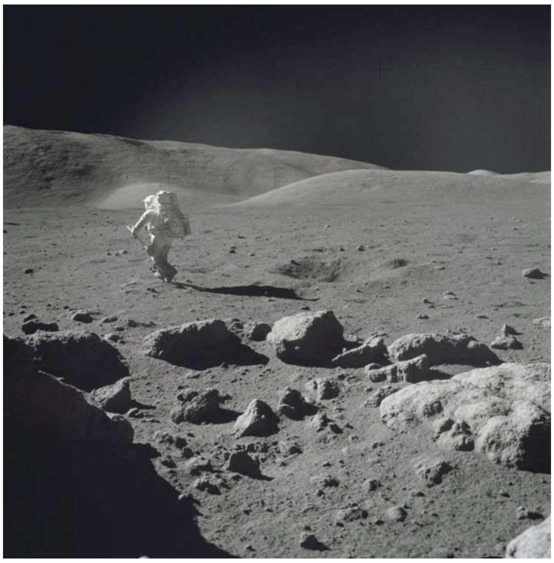


Figure 1-8: A NASA image from an Apollo mission. A human return to the Moon is considered to be the first step towards the exploration of other planets. (Credit: NASA)

1.3 Design Transfer between extreme environments

Design transfer, as applied in this PhD work, resembles a process of transfer and integration of elements of a design concept (or the whole concept itself) to another design concept. In other words, design transfer is the recycling of design knowledge that provides the efficient use of design resources. As designs for extreme environments can be developed with extensive research, testing and experience, every piece of available resource may not be wasted when designing for extreme environments.

Various design transfer attempts have already been made to use the extreme environment design knowledge further for other design concepts. Especially in the early age of human spaceflight, most of the spacecraft systems and interfaces were adapted from aerospace design knowledge. An example for the transfer between terrestrial extreme environment designs and space exploration effort is the case of px-15, a research submarine, where NASA had the opportunity to study the operation of an extreme environment habitat that can provide valuable hints for the upcoming Lunar exploration effort.

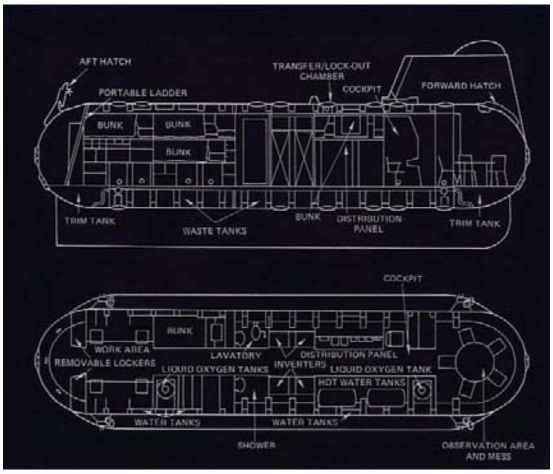


Figure 1-9: px-15 submarine (Credit: NASA)

px-15 as a design transfer case

px-15 (aka. Ben Franklin) is a submersible research vessel, built by deep-ocean explorer Jacques Piccard and Grumman Aircraft Engineering Corporation that also built the Lunar Excursion Module for the Apollo missions. A few days prior to the first Apollo mission launch, px-15 began its one-month underwater research mission, where NASA was also involved through an observer in the mission crew. Many of the parts and systems inside px-15 were similar to an Apollo spacecraft. Very valuable information on the man-machine interface in a confined and technical environment, ranging from the use of high tech equipment to improvised practical solutions was obtained. In his logbook, Captain Don Kazimir [Kazimir, 69] noted on the 28 July 1969:

“F, Busby and E. Aebersold repaired the wobbly wardroom table with two C-clamps. one "Vise Grip" and two butter knives for shims.”[9]

One further highlight, concerning the parallelism of the extreme environments (e.g. underwater-space environment) was Jacques Piccard insisting on 29 viewports in the vessel design, opposed firmly by the structural engineers. This type of conflict between the designers and the engineers resembles a typical case experienced in space mission designs. The trade offs between the decrease in structural

[9] Captain Don Kazimir registered the daily activities throughout the drift mission with explanatory sketches.

integrity and the quality of scientific observations in this case; belong to the usual progress of a design project for extreme environments.

The original drift mission was the brainchild of explorer Jacques Piccard, who had already descended to the bottom of the Marianas Trench, seven miles deep, in the submersible Trieste.
Piccard convinced Grumman Corporation of the importance of Gulf Stream exploration, and the company built both the Lunar Module, or LEM, for the Apollo mission and the Ben Franklin. Top brass at NASA in 1969 saw the Ben Franklin as a way to study the effects of prolonged space travel on human beings, since this experiment in a closed environment was in many ways analogueous to the conditions of space travel.[10]

At the threshold of human exploration of the Moon, NASA's objectives for the next phase of human spaceflight included developing systems to permit crews to live and work in a confined and isolated environment for long duration. To plan and design such systems, extensive knowledge is required of the interaction of motivated groups performing useful scientific work in a stressful, isolated, and confined environment. With this knowledge requirement recognized, NASA participated in the Gulf Stream Drift Mission (GSDM) to conduct a programme directed at studying the man-related activities of that mission. The primary objective of the GSDM was to permit the Ben Franklin, a deep submersible vehicle, to drift with the Gulf Stream at depths from 600 to 2000 feet while the crew performed scientific oceanographic studies.

General Specifications of PX_15 Ben Franklin:

Displacement: 130 tons
Length: 48 feet, 9 inches / 14,6m
Beam (over motor guards): 21 feet, 6 inches /6,4m
Height: 20 feet/ 6m
Operational Depth: 2000 feet/61m
Collapse Depth: 4000 feet/1219m
Submerged Speed (maximum): 4 knots
Life Support: 6 persons for 6 weeks
Payload: 5 tons
Total Power: 756 Kwh
Viewports: 29

Extreme environment design transfer related aspects of px-15

The potential value of this mission, from NASA's viewpoint, lies in the characteristics of the situations and activities within it, and their similarity to those in possible future space missions. The net value of the present study will be in its success in the translation of these inherent possibilities into retrievable and meaningful data. These, in turn, must be interpreted so as to reveal the interactions, causal relations, and correlations among all aspects of interest in the performances of the crew, the equipment, and identifiable antecedent and concurrent conditions.

Reference to the descriptions of the vehicle, the operational environments, the crew composition and activities indicates that the basic characteristics of this mission have similarities to those in anticipated future space missions. They may be reasonably compared in terms of habitat size and accommodations (11 cubic meters per man[11], with reconstituted food, advanced waste management, sanitation and recreation facilities); crew size and composition (6 men, with scientific and technological backgrounds); mission activities, duration and stresses (real scientific and operational tasks, for 30 days in a moving, remote, confined environment without re-supply capability); and many other attributes. Some of these (such as fidelity of stress due to real hazards) would be difficult or impossible to provide in more conventional simulations. [Gropper, 69]

[10] Press document on the TV documentary DISAPPEARANCE OF THE PX-15, produced for The Science Channel
[11] Please note the compliance to the 10 m3 of performance limit for confined habitats.

Deployables: Deployable Structures for a Lunar Base, a biomimetic design research in the framework of the ESA study Lunar Technologies

Ranging from medicine to aerospace, biomimetic principles are used in various technology and design areas. In the context of this work, an example of biomimetic concept transfer study, aiming at the development of innovative space structure designs is presented.

Study Team:

- Vienna University of Technology
  The Institute of Architecture and Design, Department for Design and Building Construction (HB 2 core research team)

- The Centre for Biomimetics, School of Construction Management & Engineering, Engineering Building, University of Reading (consultant)

- Alcatel Alenia Space (prime-contractor to European Space Agency ESA)

Scope of the study:
The purpose of the Deployables was to investigate the bionic concepts applicable to deployable structures, then to interpret the findings for possible implementation concepts. The study aimed at finding innovative solutions for deployment options for planetary surface exploration infrastructure elements and assisting to provide structural solutions from concept level down to detail scale.

Methodology of the study:
In order to bridge solutions from the nature with the space exploration effort, the following methodology was applied in this study:

- Identification of the relevant role models

- Evaluation of the identified role models for technological applications

- Selection of the roles models for further work

- Assessment of implementation options for the identified solutions (concerning geometry, material technology and other technical aspects)

- Develop analogue architectural working models to test the mechanics of the structures

- Identification of the most probable structural implementation options (with assisting visual material-sketches, drawings, models)

- Summarization of the findings as a report to ESA

Findings:

After the evaluation of various biological role models ranging from the folding principles of earwigs to growing patterns of cactus plants, a pallet of deployment options for planetary exploration infrastructures are prepared. One of these concepts is presented below in different steps of the study, including the investigation, technical analysis and the implementation phases.

- Identification of the Ladybird as a biological role model

Ladybird wings are evaluated in the frame of folding insect wings. Main features are identified at the initial phase.

Excerpts from the Deployables Study

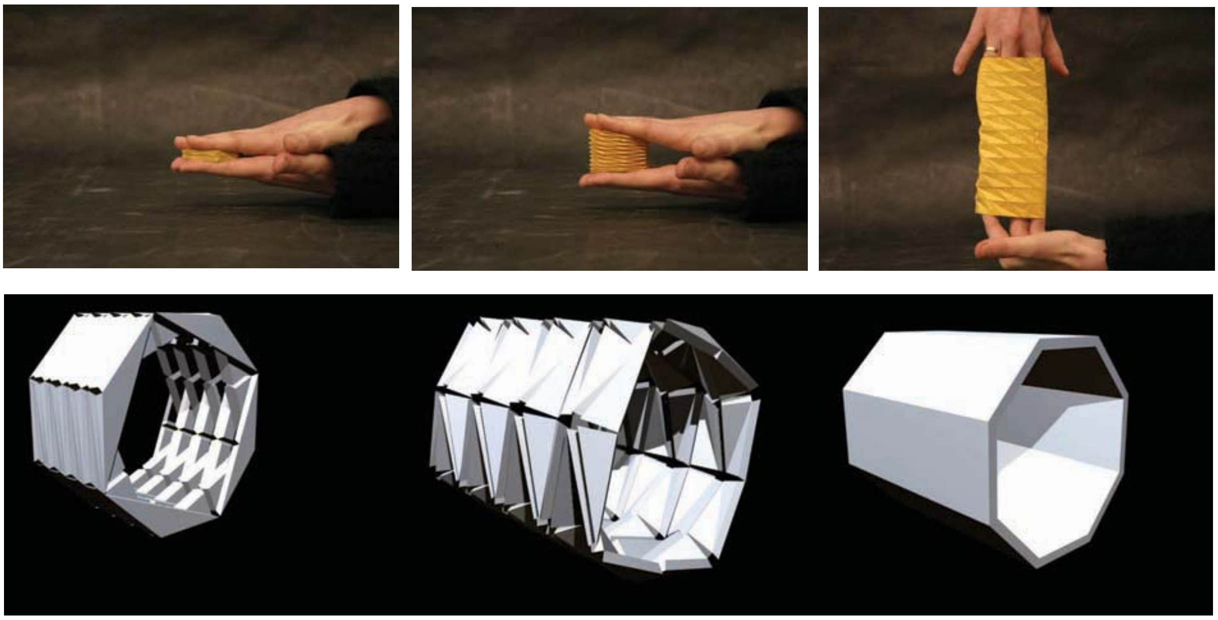
In order to portray the study process correctly, following excerpts from the mentioned study are presented on the next pages.

- **Analysis of possible role models:** Organic structures from nature, with the potential to provide structural models are analysed via info-cards in the study.

	Bionic rolemodel
Insect wings_Ladybird	
	Image
	
	Short description
The hind wings of insects are membranous outgrowths of the integument and they are sensitive to damage. Many insect groups protect their delicate hind wings by leathery or firm forewings, like earwigs (Dermaptera) and beetles (Coleoptera) do. However, the hind wings have to be much larger than the forewings in order to preserve flight capability. Consequently the hind wings need to be folded under the forewings. Wing folding is done by a combined activity of abdomen and forewings; the abdomen pushes the wings under the forewings, by a brushing movement, and the wings fold according to their pattern. The wings are packed underneath the forewings in a flexible state; deploy-rigidification (perhaps through loss of water). The deployment consists of 2 stages, whereas the process happens slowly during the first stage (possibly locking of the wings), but regularly and fast afterwards. Techtextiles for composites, 3d weaving (composite beam), integrated sandwiches deployment mechanism involves geometrical change, rigidification geometrical control – inherent in structure functional grading fibre = kitin (main structural fibre used by the insect world) ex.: ladybird (constant deployment, double fold, no muscles), dragonfly	
	Features / Keywords
Insect wings, folding, variable geometry wings, forewings, hind wings, wing deployment, rigidification, techtextiles, 3d weaving, integrated sandwiches ++ mechanism of deployment + fibrous composites + functionally graded + as non-hybrid as possible actuation: muscle driven, geometrical control in structure	

Table 1-1: Role model info card for ladybird wings

- **Technical analysis of derived deployment options**



Deployment option derived from Ladybird wing folding

General description

The main ladybird structure was again added to each other 4 times to create a ring. The ring is rotated for 45° and then added to the first ring along the transverse axis. This is repeated several times to create a self deployable tube.
The tube deploys by pulling apart the ends without rotation.

Geometry – keywords

translation:
$(2D_1 \leftrightarrow)\ 2D_2 \leftrightarrow 3D$

Evaluation regarding technical requirements — PROs

one single force initiates the translation (draft).
one single force that initiates the translation can set off the whole process to reach the possible final state of a closed construction (habitat).
small initial folded structure → decompression → large tube volume.

Issues / expected difficulties in practice — CONs

Due to deployment parameters the structure creates gaps between the panels while unfolding. To compensate this problem the structure could be diverted into a pneumatic structure (for air tightness) and a rigid panel construction for radiation shielding and micrometeorites protection (Hybrid structure). Also, the inflation process of the pneumatic structure might be used as actuation for the deployment process of the panel structure.

Table 1-2: Technical assessment card for Ladybird wing folding concept

Findings:

- **Possible application of the evaluated deployment system to planetary exploration infrastructure**

  Following the evaluation of the concept within the framework of planetary operation applications, various implementation options are identified. One of these is a deployable shielding unit for habitable lunar structures. The structure is delivered to the operation environment in folded configuration and deployed by pulling the upper edge of the system along the habitable structure. The space between the deployed jacket and the habitat is filled with lunar soil to provide a high level of protection against radiation and micro meteorites.

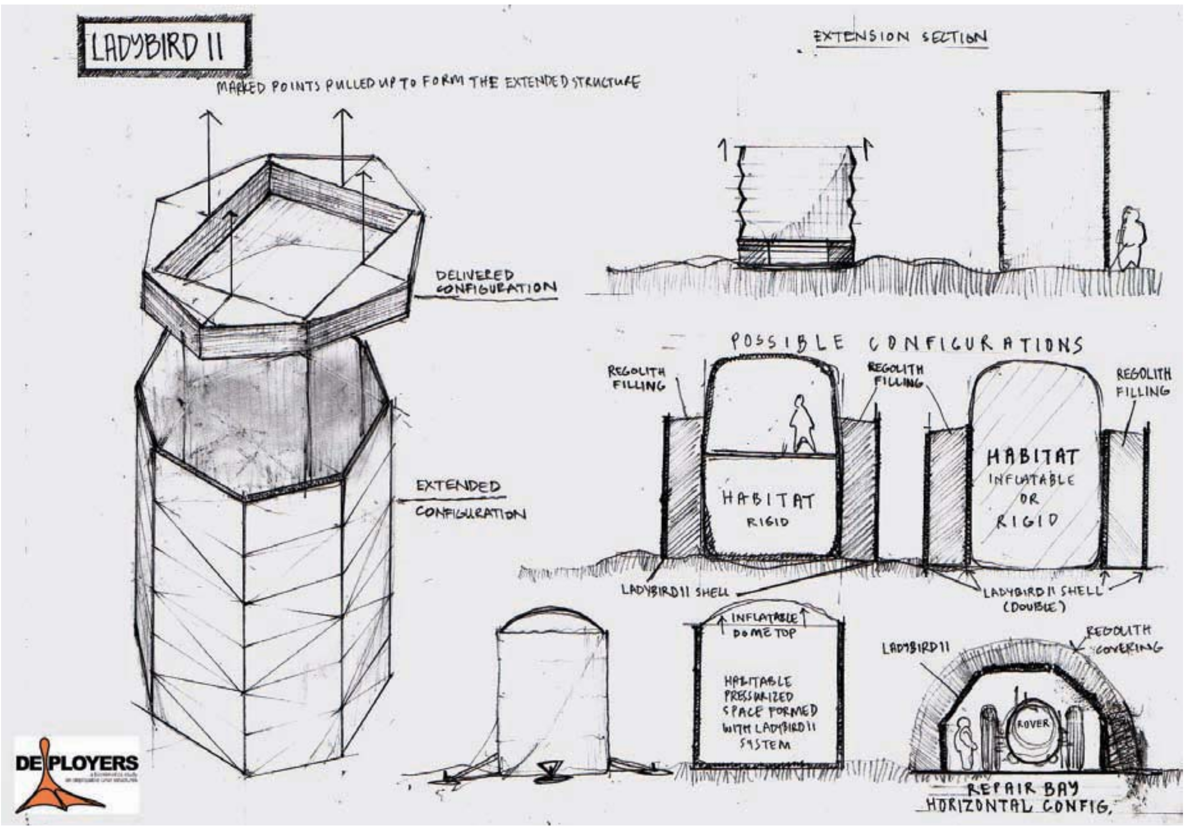


Figure 1-11: Deployable shielding jacket structure for lunar habitats[12], sketched by the author (Credit: Özdemir/HB2)

Possible Synergies with Biomimetics in design transfer frame

Biomimetics, as a proven system in design transfer effort, has its own method of categorizing, understanding and using biological role model concepts. The registration of each possible candidate for design transfer in a database system provided a practical basis to the research and design work throughout the Deployables study. Such a database regulates and consolidates the research work, resulting in a good level of efficiency. The evaluation of the candidate concepts within the framework of the application environment is also an important feature of the Biomimetic design transfer, keeping the performed work in the intended context, thus avoiding off-the-target results. These aspects of Biomimetic design transfer present valuable cornerstones for synergies with new design transfer systems.

[12] The depicted structure was designed as a deployable outer skin for regolith shielding option at the lunar surface. The transport configuration can fit into a launcher fairing easily.

1.4 Problem statement: The need for a design transfer method

Having presented a variety of the work done in inter-extreme environment design transfer area, a significant lack of methodical structure is identified. Nearly all the design transfer efforts, done up to present date are single attempts, lacking a systematic approach to the design transfer between extreme environments.

The upcoming era of human space flight includes the human exploration of Moon, Mars and Asteroids. In order to cope with the challenging space programmes, designed to implement this exploration vision, planning and design work has already been started. Formed by various segments of architecture (e.g. in-space, surface etc.), the future infrastructure for the human presence on other planets is being constructed piece by piece by designers, technicians and scientists. However the lack of a systematic design transfer approach, which can enhance these designs with the valuable experiences of the humankind in extreme environments up to now, is identified by the author, as a participant in the mentioned planning effort. The problem is:

"The lack of a systematic design transfer process, which can utilize the human knowledge in extreme environments."

This gap in the planning system for space exploration has the following impacts related to inefficient use of resources:

- Design transfer attempts stay as single efforts, hindering collective benefits. Design transfer methods and techniques are not coordinated and can produce results of differing quality.

- Wasted time on already-known subjects is a critical issue, experienced in some cases, where designers try to "re-invent the wheel".

- Skills and workforces of project participants and other external resources can not be networked efficiently. Educational institutions, for example, can not be integrated easily into the planning process.

Therefore,

a methodical approach to design transfer between terrestrial extreme environments and the space environment

is proposed as the thesis of this PhD work. Expected to be a tool for every designer, involved in space projects, this method is designed to be used to re-use design elements, concepts and techniques developed for terrestrial extreme environments by humans. This way, an efficient use of human knowledge on extreme environments for the consolidation of space exploration effort is aimed.

Figure 1-12: A sketch showing one of the earliest considerations for the interior of a Soyuz orbital module with a living room atmosphere, which was never created that way. The conventional references are likely to fail in extreme environments. (Credit:RKK Energia)

2 Hypothesis

The hypothesis of this PhD work is:

Design transfer cases from terrestrial extreme environment designs to space structure design concepts can be handled, using a methodical approach to find and to process the relevant terrestrial knowledge efficiently.

In order to bridge the methodical gap in the design transfer issue, a method with clearly defined process steps is proposed. The use of the proposed method is demonstrated via design model cases for better comprehension.

2.1 A design transfer method as a tool for space infrastructure planners : An overview to the proposed design transfer method

The subject of this PhD work is a design transfer and integration method that is designed to be used by space infrastructure planners. Using this method, design features, concepts and techniques from terrestrial extreme environments can be transferred to space structure designs, which are supposed to provide humans a living and / or working environment. The design transfer method can be thought of as a tool for designers, who are working on design concepts for inhabited space structures. The main goal of the research, presented in this PhD work, is to find out if such a method can be applicable in the design process of inhabited space structures.

The idea behind the development of such a transfer method is the need to utilize human knowledge on extreme environments to use it further for space applications. Driven by the motivation to discover the new, extend the force projection range and create new resources for humankind, space exploration is a challenging endeavour that requires extensive use of technical and mental capabilities of the humankind. Since thousands of years, humans are living, working and building in extreme environments for different reasons. They possess the knowledge on what and how to build for deserts, Polar Regions, underwater, high up in the sky or even in battlefields. Building and living in space, perceived in this work as just another extreme environment challenge for humans, has to be handled with a similar manner that helped to survive in terrestrial extreme environments. Therefore, the utilization of all the knowledge gain in terrestrial extreme environments is a necessity for space exploration planning.

The approach to the transfer of extreme environment related know-how, proposed in this work is based on the following cornerstones:

- a complete and analytical comprehension of the handled design case, where all the critical components, aspects, factors are identified and transferred into a common extreme environment language
- capability to make an extensive search on terrestrial extreme environment designs with the focus on acquired design shaping criteria
- correct identification, interpretation and transfer of the relevant terrestrial design material into intended space environment

Moving further with the above mentioned indications, a design transfer method is constructed with clearly defined processing steps. This method is designed to allow planners, independent from their skills and experience in designing for extreme environments, to locate and transfer relevant terrestrial extreme environment knowledge into their space structure concepts in form of elements and systems.

2.2 How does the method work?

In order to develop the intended transfer method into a design tool for planners, a distinct structure has to be formed. As the first step, the cornerstones of the design transfer are refined into three segments of the design transfer method (See Figure 2-1). These process segments, together with the intended products are listed as follows:

1. Definition of the design case, where the potential design-shaping factors, in regard to operational and environmental conditions are identified.

   Product: criteria that bridge the actual design to terrestrial extreme environment designs, to be used in the next step, the literature search.

2. Literature Search, in extreme terrestrial environment design records with the generated search criteria. Digital, printed and visual records of related extreme environment designs[13] are studied and their applicable design features are identified.

   Product: List of the applicable design features

3. Transfer of the selected design features is the adaptation process of the terrestrial design material (elements, features, concepts, techniques etc.) into the intended space structure design concept. The integration of the identified terrestrial design features are done in compliance with the main frame of the target design concept.

   Product: Final design concept, enhanced with terrestrial design knowledge

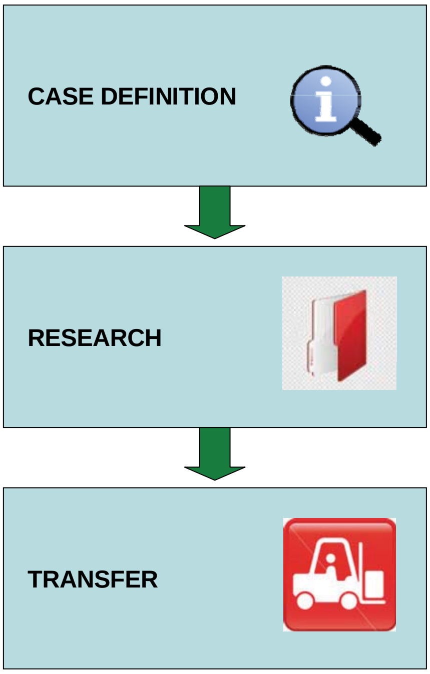


Figure 2-1: Flow chart depicting the sequence of the proposed transfer method

Having identified the main segments of the method, an articulation of single processes for each segment is the next step. The basic goal is to be able to handle a design case with clearly defined actions. The main segments and their processing steps are listed below:

[13] The construction of a common database containing all the human-made extreme environment structures can provide efficiency and quality in literature searc. Please see section Further Work.

Design Case Definition:

At the beginning of the process, the design concept segment that resembles the target for the intended transfer has to be defined with all its relevant aspects.

- *Identification of the target (receptor) design segment and the basic requirements*

is the first step of the design case definition section, where the receptor design segment and the basic expectations from the intended design concept are listed.

- *Identification of operational / environmental components and the search criteria*

produces a set of operational actions and environmental factors broken down into a list of components (e.g. unloading of containers from the lander). This way, universal extreme environment terms (e.g. pressure extreme) are addressed, bridging the space environment with the terrestrial extreme environments. An evaluation of operational and environmental components, together with the basic requirements for the intended design, provides a list of keywords for the upcoming literature search. These tags can also be standardized to category search criteria, if a database for the extreme environment design is constructed. (See Section 5 Further work and Recommendations)

Research:

Research segment of the proposed design transfer method is based on an extensive search in the literature for relevant terrestrial extreme environment designs, techniques and concepts. The findings of this literature search are evaluated to extract the relevant design features for the transfer.

- *Literature search with the generated tags and evaluation of the search results*

Having obtained a list of keywords, related to terrestrial extreme environment designs, a literature search in analogue and digital media is done, aiming to identify the candidate donor designs from terrestrial extreme environments. For instance, a literature search on the spatial configurations of submarines is done, in order to bridge the spatial features of terrestrial extreme environment habitats with the host lunar base design.

- *Evaluation of the search results*

The results of the literature search, the candidate donor terrestrial extreme environment designs are studied in order to make a list of the design features of each, applicable to the target design and its environment.

Transfer:

Condensed into a list of applicable features from terrestrial extreme environment designs, the transfer material is adapted and integrated into the receptor design concept, marking the final segment of design transfer process. The following steps of the transfer segment are taken at this PhD design research:

- *Step 1: Detailed iteration of the design requirements*

Applying an iterative approach, the intended design concept with the requirements, extended to the technical detail level are listed and studied in order to use the transfer material appropriately. This way, the selected design features to be transferred can be adapted, considering the technical expectations.

- *Step 2: Identification of the target location and its features*

Following Step 1 of the transfer segment, which provided a preview of the capabilities of the final design, the target location for the intended transfer is examined, in regard to its structural and operational aspects.

- *Step 3: The integration of the selected role model features*

The final step of the design transfer process is the integration of the selected design features into the receptor (target) design concept. With the conceptual and technical frame of the target already identified, the design transfer material can be adapted and integrated into the intended location. At this process, the abstraction of the transferred design features, where needed, is considered as critical by the author. For instance, as seen in model case 1, the functional principal of the diving bell, as a terrestrial role model is focused, rather than the structural features of this system.

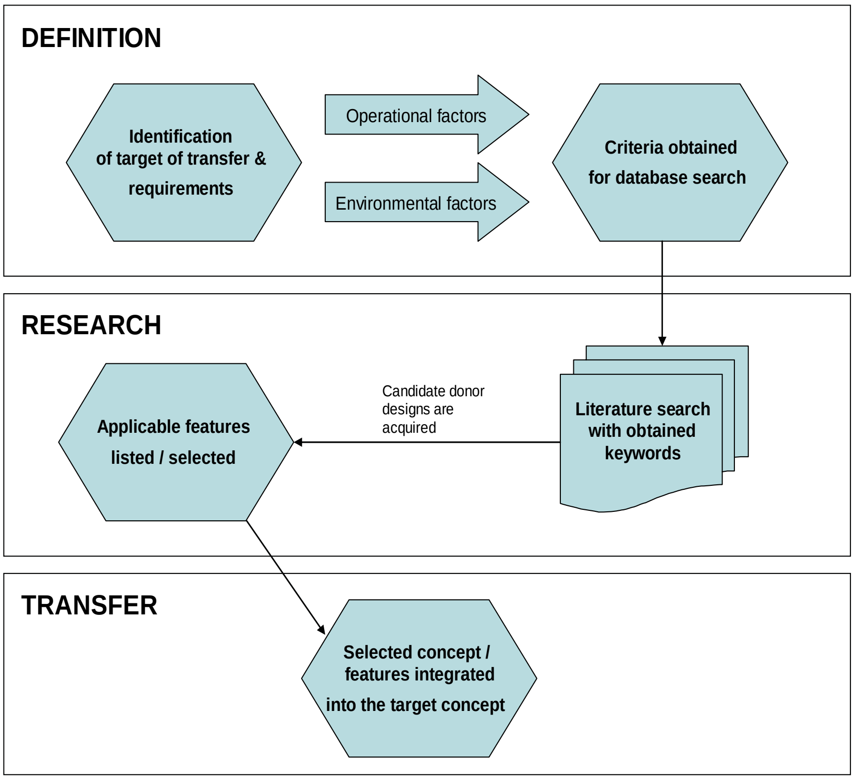


Figure 2-2: Flowchart of the proposed design transfer process

Using this transfer method, the author made design transfers from terrestrial extreme environment designs to inhabited space structure design concepts. The design model cases, where the capabilities of the proposed transfer method are demonstrated, resemble design transfer options in element and system scales. The presented work is focused on design transfers from terrestrial extreme environments to space environment. However, as explained in the section “Further work” in detail, the system can be configured to enable:

- Space to terrestrial
- Inter-terrestrial
- Inter-space[14]

[14] The transfer of space related designs into space structure concepts can also be considered in the frame of human space-flight technology development. Though, a design transfer system can enable the planners to exploit better the cumulative knowledge on space structures.

Design transfers, as a useful tool for designers working on all kinds of extreme environment projects. The approach to handling the designs will presumably stay unchanged. Therefore, the initial construction of such a transfer method, enabling systematic transfers between terrestrial and space design categories is considered to be important.

2.3 Comparison of the proposed design transfer approach to Biomimetics

As a frequently applied concept transfer system, biomimetics can be compared with the proposed design transfer approach.

Biomimetics is a special field that studies the biological role models and incorporates the identified technical solutions to the actual architectural and engineering systems. The defining factor in biomimetics is the focus on solely naturally formed systems. Taking advantage of the evolutionary pressure on these systems, that results in high optimization and efficiency, the biomimetics transfers these ideal solutions to modern designs. The main driving factor in the optimization of biological systems is the condition of survival, thus the evolutionary force. This indicates the natural evolution and development of the mentioned structures, while the proposed design transfer system studies only human-made extreme environment designs, where human logic and experience are the shaping factors.

Biomimetics:

- *Deals with naturally formed structures*
- *no human logic / design involved*
- *not only for humans, focus on efficiency*

Proposed Design Transfer Process:

- *human-made / designed*
- *based on human experience*
- *human needs / behaivour regarded*
- *space handled as just another extreme environment for humans*

Figure 2-3: Comparison of biomimetics vs proposed design transfer system

The most distinctive conceptual difference between biomimetics and the proposed design transfer process is the character of the design sources. Biomimetics is concerned with naturally formed structures and systems. The goal in biomimetic design is to understand and to interpret the solutions found in the nature, in which there is absolutely no contribution of human design work. Nevertheless, the proposed design transfer system studies solely structures, which are designed by humans, according to their needs. The main shaping factor in the naturally formed systems is the evolutionary force, which keeps the biological structures in a perfect mode for survival. The extreme environment structures like submarines, nomad tents or spacecraft are developed on the basis of human logic and experience in extreme environments. The evolution of these structures, if there is one, is the result of human work.

The methodical character of both design transfer systems are similar. The identification of the requirements / literature search / transfer of the chosen role models form the basic steps of both transfer systems.

3 Research

The proposed design transfer method is tested in a research work, demonstrating the capabilities of the method. This research work is done, by applying the proposed design transfer method on five model cases, where design concepts were to be developed in specific conceptual frames.

3.1 Methodology of the research

The following methodological structure is used to present the research work in design cases, where the proposed design transfer method is applied:

- Model case is defined
- The design transfer process is demonstrated
- Results are presented

Four out of five model cases are housed in a design project, where the design concept of a lunar station with various subsystems was to be improved.

3.2 Host Project : Kopernikus 2 Lunar Logistics Station

This section provides the basic information on the lunar logistics station, Kopernikus 2, which is used as a host project for the explanation of the proposed design transfer method with model cases.

Introduction

Kopernikus 2 is a modified design concept, based on Kopernikus station design, which was originally produced at the Lunar Base Design Workshop, hosted in ESA/ESTEC in 2002, by a group of architecture and engineering students from Technical University of Vienna, Technical University of Eindhoven and Colorado School of Mines. The Kopernikus station concept featured a commercial station to provide logistic and other services for the other stations in the South Pole region of the Moon. A draft concept of the Kopernikus was presented at the ESA / ESTEC facility at the end of the workshop and detailed further in Vienna by the students of HB2, the Institute for Design and Building Construction of the Technical University of Vienna. In this PhD work, a modified design of Kopernikus is used with the designation Kopernikus 2*,* as a host project for four of the design transfer model cases.

Figure 3-1: Original Kopernikus Station design from 2002(Credit: Team Kopernikus)

Location and Purpose

Kopernikus 2 is a logistics station, situated in the South Pole region of the Moon. The main purpose of *Kopernikus 2* is to provide logistic support for the other stations in the region. Following the first steps of continuous human presence on the Moon, it can be foreseen that a number of manned outposts and stations will be built around the lunar South Pole, where permanent sunlight[15] can be used to power the infrastructure and provide a constant thermal and illumination environment. Anywhere else on the Moon, the base design must cope with two-week day and night cycles. Since in a human habitat the continuous sunlight and a stable thermal environment could permit much simpler support systems and potentially remove sources of failure, the Polar Regions, especially the south lunar pole will be favoured for human stations. [Eckart, 99]

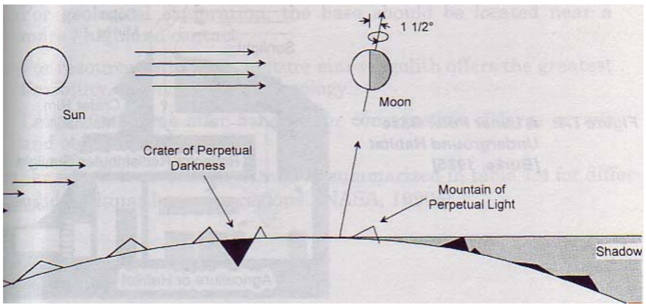


Figure 3-2: Lighting situation at the lunar south pole (Credit: Landis)

The mentioned human lunar bases that form the operational rationale of the *Kopernikus 2* project are likely to be built in the settlement phase of the lunar base development line. The phases of the lunar base development and the foreseen structural elements can be viewed below:

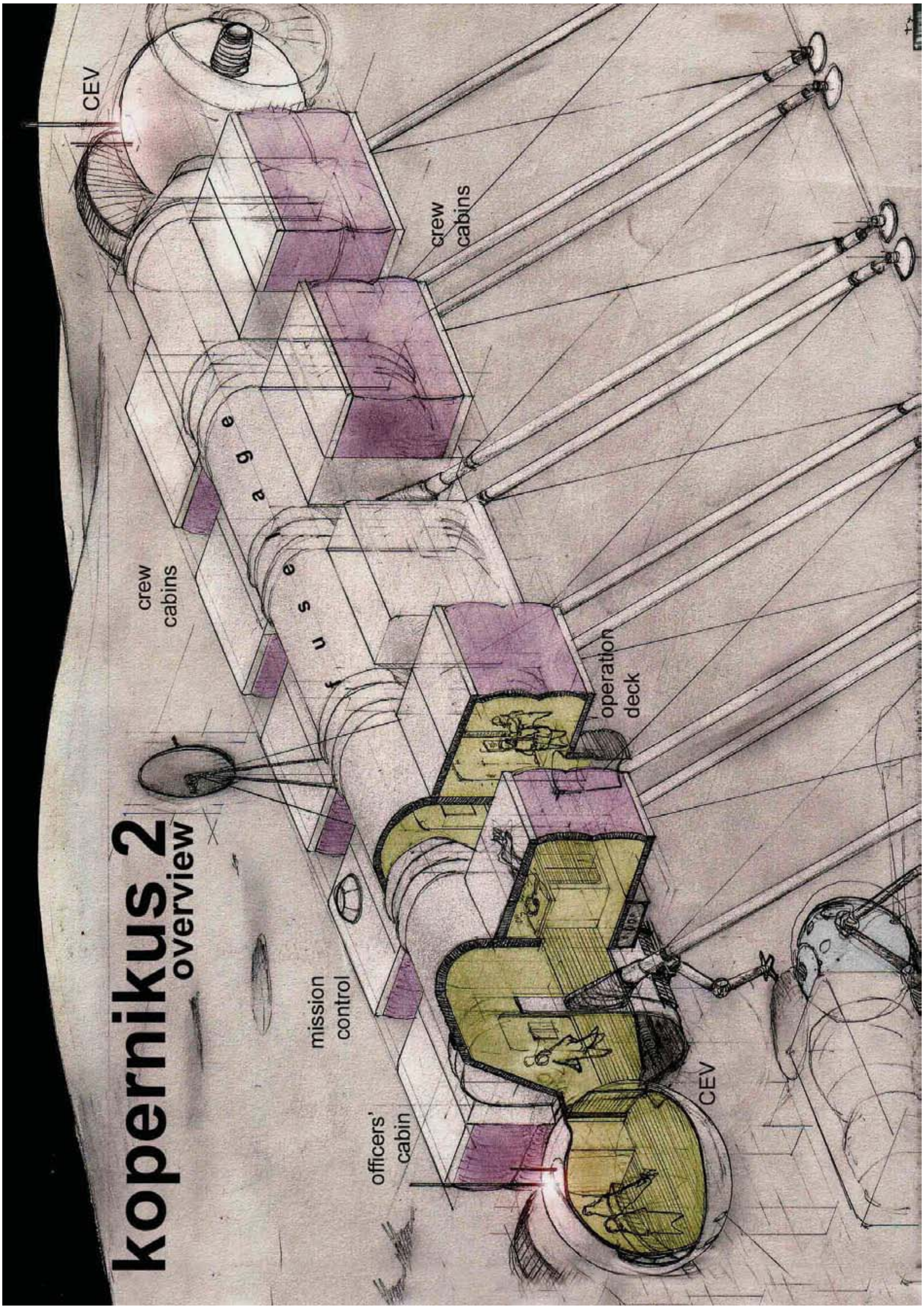
phase	**Elements**	**Tasks / Capabilities**
Precursor	Orbiters, Robotic surface rovers	Lunar topographic mapping, Surface Surveys, assessments
Pioneering	Landers with habitats, Temporarily occupied minimum base	Lunar base site preparation, Limited science facilities Pilot mining plants
Consolidation	Extended surface facilities, Permanently occupied facility	Extended science and mining facilities, Longer range surface transportation
Settlement	Fully operational lunar base	Advanced laboratories, industrial research facilities, large scale mining and manufacturing facilities, satellite outposts, long range surface exploration

Table 3-1: Lunar Base Development Phases (Cappellari, 1972; Duke, 1985)

The estimation that a number of mining and scientific bases will be built in the settlement phase, points out the need for logistic and service support to these facilities. Besides the limited resupply flow from the Earth and the in-situ resource utilization benefits, a considerable amount of logistics support from nearby logistic centres will probably be necessary. Similar to the terrestrial examples (e.g. mining towns), layers of service systems will form around the fully operational lunar bases to benefit from the economical activity in a sort of symbiotic system. All crew consumables, like oxygen, water, food etc. will be the focus of logistic requirements. Medical support, personal transport and rescue services are also likely to be required and offered.

Figure 3-3 on following page: An overview image of the Kopernikus 2 Lunar Logistics Station vessel (Credit: Özdemir)

[15] The permanent and horizontal sun rays lead to a solar power system, featuring lateral solar panels on both sides of the station. Please see sub-section Power System.


kopernikus 2
overview
officers' cabin
mission control
CEV
crew cabins
fuselage
operation deck
crew cabins
CEV

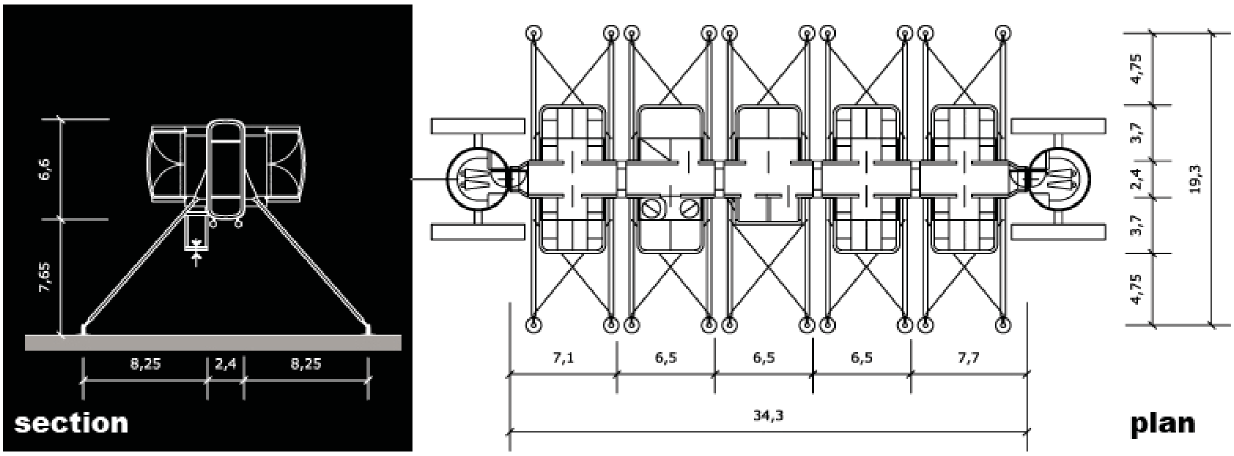


Figure 3-4: Kopernikus 2 Lunar Logistics Station with basic dimensions (Credit: Özdemir)

Design

Kopernikus 2 station has a linear pressure vessel system, which is elevated from ground by a support structure. The main hull of the station is formed by rigid and pressurized habitable units that are attached end-to-end, like the International Space Station. This rigid body forms the backbone of the station, on which the additional units are plugged. The backbone houses the inner transfer corridor, connecting all the habitable units, as well as life-support and power systems. (See Figure 3-7) Crew cabins, command structure and the medical station are attached to the sides of the backbone hull. Crew cabins are partly inflatable modules that are stowed in a folded configuration in transport and expanded after assembly to the backbone (See Figure 3-8).Two rescue boats are mounted at both ends of the backbone structure, providing safe evacuation of the station in an emergency situation. Each segment of the station has its own supporting legs and is prefabricated.

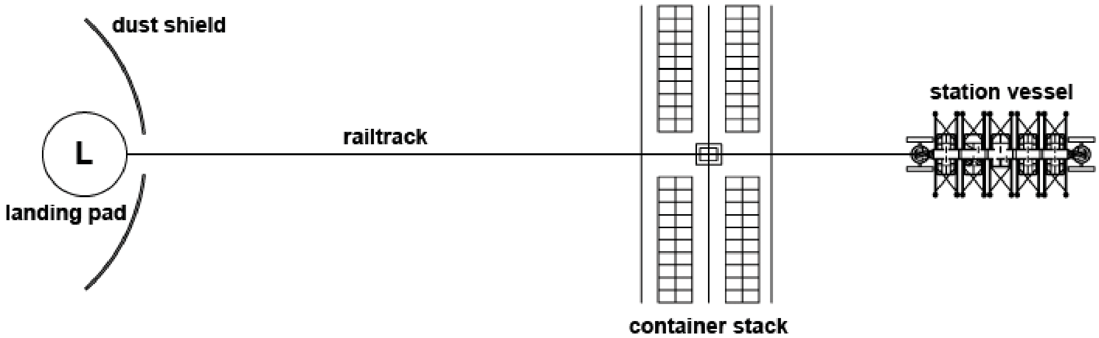


Figure 3-5: Kopernikus 2 Logistics Station Overview (Credit: Özdemir)

The Kopernikus 2 Station vessel is elevated approx. 7m from the ground, avoiding disturbance from regolith dust, thrown around during vehicle operations. Protecting the mechanical components of the station, like docking interfaces, is critical to the operational and crew safety of the whole system. The elevated configuration also provides a clear zone below the station, where SMU (Surface Mobility Unit) vehicles and heavy containers are being moved.

Figure 3-6: Halley IV Antarctic station. Elevating the structure for protection against environmental hazards is also applicable in terrestrial extreme environments. (Credit: Hugh Broughton architects)

The rigid fuselage[16] of the Kopernikus 2 station houses the main body of the power and life-support systems. These technical systems, together with their lines and interfaces are housed under the floor plate and over the ceiling claddings, running along the linear structure. All plug on cabins are connected to these interfaces and feed their own subsystems.

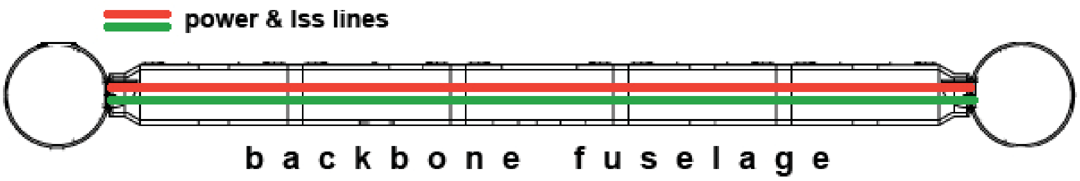


Figure 3-7: The fuselage (the rigid hull) of the Kopernikus 2 Station vessel holds the power and life-support systems (Credit: Özdemir)

Each plug on module has its own life-support and power system which are connected to the main systems of the station vessel. The station has five crew cabins, each designed to accommodate two persons. Plug-on crew cabins are hybrid structures with a rigid segment, holding the bunk, storage space and the integrated technical components(e.g. lighting, ventilation); and an expanded soft shell segment for living space. The units are deployed by pressurization. For every crew member there is a private sleeping cell, storage unit and a table in the crew cabins. The sleeping cell of the crew cabin is shielded with a layer of water, surrounding the cavity, for radiation protection during sleeping / resting hours.

[16] The term „fuselage" is used, in order to emphasize the similarity and the connection between space and aviation technologies. The term" vessel" is used for the inhabited segment of the Kopernikus 2 Station, reflecting the almost nautical character of a lunar station structure.

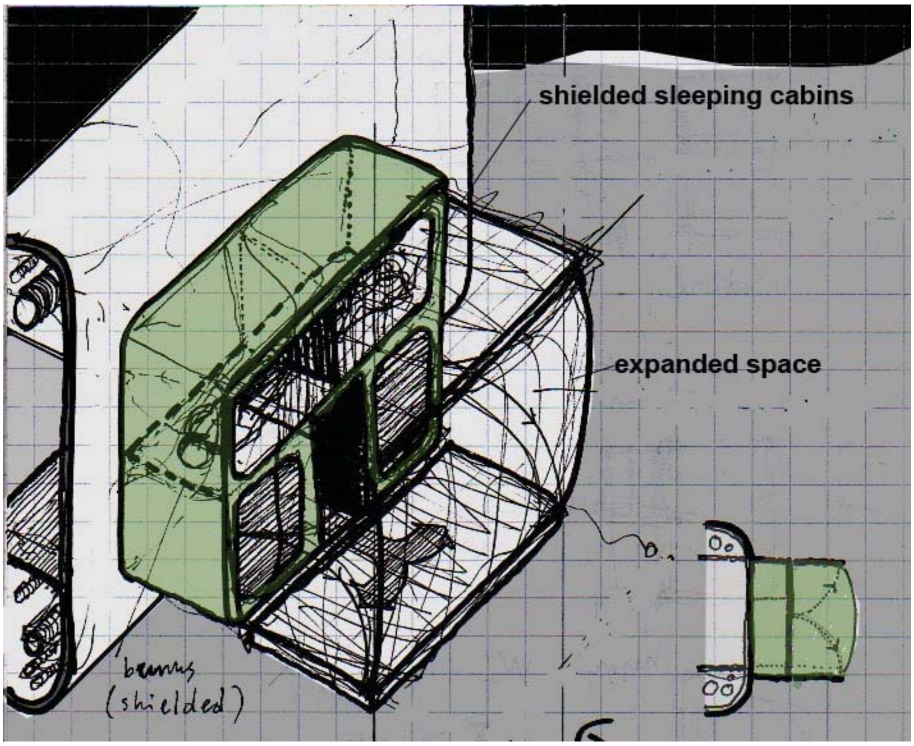


Figure 3-8: Early sketch, depicting the crew compartment layout of Kopernikus 2 (Credit: Özdemir)

Construction

The construction of the Kopernikus 2 Lunar Logistics Station is thought to be a multi-phased process. Basic requirements for the construction of Kopernikus 2 Lunar Logistics Station are as follows:

- Heavy launcher capability (e.g. Ares V)
- Lunar cargo lander capability
- Erection of a rail-track system
- Construction hardware on building site, featuring a rail-track based construction cart with hoisting platform

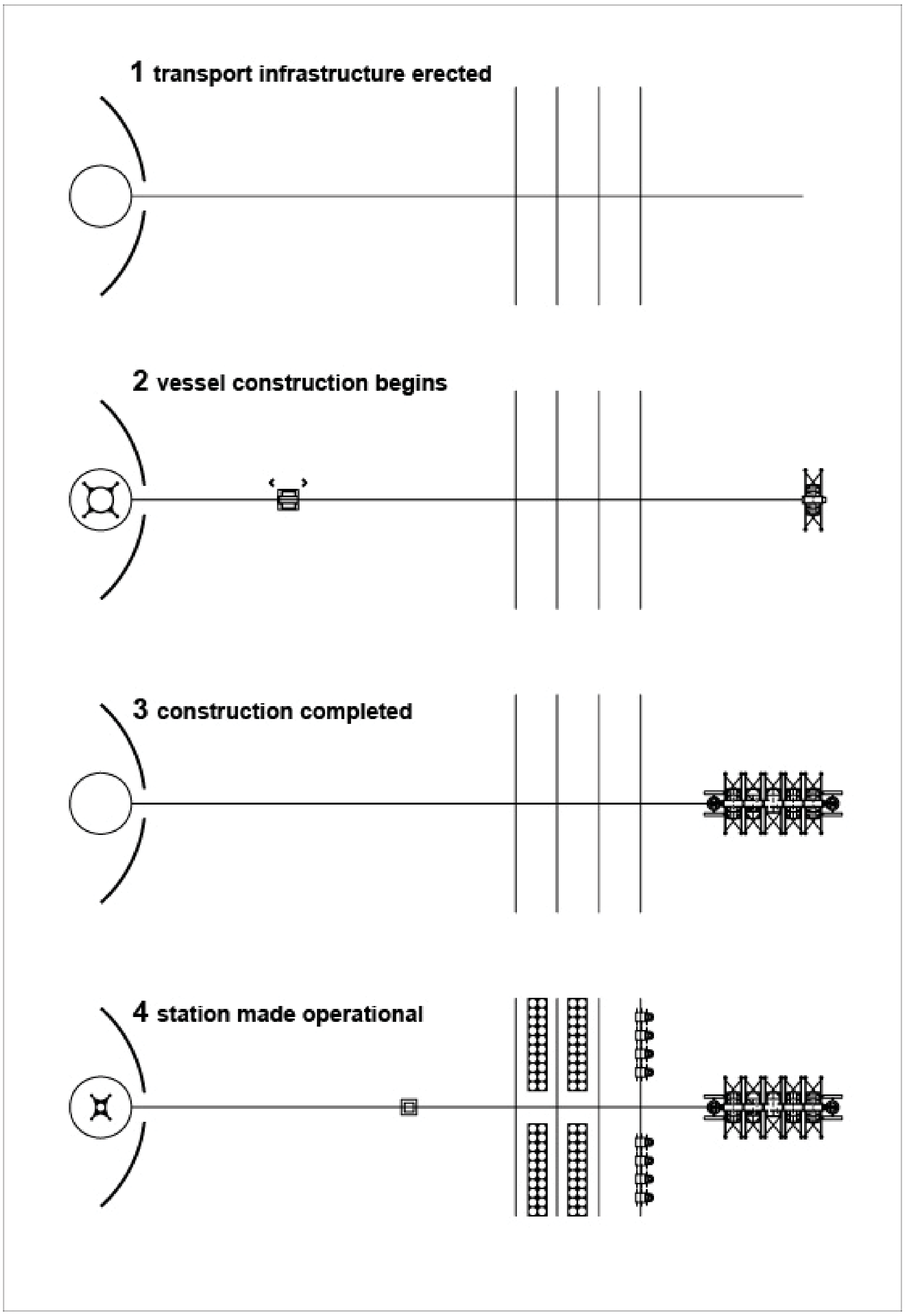


Figure 3-9: Development phases of the Kopernikus 2 Lunar Logistics Station (Credit: Özdemir)

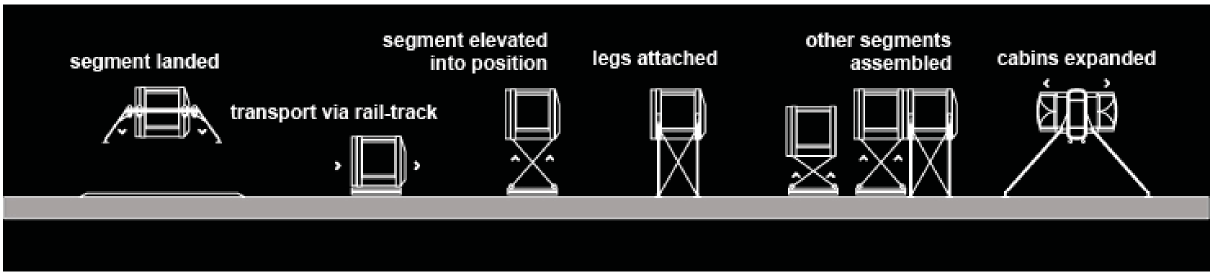


Figure 3-10: Construction sequence of the Kopernikus 2 Station vessel

The construction of the Kopernikus 2 Lunar Logistics Station is proposed to be applied in the following steps:

1. The basic infrastructure at the building site is erected. The landing pad with its dust shield and the rail-track system is the first layer of the Kopernikus 2 Station to be built in order to provide a starting bed for the construction of the vessel.

2. Main segments of the station vessel are landed one by one at the pad and transported to the vessel construction location via the rail-track. Each segment is elevated and aligned with other segments. Brought into correct position, they are assembled to other segments, forming a linear build-up.

3. Assembly of the station segments is completed. The vessel is pressurized and the plug-on modules are deployed. Sub components (e.g. solar panels, deployable maintenance unit) are mounted. Station crew moves in.

4. Elements of the container terminal are delivered and assembled. SMU vehicle components, containers are integrated into the system. The Kopernikus 2 Lunar Logistics Station is made operational.

The construction of the Kopernikus 2 Station can be done by robotic capabilities, considering the series of systematic assembly of the segments.

Figure 3-11: Two terrestrial analogues[17] for the construction of Kopernikus 2 Station vessel. A hoisting platform developed to service A 380 Airbus airliner and main segments of a Type XXI submarine of WW2 era (Source: Flugfeld Fahrzeuge, U-boat database)

[17] Not only design concepts but also techniques can be adopted from terrestrial extreme environments. Building the vessels in segments, for instance, is applied since WW2 as a submarine construction method.

Operations

The main services of the Kopernikus 2 focus on logistic support (i.e. delivery of consumables), and personnel & medium-cargo transport. These services are done by the surface mobility units (SMU), that are capable of transporting humans and equipment in all terrain conditions of the lunar surface. A typical SMU has a mobility chassis, a pressurized cockpit and a cargo / crew cabin component. These components can be stored in different numbers, according to the actual requirements. The modular nature of the system enables mission specific configurations. For each delivery / collection mission a cockpit, a chassis and a cargo unit or a logistics container or a crew cabin are assembled to a vehicle system, by the manipulator arm system of the station. The vehicle systems can be inspected and repaired in the expandable garage of the station.

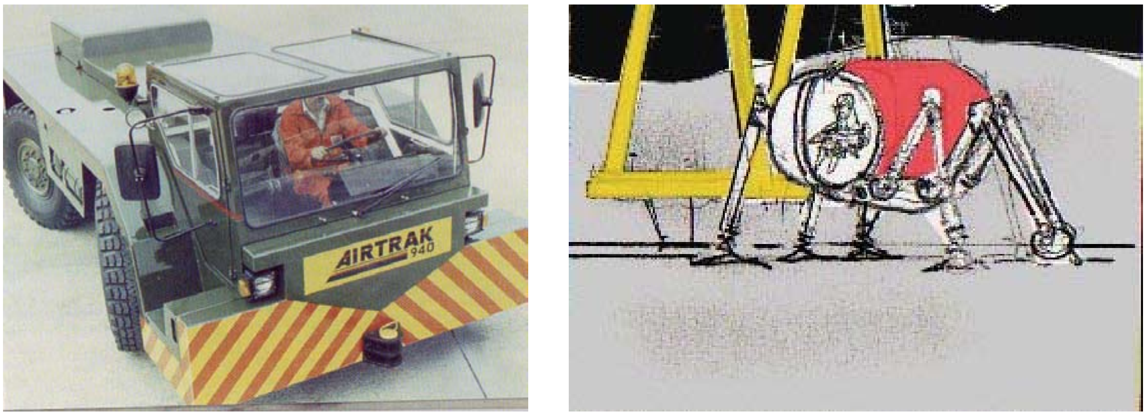


Figure 3-12: Right, Surface Mobility Unit (SMU) of Kopernikus 2, left, its terrestrial component[18], an airport vehicle (Source: Flugfeldfahrzeuge, Özdemir)

All the operations of the Kopernikus 2 Station are monitored, controlled and coordinated from the control centre. Together with the operation deck, where EVA and docking interfaces are integrated, the operation control cabin forms the utility core of the Kopernikus 2 Station vessel. The officers' cabin and the medical care unit are connected to this core, to provide a good level of operational efficiency.

Figure 3-13: An image from the control room of the US Navy submarine Nebraska. The control crew work in a dense technical environment and keep visual and vocal contact with each other during operations.[19] (Source: US Navy)

[18] The airport / apron vehicles have a similar structural composition to SMUs, comprised of chassis, cockpit and payload modules.

Power System:

The availability of sufficient amounts of electrical power is critical to the safe operation of a lunar base. All the systems of the station (e.g. life support, transport systems) require sufficient and uninterrupted power to function correctly. The power supply system of the Kopernikus 2 Station is based on solar panels, attached to both sides of the station, on the support legs. Since Kopernikus 2 is located at the South Pole region of the Moon, a more vertical configuration of panels are intended, considering the permanently low degree of sun rays. (See Figure 3-14)

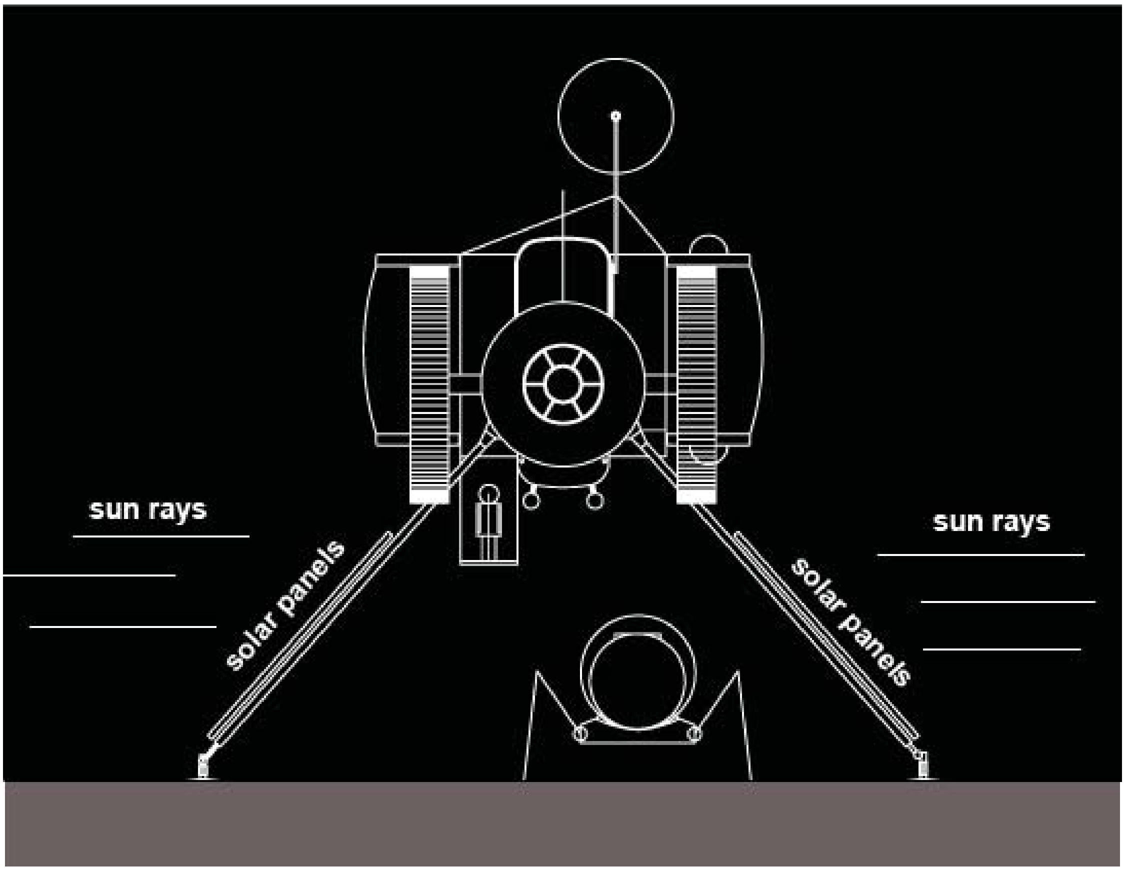


Figure 3-14: Positioning of solar panels at the station vessel (Credit: Özdemir)

[19] During the operations, the activity in the control room of the Kopernikus station is comparable to the ones of submarines, battleships or the oil rigs.

Radiation Protection System:

Radiation protection is an important issue for any space mission where there is no powerful magnetic field or dense atmosphere protecting the astronauts. An often used principle in radiation protection is ALARA, which is an abbreviation for "As Low As Reasonably Achievable". The aim is to minimise the risk of radioactive exposure and/or amount of dose, while keeping in mind that some exposure may be acceptable in order to complete the required task.

The radiation protection system of the Kopernikus 2 Station is based on hull integrated shielding, providing a reasonable level of radiation inside the station vessel. Based on this method of shielding, different sorts of material sets can be proposed. A composite structure of Boron Carbide, High Density Polyethylene (HDPE) and the aluminium shell of the main fuselage segments of the station is considered to be a suitable solution.

In addition to the hull integrated radiation protection of the station vessel's fuselage, sleeping cells of the crew cabins are shielded with a layer of water, to give the crew an increased level of protection in sleeping hours.

In order to provide the station crew a temporary shelter during the Solar Particle Events (SPEs), where lethal amounts of solar energetic particles are striking the lunar surface, a temporary entrenchment in the middle segment of the station vessel is planned. Using water filled plastic bags; the core of the vessel is shielded temporarily by the crew, for protection against radiation. Connected to the hygienic facility and the galley, the station crew can stay in the storm shelter during the SPE in acceptable habitability conditions.

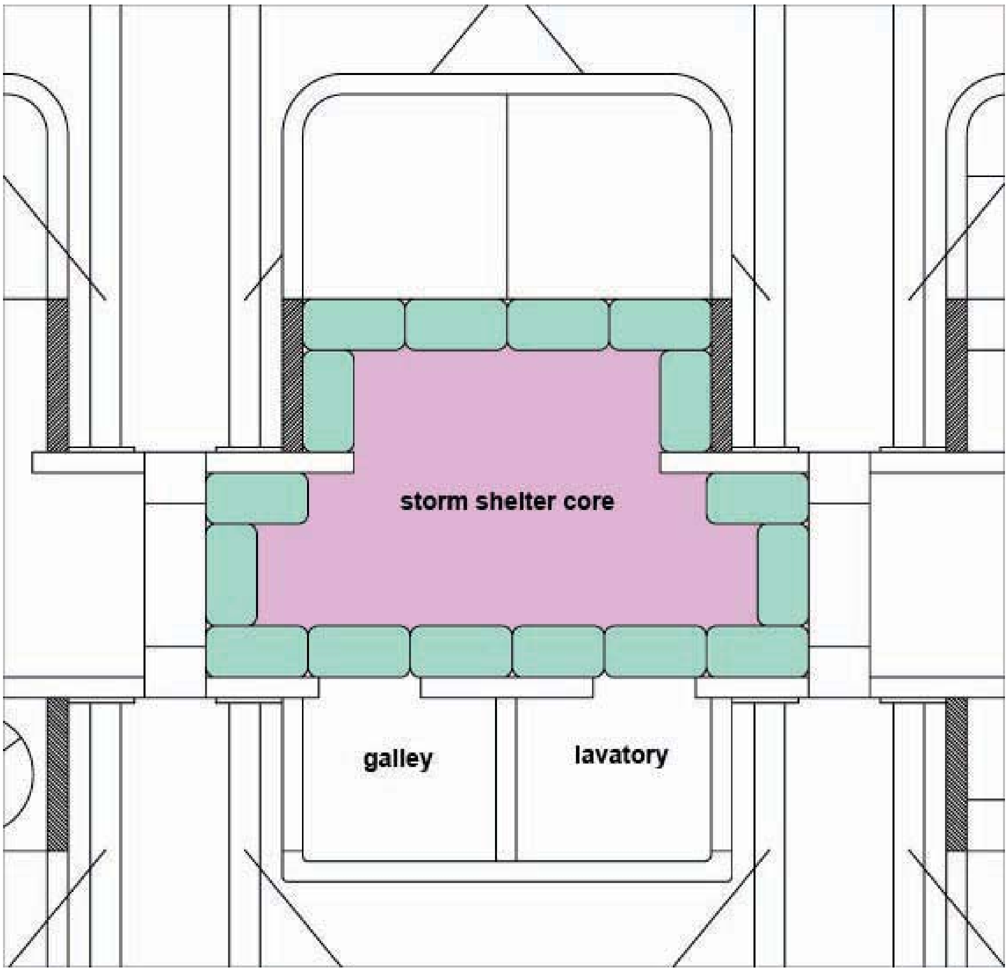


Figure 3-15: Temporary storm shelter of Kopernikus 2 Station (Credit: Özdemir)

Life Support System:

The design of a lunar base life support system is governed by the objective to maintain an environment, suitable for the well-being of humans and systems in an isolated volume [Eckart, 99]. An integrated life support and environmental control system provides the Kopernikus 2 crew mainly with:

- Atmosphere management, controlling the composition, humidity, temperature, pressure, contamination as well as the generation of station's inner atmosphere and ventilation.

- Water management[20], providing potable and hygiene water, as well as recovery and processing of waste water

- Waste management, dealing with the collection, storage and processing of human waste and trash

The life support system equipment of the Kopernikus 2 Station is integrated in the rigid fuselage section of the vessel, under the floor level and above the ceiling cladding, running along the linear structure. The equipment is accessible via opening hatches for servicing and repair activities. Crew cabins, attached to the rigid body of the station are plugged on to this main life support system, where their own ventilation and air-conditioning systems are fed from the main unit.

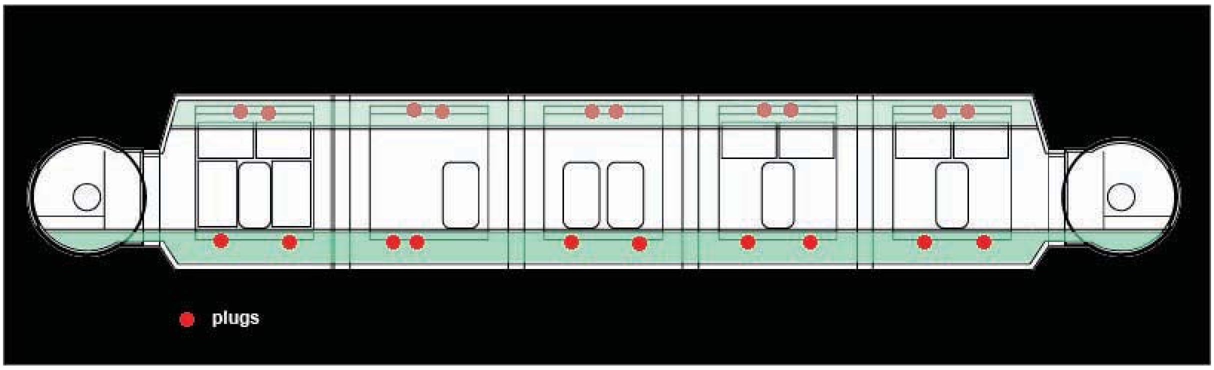


Figure 3-16: Image depicting the positioning of the integrated life support system of Kopernikus 2 Station (Credit: Özdemir)

[20] A water management system, as a potential ancestor of the mentioned LSS system of Kopernikus 2, is recently installed at the International Space Station.

Interface units:

Kopernikus 2 Station vessel has two external interface units, through which crew or equipment transfer to other units or the external environment is provided. These two units are:

- Deployable Maintenance Unit (DMU) that is connected to the operation deck via flexible transfer tunnel.
- Docking and EVA adaptor, which is used to insert and collect the crews to / from external pressurized units like the Surface Mobility Units (SMUs).

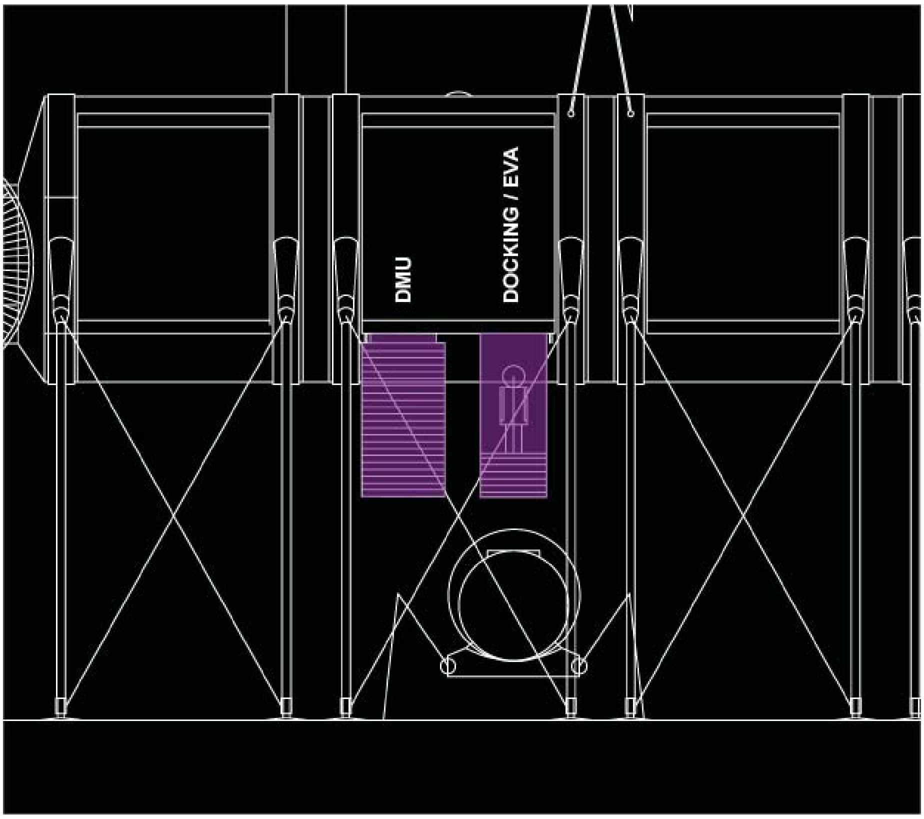


Figure 3-17: Interface units of Kopernikus 2 (Credit: Özdemir)

The DMU is a deployable soft shell structure that allows the crew to repair and service Surface Mobility Units (SMUs). It is stowed under the operation deck and does not distract the surface traffic of the cargo operations.

Docking / EVA adapter is simply a docking module, with two integrated suitlocks. This cylindrical structure, connected to the operation deck like the DMU, is used to dock on to Surface Mobility Units for direct crew ingress and egress. The two suitlocks hold two space suits, giving an EVA option to the station crew for an emergency case. The lower segment of the structure is flexible in order to provide an ideal docking to units below. This segment can be retracted after use for undisturbed clearance below the station.

3.3 Model case 1 (element scale) : Deployable Maintenance Unit (DMU) of Kopernikus 2 Lunar Logistics Station

The deployable maintenance unit (DMU) of the Kopernikus 2 Lunar Logistics Station is designed using the proposed transfer method. This model case is focused on the transfer and the integration of a diving bell design into the Kopernikus 2 Station.

3.3.1 Model case definition

Model Case 1 (MC1), the first design transfer model case of this work resembles the transfer in element scale and features the design development of the Deployable Maintenance Unit (DMU). The DMU is an element, used to create a temporary confined working environment outside the station interior. It is a station-based external unit, accessed from the operation deck of the Kopernikus 2 Station vessel.

Identification of the target segment and the basic requirements

The surface mobility unit (SMU) is the main element for delivery / collection operations, providing the transport of cargo containers and crew cabins. Exposure to regolith dust and mechanical breakdowns can make the regular servicing and repair of these vehicles necessary. The duration of the intended repair and maintenance activities outside of the station as an extra vehicular activity (EVA) poses a risk to crew health, regarding the radiation levels, vacuum environment, temperature extremes and micro-meteorites. In addition, EVAs in bulky spacesuits are not easy to execute in lunar conditions [Brian, 82]. In order to minimize the mentioned risks, an expandable confined space, directly accessible from the station interior is needed. The expandable structure must cover the vehicle, to be serviced completely and provide enough space around it for the repair crew to operate. The structure must be retractable to let the vehicle drive away after the servicing operation and not to interfere with other activities (e.g. loading / unloading process) taking place around the station. Considering these facts, the main points can be briefly defined as follows:

Target/Subject of Transfer: An expandable / retractable confined space

Requirements:

- Direct access from the station interior
- Equal pressure level with the station interior
- Radiation / Thermal / Micro-meteorite protection
- Plenty of space for repair / maintenance activities

Identification of operational / environmental components and the search criteria

The operational and the environmental components are listed, given the maintenance operation and the lunar environment as the main frame.

Intended use and operational components:

Repair and maintenance of surface vehicles in a deployable and confined environment

- Deployment of the unit
- Operation crew ingress into the unit
- Repair or maintenance work
- Operation crew egress into the main vessel
- Retraction of the unit

Environment: Lunar Surface

Environmental Components:

- Vacuum
- High levels of radiation
- Micro-meteorites
- Temperature extremes
- Dust
- Rough terrain features (craters, ridges, crevices etc.)
- 1/6 gravity

Terrestrial literature search tags:

- Permanent maintenance structures (Military, aerospace, marine technology)
- Deployable maintenance structures (Military, aerospace, marine technology)
- Diving bells

3.3.2 Research

The research work on the development of the deployable maintenance unit of Kopernikus 2 Lunar Logistics Station is as follows:

Literature search with the generated tags and evaluation of the search results

Using the identified tags, a literature search in digital and printed media is applied. The relevant information, acquired in this process is as follows:

Temporary Servicing Shelters

Deployable servicing shelters are light weight and easy transportable structures that can be erected for repairing and maintenance purposes. These structures are mostly inflatable and do not need any foundations. They can even be linked together to form larger structures ideal for temporary shelters, tents, decontamination changing rooms, helicopter hangers, field hospitals, sports halls, field headquarters, etc. Considering the military systems, the deployable structures can dramatically reduce deployment logistics, including the amount of time, people and equipment required to set up field operations.

Figure 3-18: An artist's impression of the currently developed inflatable aircraft hangar. The rapid deployment and dismantling of the unit is a critical design driver, in regard to the military use.
(Source: US Air Force Materials and Manufacturing Directorate)

Currently, the researchers at the U.S. Airforce Research Laboratory's Materials and Manufacturing Directorate, are developing a new temporary aircraft shelter for deploying forces that is significantly lighter, faster to transport, and easier to construct. Shelters made with inflatable air beam technology could greatly reduce the manpower required to set up deployable shelters, as the existing shelter requires eight people and the inflatable shelter requires five. It is expected to reduce deployment time by 75 percent, and labour hours required by deployed forces to construct shelters by nearly 85 percent. Researchers anticipate that the shelters will be 60 percent lighter, and will require only a single shipping container in lieu of three which will allow twice as many shelters to be shipped per transport aircraft.

Beside their light weight, rapid deployment / retrieval and all weather properties the inflatable / deployable shelters are erected independently from any other service units. This fact indicates a partial use of the shelter concept in the design development of the deployable servicing unit of Kopernikus 2 station.

The applicable features of temporary inflatable shelters for the proposed design transfer are:

- Light weight / inflatable structural system without foundations
- Deployment and retrieval techniques

Diving Bells

A diving bell is a cable-suspended airtight chamber that is lowered underwater to provide a confined space for operations or a means of transport. The air pressure inside the bell is kept at the ambient water-pressure on the bottom of the bell, so that the inside is kept dry. Diving bells in different forms and sizes have been used for a long time to salvage cargoes and to fulfil underwater construction works. To prevent floating up and capsizing, diving bells always have to be heavy, and can be used only when adequate lifting capacity is available. The refreshment of the air inside the bell takes place from the surface. In general the diving-bells are electrically lighted on the inside, supplied by a cable from the surface and a telephone communication. Unlike a submarine the diving bell is not designed to be steered by its occupants independently from surface units.[21]

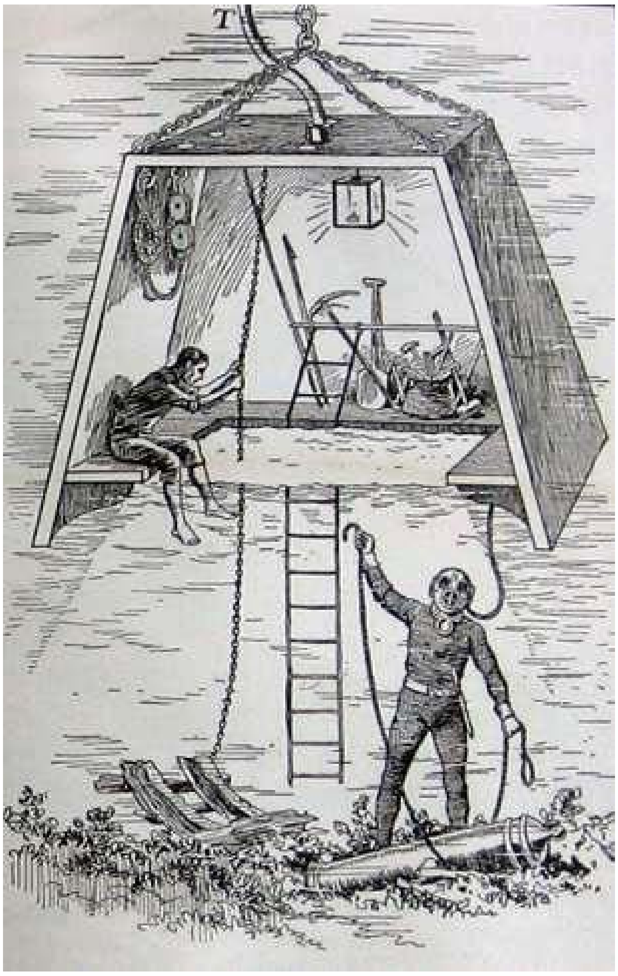


Figure 3-19: 19th century sketch depicting a diving bell operation (Credit: Lawrenz)

It is generally agreed that the diving bell invented by Edmund Halley is the forerunner of the modern diving bell. In 1690, Halley designed and built a diving bell in the form of a truncated cone. In Halley's design, the diving bell atmosphere was replenished by two air filled containers, which were lowered down from the surface ship. By alternating the barrels, a continuous fresh air-feed to the diving bell was planned. (See figure x-x) This simple method of replenishing air was intended to eliminate the air-supply hose that has to be connected to an air-pump on the surface unit and provide the underwater unit more manoeuvrability. One has also to consider that, the design and production of an air conveying, water tight hose was a challenge at that time.

[21] Concerning their limited mobility aspect, diving bells are thought to be classified under the category "Underwater – utility" in the future database E2D2. This way they are not likely to interfere with the underwater vehicle rcords, needlessly. Please see the "Further Work" section for extended information.

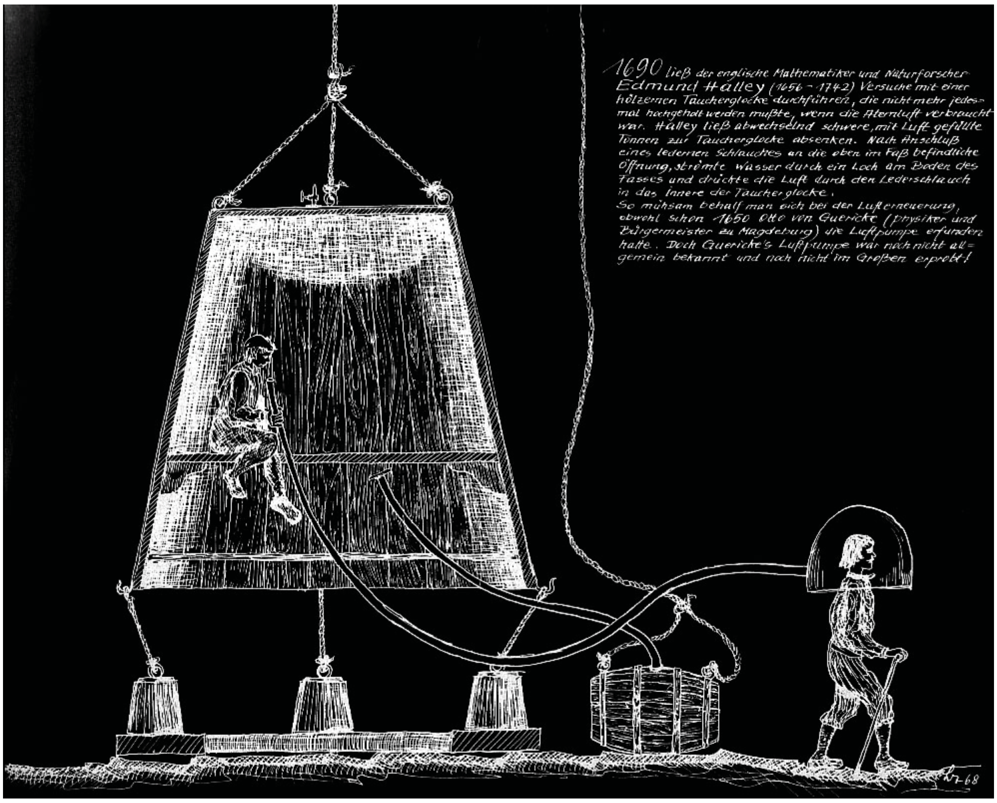


Figure 3-20: Halley's diving bell design, dated 1690 (Credit: Lawrenz)

The modern application of the diving bell is a simple transport-bell, used to transfer divers from the deck of the diving-vessel to the area where they have to do their work and back again. The principle of a diving bell stays the same, as it is a closed dome with a number of glass view ports, standing on an open construction, based on a working floor. The divers stay under the dome during the transfer to the operation depth. The air-pressure inside of the dome is equalized in accordance to the ambient water-pressure, so that the divers stay with the upper part of their body in a dry surrounding. Upon arrival at the operation depth, divers leave the bell through the openings in the side. During the underwater operation the bell is kept in the required vertical position, with the help of a ballast-weight. In order to keep the dome atmosphere free of water and breathable, the bell has a continuous air-feed from the diving-vessel. After completing the underwater work, the divers make their ingress into the bell again and are pulled back to the surface. Depending on the operation depth and duration, decompression stops have to be done at certain depths for certain durations.[22] Despite the installation of self contained units like compressed air bottles for emergencies, diving bells are still dependant on the surface components, indicating that the diving bell design has not changed dramatically since its earlier forms.

Following the conceptual and operational assessment, the diving bell is selected as the main terrestrial extreme environment design role model. Following features of the diving bell concept are applicable to the development of the deployable servicing unit of the Kopernikus 2 station:

- Creation of a semi-confined environment for utility activities in an extreme environment
- Deployment technique from the main vessel
- Main form of the diving bell body
- Atmospheric, data and energy feed from the main vessel

[22] Since the diving bell is an open construction, a decompression phase on board the surface ship is not possible.

3.3.3 Transfer

Transfer and integration of the selected design features into the Kopernikus 2 Station design concept

Having selected the diving bell as the main donor concept, the transfer of the selected donor concept occurs in the following steps:

Step 1: Detailed iteration of the design requirements

Target/Subject of Transfer: An expandable / retractable confined space for vehicle repair and maintenance

Basic Requirements:

- Direct access from the station interior (operation deck)
- Equal pressure level with the station interior
- Radiation / Thermal / Micro-meteorite protection
- Plenty of space for repair / maintenance activities
- Energy, Data and Life support system connection to the main station

Technical Requirements:

- 250 m3 of pressurized space (enough to hold a SMU and the servicing volume) shall be provided
- Internal energy and data ports shall be provided
- A sealing frame system on the joint edge between the floor and the side walls is required to achieve air tightness
- System deployment and retraction shall not interfere with the operational traffic and the structural elements of the station
- System shall feature light weight structural elements, as it is a deployable system. Total mass is dictated by the bearing capacity of the main station structure and the deployment system
- The system should be integrated into the main station structure in the stowed configuration

Step 2: Identification of the target location and its features

The deployable maintenance unit will be installed right under the operation deck. Crew and equipment ingress/egress shall be made via operation deck. The unit shall be deployed down on the ground level, allowing a direct access for the vehicles. (See Figure 3-21)

Step 3: The integration of the selected role model features

Terrestrial diving bell concept, selected as the main donor for the design transfer process, is analysed, considering its functional meaning and capabilities. A diving bell is simply used to create a suitable working environment under the water. Atmospheric and lighting conditions are aimed to be transferred from the surface to the location deep underwater. Analytically, the operation of a diving bell can be explained via the following sequence:

1. Situation: Operation crew and equipment is on a surface ship. Operation location is at the sea floor or at a given depth underwater.

2. Operation starts with the crew and equipment ingress into the diving bell.

3. The unit is lowered onto the operation depth.

4. Unit reaches the operation depth. Crew starts and completes the repair, retrieval or any other activity. Air replenishment, power transfer and communication are provided continuously.

5. Unit is retracted back to the sea surface, completing the decompression intervals.

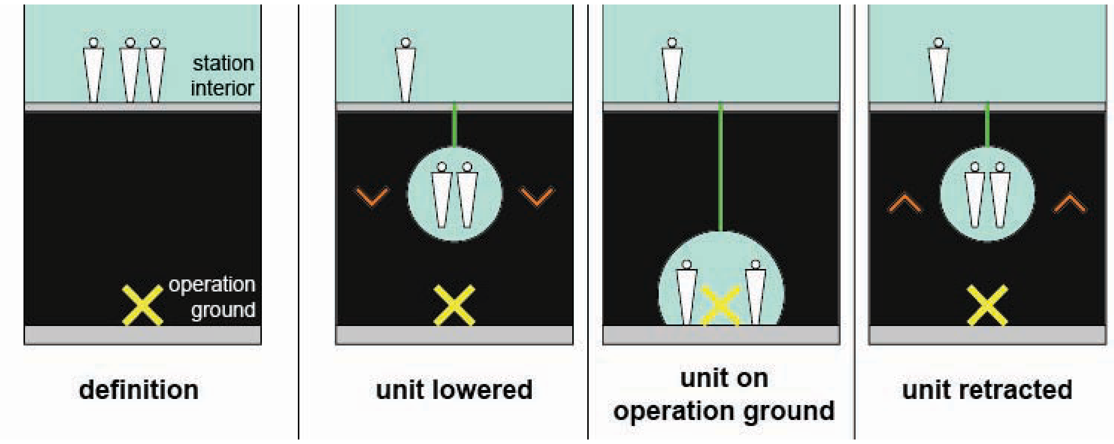


Figure 3-21: Analytical scheme depicting the functional principle of the diving bell concept (Credit: Özdemir)

The direct transfer of the above presented sequence would look, as depicted in Figure x-x. However, considering the different conditions in the lunar environment, the diving bell operation concept is adapted into the following sequence:

1. Situation: Operation crew and equipment is in the station vessel. Operation location is on the lunar floor, right under the operation deck.

2. Operation starts with the lowering of the unit to the operation ground.

3. Atmospheric, temperature and lighting conditions of the DMU cabin are equalized with the station interior. Crew and equipment are transferred into the unit through a connection tunnel.

4. Crew starts and completes the repair, service, or any other activity on the subject of duty (e.g. SMU vehicle). Crew leaves the DMU by climbing back into the operation deck of the station.

5. DMU is depressurized and retracted back to the station vessel.

The most peculiar feature of the DMU, in respect to the terrestrial diving bells, is the crew safety and comfort. The DMU crew accesses and leaves the unit right before and after the surface activity, increasing the operational efficiency besides crew safety.

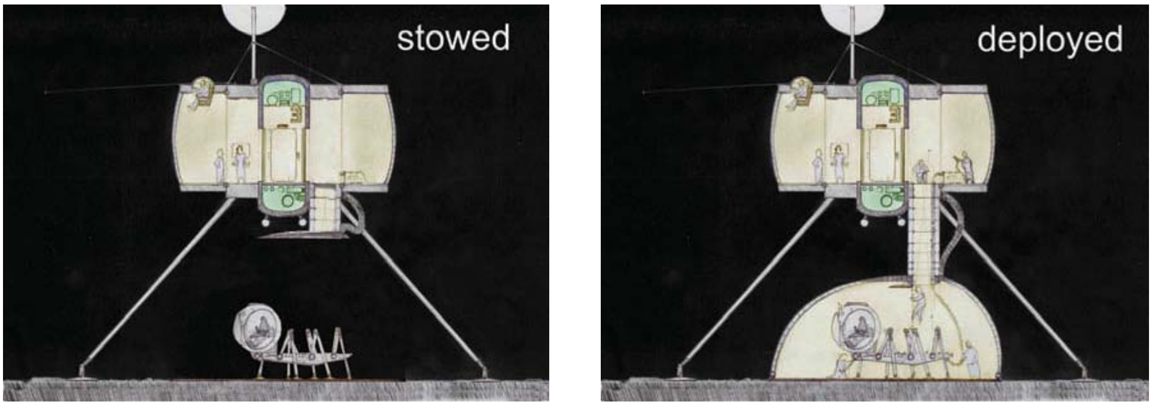


Figure 3-22: DMU in before and during the operation (Credit: Özdemir)

3.3.4 Final Design

The end product of the design development process is the Deployable Maintenance Unit (DMU). DMU is an integrated maintenance structure and is capable of providing the service crews a confined environment during their operations. Three elements of the structure are as follows:

- The flexible connection tunnel, a bellow-like passage way connecting the DMU cabin with the EVA deck of the Kopernikus 2 Station
- The rigid cabin roof[23] and the flexible side walls, defining the main space of the unit
- The rigid base plate, providing the floor of the unit for the vehicles

Following operational factors of the DMU are considered, when shaping the final design:

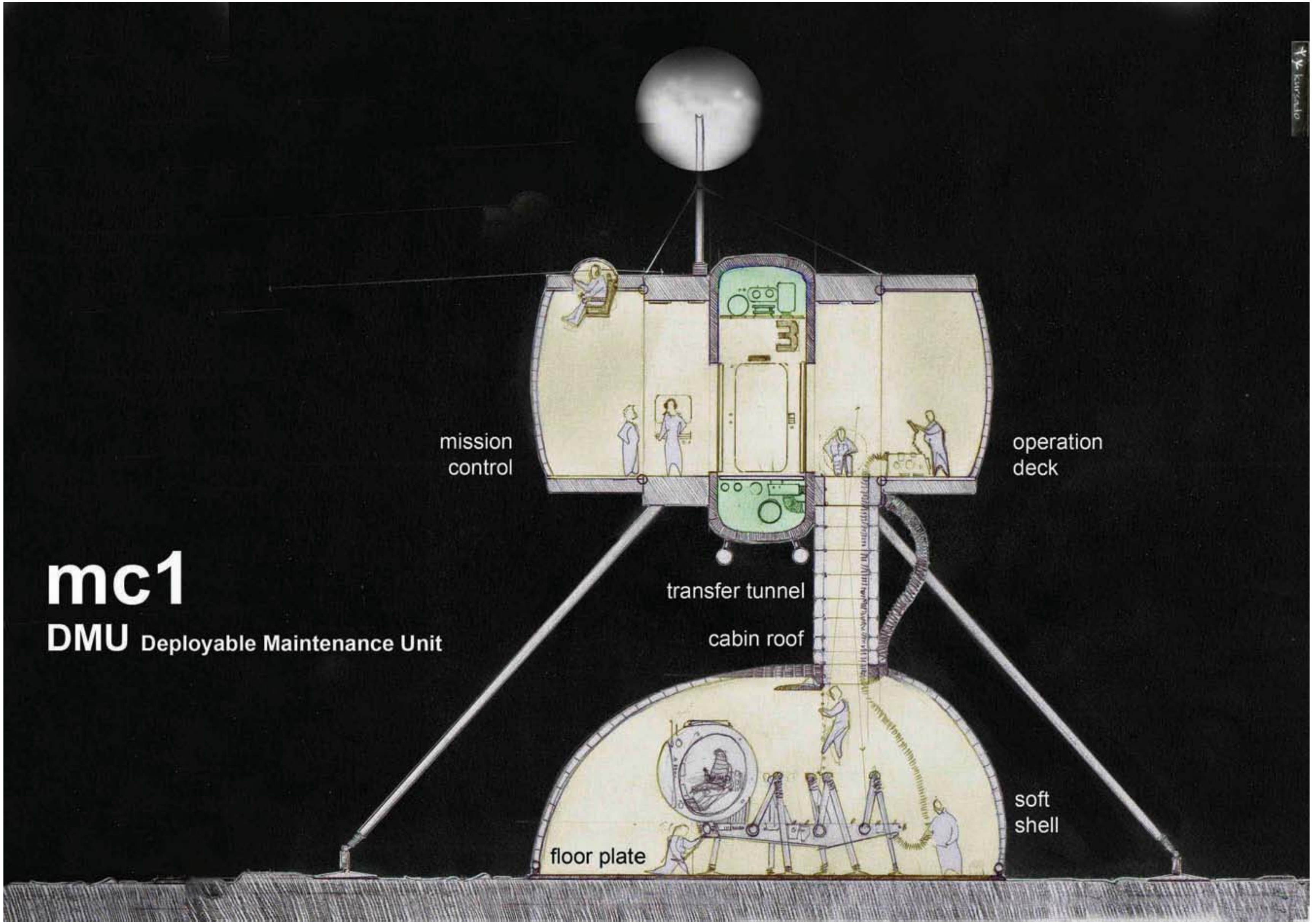
Operational Factors:

- Limited extra vehicular activity (EVA) durations
- Handling of bulky hardware
- Dispatch from / return to main unit
- Limited manoeuvrability

The unit is stowed under the operation deck and can be lowered down onto the base platform, where the vehicle to be repaired is parked. Upon lowering and attachment to the base plate with sealing linings, the unit is pressurized and the crew, with their equipments, make the ingress via the flexible connection tunnel. The crew is thought to wear safety overalls with emergency equipment, not space suits, since the DMU interior is a confined space. After completing the service / repair activity, the crew climbs back into the station's EVA deck through the access tunnel and the hatch between them is closed. Depressurizing the DMU is followed by the detachment of the inflatable walls from the base plate. As the final action, the system is pulled up and retracted into the stowage position under the operation deck platform. (See Figure 3-21)

On the next page, Figure 3-23: Section through Deployable Maintenance Unit (DMU) and the operation deck of Kopernikus 2 (Credit: Özdemir)

[23] The roof segment of the DMU is designed to house the required systems and their mechanical bodies.


mc1
DMU Deployable Maintenance Unit
mission control
operation deck
transfer tunnel
cabin roof
soft shell
floor plate

The final design concept of the DMU can be compared with its terrestrial extreme environment role model, the diving bell, considering similar operational factors.

DMU is thought to provide the following capabilities:

- To service and repair the Surface Mobility Units (SMUs) within the stations environment and without the need to do any risky Extra Vehicular Activities (EVAs). This feature consolidates a high level of self-sufficiency of the Kopernikus 2 Lunar Logistics Station.

- To service and repair surface vehicles of other stations, giving an option to offer a broad palette of commercial services. Since the Kopernikus 2 is a commercial lunar logistics base, a maintenance service might be attractive for other stations in the area.

- To transfer crew and equipment in and out of the surface vehicles, in case of a breakdown at the docking adapter. The docking adapter, situated right next to the DMU interface is provided with a back up system, this way.

	diving bell	**DMU**
stability	achieved by structural heaviness & ballast	unit attached to base plate with sealing linings
crew access	crew ingress & egress on surface	crew ingress after pressurization crew egress prior to retraction
connection to main unit during operation	only comms line, no physical connection	uninterrupted connection to main unit via tunnel
exposure to outer environment	crew has to go out to perform the operation	crew stays in unit
air / power / comms feed	from surface ship via umbilical	from station via umbilical
emergency escape	risky, with diving suits	rapid evacuation option via connection tunnel

Table 3-2: Comparison of the basic operational features of DMU and the diving bell role model

A comparative assessment of the DMU design to the terrestrial diving bell designs is presented below:

- Stability is a key factor in both designs. Operating in pressure extremes and using heavy hardware, both units need a certain level of stability during their work. Diving bells use their heavy structure and extra weights, attached to the cabin bottom for underwater stability, thus avoiding capsizing. DMU is designed to be attached to a base plate for stability, where the plate functions as a bottom cap for the pressurized unit. The weight of the repaired vehicle keeps the plate, thus the system stable. The base plate can also be attached to the ground, if light-weight hardware is to be serviced.

- Crew access to DMU is possible via the connection tunnel, while the diving bell can be manned and unmanned only on the surface. This capability enables DMU crews to be re-configured during the service operations. For example, crews can work in shifts in the DMU to maximize efficiency and minimize the exposure to radiation. Visual contact to the EVA deck of the station is another factor that improves the operational quality of the service activities in the DMU.

- An all-time physical connection to the main unit is provided in DMU, through the connection tunnel. Crew, hardware and custom mission equipment (e.g. extra data / power lines) addition or replenishment is possible throughout the operation. These capabilities provide a high degree of flexibility and adaptability, considering the nature of service / repair operations. Diving bells, in contrary, are accessible only when they are above the sea surface. The connection during the operations is the communication line.

- Exposure to the outer environment can pose a high level of risk for the crew of both units and their missions. The DMU crews stay in their unit, in a confined environment, while doing their activities. Diving bell crew have to leave their cabin and undertake an EVA outside their confined environment. The equal / similar pressure and temperature levels enable the DMU crews do challenging EVA duties just wearing safety overalls, rather than bulky space suits. DMU crews are not exposed to hazards like vacuum, lunar dust, high levels of radiation, steep changes in temperature and micro meteorites by staying in their unit.

- Air / Power / Data / Communication feed can be done in both designs during the operation via umbilical lines to the main units. Additional lines can be installed through the connection tunnel of the DMU, as such solutions are often applied in space habitats. (See Figure 3-23)

- Rapid evacuation of the unit in an emergency case is an important safety aspect. The uninterrupted access to the main station vessel provides an all-the-time egress option from the DMU. In case of emergencies, like pressure loss or fire, DMU crew can easily and rapidly climb back into the station or receive direct assistance from the operation deck above.

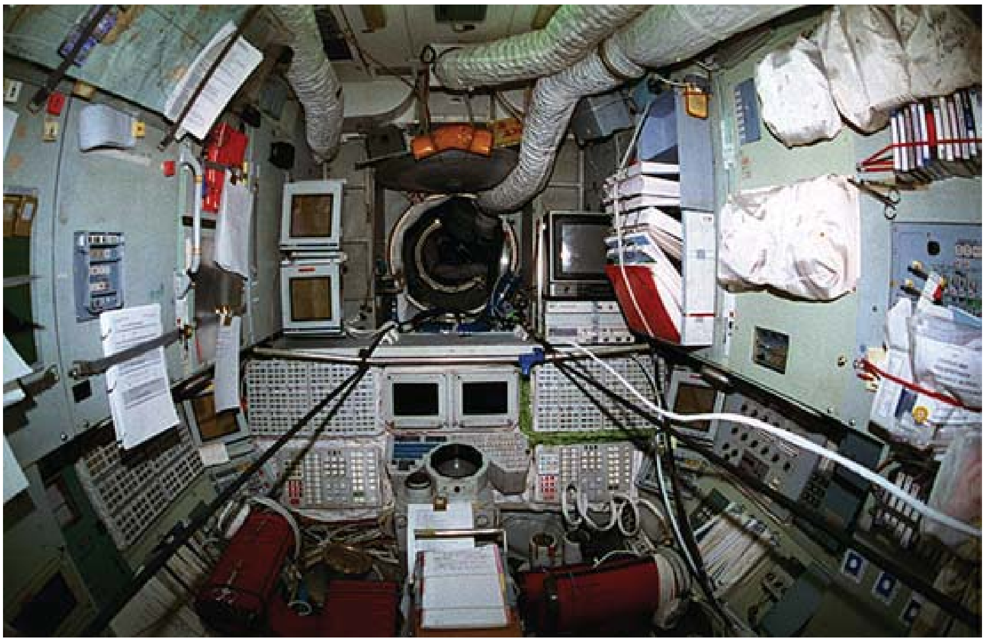


Figure 3-24: An image from the interior of the retired Mir space station. Note the improvised connection lines between the modules[24] (Criedit: NASA)

[24] This situation can also be seen at the section drawing, depicting the umbilical connections between the operation deck and the DMU interior. (see Appendix image x-x)

3.4 Model case 2 (element scale): Crew Escape Vehicle (CEV) of Kopernikus 2 Lunar Logistics Station

The proposed design transfer method is used to develop a crew escape vehicle for the Kopernikus 2 Lunar Logistics Station. The deployment system of free-fall lifeboats and the structures of simple mobility systems donated shape-giving features to the design concept of the Crew Escape Vehicle (CEV).

3.4.1 Model case definition

Model Case 2 (MC2) resembles a design transfer case in element scale and features the design development of the Crew Escape Vehicle (CEV). In MC2, the focus is on the free-fall lifeboats of the ocean going ships as the terrestrial role model. In addition, simple terrestrial mobility systems that are suitable for rough terrain are assessed and some features of these are incorporated in the design concept of the CEV.

Identification of the target segment and the basic requirements

Kopernikus 2, as a habitable lunar station, is operating in a hostile environment. Although the station is designed to minimize the risks that station crew may face, an option to abandon the station in an emergency case has to be considered. Therefore, rescue vehicles, providing safe and fast escape from the station and capable of sustaining the whole crew for a period of time are foreseen as the main element of the crew escape system. Considering these facts, the main points can be briefly defined as follows:

Target/Subject of Transfer: An integrated rapid-dispatch rescue vehicle unit

Requirements:

- Capability for fast and safe escape from the main station
- Good level of integration to the main station
- Direct access from the station interior
- Capability to sustain the whole crew (enough space, beds, life-support, hygiene, medical assistance systems - also for incapacitated crew members) until the rescue teams arrive
- Capability to drive away from the station to a rendezvous point on rough lunar terrain
- Integrated communication systems
- Radiation / Thermal / Micro-meteorite protection

Identification of operational / environmental components and the search criteria

The operation type, environment and relevant factors, concerning the Crew Escape Vehicle (CEVs) are listed below:

Intended Use and operational components:

Emergency escape of crew with life-boat from the station and contacting / reaching rescue measures

- Use of the unit as a crew space in daily routine
- Crew ingress from the main vessel

- Decoupling from the main vessel and deployment to the lunar surface
- Reaching the safety clearance from the endangered zone
- Contacting the rescue units
- On-board medical care of the incapacitated crew members
- Proceeding to the rendezvous point with the rescue units
- Transfer of crew into the rescue unit

Environment: Lunar Surface

Environmental Components:

- Vacuum
- High levels of radiation
- Micro-meteorites
- Temperature extremes
- Dust
- Extreme lighting conditions
- Rough terrain features (craters, ridges, crevices etc.)

Terrestrial literature search tags:

- Confined extreme environment habitat-integrated crew escape / rescue systems
- Underwater crew escape systems
- Marine surface vessel crew escape systems
- Non terrestrial search tag: Space structures crew escape systems
- Simple mobility systems (Mono & Diwheels, rolling systems)

3.4.2 Research

The research work on the development of the crew rescue unit of Kopernikus 2 Lunar Logistics Station is as follows:

Literature search with generated tags and the evaluation of the search results (candidate donors)

Literature search with the generated search tags was made in printed and digital media in following aspects:

Structural and Operational Aspect

Free-fall Lifeboats

Free-fall lifeboats are designed as escape capsules for crew abandoning ship or a rig, and provide a safe and swift means of evacuation. Because it represents an apparent improvement in safety over conventional lifeboat systems, the free-fall lifeboat has become a common lifesaving appliance on cargo ships and fixed offshore installations. They have been used for a number of years and have been responsible for saving many lives. During a recent emergency case, a crew of 14 escaped from their sinking vessel in heavy seas off Newfoundland. As Lloyd's List stated at the time: "The men were able to launch [the freefall lifeboat] despite the violent motion of the sinking ship[25] which would have made escape by a conventional lifeboat doubtful. The men were later picked up by a Spanish trawler and all were unharmed."

Free-fall lifeboats are stored onboard the main vessels, at the ship's stern and on their deployment rail, pointing downwards to the plunging direction. The crew ingress is done via the main hatch, at the back of the boat, and the unit released free on the inclined deployment rail to plunge into the water. The freefall lifeboats are completely enclosed structures and can withstand the storage and operational conditions of the high sea environment.

Just as with conventional lifeboats, the correct procedures must be followed when using freefall lifeboats. To ensure that every crew member knows and understands what to do in an emergency, it is necessary to be fully acquainted, not only with the inside of the lifeboat, but also drilled in evacuation procedures. In addition, on-site maintenance must be carried out to meet both company and legislative requirements. Most maritime regulatory authorities have accepted the free-fall concept and have developed design and certification criteria for these lifeboats.

[25] A conventional lifeboat and its launch system, depending on pulleys or other systems would probably have been inadequate for a fast and safe evacuation under extreme conditions. Free-fall life boats are among the state-of-the-art equipment, designed for extreme environments.

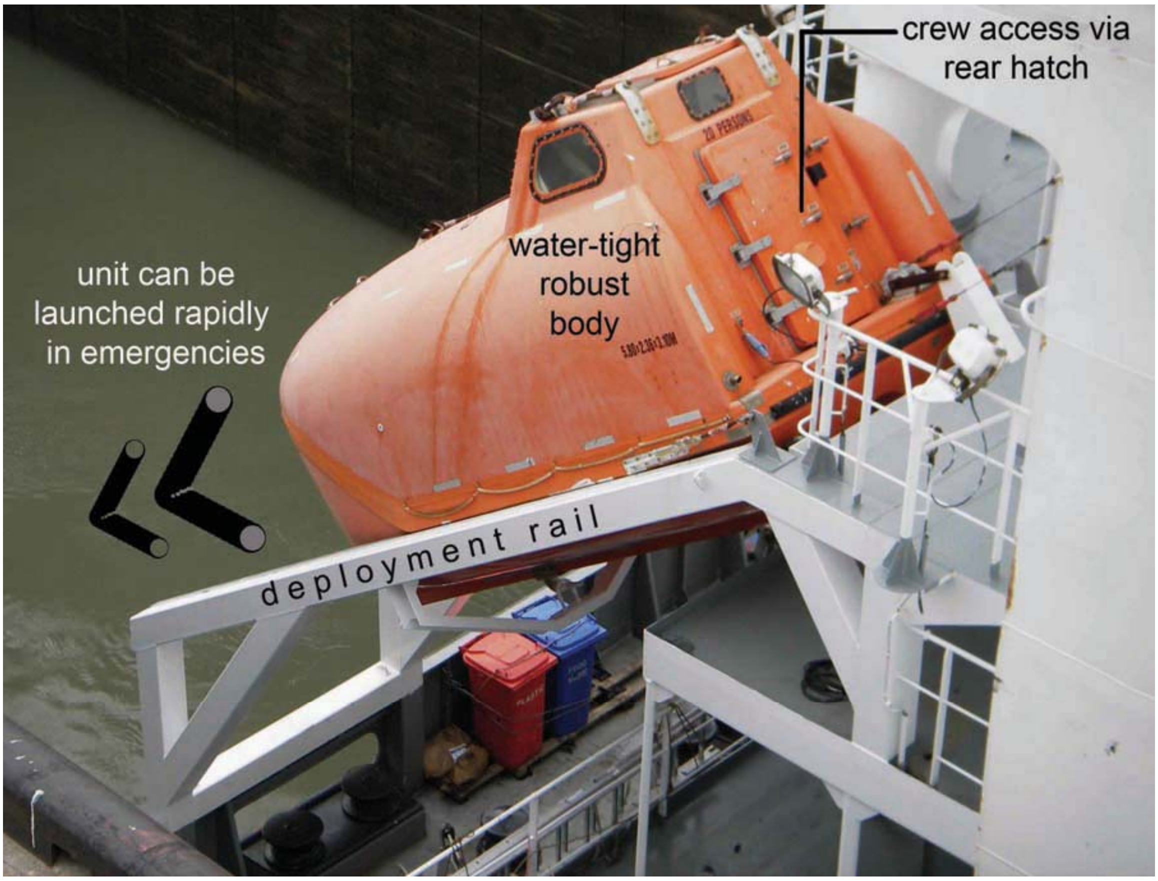


Figure 3-25: A free-fall lifeboat installed on an ocean-going vessel
(Background image credit: Strickland, edit: Özdemir)

Applicable features of freefall lifeboat concept for the proposed design transfer are:

- On-board storage of the unit
- Deployment system
- Crew access system

Assured Crew Return Vehicle (ACRV): Soyuz capsule as a lifeboat for ISS

Type: Lifeboat

Destination: Space Station Orbit.

Agency: ROSKOSMOS

Manufacturer: RKK Energia

During the development phase of the International Space Station (ISS), an immediate return-to-earth option for the station crew in case of an emergency was to be provided via crew capsules. In this frame, a re-configured model of already existing Soyuz crew capsule was proposed.

Soyuz is a series of manned spacecraft, designed for the Soviet space programme and used currently as a transfer vehicle between earth and the earth orbit. Originally intended for Moon orbit missions, The Soyuz spacecraft model has launched more human spaceflight missions than any other platform. This feature marks the Soyuz series as a reliable man-rated vehicle for human missions.

The Soyuz spacecraft is composed mainly of three modules:

- An orbital module, which provides accommodation for the crew during their mission
- A headlight shaped descent module, which returns the crew to the Earth surface
- A service module, which contains the hardware and the propulsion unit

The modular concept is highly adaptable. By changing the fuel load in the service module, and the type of equipment in the orbital module, a wide variety of missions can be performed. The nominal crew size of Soyuz is 3.

In the discussion of a rescue spacecraft for the space station crew, NASA wanted the station lifeboat to be simple, reliable and available all the time. The spacecraft's mass was limited to just 4,5 tons and it had to be small enough to fit into the Space Shuttle cargo bay or to be launched by a regular rocket. Its main mission would be to undock from the station to re-enter the Earth atmosphere and land. Finally, the "lifeboat" would use existing technology and require absolute minimum hardware for post-flight servicing. All these requirements indicated the re-configuration of Soyuz as a lifeboat spacecraft.

Upon the decision to use the Soyuz design as a basis for the required lifeboat, designers proposed a radical upgrade of the Soyuz to accommodate eight people. The spacecraft would be launched exclusively onboard the Shuttle. The 12.5-ton vehicle could remain docked to the station for five years. Nevertheless, this concept did not leave the production lines. It was decided to use a standard Soyuz vehicle as a lifeboat for the ISS crew. As the station will accommodate a crew of six by 2009, the Soyuz lifeboat design may still be an actual answer to the escape vehicle need.

Figure 3-26: Artist's impression of the Soyuz lifeboat vehicle with the crew on board, as it leaves the endangered space station. (Credit: Zak)

The Soyuz lifeboat concept provides the following features for an escape vehicle for space applications:

- High level of reliability by the use of a proven system
- Low level of structural complexity, considering the integration of the unit into the main system
- Plenty of space for the rescued crew
- Simple mission plan to reach the rescue units/ location
- High level of adaptability, as an extension to the space station

Personal Rescue Enclosure (PRE)

Type: Bailout

Destination: Space Station Orbit.

Agency: NASA

Manufacturer: NASA Houston

The Personal Rescue Enclosure (PRE) Rescue Ball was an 86 cm diameter one-person life raft for transport of astronauts from a spacecraft in distress to the space shuttle. Crew members were to climb into the ball, take a fetal position, and be zipped inside by a space suited crew member.

Based on the original rescue ball concept of NASA with the following features:

- 1 person fetus transport position
- Short-term life support system
- Communications system
- Kevlar, urethane construction with outside thermal protection cover and lexan window
- Astronaut transfer from one orbital space vehicle to another
- Max. Dia.: 0.86 m   Habitable Volume: 0.33 m3

Figure 3-27: PRE (Personal Rescue Enclosure) demonstrator of NASA (Credit: NASA)

The comparative assessment of PRE, as a role model for the crew escape system[26] of the Kopernikus 2 Station is presented in the section Final Design.

[26] PRE resembles a single-person rescue system like a rescue suit. Since the whole crew of the Kopernikus 2 are to be rescued in a case of emergency, more capable systems are favoured.

Mobility aspect

Concerning the mobility aspect of the CEV concept, possible terrestrial role models with simple mobility systems like mono- and diwheels are assessed for design transfer compatibility.

Mono- / Diwheel Vehicles

Mono- and diwheel vehicles are transport systems, in which the passenger or payload unit is integrated into the wheel itself. Driven by the motivation to simplify and minimize the mobility system - and related mechanical issues- on vehicles, the mono- and diwheeled systems were tried in various forms.

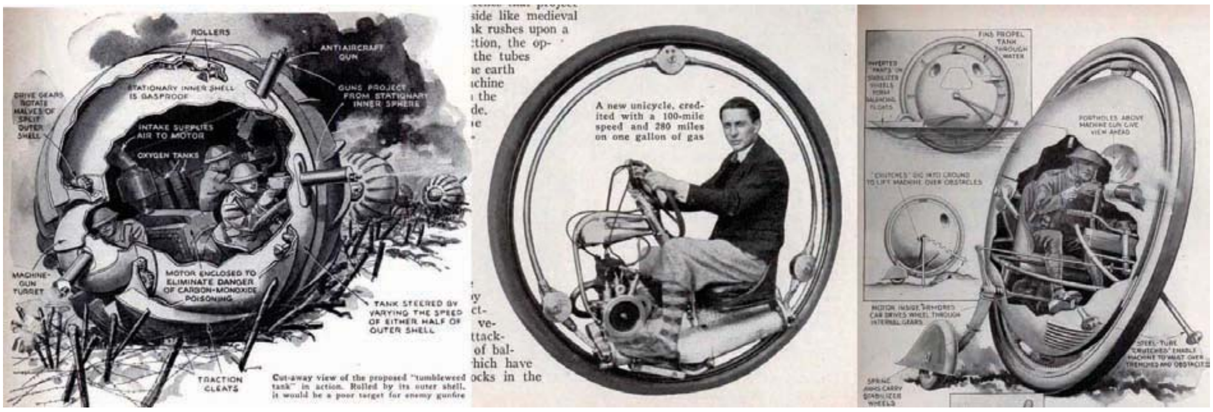


Figure 3-28: Various mono-wheel vehicle designs (Credit: Popular Science)

Mono-wheel vehicles represent the simplest and the most minimal form of wheeled mobility systems. Elimination of the complicated and energy consuming transmission mechanisms, positioning of the cabin right on the centre of gravity of the vehicle, hence stating a good level of stability and the compact overall configuration are the advantages of these designs. The use of this concept in military vehicles, operating in rough and hazardous environments was planned in concept scale. Nevertheless, these vehicle designs were not built in large numbers due to important drawbacks, listed as:

- Steering problems on rough terrain
- Limited horizontal stability[27]
- Poor visibility
- Limited payload capacity
- Problematic ingress / egress of the rider

In regard to above mentioned reasons, the mono-wheel systems are discarded in the design transfer process.

[27] A possible cure to the stability problem is the use of gyroscopic stabilizers, which are commonly installed in the contemporary mono-wheel applications.

Figure 3-29: Krupp Kugelpanzer prototype. This diwheel one-man armoured vehicle was designed to operate under extreme conditions of battleground environment. (Source: www.jagdtiger.de)

In order to eliminate the steering and the horizontal stability problems of mono-wheel systems, di-wheel systems are developed as a reliable option.

- Plenty of clearance for different passenger / payload cabin sizing between the wheels
- Overall structural simplicity
- Simple steering by independent rotation of the wheels
- Uncomplicated and efficient power transmission to wheels
- Potential capability to operate on rough terrain
- Good level of visibility

enabled the designers to justify the diwheel concept for utility and military uses in different forms. The classical tracked armoured vehicle mobility system is a simple derivation of diwheel system by replacing the wheels with tracks. As seen in Figure 3-29, the diwheel concept can be efficiently applied to extreme environment vehicles, operating in extreme environments. Having discovered this fact, diwheel system is taken as the main role model for the mobility system of the crew escape unit of the Kopernikus 2 station. Following advantages of the diwheel system are planned to be exploited in the crew escape vehicle design:

- Capability of operating on rough lunar terrain : A diwheel system can negotiate or avoid extreme terrain features of the lunar environment (e.g. craters, boulders)
- Capability of operating in pressure extremes: A pressure optimized cabin structure can be placed between the wheels with suitable sizing
- Elimination of long transmission ways and the integration of the chassis into the vehicle cabin structure: This feature of the diwheel system can result in an increase of efficiency and a decrease in overall mass, while optimizing the cabin interior volume.

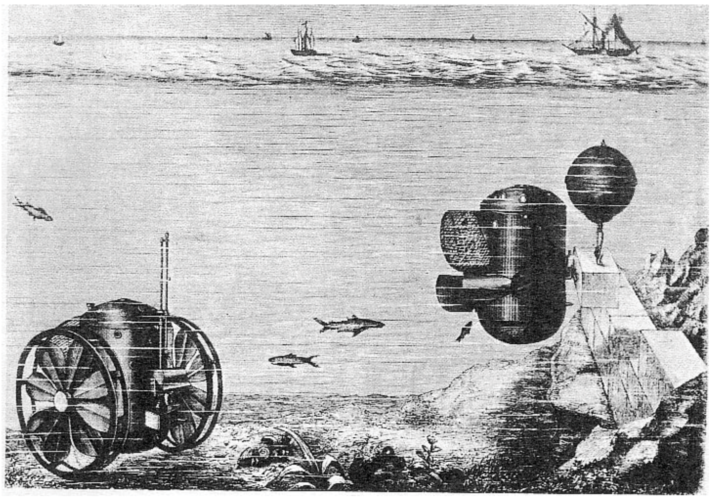


Figure 3-30: A diwheel design as an underwater vehicle concept, by W. Bauer, dated 1859. Simple and sturdy design of diwheel vehicles is suitable for extreme environment duties, such as underwater operations. This mobility concept is selected as a role-model for the design transfer. (Credit: Lawrenz)

3.4.3 Transfer

Transfer and integration of the selected design features into the Kopernikus 2 Station design concept

Having selected the free-fall lifeboat as the main donor concept, the transfer and integration of the selected design occurs in the following steps:

Step 1: Detailed iteration of the design requirements

Target/Subject of Transfer: A rapid deployment escape vehicle for the station crew

Basic Requirements:

- Direct access from the station interior (operation deck)
- Equal pressure level with the station interior
- Radiation / Thermal / Micro-meteorite protection
- On-board life support system

Technical Requirements:

- Two units will be attached on both ends of the station vessel structure
- 30 m3 of pressurized space for each unit shall be provided
- Vehicle configuration shall be arranged with the capability to hold and sustain the whole crew (10) in emergency case.
- Interior configuration shall be arranged to be used as an extension of the station's interior space.
- Internal energy and data ports shall be provided

- System shall feature light weight structural elements, as it is a main vessel-based-deployable system. Total mass is dictated by the bearing capacity of the main station structure and the deployment system

- The system should be integrated into the main station structure in the stowed configuration

Step 2: Identification of the target location and its features

Two crew escape vehicles (CEVs) will be installed on both ends of the Kopernikus 2 Station vessel. The vehicle cabins shall be used as an extension of the station interior space in normal routine. In case of an emergency in the station (e.g. fire, capital pressure loss in the main vessel), the CEVs will be dispatched from the station with the station crew on-board.

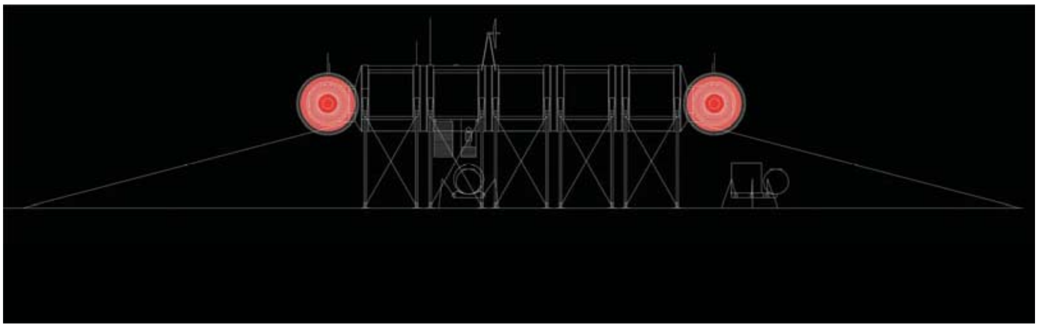


Figure 3-31: The intended positions of the escape vehicles at both ends of the Kopernikus 2 vessel (Credit: Özdemir)

Step 3: The integration of the selected role model features

The selected design features from the terrestrial role models are adapted for integration into the intended design segment.

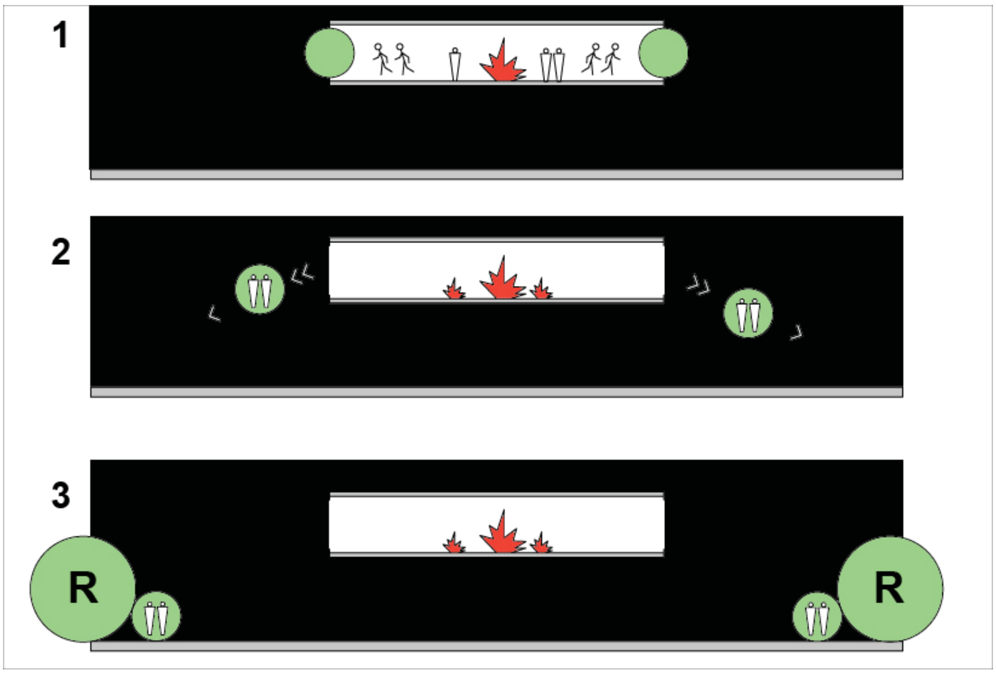


Figure 3-32: Image depicting the escape sequence using the CEVs (Credit: Özdemir)

The typical operational sequence for CEVs is depicted in Figure 3-33. The three main segments of the emergency escape from the station are as follows:

1. In a case of a major emergency in the station (e.g. fire, pressure loss) the crew runs into the lifeboats, if evacuation alert is given.

2. Upon crew ingress, CEVs are dispatched from the station. After ground contact, both units drive rapidly to reach the safety clearance from the endangered zone around the station.

3. CEVs contact and meet the external rescue measures by their own capabilities.

Major operational factors:

- Easy, fast and safe crew access into the unit
- Easy, fast and safe decoupling of the unit from the main vessel
- Medium level of mobility on rough (lunar) terrain
- Good level of compatibility to other docking interfaces

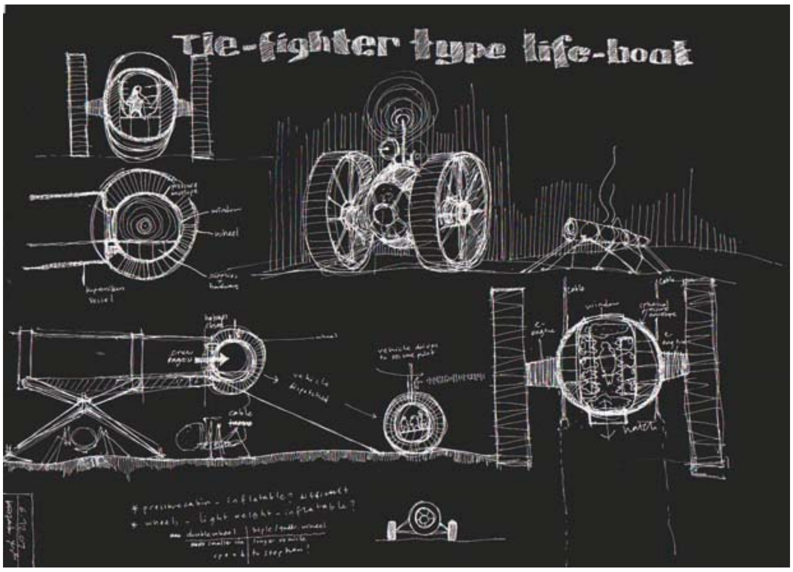
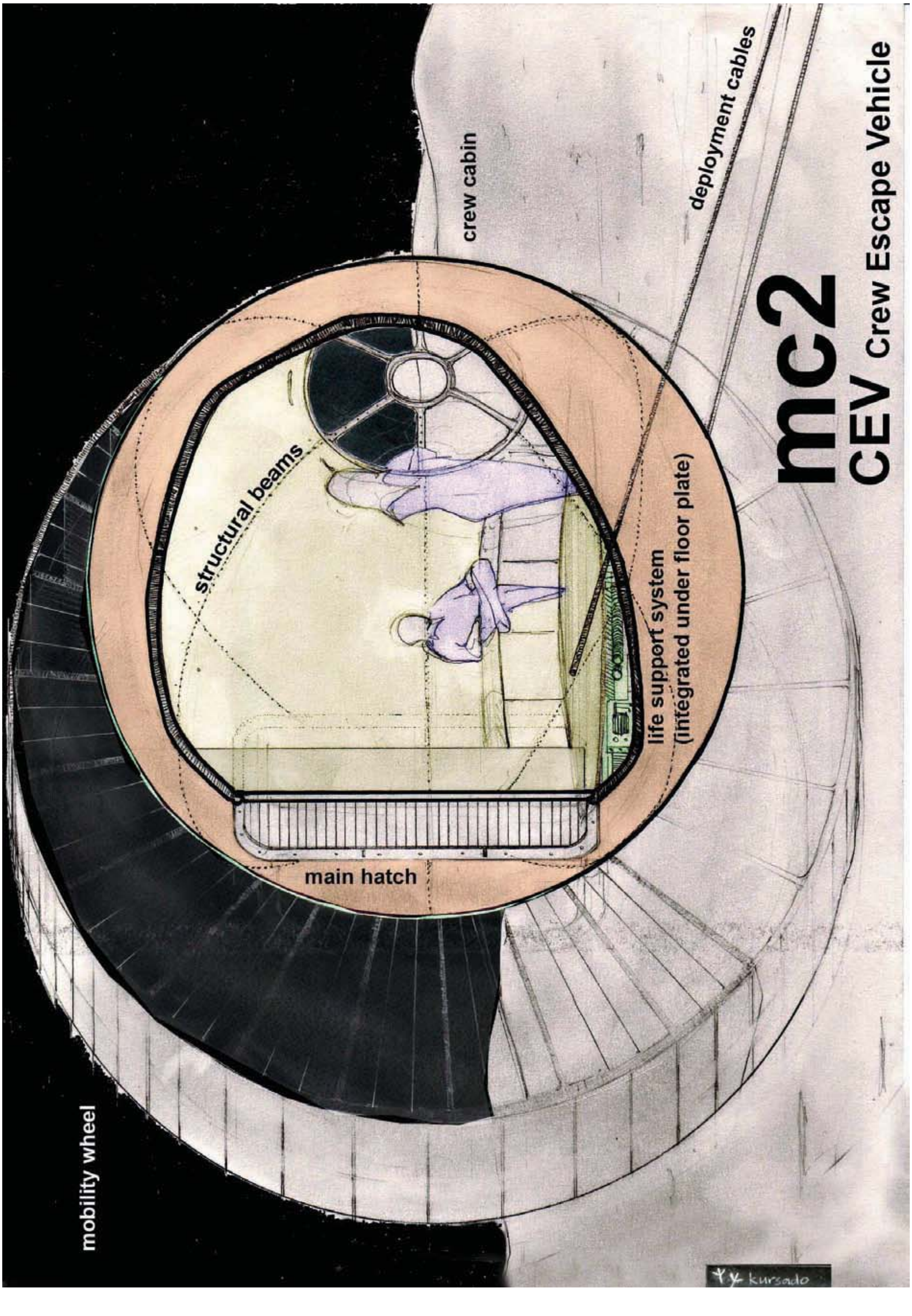


Figure 3-33: Preliminary sketch depicting the CEV unit of the Kopernikus 2 Station (Credit: Özdemir)

Figure 3-34 on the next page: CEV unit of Kopernikus 2. The spherical crew cabin is thought to be used as an extension of the station's interior in daily use (Credit: Özdemir)


mc2
CEV Crew Escape Vehicle
crew cabin
deployment cables
structural beams
life support system
(integrated under floor plate)
main hatch
mobility wheel
kursado

3.4.4 Final Design

As the result of the design development process of the Crew Escape Vehicle (CEV) unit of the Kopernikus 2 Lunar Logistics Station, a rescue vehicle design concept with the following specifications is produced:

- Spherical pressure vessel with 33 m3 of internal volume
- Multi-layered aluminium shell covered with High Density Polyethylene (HDPE)
- Under floor-integrated life support system
- Nominal crew capacity: 6 to 10
- Mobility sytem: Diwheel system with fuel-cell propulsion
- 1 circular viewport at the cabin bow-side

The CEV units, attached to the both tips of the station vessel, provide the safe and fast evacuation of the crew in an emergency situation, besides a peace-time use[28] as a semi-social area for the station inhabitants. The on board systems of the unit is plugged on the main life support and power systems of the station, being charged and replenished continuously. CEV can sustain the whole Kopernikus crew of 10 in emergency situations for short periods. The simple and robust mobility system, featuring direct drive side wheels, provides mobility on rough lunar terrain, in order to reach the designated rescue measures. The detachment system features two pairs of inclined cables, forming slide-down ramps for the CEV units. The simple mobility system and the detachment concept are the benefits of the design transfer process, applied to this model case.

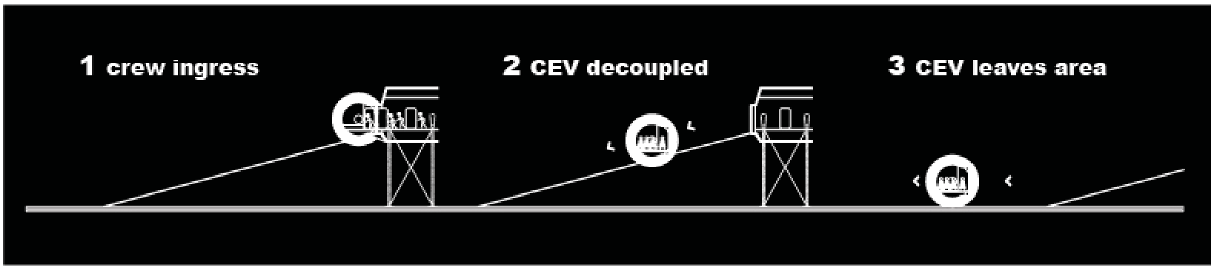


Figure 3-35: Escape sequence of the CEV unit. CEV leaves the station and the endangered area rapidly by sliding down on the cables to the lunar ground (Credit: Özdemir)

The escape sequence of the CEV unit is comprised of the following steps:

1. Upon the call to leave the station, the crew access into the CEV units, depending on the safe escape routes of the emergency
2. Having boarded the unit, the crew closes the transfer hatch and get ready for the launch. The detachment system is activated by the crew and the unit is set free on the deployment cables.
3. CEV slides down the cable ramp onto the lunar ground and leaves the endangered area fast and safely.
4. The external rescue units (e.g. stations in the area) are contected and the CEV proceeds to these units.

[28] Planetary exploration infrastructure expert S. Ransom states that the crew have to be instructed and trained not to interfere with the all-time operational readiness of the lifeboat units.

5. CEV docks onto the designated rescue unit. The crew is transferred.

CEV system is based on the block evacuation of the crew by quick-access and shirt-sleeve environment units. Taking other applicable crew rescue systems into consideration, a comparative assessment of rescue techniques is done. CEV is compared to the evacuation of the crew using:

- Escape suits or PRE-like pods for each crew member

- A lifeboat vehicle, held launch-ready all times under the station, on the lunar ground

Various criteria, defining the reliability and the efficiency of a crew rescue system are studied via a trade off assessment, leading to the justification of the selected system as the most appropriate option to be used at the Kopernikus 2 Lunar Logistics Station.

	CEV	**Escape Suits**	**Lifeboat-on-ground**
crew evacuation speed	high	very low	low
level of accessibility	high	low	medium
peace-time use / integration level	yes / high	no / low	no / low
level of operational reliability	high	low	medium
level of self-sufficiency and range	high	very low	high
level of compatibility with external rescue measures	high	low	high

Table 3-3: Comparison of the basic operational features of CEV, Escape Suits and Lifeboat-on-ground concepts.

- <u>Crew evacuation speed</u> is a crucial factor for the escape systems. Exploiting the rapid free-fall/slide dispatch system, CEVs have a significant advantage to the other concepts, in means of evacuation speed. The donning of escape suits in an emergency case, the possible problems of equipping incapacitated crew members and the evacuation via an airlock mark the personal escape systems as unsuitable for the Kopernikus 2 station. Lifeboat-on-ground option is also inferior to the CEV concept, regarding the transfer of the whole crew, including the incapacitated ones, into the lifeboat via docking hatch.

- <u>Level of accessibility of the unit in an emergency case</u> can determine the efficiency of the crew escape system. Installed on both ends of the linearly configured Kopernikus 2 Station, CEVs are all-time, all-case accessible by the crew. Even in case of an emergency in the middle segment, the crew can access one of the lifeboats, without being trapped in the station. Contrary to the CEV concept, escape suit and lifeboat-on-ground units may not be accessible for all, if the middle compartments get blocked for some reason.

- <u>Peace-time use</u> of the units avoids the functional inefficiency, integrating these spaces into the daily life of the stations. Both CEV units are used as extensions of the station interior, functioning as social areas for the crew. This way the spatial efficiency is increased and the crew is familiarized with the emergency equipment. In contrast to this situation, a lifeboat on the surface would stay idle in peace-time, blocking the operation area. Similarly, the emergency escape suits would also stay idle, costing storage space in the operation deck.

- Operational reliability of a crew escape system is marked by the performance in emergency conditions. While CEVs can evacuate the station effectively and reach the closest rescue measures, emergency escape suits and a lifeboat-on-ground option have significant drawbacks in operational aspect. Escape suits provide only limited protection from the environmental hazards and a short duration life support. They have to be used in combination with other rescue measures, as evacuated crew in escape suits or enclosures have to be rescued separately[29] and quickly. A lifeboat parked under the station can be effective operationally only when the crew make a safe and rapid ingress into the unit. The lifeboat has to leave the endangered zone under the station also rapidly.

- Range and the self-sufficiency of an escape unit determine the chance of survival upon evacuation. While the escape suits are not self-sufficient systems, CEV and lifeboat-on-ground concepts are designed to operate on their own until they make contact with other rescue units.

- Compatibility with external rescue units is the key factor in integration of the station evacuation system into a larger rescue system. As the escape units have to be contacted by external rescue units, a good level of physical compatibility between these structures is required. CEV and lifeboat-on-ground can be docked by external rescue structures for the crew transfer into the confined environment. Evacuated crew in escape suits have to ingress these units upon evacuation, which is only possible by an airlock system.

Through this assessment, the CEV option is qualified as the most suitable option for the Kopernikus 2 Lunar Logistics Station.

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[29] Though an external help from other stations in the vicinity can be supposed, the crew rescue system has to be designed at the highest possible self-sufficiency level.

3.5 Model case 3 (system scale): Spatial system of Kopernikus 2 Lunar Logistics Station

In this design transfer model case, the spatial layout of the Kopernikus 2 Station is developed using terrestrial role models, in regard to their operational similarity to the Kopernikus 2.

3.5.1 Model case definition

Model Case 3 (MC3) resembles a design transfer case in system scale and features the design development of the spatial configuration inside the Kopernikus 2 Lunar Logistics Station vessel. In MC3, the focus is on the spatial arrangements of the military submarines as the terrestrial role model. Taking the presence of a crew inside an extreme environment habitat and the improvements, made to upgrade the operational qualities into consideration, military submarines are used as the main terrestrial role model for this design transfer case. I addition, lessons learnt from the polar expedition habitats are also integrated into the spatial concept of the Kopernikus 2 Station vessel design.

Identification of the target segment and the basic requirements

Kopernikus 2 is a habitable system operating in an extreme environment. The crew of the station spend their whole time in Kopernikus 2, beside their working hours. The spatial layout of the station has to be configured in a way that the private, social, functional and operational spaces are integrated into the Kopernikus 2 structure, providing optimum conditions for a closed habitable system. The terrestrial habitable structures operating in extreme environments can present relevant design solutions to this requirement. Considering these facts, the main points can be briefly defined as follows:

Target/Subject of Transfer: The spatial configuration of Kopernikus 2 station

Requirements:

- Compatibility with the structural system of the station (linear/add-on modules)
- Good level of integration to the other systems of Kopernikus 2 (e.g. EVA interfaces)
- High level of operational efficiency, good networking of operational and crew spaces
- Private / social comfort, hygiene and safety for the crew

Identification of operational / environmental components and the search criteria

In this section, the planned use of the station’s spatial configuration, with its components is identified. One main literature search tag for the terrestrial role models is acquired. The findings of this process are as follows:

Intended use and operational components: Providing the station crew with sleep / work / hygiene / social spaces

- Providing command and control spaces
- Providing operation spaces (e.g. EVA deck)
- Providing social spaces (e.g. canteen)
- Providing private spaces
- Providing hygiene facilities
- Providing multi-use spaces (e.g. social/4-eye/private spaces)
- Configuration of the spaces on a linear basis

Environment: Outer environment was not assessed in this section, due to the internal configuration character of the model case.

Terrestrial literature search tags:

- Confined extreme environment habitat spatial configurations (e.g. submarines, aircraft, polar stations)

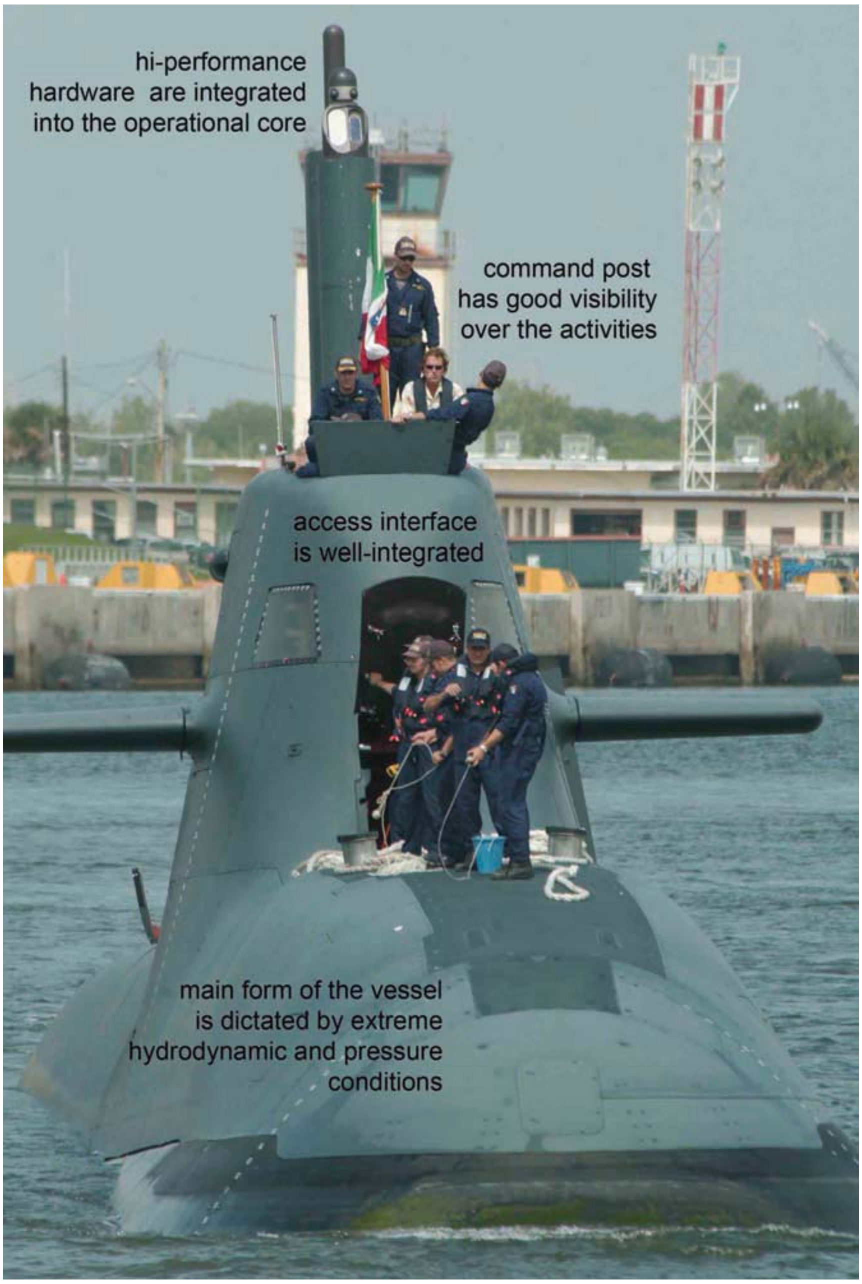


Figure 3-36: Submarines, just like space habitats, are enclosed and technical environments for the crews, operating under extreme conditions. Image of the Italian navy submarine S 526 during a port visit. (Credit: US Navy)

3.5.2 Research

The research work on the development of the spatial configuration of Kopernikus 2 Lunar Logistics Station is as follows:

Literature search with generated tags and the evaluation of the search results

Using the identified tags, a literature search in digital and printed media is applied. The relevant information, acquired in this process is as follows:

Spatial configurations of military submarines

A submarine is a watercraft capable of operating underwater. The development of the submarines was, similar to most technological improvements, triggered by military purposes. The stealth of submarine units is the key figure of their tactical and strategic value. First examples of the submarines were of limited capability and size. As submarine technology developed, larger vessels were built with long duration mission capabilities and increased fire power.

The two shape giving factors for the development of the spatial arrangement of military submarines are as follows:

- Vessel size increased throughout the development history of submarines. As the structure, propulsion, life support and armament technology progressed further; the submarine sizes became larger to house more crew and equipment for more capabilities.

- Mission durations were increased as the vessel sizes became larger. Very similar to the spacecraft design, longer mission durations required increased habitability levels. As the first submarines were only capable of barely providing a seat for each crew member, recent models of military submarines have crews of more than 100 and operate submerged for six months.

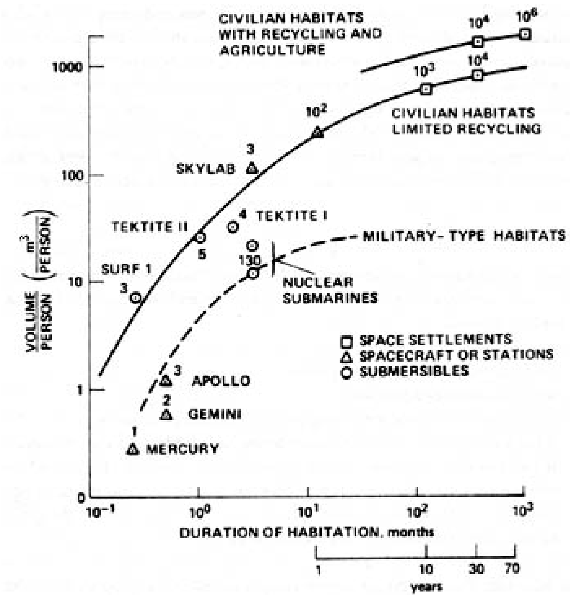


Figure 3-37: A volumetric comparison of habitable spaces of nuclear submarines and spacecrafts. Note the minor figures[30] of the early spacecraft-Apollo and Mercury (Credit: NASA)

[30] Early submarine types did not offer more space than the Apollo spacecraft, where the crew had only cockpit seats and the lunar excursion module interior for roughly a week. Gemini spacecraft had even less pressurized volume: 2,28 m3 per person [Leitenberger, 08]

The spatial configuration of early military submarines featured cramped crew positions, similar to aircraft cockpits. These were used just for mission durations defined by hours. As the military duties for submarines became more demanding, like executing high-sea patrols and battling ocean-going vessels, sleeping and eating spaces had to be provided for the crew. In order to avoid the space loss and to save mass, all the crew spaces were somehow integrated into the operational posts of the submarines. This integration was rather “stuffing” the sleeping bunks between the torpedoes in the WW1 and WW2 submarines. This way, the crew spent also their off-duty hours at their operational positions, which kept the reaction time in alert situations very short. The exhaustion threshold was also very low due to the mentioned low level habitability of these boats. The psychological impact of these conditions on the submarine crews was enormous.

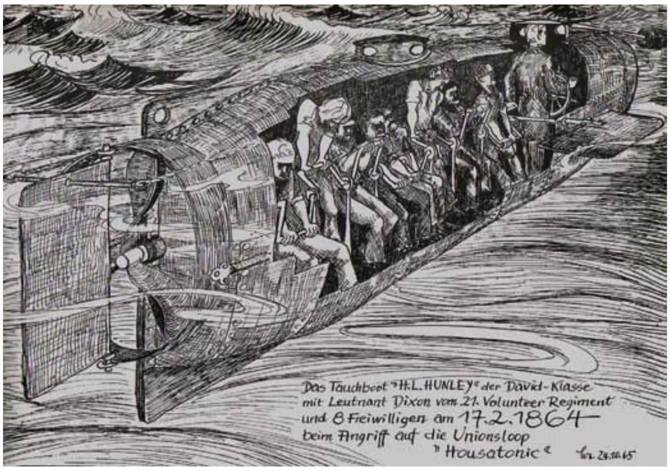


Figure 3-38: A cutaway sketch of the Hunley submarine from 1865. The cramped inner space resembles the very short operation duration of the vehicle. (Credit: Lawrenz)

A good remark [Kaplan, 97], depicting the spatial arrangement philosophy of the WW1 and WW2 submarines is as follows:

“In the same way as combat bomber aircraft were built around bombs, guns and fuel tanks, U-boats were built around the torpedoes, engines, diesel tanks and batteries. Such space as remained was for the crew, their kit and their provisions.”

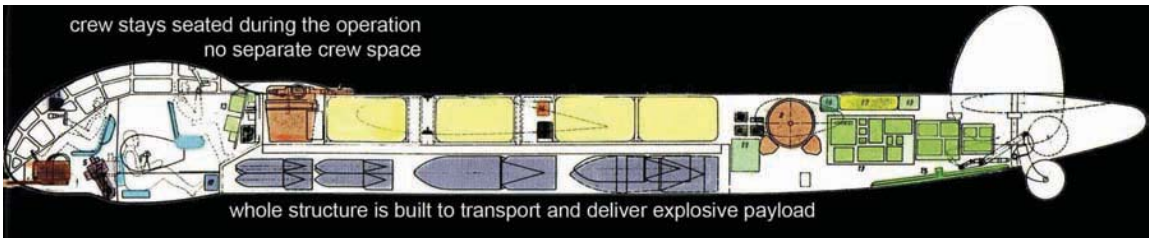


Figure 3-39: Another extreme environment structure, built around operation hardware: A Junkers 288 bomber aircraft and her configuration in respect to the crew cabin. Due to its capabilities and thus the size, the crew space is just limited to an operation post with minimal volume. (Background image credit: Lorenz, edit: Ozdemir)

WW1 submarines were built in a way, in regard to the habitability conditions, just about the tolerance limit of the crews. The notes of a first watch officer on a WW1 German submarine U-9, Johannes Speiss[31] reflects the tough conditions inside a submersible vessel of the period:

"Far forward in the pressure hull, which was cylindrical, was the forward torpedo room containing two torpedo tubes and two reserve torpedoes. Further astern was the Warrant Officers' compartment, which contained only small bunks for the Warrant Officers (Quartermaster and Machinist) and was particularly wet and cold. Then came the Commanding Officer's cabin, fitted with only a small bunk and clothes closet, no desk being furnished. Whenever a torpedo had to be loaded forward or the tube prepared for a shot, both the Warrant Officers' and Commanding Officers' cabins had to be completely cleared out. Bunks and clothes cabinets then had to be moved into the adjacent officers' compartment, which was no light task owing to the lack of space in the latter compartment. The crew space had bunks for only a few of the crew - the rest slept in hammocks, when not on watch or on board the submarine mother-ship while in port.[32]

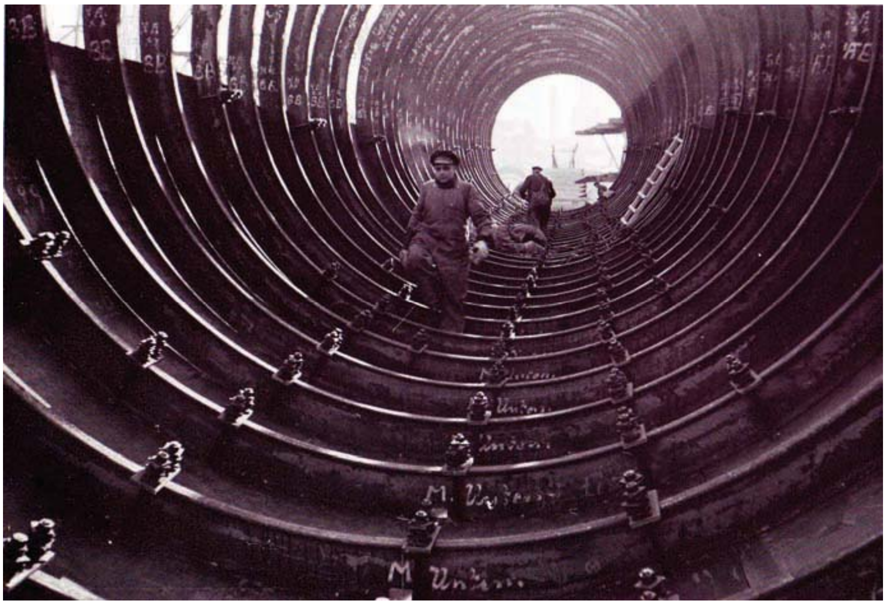


Figure 3-40: A submarine under construction in Germania Werft, Kiel. The main envelope for the spatial arrangement of a submarine vessel is dictated by the hull structure (Credit: Kaplan)

On the port side of the officer's compartment was the berth of the Chief Engineer, while the centre of the compartment served as a passageway through the boat. On each side was a small upholstered transom between which a folding table could be inserted. Two folding camp-chairs completed the furniture.[33]

The central station was abaft the crew space, closed off by a bulkhead both forward and aft. Here was the gyro compass and also the depth rudder hand-operating gear with which the boat was kept at the required level similar to a Zeppelin. The bilge pumps, the blowers for clearing and filling the diving tanks - both electrically driven - as well as the air compressors were also here. In one small corner of this space stood a toilet screened by a curtain and, after seeing this arrangement, I understood why

[31] The personal notes of Spiess are retrieved from his book Submarines and the War at Sea, 1914-1918, Mac Millan, London, 1991

[32] The spaces for the ordinary crew were just built in the rest spaces of the utility compartments. This low level of habitability changed as the submarine missions were extended in the WW2 period. The boat U-9 resembles an early period military submarine.

[33] The officer's quarters were slightly differentiated from the ordinary crew spaces in the WW1 submarines. The proximity to the operational spaces was recognizable in the configuration.

the officer I had relieved recommended the use of opium before all cruises which were to last over twelve hours.[34]

The conning tower was the battle station of the Commanding Officer and the Watch Officer. Here were located the two periscopes, a platform for the Helmsman and the 'diving piano' which consisted of twenty-four levers on each side controlling the valves for releasing air from the tanks. Near these were the indicator glasses and test cocks. Finally there was electrical controlling gear for depth steering, a depth indicator; voice pipes; and the electrical firing device for the torpedo tubes. Above the conning tower was a small bridge which was protected when cruising under conditions which did not require the boat to be in constant readiness for diving."[35]

Figure 3-41: The section of the salvaged U-boat U 534. All the habitable spaces of a submarine are housed inside the cylindrical pressure hull. Analogous to space habitats, the pressurized vessel is equipped with a network of utility systems. (Credit: Barr)

The spatial configurations of the submarines, considering the habitability aspects, changed slightly in the WW2 submarines, as a result of extended mission durations. As the submarines were deployed to attack ocean going vessels and got larger in size, spatial arrangements were made in the submarine designs accordingly, in order to sustain the crews for longer duties. However the relative positioning of the crew compartments to the operational areas did not change significantly.

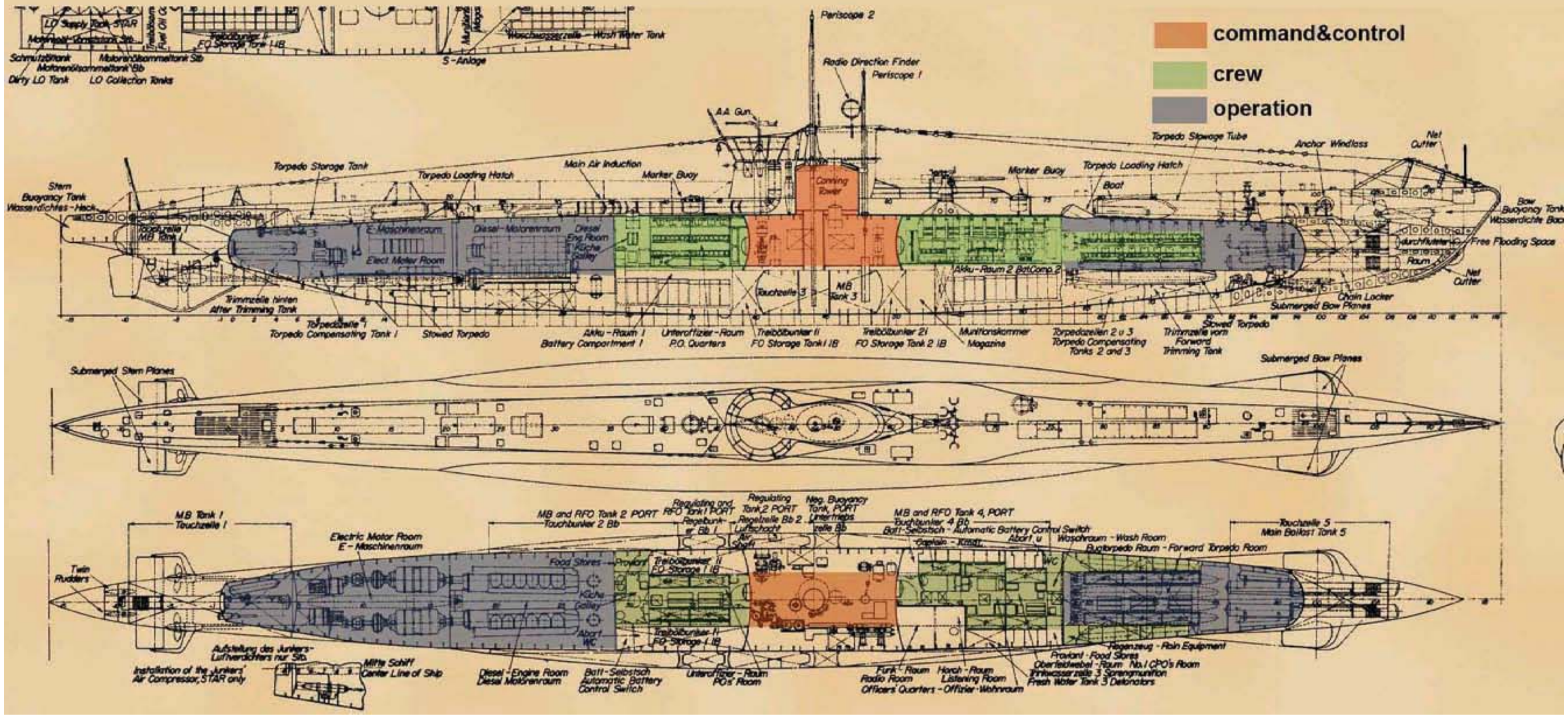
On the next page, Figure 3-42: Spatial configuration analysis of a Typ VII-C German U-Boat (Background image credit: Taylor, edit: Özdemir)

[34] The central station as the heart of the operational segment of an U-Boat forms the spatial core of the whole vessel, as the other utility and crew spaces are tailored around it. This aspect of the submarine design was also applied in the WW2 submarines.

[35] The conning tower is an extension of the central station, completing the operational centre with an exterior post for surface operations.

u 570

german submarine spatial layout



The crew spaces of a typical WW2 submarine extended from the operational core of the vessel, the control room, to the both ends of the structure, where torpedo and machine rooms were placed. The sleeping bunks and the lockers of the torpedo crews were even diffused into the forward torpedo room, which provided a high level of operational readiness of the crews, but distracting the crew comfort dramatically. The operational segments of the submarine system like the control room, engine room and the torpedo rooms were connected to each other via crew rooms. Taking the traffic in and between the operational spaces, which runs through the crew quarters, into consideration, the low level of the crew comfort in the daily routine on the boat can be easily seen at first glance. The crews of this period had to live and work practically in the same place, which is a huge performance-disturbing factor on long duration duties.

Figure 3-43: A u-boat sailor doing hygienic care between torpedo tubes. A usual scene for the submarine crews of WW2. (Credit: Kaplan)

In the post-WW2 era, submarines were developed to operate with longer mission durations and with more demanding mission profiles. These challenges had impacts on the habitability levels of submarine vessels. As the submarines got more powerful and larger in size[36], crew spaces became more tolerable in terms of crew comfort. Contrary to WW2 models, crew quarters were arranged as independent sections in the vessel. Isolated from the harsh nature of operational activities, but well connected to operation decks, crew spaces were integrated better into the submarine vessel system than before.

On the next page, Figure 3-44: Spatial configuration analysis of an Astute-class nuclear submarine (Source raw image: British Defence Ministry edit: Özdemir)

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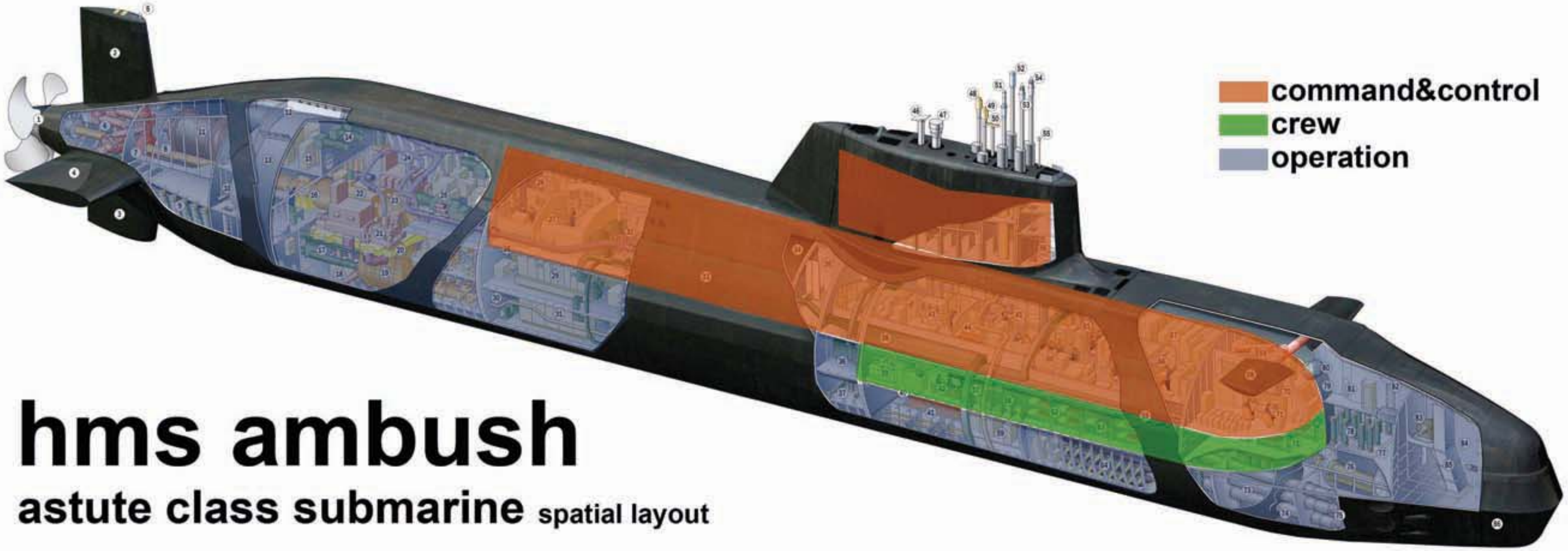
[36] Modern ocean-going military submarines are not comparable to the “ships of the WW2 Era with diving capability”, neither in size nor in operational profile. In modern submarines, crew are known to do even jogging inside the vessel.



hms ambush

astute class submarine spatial layout

The literature search on the military submarines provided following features for the design transfer:

- Concentration of operational spaces around a core
- The need to isolate the crew spaces from the operational traffic, without disturbing the operational efficiency level
- Networking the commander and the operation control crew cabins with the operational zone
- The need to create private, semi-private and social spaces for the crew
- Incorporating alternative-uses of the technical zones for the crew when it is possible (e.g. wintergarten - see Results section)

Polar Expedition Habitats

Crews of the early polar expedition teams had to stay in cramped crew quarters for months, in low habitability levels. The first segment of a polar exploration, by nature, dictated travelling onboard an expedition ship. Vessels, like *Fram* of Amundsen, were capable of accomplishing polar expeditions without taking any additional logistic help during their missions. This meant a large amount of consumable provisions, which were stored on board, and the scaling down of crew spaces to ultimate tolerance limits. The crew had their minimal quarters, where conventional sleeping bunks were integrated. The expedition segment on land required covering of long distances, thus erecting temporary shelters and a long-duration shelter for the winter period had to be undertaken. Taking the technical issues like heat loss prevention and transportability, all crew habitats were built small in size, which decreased the habitability conditions like sleep comfort dramatically. Especially during the winter period, where the crew is accommodated in wooden huts mostly, the need for private space was solved poorly using sleeping bunks, while avoiding waste of volume inside the habitat. The sleeping bunk represents, as observed throughout the polar expedition history, a limited but very important piece of private space, which can be created easily inside crew shelters. "Most behavioural experts and winter-over personnel agree that individual adjustment to isolation and confinement benefits from the availability of personal space."[37]

The following recommendations concerning the privacy and personal space issues on an isolated habitat by Jack Stutster [Stutster, 96], provide some hints about the spatial configuration of Kopernikus 2 and are indicated as follows:

- Include a privatized sleep chamber for each member of the crew.
- Avoid "hot bunking", or the sharing of sleep chambers on a shift basis.
- Expect crew members to withdraw periodically from social contact with other members of the crew.
- Expect territorial behaviour, such as attempts by crew members to usurp a workstation or storage area for personal space, if adequate personal space is not available.[38]

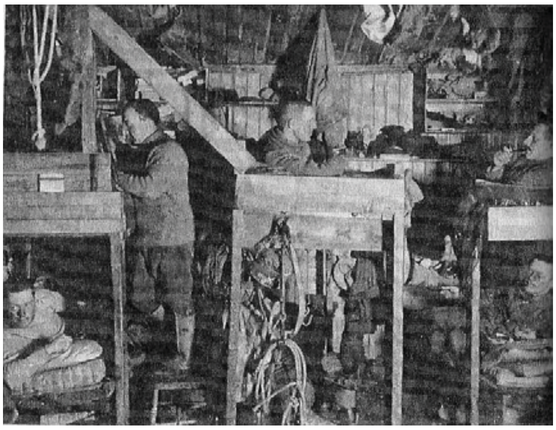


Figure 3-45: Two images depicting two different crew quarter environments from past Antarctic expeditions. Left, the bunk area of Scott's hut, McMurdo Sound; right, compact tents on for trail camping. (Credit: Stutster)

[37] Quoted from Stutster J., Bold Endeavors, 1996. A similar approach to the arrangement of crew spaces is recommended also for space habitats by Stutster.

[38] Personalizing space is observed to be a normal human reaction to confined environment living. Flexibility of spatial arrangements may provide enough space for the compensation of the territorial behaviour.

3.5.3 Transfer

Transfer and integration of the selected design features into the Kopernikus 2 Station design concept

Having identified the spatial characteristics of various extreme environment habitats, the transfer and the integration of selected design features is done in the following process:

<u>Step 1: Detailed iteration of the design requirements</u>

Target/Subject of Transfer: The spatial configuration of Kopernikus 2 Lunar Logistics Station

Technical Requirements:

- All internal spaces of the station shall be grouped along the linear main structure of the station.
- Private, social and utility spaces for a crew of 10 shall be provided
- Crew quarters will be formed by modules, each for 2 people. Modules shall be deployable / expandable, considering transport capabilities.
- Each crew cabin shall have a pressurized volume >40 m3
- Crew quarters, social and hygienic facility shall not distract the operational routine in the station and vice versa.
- An operation deck, equipped with EVA and docking interfaces shall be integrated.
- A command and control post shall be integrated, in connection to the operation deck.
- Lifeboats, to be installed at both ends of the station, shall be integrated into the spatial layout of the station
- Escape routes to the lifeboats shall not be distracted by crew or operational modules

<u>Step 2: Evaluation of the target segment with relevant features</u>

Kopernikus 2 Lunar Logistics station has a linear and add-on structure, elevated from the ground with support legs. The main fuselage, being the core of the system, is envisaged to be built first as a basis for the add-on modules. Expandable crew cabins and the operational modules are plugged onto the fuselage unit. Two lifeboats at both tips of the station provide safe and rapid escape in case of a major emergency.

The linear character of the station dictates a homogenous build up of modules along the fuselage. The add-on units can be plugged either on the sides, or at the top of the core fuselage.

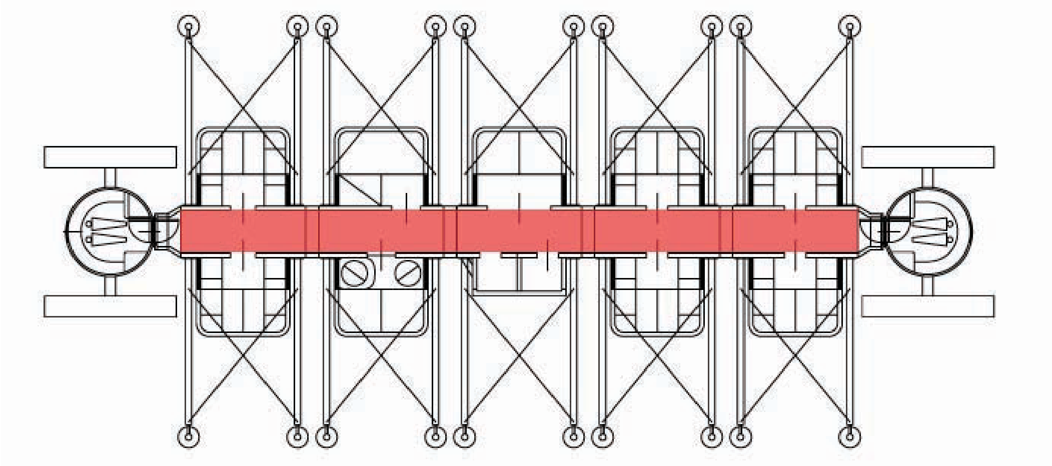


Figure 3-46: Kopernikus 2 Station vessel is based on a linear fuselage (marked red), forming the main translation route of the station. (Credit: Özdemir)

The following main structure-related factors have to be incorporated in the development of the spatial configuration design of Kopernikus 2 Station:

- Homogenous distribution of modules along the fuselage, considering structural stability
- Structural compatibility of add-on modules, avoiding distraction of other systems (e.g. onboard crane)

Step 3: The integration of the selected role model features

The literature search, focused on the spatial configurations of military submarines and polar expedition habitats, provided additional factors for the design development, other than the previously identified basic requirements. The selected design role model features to be integrated into the spatial configuration of Kopernikus 2 Station are interpreted as follows:

- Operation deck and command structure shall form the core segment, equipped with EVA interfaces and a command post
- Commander and the operation officer cabin shall be networked to the operational core
- Crew cabins with adequate private space shall be integrated
- Crew zone shall be separated from the operational zone by a social space / canteen
- Both lifeboat s shall be designated as social / semi-private spaces. The units stay accessible all of the time.

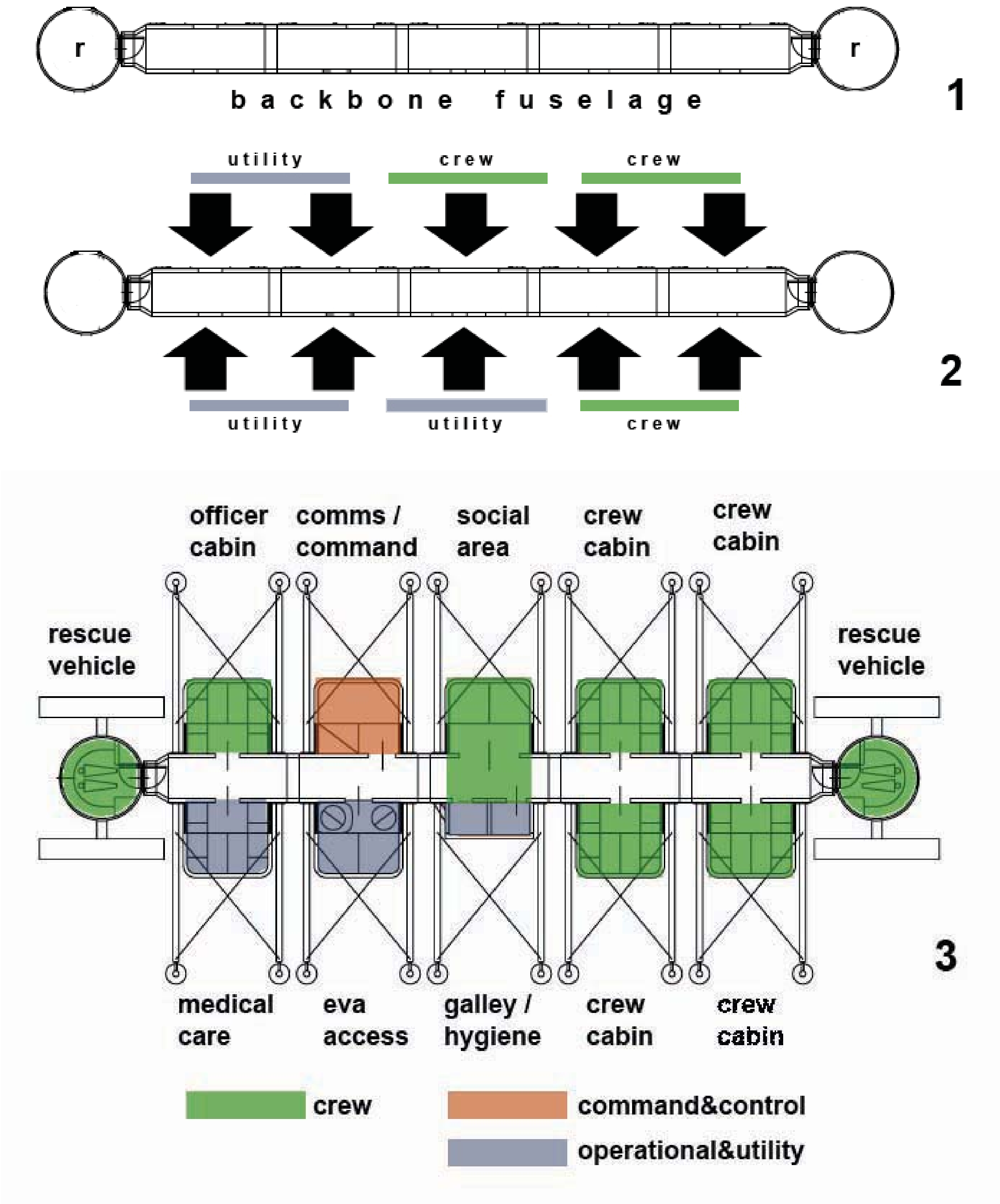


Figure 3-47: Evolution of the Kopernikus 2 Station's spatial configuration (Credit: Özdemir)

The implementation of all mentioned requirements and the adopted features is done via an evolution sequence of the design. The evolution steps, as seen in Figure 3-47, are described below:

1. The initial basic structure is composed by:

- A linear backbone fuselage comprising 5 segments attached to each other
- Two lifeboat units (marked with **r**), installed at both ends of the vessel

This structure is the basis for a station system, where the following are to be plugged on:

- 4 crew cabins, each for 2 crew members
- 1 canteen unit as a social area for the crew
- 1 utility unit with integrated hygiene facility and galley
- 1 officer’ s cabin, in connection with the command deck
- 1 medical care cabin, in connection with the operation deck
- 1 command post cabin with good level of visibility over the station systems
- 1 EVA deck, equipped with docking / EVA interfaces and the DMU (Deployable Maintenance Unit)

2. Considering the criteria obtained from the terrestrial role models, the plug-on spaces are grouped to be attached to the station as follows:

- Crew spaces containing crew cabins and the social area
- Utility spaces containing the operation / command structures and the service unit (hygiene / galley)

3. The identified spatial groups are implemented into single cabin structures. The station vessel is divided into two segments by the social area and the service unit group. Operational spaces and the officers’ cabin are collected in one half, while the somewhat isolated crew quarters are positioned on the other. Lifeboats on both ends present an assured escape option for the crew in a major emergency onboard the station.

3.5.4 Final Design

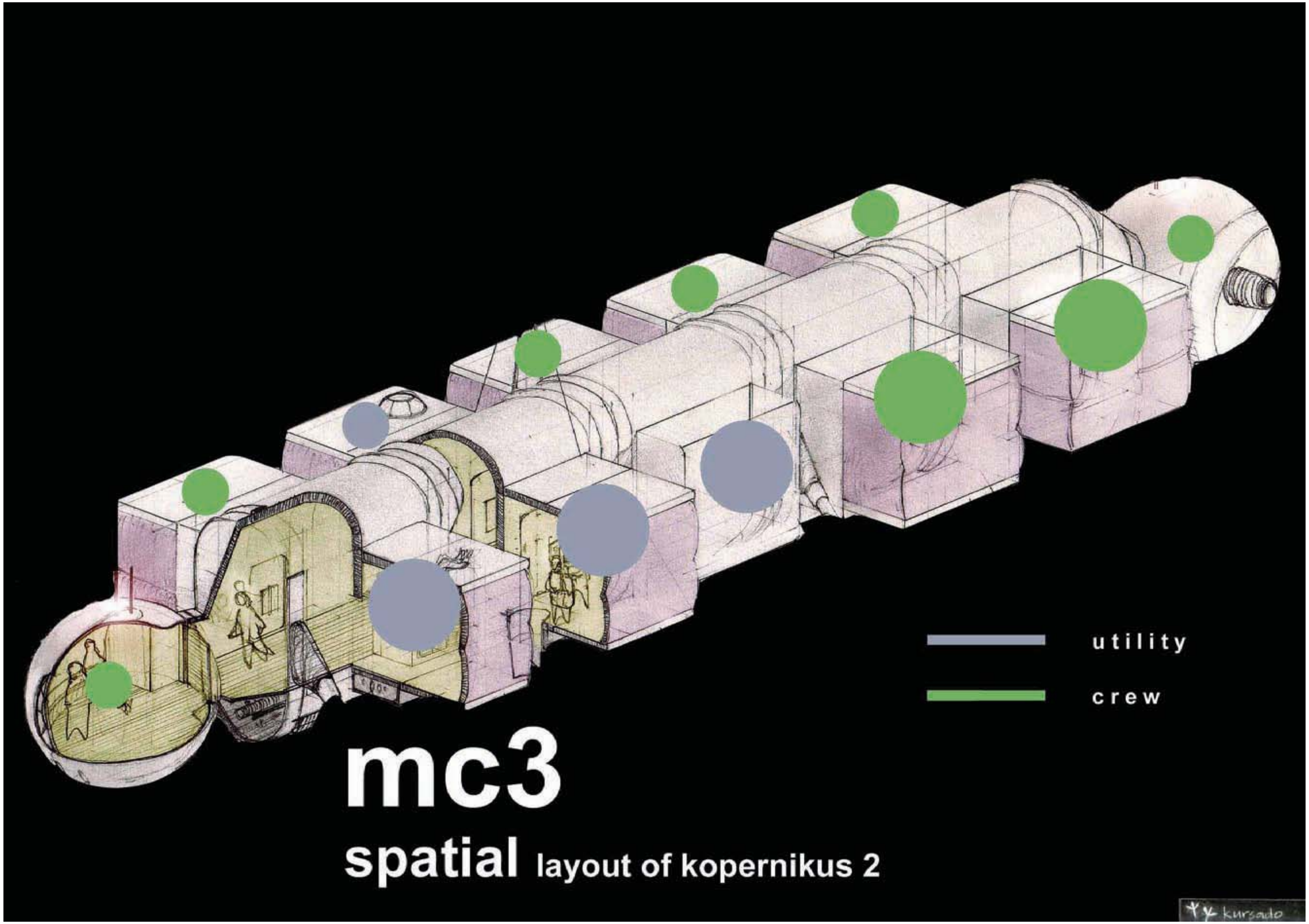
The spatial layout of the Kopernikus 2 station is based on the principle of having an operational core and using this zone as an orientation mark for the other spatial groups. The goal is, as emphasized before, keeping the operational efficiency level of the station high by:

- Networking the utility spaces physically, thus assuring continuous visual and dynamic contact between the posts

- Providing the crew a peaceful environment for off-duty hours, with private / semi-private / social zones

The command and control room, in which all the systems of the station are continuously monitored and steered, together with the operation deck, form the technical heart of the Kopernikus 2. The crew cabins, each providing accommodation for two crew members are attached on the backbone corridor on both sides, create a diffuse crew area, where together with the social space, resemble another psychological climate onboard the busy logistics station.

On the next page, Figure 3-48: Spatial configuration analysis of Kopernikus 2 Station vessel. Note the compact arrangement of command and operational units. The crew areas are connected to the operational area, but not distracted by the traffic (Credit: Özdemir)


mc3
spatial layout of kopernikus 2
utility
crew
kursado

A clear division of the vessel into operational and crew zones is distracted, on purpose, by the use of both lifeboats as semi-private crew spaces. The symmetrical position of these two interiors provides a balanced spatial integrity inside the station, avoiding the harsh separation of operational and crew zones. Lifeboat interiors provide a suitable atmosphere to the crew to have private talks or informal group meetings, having a different character from the crowded main social zone, positioned amidships. This way, the whole inner space of the station is used by the crew, efficiently and without disturbing the operational activities.

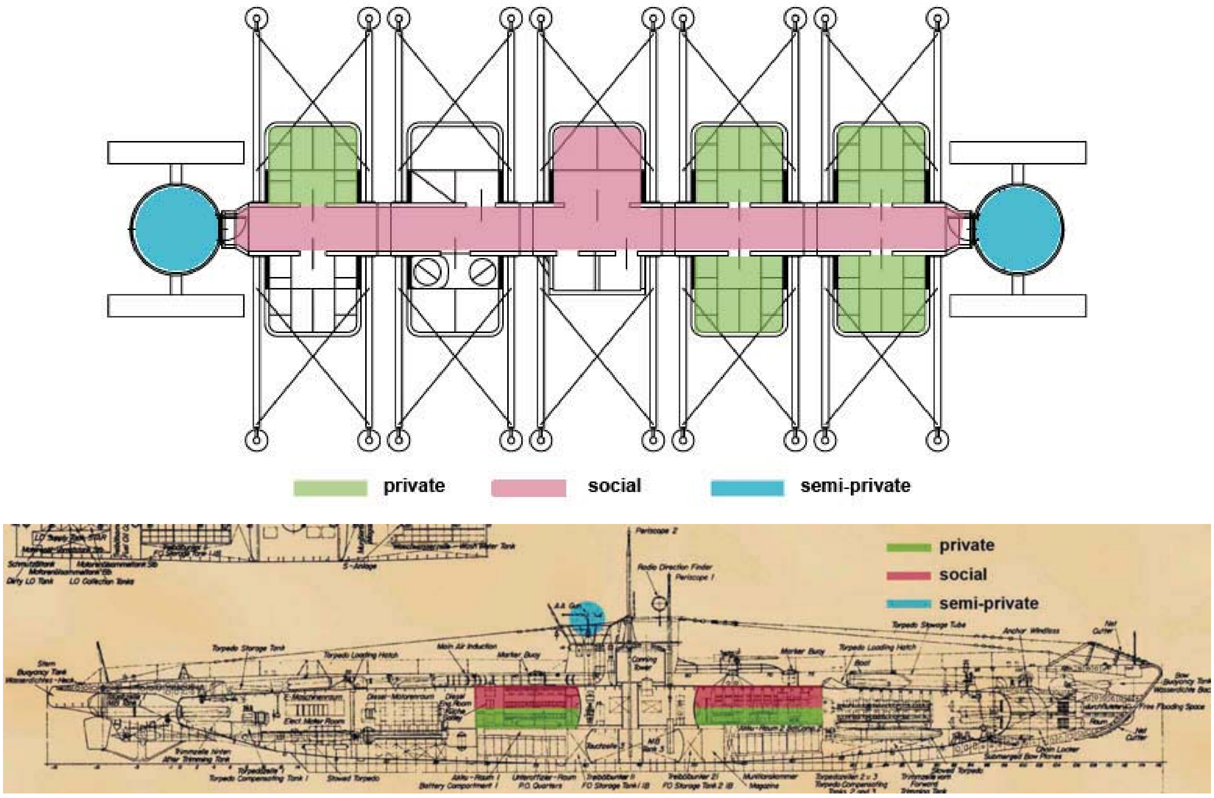


Figure 3-49: Distribution of private, social and semi-private[39] zones onboard the Kopernikus 2 Station vessel and on a Type VIIC submarine (Background image credit: Taylor, edit: Özdemir, cad: Özdemir)

The social area, with its central location, symbolizes a kind of transition and fusion zone between the crew and the operational halves of the station. The social area is thought to be used also during the duty hours of the crew, for a quick break and escape from the heavy traffic of the utility zone. Furthermore, the continuous visual contact through the backbone corridor is an impressive feature of the station. Feed-back[40] from astronauts indicate the importance of visual relations between the utility and the crew zones of the space stations, giving the crew a feeling of safety and motivation in their challenging routine onboard.

[39] The improvised use of the Wintergarten as a semi-private zone on board the submarines is transferred to Kopernikus 2 in the form of lifeboat interiors.
[40] During the Human Mission to Mars (HMM) Study of ESA, in which the author was involved, comments from current and retired space mission crews were regarded, as a part of the design process.

Figure 3-50: Submarine tower as a multi-use zone for the crew. Left, a scene from a Type VIIC U-Boat Wintergarten[41] and right, a modern American submarine crew on the most attractive spot of their vessel (Credit: Kaplan, US Navy)

The use of lifeboat units (CEVs) for alternative crew spaces marks a remarkable feature of the submarines that is transferred to the Kopernikus 2 design. The mentioned Wintergarten is a circular anti-aircraft gun platform, attached to the back of the conning tower on German submarines. A watch duty at the conning tower, even in bad weather conditions, meant a short period of liberation for the crew from the cramped and stifling interior of the submarine. The Wintergarten, similar to a balcony, was favoured by the crew for a personal talk or just watching the sea when no alarm situation was called. This behaviour marks the need of multi-use, semi-private spaces in an extreme environment habitat, to avoid stress build-up during the space missions. A good level of spatial flexibility has to be considered and alternative use options for the crew can be provided, even in case of highly technical and specific units like CEV lifeboats. Enjoying the open sight, extending to the lunar horizon, the Kopernikus 2 crew has a better chance than the U-boat crews to relax and have a private talk with companions.

[41] Wintergarten was a circular anti-aircraft gun platform, attached to the conning towers of WW2 German U-Boats. This platform was often used by the boat crews like a balcony to smoke and enjoy the fresh air in the very few moments available during their dangerous missions. A typical case for multi-use spaces.

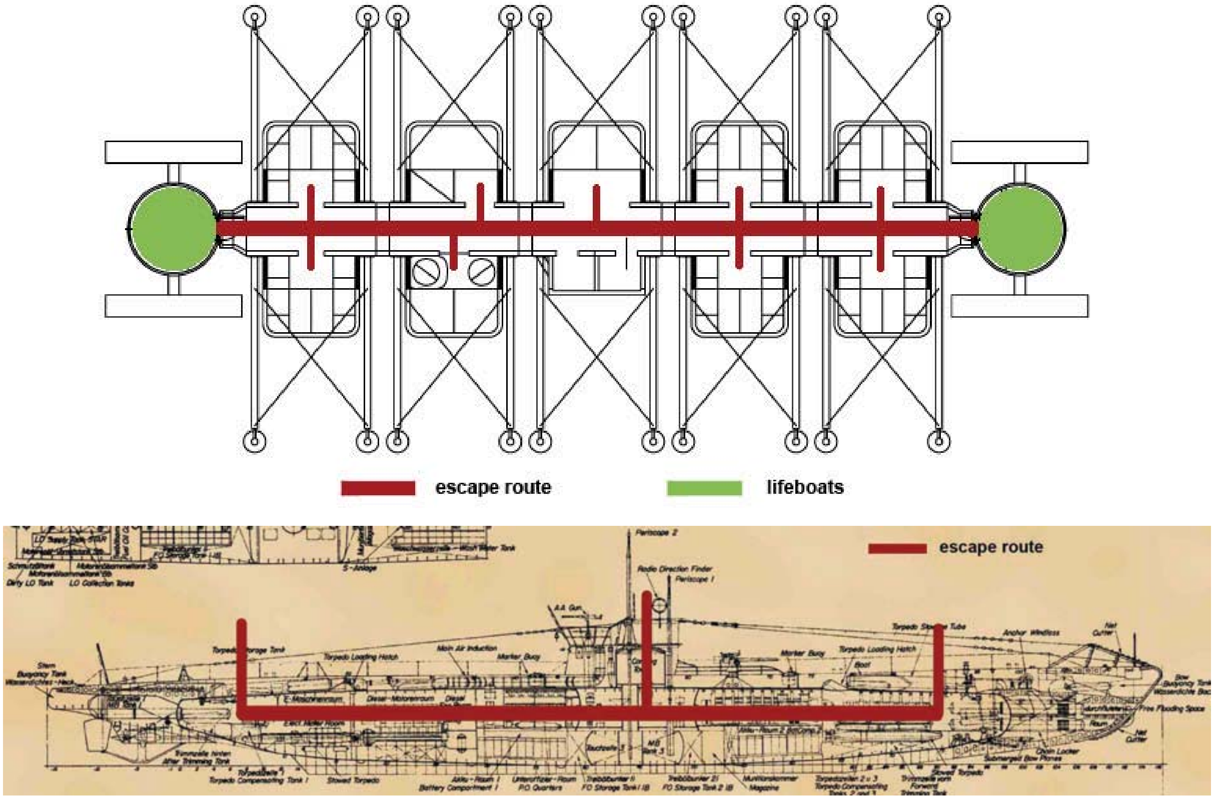


Figure 3-51: Positioning of the lifeboats and the escape routes in Kopernikus 2 Station vessel vs. the escape routes onboard a Type VIIC submarine. (Background image credit: Taylor, edit: Özdemir, cad: Özdemir)

The main translation corridor, running along the station, resembles a backbone for the whole spatial system. Connecting all operational and crew spaces onboard the station, the backbone corridor functions like a balance pole with two counterweights, the lifeboats on both tips. The balance pole with two counterweights analoguey resembles, on the other hand, the effective access to the lifeboats by the crew in emergency situations. Unlike a VIIC submarine, where the crew has to leave the submerged boat in rescue equipment via two hatches at both ends and the conning tower of the vessel, Kopernikus 2 crew can leave the endangered zone in one of the lifeboats, depending on their proximity in an emergency.

Figure 3-52: Analogueous to the space habitats, crew areas on board a submarine tend to expand, to wherever possible. Multi-use areas can be re-configured for different purposes. The image shows the crew of U 29 enjoying an open air lunch on the deck during a port stay. (Credit: Kaplan)

3.6 Model case 4 (system scale): Cargo terminal system of Kopernikus 2 Lunar Logistics Station

The cargo handling system of Kopernikus Lunar Logistics Station, as the main element of its operations, is designed using the proposed design transfer method. This model case is focused on the transfer and integration of terrestrial container terminal features into the Kopernikus 2 Station design concept.

3.6.1 Model case definition

The container terminal system of the Kopernikus 2 station resembles the core of the logistics operations of the station. The main operational duty of Kopernikus 2 station is to provide logistics and service support to the other facilities in its vicinity. The over-take, storage, delivery and collection of the cargo items (e.g. logistic containers) require a handling system integrated into the Kopernikus 2 station, within a container terminal segment. The landing pad, surface mobility units (SMUs) and the cargo containers are the main elements of this logistics system.

Identification of target segment of transfer and requirements

Target/Subject of Transfer: The cargo handling system of Kopernikus 2 station

Requirements:

- Capability of reception, storage and transhipment of logistic payloads
- Compatibility with the station main vessel structure
- Compatibility with the Surface Mobility Units (SMUs)

Identification of operational / environmental components and search criteria

The operation type, environment and relevant factors, concerning the cargo handling system of Kopernikus 2 are listed below:

Intended use and operational components:

Handling of logistics containers at the Kopernikus 2 Station system

- Unloading of the containers from the landers at the landing pad
- Transport of the containers to the storage zone
- Placing of the containers into the designated position in the stack
- Extraction of the containers from the stack for delivery
- Loading / unloading of various cargo elements to / from SMUs
- Assembly and manning of SMUs
- Storage of cargo containers and SMU components

Environment: Lunar Surface

Environmental Factors:

- Vacuum
- High levels of radiation
- Micro-meteorites
- Temperature extremes
- Dust
- Extreme lighting conditions
- 1/6 gravity

Terrestrial literature search tags:

Container terminals

3.6.2 Research

The research work on the development of the container terminal system of Kopernikus 2 Lunar Logistics Station was done as follows:

Literature search with the generated tags and the evaluation of the search results:

Terrestrial Container Terminals

Using the identified tag, a literature search in digital and printed media on container terminals is applied. The relevant information, acquired in this process is as follows:

Container terminals are facilities, where cargo containers are transhipped between transport systems, in order to provide a continuous chain of good transport. Mostly, cargo terminals are integrated into seaports, to provide the transfer of cargo from the container ships to onward transport systems, like road and railway trailer vehicles.

Receptor container terminals that are primarily designed to receive and tranship containers, three main segments are clearly visible:

1 Intake segment is the gate to marine systems. This segment features the interface units, designed to service container ships. Pier systems, quayside cranes are among these infrastructure elements.

2 Storage segment, also referred to as container yard, where containers are stored in stacks, waiting for transhipment process. The transport vehicles, like straddle carriers and cranes provide the connection between the intake and storage segments.

3 Dispatch segment is the main interface of the container terminals to land-based transportation systems. Containers are transferred from the storage to the dispatch segment via straddle carriers and transfer cranes for further transport.

For both ships and ports, speed, safety and cost-efficiency of container terminals are key issues. The quality and efficiency of container terminals are of great importance to the smooth functioning of the global supply chain.

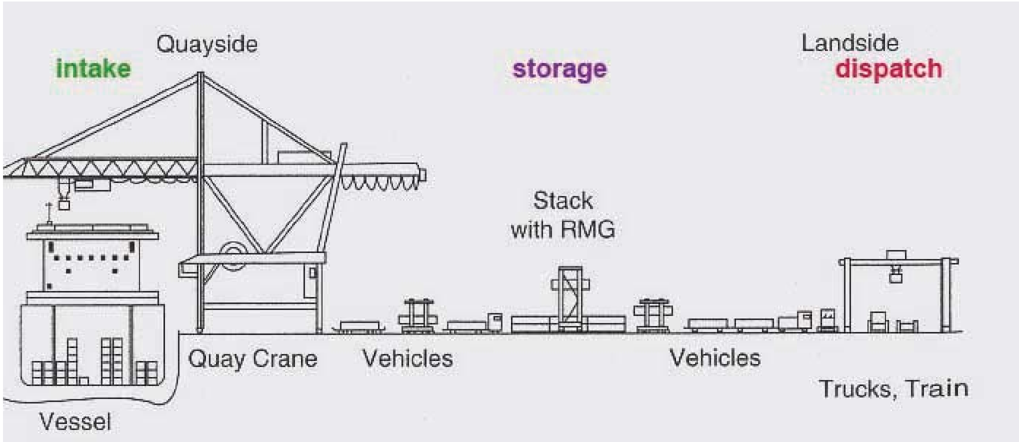


Figure 3-53: Typical Container Terminal Layout[42] (Credit: Yun)

The literature search on container terminals provided the following feature for the design transfer:

- The entire container reception, storage and transhipment system configurations and elements

[42] Note the intake / storage / dispatch sequence of the configuration, taken as the main donor feature for the design transfer.

3.6.3 Transfer

Transfer and integration of the selected design features into the Kopernikus 2 Station design concept

Having selected the container terminals as the main donor concept, the design transfer process occurs in following steps:

Step 1: Detailed iteration of the design requirements

Target /Subject of Transfer: The cargo reception, handling and the delivery system of Kopernikus 2 Lunar Logistics Station

Technical Requirements:

- A cargo transport system between the lunar surface and orbit shall be provided
- A container unit as the basic module of the transport shall be provided
- The container unit shall be launcher / lander compatible and stackable for storage purposes
- A landing pad for the incoming cargo landers shall be provided
- An automated cargo unloading / loading system shall be provided
- An automated cargo transport system within the station shall be provided
- A storage area for the containers in connection with the station vessel and the landing pad shall be provided
- An inter-station container transport vehicle design shall be provided

Step 2: Identification of the target location and its features

The container terminal system of Kopernikus 2 Lunar Logistics Station shall form the outer utility body of the station system. The inhabited segment of the station, the vessel shall be connected to the container terminal and house the command / control centre and the crew for the logistic operations.

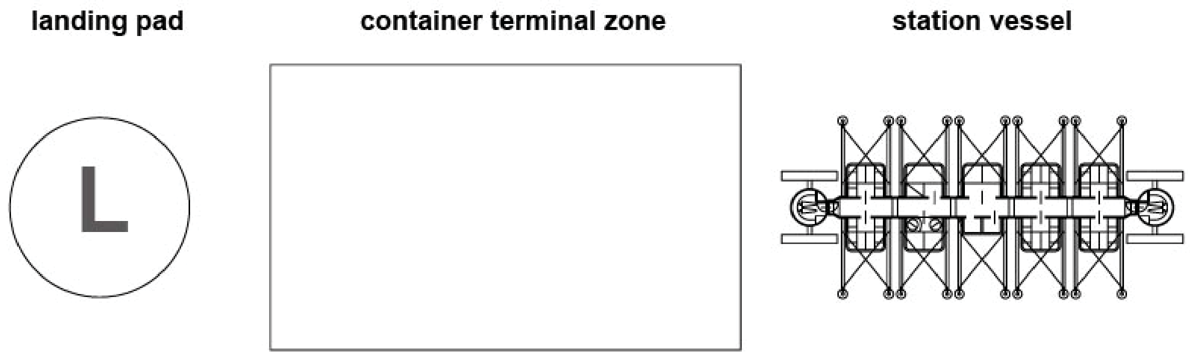


Figure 3-54: The basic layout of the Kopernikus 2 Lunar Logistics Station. The design development features the integration of three segments, equipped with required elements (Credit: Özdemir)

The critical points of the station system design, concerning the general layout are:

- Good level of networking of the three mentioned zones : landing pad / container terminal / station vessel
- Good level of operational independency between the zones, allowing simultaneous activity
- Autonomous cargo handling capability (station crew is only in SMU operations involved)

Step 3: The integration of the selected role model features

In order to construct a solid adaptation process for the cargo terminal system and elements, a comparative operational analysis is done. The operations, included in each segment of a terrestrial container terminal system and the corresponding activity in the Kopernikus 2 Station are identified.

Operational Analysis:

The intake segment comprises the following operational components:

- Unloading containers from the container ship / unloading the containers from the cargo lander
- Loading containers on transfer vehicles / loading the container on the transport cart
- transferring the containers to storage area / likewise

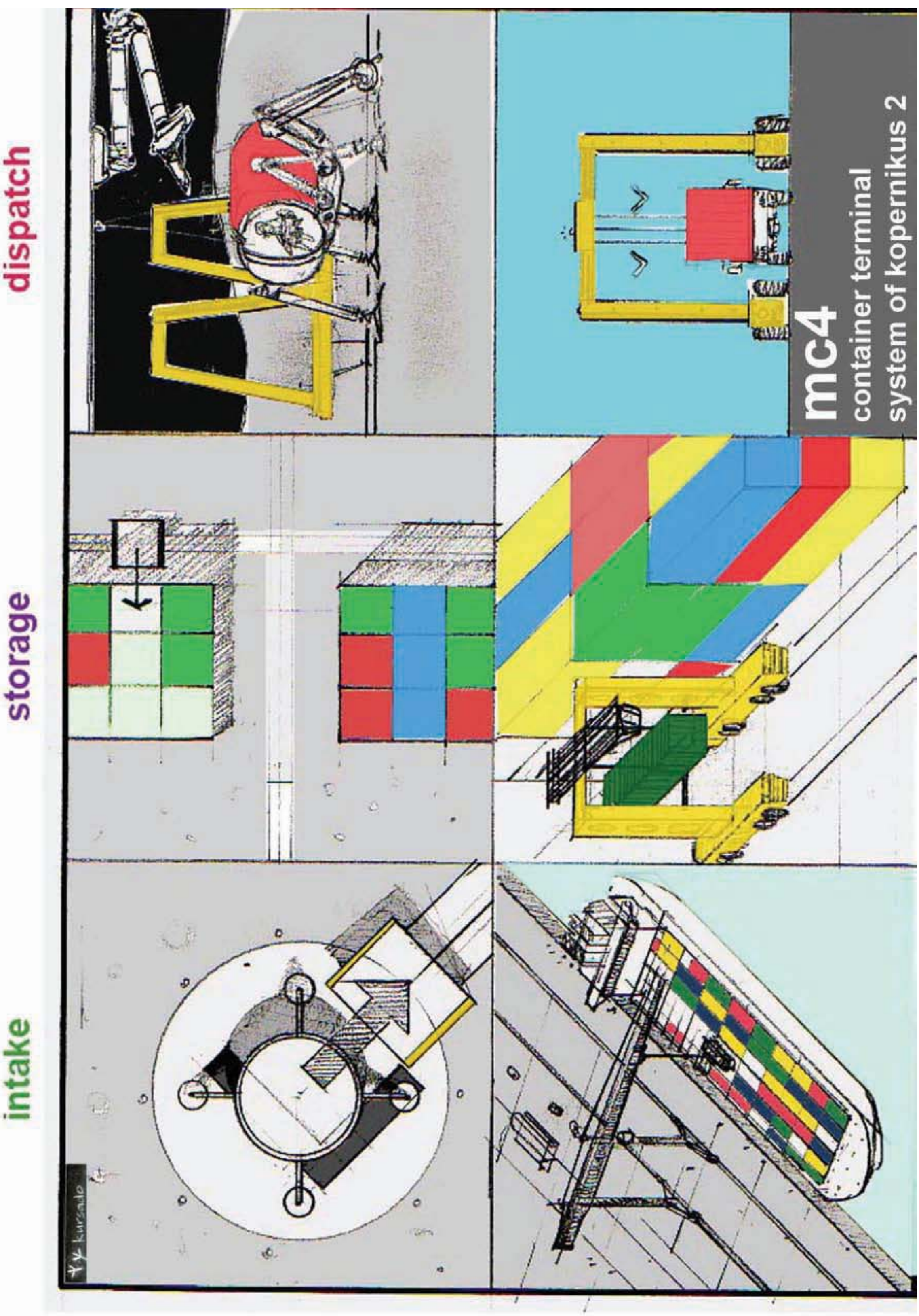
The storage segment comprises the following operational components:

- placing the container into the designated position in the stack / likewise
- extracting the container from the stack / likewise

The dispatch segment comprises the following operational components:

- loading the container on the transport vehicle / likewise
- manning the transport vehicle / likewise
- setting the transport vehicle on its course to the delivery location / likewise

On the next page, Figure 3-55: Basic comparison of the operations in a container terminal with Kopernikus 2 Lunar Logistics Station (Credit: Özdemir)



kopernikus 2

container terminal

Following the operational analysis of a container terminal, A study of the main elements of the cargo handling phases enabled the author to identify the design guidelines for each unit. Ranging from container ships to straddle carriers, a terrestrial container terminal holds a number of transport, storage and transhipment elements that make the cargo handling operations possible. In Kopernikus 2 case, similar elements will be needed to recept, store and deliver the containers.

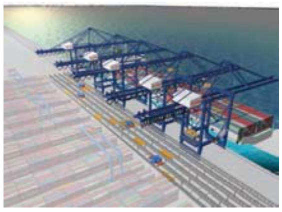
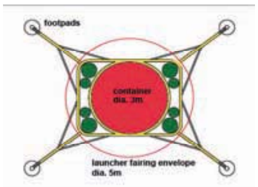
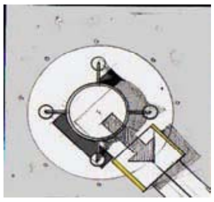
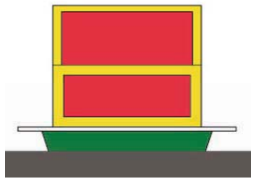
	intake		
container terminal	 container ship	 pier	 quayside crane
Kopernikus 2 Station	 cargo lander	 landing pad	 crane-equipped cart

Table 3-4: A comparative chart for the intake operation elements of container terminals and the Kopernikus 2 Lunar Logistics Station (Credit: Özdemir)

Intake segment:

- The huge container ships that are transporting the containers overseas can be interpreted as the cargo landers, delivering their payloads to the landing pad of the Kopernikus 2 station.
- The pier, where the container ships dock at, is integrated into the Kopernikus 2 Station system as the landing pad, where the cargo landers land and deliver their payloads to the transport cart.
- The quayside cranes, which are used to extract the containers from the ships and load them into the container stacks or the transport vehicles correspond to the transport cart of the Kopernikus 2 Station. The transport cart has an integrated onboard crane that helps the vehicle unload the containers from the lander autonomously.

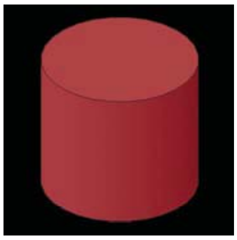
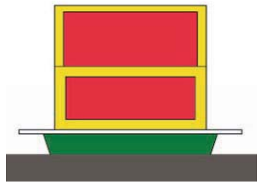
	storage	
container terminal	 ISO container	 straddle carrier
Kopernikus 2 Station	 kopernikus type container	 crane-equipped cart

Table 3-5: A comparative chart for the storage operation elements of container terminals and the Kopernikus 2 Lunar Logistics Station (Credit: Özdemir)

Storage segment:

- ISO container is the basic unit of mass container transport systems. With a section of 243.8 cm / 243.8 cm and varying lengths, ISO containers are designed to be transported by ships, aircrafts or motorway and railroad trailers. They are made of steel and can be stacked for storage, forming huge blocks. Kopernikus type container, with its cylindrical form measuring 3 m of diameter and height, is the basic cargo unit of the station system. Kopernikus containers fit into payload fairings of conventional launchers, thus have a high degree of transportability from the earth to orbit. These units are considered to be moved between earth and lunar orbits by tug vehicles. The kopernikus containers, stored in a parking lunar orbit are carried to the surface by automated cargo landers, which land at the Kopernikus 2 Station for delivery. Empty containers can be transported back to lunar orbit by the cargo landers. Kopernikus type containers can be stacked into two storey blocks and are moved by the crane equipped cart in the station system.

- Straddle carriers are transport vehicles that are used in the container terminals to move the containers between quayside, storage and transhipment zones and systems. They can stack, extract, load unload and transport containers. A crane equipped cart[43] is designed for the Kopernikus 2 Station system for container handling. With its integrated rectangular frame-type crane, these vehicles can unload the containers from the landers at the landing pad, move them to storage area and place them into the designated position in the stack.

[43] As the main element of the automated container handling system, the crane-cart is compatible with all the other infrastructure elements, like SMUs and payloads of different size and use (e.g. a crew cabin, replacing the logistics container).

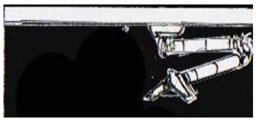
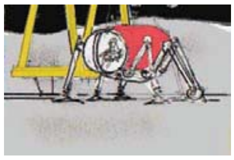
	dispatch			
container terminal	 straddle carrier	 gantry crane		 container truck
Kopernikus 2 Station	 crane-equipped cart	 crane-equipped cart	 onboard crane of Kopernikus2 Station vessel	 SMU

Table 3-6: A comparative chart for the dispatch operation elements of container terminals and the Kopernikus 2 Lunar Logistics Station (Credit: Özdemir)

Dispatch segment:

- As explained in the storage segment, terrestrial straddle carriers are substituted by the crane-equipped cart of Kopernikus 2 Station, for cargo handling operations. The Kopernikus 2 cart can extract the containers from the stack, transport and load them on the SMUs (Surface Mobility Units)

- The transport cart of Kopernikus 2 Station replaces also the gantry crane of terrestrial container terminals for loading purposes. Gantry cranes are used to load and unload containers from various land based transport vehicles (e.g. trailer trucks, railroad carts) The crane equipped cart, together with the onboard crane of the Kopernikus 2 station, can load containers on the SMUs, to configure them for delivery operations.

- The most common landbased container transport vehicle, the container truck , is interpreted as the Surface Mobility Unit (SMU) of the Kopernikus 2 lunar Logistics Station. SMUs are designed to deliver and collect containers to and from other bases in the area. With their six-legged mobility chassis, these units have a high degree of mobility on the rough lunar terrain.

With the mentioned similarities, thus the interpretations identified, the Kopernikus 2 Cargo terminal system design is constructed.

3.6.4 Final Design

The final design concept of the Kopernikus 2 Cargo Terminal and the main elements of the system are described below:

Cargo Lander:

Kopernikus Cargo Lander is designed to transport the logistic containers between the Kopernikus 2 Station and the lunar orbit. The cargo lander can ferry one kopernikus type cylindrical container each time and is fully automated.

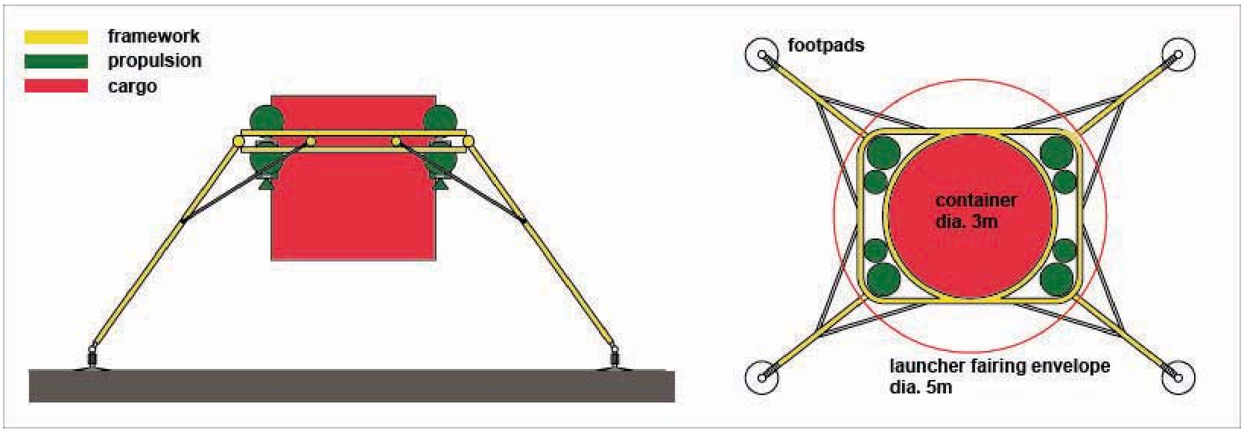


Figure 3-56: Schematic image of the Kopernikus Cargo Lander (Credit: Özdemir)

The lander comprises a structural frame, four support legs and footpads and four propulsion units. The cargo is placed in the middle of the frame and proportionally in the lower segment, providing stability during landing. The Kopernikus cargo lander is thought to be compatible with the earth-moon launchers, like Ares 5 and Ariane 50 t, with its 5 m diameter stowed configuration. The cargo lander is practically a shuttle vehicle, transporting loaded containers from the lunar orbit to surface and empty ones vice versa.

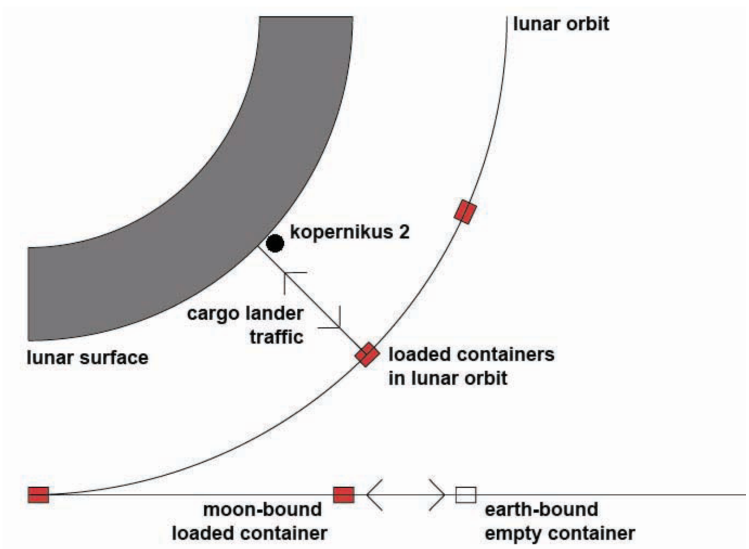


Figure 3-57: The logistics supply scenario for Kopernikus 2 Station (Credit: Özdemir)

The cargo supply system of the Kopernikus 2 Station, as depicted in Figure 3-57, functions as follows:

- Containers, loaded with supplies or equipment are transported from the Earth to the lunar orbit by cargo tug units.
- Loaded containers are parked in the lunar orbit, ready for collection
- Loaded containers are picked up by cargo landers and ferried down to the Kopernikus 2 Station
- Cargo landers bring an empty container back to the lunar orbit each time. Empty containers are also parked in the lunar orbit
- Empty containers are brought back to Earth orbit by cargo tug vehicles.

Kopernikus-type container:

The Kopernikus-type freight container, with 3 m diameter and 3 m height resembles the basic cargo block of the logistic transport system. Consumables, supplies and hardware can be ferried in these pressurized containers form earth orbit to lunar surface stations, eventually using future commercial transport services [Ashford, 2002]. These containers are thought to be filled in the earth orbit or surface, and then transported to lunar orbit. The cylindrical shape is a result of pressure optimization. The Kopernikus-type containers can be stacked to a two-storey storage block .

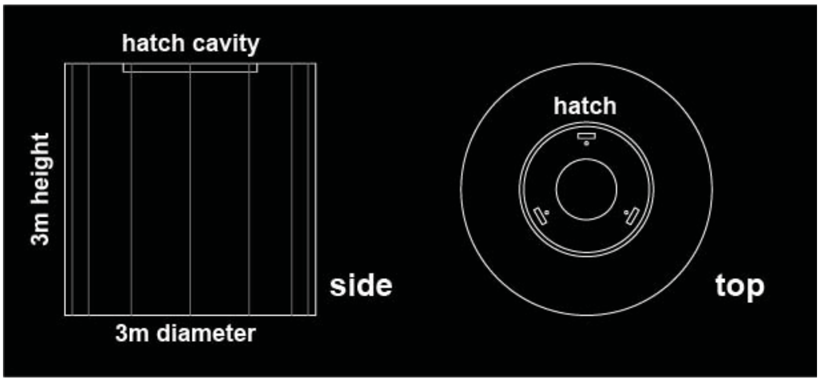


Figure 3-58: Kopernikus type container (Credit: Özdemir)

The container is accessible via its circular hatch on one end, which is built in a cavity to keep a clean envelope outline. The containers can be docked onto by receptor station’s interfaces for access. For easier handling, grapple fixtures are thought to be integrated in the side walls. Kopernikus-type containers are designed to be transported by launchers, orbital tugs, cargo landers and Surface Mobility Units (SMUs) of the Kopernikus 2 Lunar Logistics Station.

Landing Pad:

The landing pad of the Kopernikus 2 Station is a fixed infrastructure and is the transport interface to lunar orbit. Cargo and crew landers can land, be serviced and fly back to lunar orbit using this pad. The landing pad is a circular surface, equipped with navigation lights and an arched dust shielded flanking the station facing side. The dusty terrain, surrounding the landing pad poses a potential threat to other components of the station. Lunar surface dust is ejected during the landing, as the thrusters of the lander blow on the surface. The lunar dust, extremely adhesive and electro-statically loaded, sticks to all surfaces and may cause serious problems to mechanical systems. Therefore, a dust protection shield has to be installed right next to the landing pad, just like the Jet Blast Deflectors (JBDs) on aircraft carriers used to shield crew and equipment from the effects of the ejecta from landing / launching events. (See Figure x-x). The landing pad is connected to the container terminal and the station vessel by a rail-track. Cargo and crew landers can be serviced (e.g. fuelling) on the landing pad or carried over the rail-track nearer to the station by the transport cart.

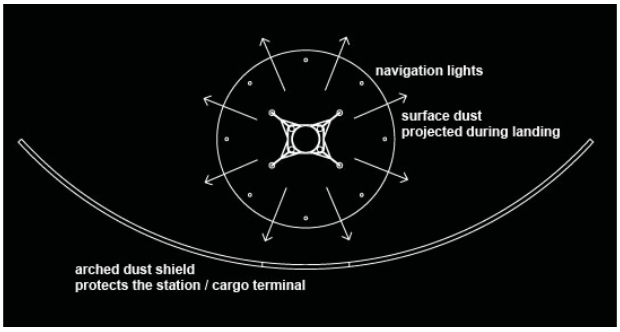


Figure 3-59: The Kopernikus 2 landing pad dust protection system[44] and a terrestrial analogue: Jet Blast Deflector (Credit: Özdemir / US Airforce)

[44] The dust shield of the Kopernikus 2 does not need to be retractable, since no all-flat profile of the system is needed.

Integrated transport system:

In order to move cargo containers inside the container terminal of the Kopernikus 2 Station, a rail-tracked transport system is designed. A simple transport platform, equipped with a crane can unload, transport and load containers. The rail-track connects the landing pad to the storage area and the station vessel. Containers, unloaded from the incoming landers can be carried to the storage are and placed into the stack. The containers to be delivered to other stations can be extracted from the stack by the transport cart and transshipped to the Surface Mobility Units (SMUs) as mentioned in the operational analysis section.

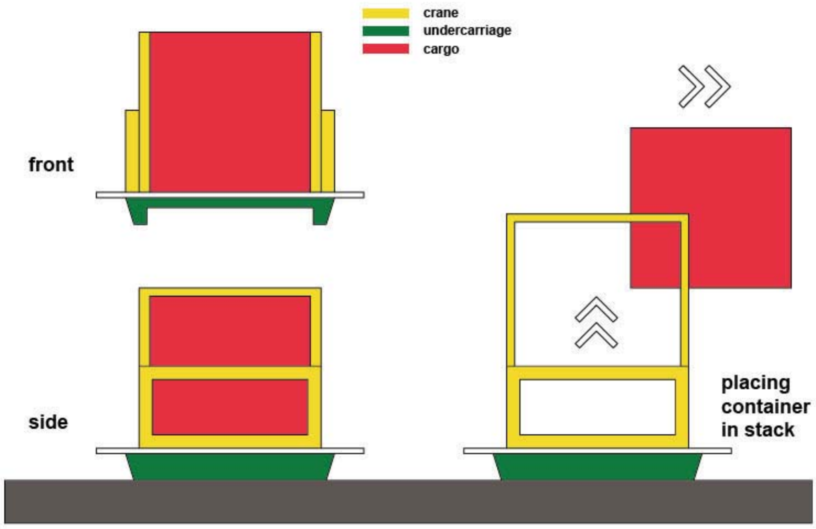


Figure 3-60: The crane equipped transport cart (Credit: Özdemir)

The crane-equipped transport cart is practically the lunar version of terrestrial straddle carriers, which are responsible for the transport and handling of the containers inside the container terminals. The cart, moving on the rail track, can also move equipment, crew and even the landers from the landing pad to the station vessel.

Surface Mobility Unit (SMU):

SMUs are walking transport vehicles, designed to deliver / collect containers to / from other lunar stations. A SMU is formed by three main segments:

- Mobility chassis is a six legged platform, designed to provide a base structure for the payload and the cockpit. The six walking legs provide the vehicle a good level of dynamic stability on the rough lunar terrain.

- Cockpit module is a spherical pressurized unit, designed to provide the crew a shirt sleeve environment. The two person crew enters the cockpit via the top hatch from the station vessel's docking interface directly. The cockpit has two large windows that give the crew a good level of visibility while driving.

- Payload module is the Kopernikus type container, mounted on the chassis. The loading and the unloading process at the station is done by the crane-equipped cart. (please see operational analysis section)

SMUs are designed to be reconfigurable, allowing the storage of vehicle components in different numbers. The components are standard and interchangeable. Basic configuration SMUs are stored next to the container stack.

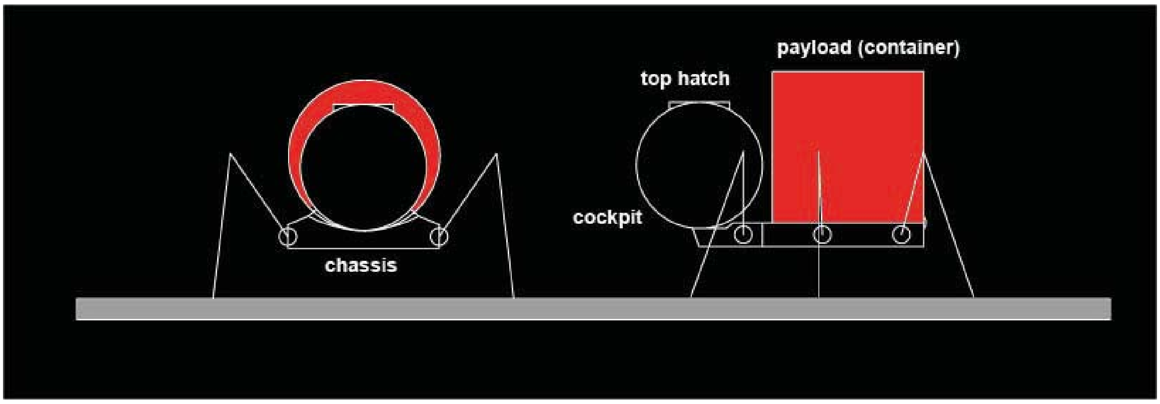


Figure 3-61: Basic SMU configuration (Credit: Özdemir)

Typical Cargo Reception Operation Sequence:

The container intake from a lander into the station system occurs in as follows:

- Cargo lander lands on the landing pad
- Container is loaded on the transport cart
- Transport cart drives to storage area
- Container is placed into the designated position in the stack

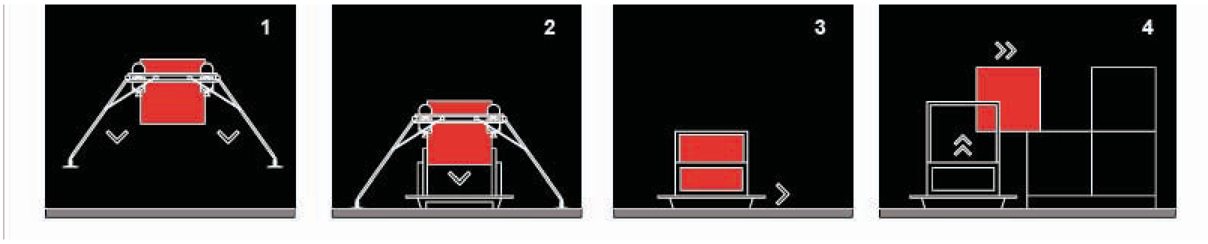


Figure 3-62: Typical cargo reception operation sequence (Credit: Özdemir)

Typical Cargo Delivery Operation Sequence:

The container delivery operation to other bases occurs as follows:

- Ordered container[45] is extracted from the stack by the transport cart
- Transport cart moves the container to the SMU, which is autonomously brought into position
- Container is loaded on SMU
- Loaded SMU is moved along the track under the station vessel
- SMU crew enters the cockpit directly from the operation deck via the docking interface
- SMU drives to the target station to deliver the container

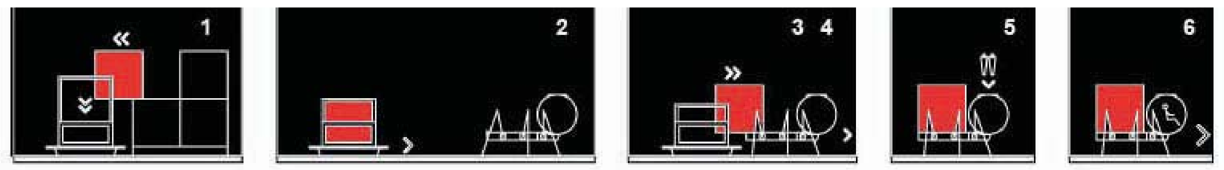


Figure 3-63: Typical cargo delivery operation sequence (Credit: Özdemir)

[45] All operations are commanded and coordinadet from the operation deck of the Kopernikus 2 Station.

The cargo terminal component of the Kopernikus 2 Lunar Logistics Station is designed in a similar manner as a terrestrial container terminal, concerning its main elements and operations. With this model case, the capability of the proposed design transfer method in system scale is demonstrated. An analysis of the main role model into its elements and operations provided a systematic transfer and integration of the design features into the target design, the Kopernikus 2 Cargo Terminal Facility Concept.

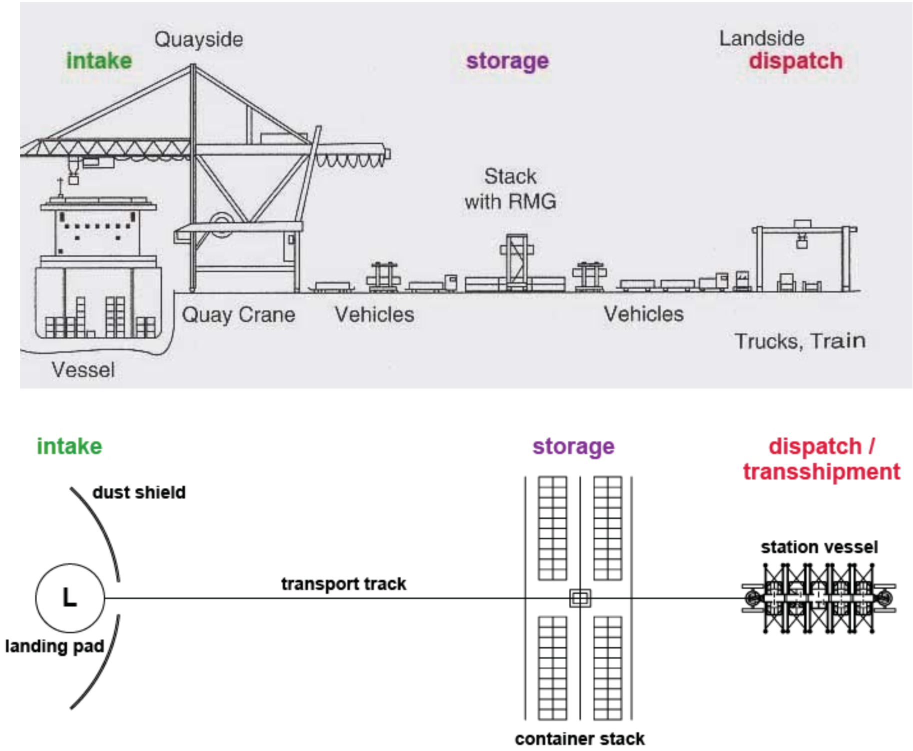


Figure 3-64: Schematic comparison of a typical terrestrial container terminal with Kopernikus 2 Station (Background image [top] credit: Yun, edit / cad: Özdemir)

3.7 The application potential of the design transfer method to the currently planned space missions

Having demonstrated the possible use of the proposed design transfer method in the frame of a future lunar base project, the benefits of design transfer are investigated within current projects in this section. The actual effort in space infrastructure planning is covered in :

- Space and planetary exploration planning
- Commercial space infrastructure planning (e.g. space tourism)

Integration into Space and Planetary Exploration Infrastructure Plans

- Relevant segments of the system architecture:

In-space: potential elements / use ISS-like space station structures

The international space exploration plans foresee in the next decades multiple robotic and human missions to the Moon[46] and robotic missions to Mars, Phobos and other destinations (e.g. Saturn Moon Europa). Notably, since the announcement of the US space exploration vision by President George W. Bush in 2004, the US has made significant progress in the further definition of its exploration programme focusing in the next decades in particular on human missions to the Moon. Russia, Japan, China, India also have long-term space exploration programmes and are working on their implementation. The US and Russia have started work on new generation crew transportation systems. China has recently acquired human access to space capability and is further developing human spaceflight capabilities. In 2001, ESA initiated the Aurora programme and has within the framework of this programme developed a long-term roadmap for space exploration.

The space exploration plans address ambitious long-term goals requiring significant resources and innovative capabilities for its implementation. In view of this they can only be realised on the basis of broad international public and private sector cooperation and a cost-effective approach to mission implementation.

ESA defines the characteristics of sustainable space exploration as:

- Driven by long-term goals and objectives
- Follows similar exploration sequence for different destinations
- Includes repeated missions to identical destination
- Relies on capabilities common for different missions to identical or different destinations
- Prepares extended virtual and real human presence and exploitation activities
- Requires broad international coordination and cooperation

In order to implement its exploration objectives, ESA announced various studies, in which the preliminary planning of the space and planetary exploration infrastructure is assessed. One of these studies, in which the author was involved, house the last model case for the proposed design transfer method.

[46] Moon is considered as a stepping stone towards the Mars, which actually is the ultimate target of near term human exploration of the solar system.

3.7.1 ESA study “Analysis of Surface Architecture for European Space Exploration” as a design transfer environment

An ESA study, in which the author was involved, is used in this section as a model case platform.

Study Team:

Liquifer Systems Group as sub contractor for Thales Alenia Space Italia SpA

Purpose and the scope of the study:

The objective of this study was to analyse the planetary surface architecture with the objective to define an optimum architecture for operating on Moon and Mars taking due account of the European technological heritage, existing and planned European and international transportation systems and European and international space exploration plans.
The goals of the study were:

- Consolidate high-level requirements for the planetary surface system architecture by integrating requirements derived from the analysis of the economic-, scientific- and policy-driven scenarios

- Analyse and evaluate different surface architecture solutions for exploration/ utilisation of Moon/ Mars taking due account of exploration and utilisation goals and requirements

- Assess the architecture against the stakeholder requirements

- Define high-level requirements for surface building blocks/ capabilities

- Define requirements for the in-space architecture/ building blocks (e.g. telecom,navigation, staging posts, observation) and transportation needs

- Develop a roadmap for build-up of architecture/ capabilities identifying in particular needs for near term capability demonstration missions

- Analyse needs for international coordination and identify opportunities for international cooperation

- Estimate the overall implementation cost including infrastructure development and operations over time

- Analyse risks, impediments and enablers related to the infrastructure build-up and operations.

Methodology of the study:

Focused on the design of mobile surface habitats of the infrastructure system, the study group applied the following methodology:

- Identification of the activity segment (i.e. surface infrastructure elements) by ESA

- Identification of the infrastructure element to be designed within the infrastructure palette (i.e. mobile habitats)

- Identification of the requirements and conditions for the design concept

- Identification of the terrestrial based applications, that can be adapted to the design

- Construction of the design concept in the frame of the surface system architecture study and identified requirements

- Assessment of alternative concepts (performing comparisons and trade offs)

- Assessment of the required technologies for the design (including their Technology Readiness Levels –TRLs-)

- Evaluation of the proposed concept in means of its compliance to the larger study frame and the system architecture, European capabilities and stake-holder requirements and its compatibility to international cooperation options

- Documentation of the whole research and design activity in a technical report format for ESA evaluation

Findings of the study:

- Preliminary assessments of mobile planetary habitat options

- Preliminary design options of a pressurized rover

- Preliminary design of a deployable camping unit for unpressurized rover crews(detailed below)

3.7.2 Model case 5: Deployable Camping Pod for unpresurrized planetary surface vehicles

Model Case 5 (MC5) resembles a design transfer case that is in element scale and related to the current planning process for the planetary exploration effort. MC5 depicts the design development of a vehicle-integrated and deployable one-person habitat, thought to be used during extended surface excursion missions.

3.7.2.1 Model Case Definition

In order to comply with the study programme, the study team investigated the options of using unpressurized surface vehicles in combination with the pressurized mobile habitats for planetary surface exploration. During the investigations on various surface vehicle concepts, one of the solutions, designed to overcome the limited range of these units was to integrate a minimized one-person-habitat onto the vehicles. This solution was implemented in the form of a mobile camping unit.

Deployable Camping Pods (DCPs) are vehicle-mounted mobile units designed for unpressurized vehicle crews to be used as sleeping/resting bags during long surface excursion missions. Practically like a camping tent, the DCP provides the astronauts a confined space to lay down, rest or sleep during missions without getting into a static habitat.

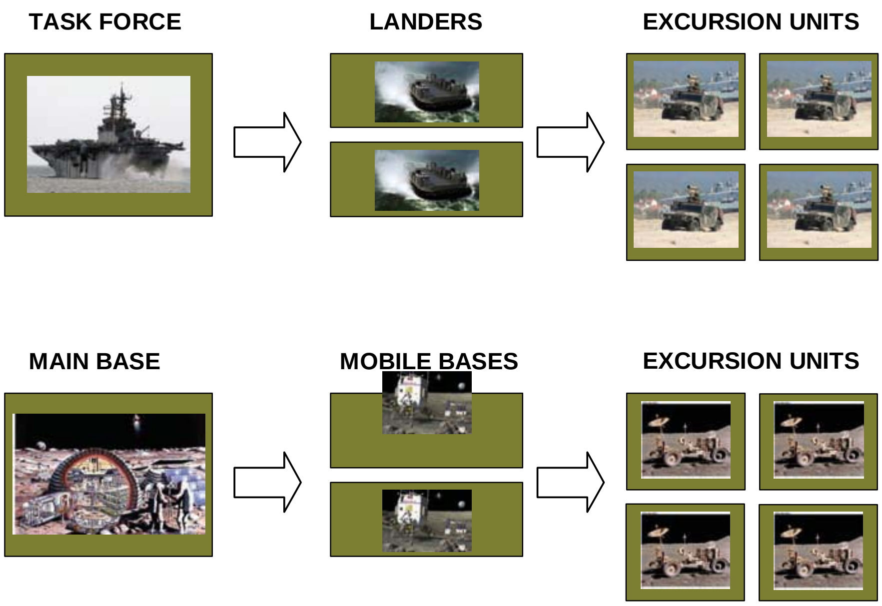


Figure 3-65: A comparative sequence chart for military operations vs planetary surface exploration (Credit: Özdemir)

In order to have a better understanding of the use of unpressurized surface vehicles for surface missions, planetary exploration infrastructure can be compared to the military operations architecture. The structuring of the whole system of a military expedition force, in regard to the break-up of main task force groups down into the operation vehicle and team scale, have a structural similarity to the system architecture of the planetary exploration infrastructure, where main bases hold and support the mobile bases and the mobile bases dispatch a number of surface vehicle units, respectively. In this sense, the unpressurized surface vehicle units[47] (i.e. the buggies) correspond to the operation teams, which are deployed to the mission zone by lander units. (See Figure 3-65)

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[47] In the current surface exploration infrastructures, buggies are planned to be used as simple and light-weight platforms, wherever a practical extension of mobility capabilities are needed.

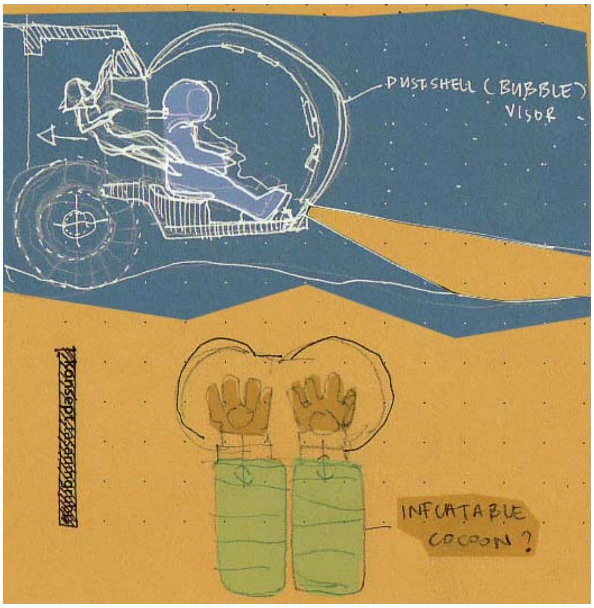


Figure 3-66: Initial sketch depicting vehicle mounted habitat pods (Credit: Özdemir / LSG)

DCPs are designed to be integrated in surface mission infrastructures, where unpressurized surface vehicles, buggies, are used to extend the operation range of the crews. Every astronaut in a spacesuit on the lunar surface is exposed to dangerous levels of radiation, temperature extremes, sticky regolith dust and micro meteorites. Space suits have protection measures against radiation, temperature extremes and micro meteorites. The space suit is a mini habitat, in which the astronaut can operate in a relatively confined environment. However, the protection level of spacesuits is not suitable for long duration extra vehicular activities. During surface excursion missions, where unpressurized buggies are used in order to extend the outreach of the crews, astronauts stay in their space suits the whole time. When EVA durations, which extend 10 hours, are mentioned, an option for the operation crew to take a rest in order to regenerate and keep the operational effectiveness level in green zone is indicated to be critical.

Identification of the target segment and the basic requirements

Having identified the mentioned facts, the main frame of the design transfer can be viewed as follows:

Target of design transfer: A mobile and vehicle-mounted camping unit for unpressurized surface vehicle crews

Requirements:

- The level of protection in the space suit shall be maintained as it is inside the space suit
- The unit shall be portable and vehicle-integrated, giving an option to be deployed during the buggy ride period of missions
- Dust mitigation and radiation / micro-meteorite protection measures shall be integrated in the design
- An option to use in-situ materials shall be provided
- The unit shall be re-usable
- A safe transfer between the space suit and the camping unit shall be provided

Intended use and operational components:

Sleeping on the surface vehicle

- Deployment of the unit
- Crew ingress into the unit
- Crew resting/sleeping in the unit
- Crew egress from the unit
- Retraction of the unit

Environment: Lunar Surface

Environmental Components:

- Vacuum
- High levels of radiation
- Micro-meteorites
- Temperature extremes
- Dust
- Rough terrain features (craters, ridges, crevices etc.)
- 1/6 gravity

Literature search tags:

In order to demonstrate the space-to-space transfer capability of the proposed design transfer system, a space-related literature search is included in this design transfer process. Following literature search headlines are identified:

- Portable shelters / camping structures (Tents, Bivouacs, Sleeping pods)
- Sleeping on / in the vehicle options
- Deployable one-person units for space missions, e.g. space suits (The literature search is not limited to terrestrial category in this model case, due to the nature of the study)
- Apollo Lunar Roving Vehicle (LRV)

Figure 3-67: Dusty gear of the Apollo 17 astronauts stowed in the Lunar Module after an EVA. Dust poses a serious problem to all lunar habitats. (Credit: NASA)

3.7.2.2 Research

Literature search with generated tags and the evaluation of the search results:

Using the identified tags, a literature search in digital and printed media is applied. The relevant information, acquired in this process is as follows:

Portable shelters:

Designed to be used in outdoor environments for camping, duties or in case of emergencies, the portable shelters provide their users an insulated sleeping place.

Tents are temporary shelters consisting of sheets of fabric or other material draped over or attached to a frame of poles. Tents have become the main element of outdoor camping because of their light-weight and structural simplicity. Tents may have rigid, flexible and inflated poles to sustain their required shapes. Modern tents use mostly flexible poles made of fibreglass or aluminium and sheets made of synthetic, waterproof textiles. Tents resemble an important role model character for the design transfer with their following features:

- Minimal weight
- Easy transport, high compatibility with backpacks
- Easy to pitch and strike

Bivouac sack is practically an external envelope that provides protection against outdoor conditions. A bivouac sack (bivy) can add extra 5-10° to the comfort limit of a sleeping bag. A typical bivy sack is:

- Light-weight / Easy to transport
- Compatible with backpacks
- Easy to deploy and repackage – even in extreme situations (see Figure 3-68)

Figure 3-68: Rock climbers sleeping in a bivy sack in their extreme operation environment, a rock wall (Credit: Siegmund)

Cocoon Sleeping System is an air-inflated, waterproof, down filled sleeping shelter incorporating an inflatable mattress and a waterproof detachable canopy. The shelter is rated to be thermally comfortable between -43 to 21°C depending on the air pressure inside the bag which controls the loft of the down. Its reasonable weight and size allows the motorcycle campers to use the system effectively. Following features of the system provided hints for the design development of the DCPs:

- High level of Integration of a sleeping bag and a shelter into one single concept
- Low weight
- Easy deployment and retrieval
- High level of transportability (e.g. by motorcycle)

Figure 3-69: Cocoon 4[48] is a highly transportable and well insulated inflatable shelter (Credit: Pneugear)

The Survival Pod is a waterproof shelter, a storage unit for first aid and food supplies, an emergency stretcher, a water purification unit and even a lifeboat in extreme situations. The compact, durable design was inspired as a response to the devastating and recurring flood situation in Mozambique that left hundreds of thousands homeless and bereft of clean water, food and shelter. Survival Pod can be easily transported in backpack-configuration and deployed easily according to the situation as a stretcher, a shelter, a water purifier or a raft.

Figure 3-70: Different configurations of the Survival Pod (Credit: Euforia Design)

[48] In regard to its high profile capabilities, Cocoon systems are also tested for military use. Low weight and high level of thermal protection was considered to be important factors, in a field test, done by Canadian Army officials.

Survival pods have the following relevant features for the design transfer:

- High level of transportability
- High level of functional flexibility

Using the vehicle as a temporary habitat:

Not only designs developed for extreme environments, but also techniques incorporated by humans to use in harsh conditions, can be transferred to space habitat concepts. Depending on their duties, daily routines and the environment, it is often a normal case that people use their vehicles as a temporary habitat / shelter. The mobility unit, the vehicle or a draft animal, can provide a shelter or help to build one, in case of sleeping during the ride, duty or operation. Staying in, on, under or near the mobility unit, the user keeps operational readiness level high and can exploit various systems of the unit (e.g. power, structural system).

Figure 3-71: Using the mobility unit as an accommodation element in three different environments. In lunar environment, the crew will probably need more than a seat and the warmth of the mobility unit.[49]
(Sources: Friedman Archives / www.paintedsork.com)

The relevant design transfer characteristics of the mentioned behaviour are as follows:

- Exploiting various systems of the vehicle for a shelter (i.e. structural, power, environmental protection systems)
- Integrating the shelter into the vehicle structure

<u>Car-top tents</u> are designed to fit onto vehicle roofs to provide an elevated camping platform. Car-top tents have a higher degree of protection against wild animals and rainwater due to their elevated position. The applicable feature of car-top tents for the design transfer process is:

- Integrating the shelter into the vehicle structure

[49] Nevertheless, a similar approach to the sleeping-en-route case can be applied, as seen in the DCP design. The DCP uses the power and the structural system of the mobility unit.

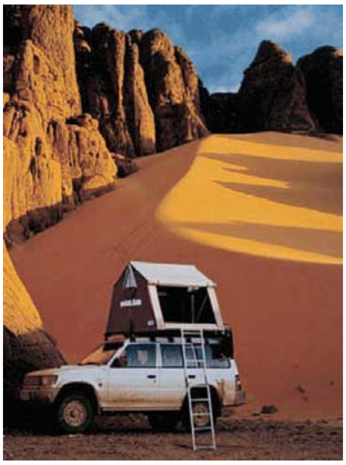


Figure 3-72: Car-top tents are good vehicle-integrated habitats (Credit: Autohome)

One-person units for space use:

Spacesuits are protective garments designed to provide the EVA crews a one-person confined environment to operate in space conditions (e.g. pressure extremes, radiation and thermal protection etc.) There are two protective envelopes employed in the space suit: an inner pressurizable envelope, and an outer thermal and micro-meteoroid protective envelope. Space suits have integrated life support systems to achieve and control conditions inside the garment similar to the earth's atmosphere. With internal sensors and a communication system, a space suit is a one-person habitat, operating in extreme conditions. Currently, extensive research on hard shell and rear-entry suits is being done, in order to comply with the future planetary mission profiles.

Figure 3-73: A rear-entry Orlan-DM space suit. Note the backpack-integrated life support system (Credit: NPP Zvezda)

The following relevant characteristics of spacesuits are marked as applicable by the author:

- Integrated life support, environmental protection and communication systems
- Rear entry suit configuration, providing ingress and egress without structural dismantling

Collapsible Hyperbaric Chamber (CHC) is also a one-person habitat, designed to be used in space stations in cases of decompression sickness. CHC is practically an inflatable cocoon with an end-cap. The person to be treated is placed inside the soft-shell unit[50]. The system is pressurized up to the required treatment levels upon sealing the unit with the end cap, where a small window is integrated for visual contact. The unit can be easily stored and operated onboard a space station and saves the mass / volume of a rigid pressure chamber or an airlock.

The following features of this concept are evaluated as applicable for the design transfer:

- Inflatable structural system
- Deployment geometry

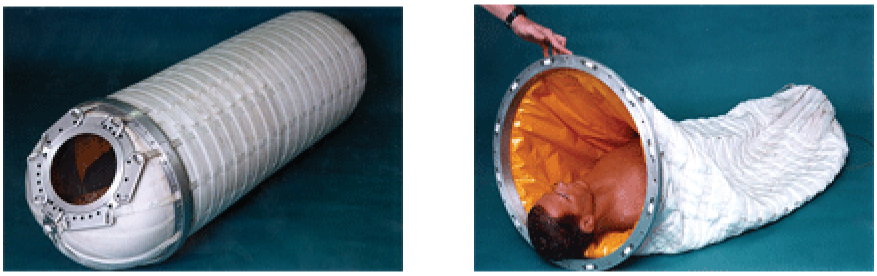


Figure 3-74: Two images of a Collapsible Hyperbaric Chamber, developed by ILC dover for space missions. This one-man habitat is a volume-efficient solution designed for inhabitable space structures. (Credit: ILC Dover)

[50] There is a distinct similarity between the CHC and the collapsible shower module of the Skylab sation, considering both forms and geometries.

Apollo Lunar Roving Vehicle LRV as a role model for the buggy design

The Lunar Roving Vehicle (LRV) was an electric vehicle designed to operate in the low-gravity vacuum of the Moon and to be capable of traversing the lunar surface, allowing the Apollo astronauts to extend the range of their surface extravehicular activities. The Apollo Lunar Roving Vehicle (LRV) could fit folded tight against the side of the Lunar Module for carriage. Deployment of the LRV by the astronauts from the LM was achieved with a system of pulleys and braked reels using ropes and cloth tapes. LRV was a light weight lunar surface vehicle with a simple structure and elements like canvas seats. The LRV was designed to operate for 78 hours during the lunar day. It could make several exploration sorties up to a cumulative distance of 65 kilometres. The use of LRV upgraded the exploration range of the Apollo crews, dramatically. Harrison Schmitt[51] of Apollo 17 stated, "....the Lunar Rover proved to be the reliable, safe and flexible lunar exploration vehicle we expected it to be. Without it, the major scientific discoveries of Apollo 15, 16, and 17 would not have been possible; and our current understanding of lunar evolution would not have been possible."

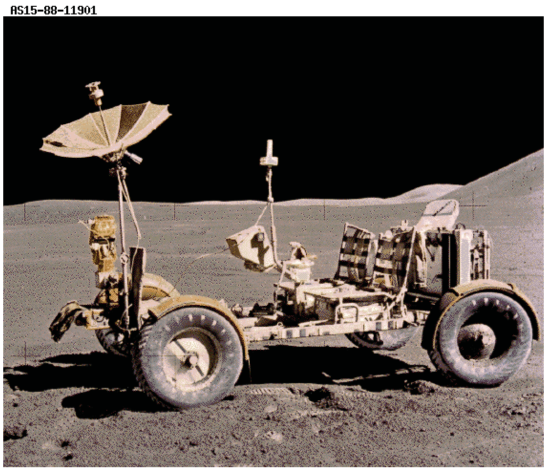


Figure 3-75: Apollo Lunar Roving Vehicle on the operation ground. Note the simple and sturdy structure. (Credit: NASA)

The Apollo Lunar Roving Vehicle provides a sound fundament for the conceptual design of planetary rovers. Following points can help define a new surface vehicle design:

- The need for a light weight, simple structure surface vehicle design to extend the surface exploration range
- The mission range of the rover and the crew can be extended further by installing an integrated habitat on the unit
- Safety measures have to be integrated into the operation profile of the rover (e.g. using twin rovers for increased safety)

[51] Harrison Schmitt is the only scientist-astronaut, who landed on the Moon. His findings during the Apollo 17 mission include the discovery of a new lunar soil type. Apollo 17 had the longest total lunar surface extravehicular activities and the largest lunar sample return amount. The Lunar Rover played a critical role in these achievements.

3.7.2.3 Transfer

Transfer and integration of the selected design features into the Kopernikus 2 Station design concept

Having evaluated terrestrial and this time also space related role model candidates and their relevant characteristics, the transfer and integration of the selected design features occurs in the following steps:

<u>Step 1: Detailed iteration of the design requirements</u>

Target/Subject of Transfer: A vehicle-integrated one-person habitat for unpressurized surface vehicle crews

Technical Requirements:

- A minimum pressurized volume of 1 m3 for each unit in deployed configuration shall be provided
- Internal energy and data ports shall be provided
- The environmental factors of the space-suit interior shall also be provided for the unit (e.g. pressure, temperature, radiation protection)
- The unit shall be portable and vehicle-integrated. The option to keep one or both of the units deployed giving during the buggy ride (e.g. in the case of an emergency) shall be provided
- Dust mitigation and radiation / micro meteorite protection measures shall be integrated in the design
- An option to use in-situ materials shall be provided
- The unit shall be re-usable
- A safe transfer between the space suit and the camping unit shall be provided
- System shall feature light weight structural elements as it is a main vessel-based-deployable system. Total mass is dictated by the bearing capacity of the main station structure and the deployment system
- The unit should be integrated into the main station structure in the stowed configuration. It shall not interfere with any other elements, installed on the rover system.

<u>Step 2: Evaluation of the target segment with relevant features</u>

The Deployable Camping Pods (DCP) will be mounted on unpressurized surface excursion vehicles, in order to provide the crew extended capabilities for long duration surface missions. The surface excursion vehicles (buggies) are, similar to the Apollo LRV, mobility units, designed to extend the exploration range of surface crews. Light-weight, simple and sturdy built, buggies are versatile vehicles, which can assist surface missions like scientific field studies, hardware deployment or even rescue.

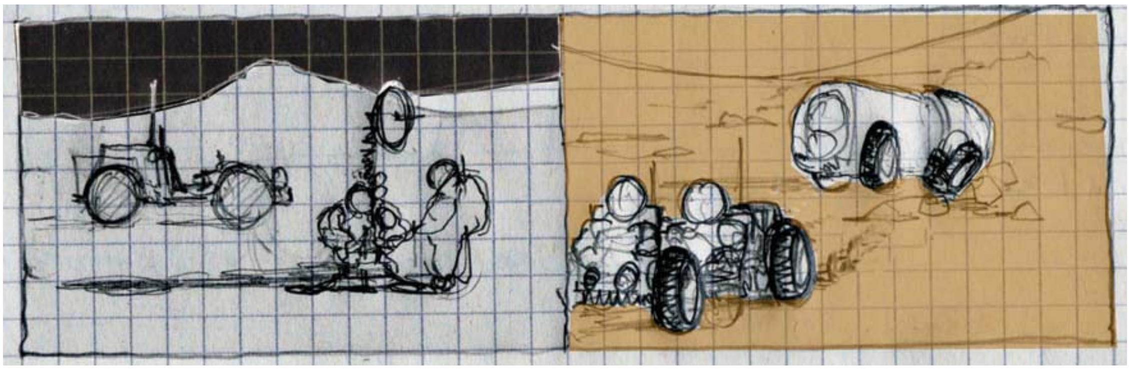


Figure 3-76: An initial sketch from the mentioned Surface Architecture Study, depicting two different operations of unpressurized surface vehicles. Hardware deployment on a given location and a safe return to base from a troubled pressurized vehicle (Credit: LSG / Özdemir)

The DCPs are expected to be mounted at a certain position on the buggy where the units are:

- easily accessible by the crew at every case (e.g. emergency cases, where the vehicle is not in a horizontal position)
- not distracted by the other systems of the vehicle (e.g. payload, driving positions)
- free from dust, thrown up during the ride

Step 3: The integration of the selected role model features

The literature search with the obtained criteria provided a variety of role model candidates and a number of relevant design features. Besides the technical requirements, the DCP design is based on the following characteristics, which are provided by the mentioned role models:

- compatibility with the buggy systems
- light-weight deployable / retractable structure (e.g. inflatable)
- vehicle-based deployment and retraction
- use of rear-entry space suits for direct transfer between the DCP and the spacesuits

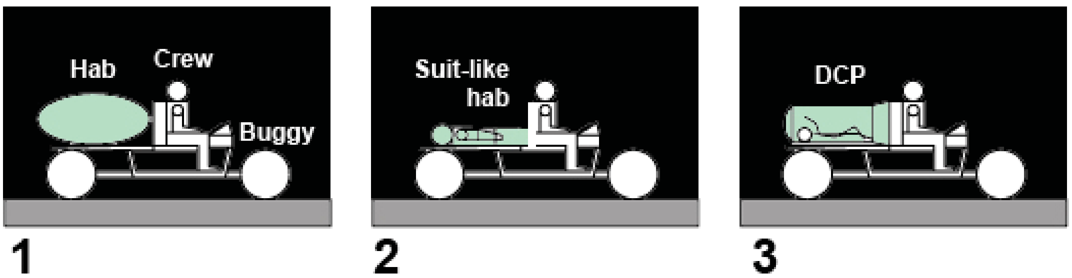


Figure 3-77: Evolution of the DCP concept (Credit: Özdemir)

The implementation of all mentioned requirements and the adopted features is done via an evolution sequence of the design. The evolution steps, as seen in Figure 3-77, are described below:

1 The initial basic layout is composed by

- A vehicle mounted, 1-person, deployable habitat
- The unpressurized surface vehicle (buggy) crew of 2
- The unpressurized surface vehicle (buggy)

These three elements have to be combined within a system, where the following are provided:

- A safe and dust-free connection between the habitat and the spacesuit
- High level of structural integrity
- Option to use the vehicle without DCP (i.e. detachment option)

2 The initial consideration for the habitat character is to use a similar structural system to a space suit. This decision points out an inflatable, one person habitat, which is connected to the suit of the crew.

3 DCP design is formed as the last step of the development process. The spacesuit-like character is combined with the structural form of a Collapsible Hyperbaric Chamber (CHC). The end product is an inflatable, cocoon-like deployable habitat, attached to the backpack of the spacesuits of the buggy crew.

3.7.2.4 Final Design

DCP, being the end-product of the mentioned design transfer and development case, is light-weight and vehicle mounted one-person habitat, composed of rigid and soft elements. The main segments of the DCP are as follows:

1. Root Segment[52] houses the hatch, the connection interface to the space suit and the buggy, the integrated Life Support System (Oxygen tank, ventilation pumps, batteries). This rigid segment is the service module of the unit.

2. Soft Segment is the inflated part of the unit. Stowed in a closed bellow form, the soft segment forms the main space of the DCP like a cocoon in deployed configuration. The structure is similar to the spacesuits, possessing pressure, micro meteorite, thermal and radiation insulation layers.

3. End Cap completes the tubular structure of the DCP. Control interfaces for the astronaut and a small window are integrated into this rigid part of the unit.

In the stowed configuration, the inflatable soft segment of the unit is folded, like a bellows, and stored between the rigid end cap and the root segment. When the unit is pressurized, the tubular soft segment inflates and pushes itself and the end cap away from the root segment. The deployed configuration is, similar to the Collapsible Hyperbaric Chamber, an inflated soft-structure cylindrical body with a rigid root segment and an end cap. (See Figure 3-78)

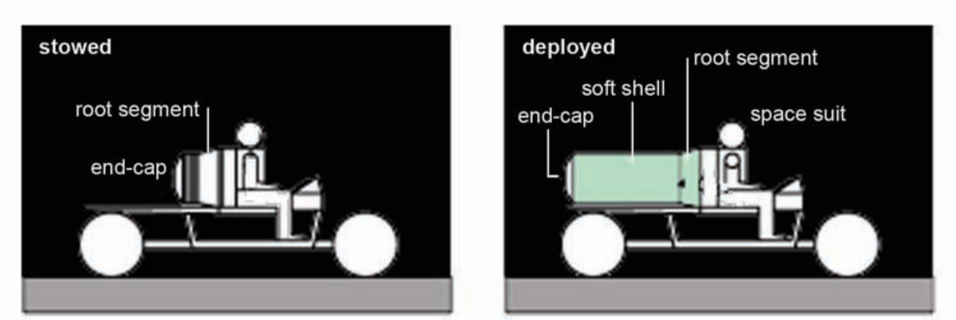
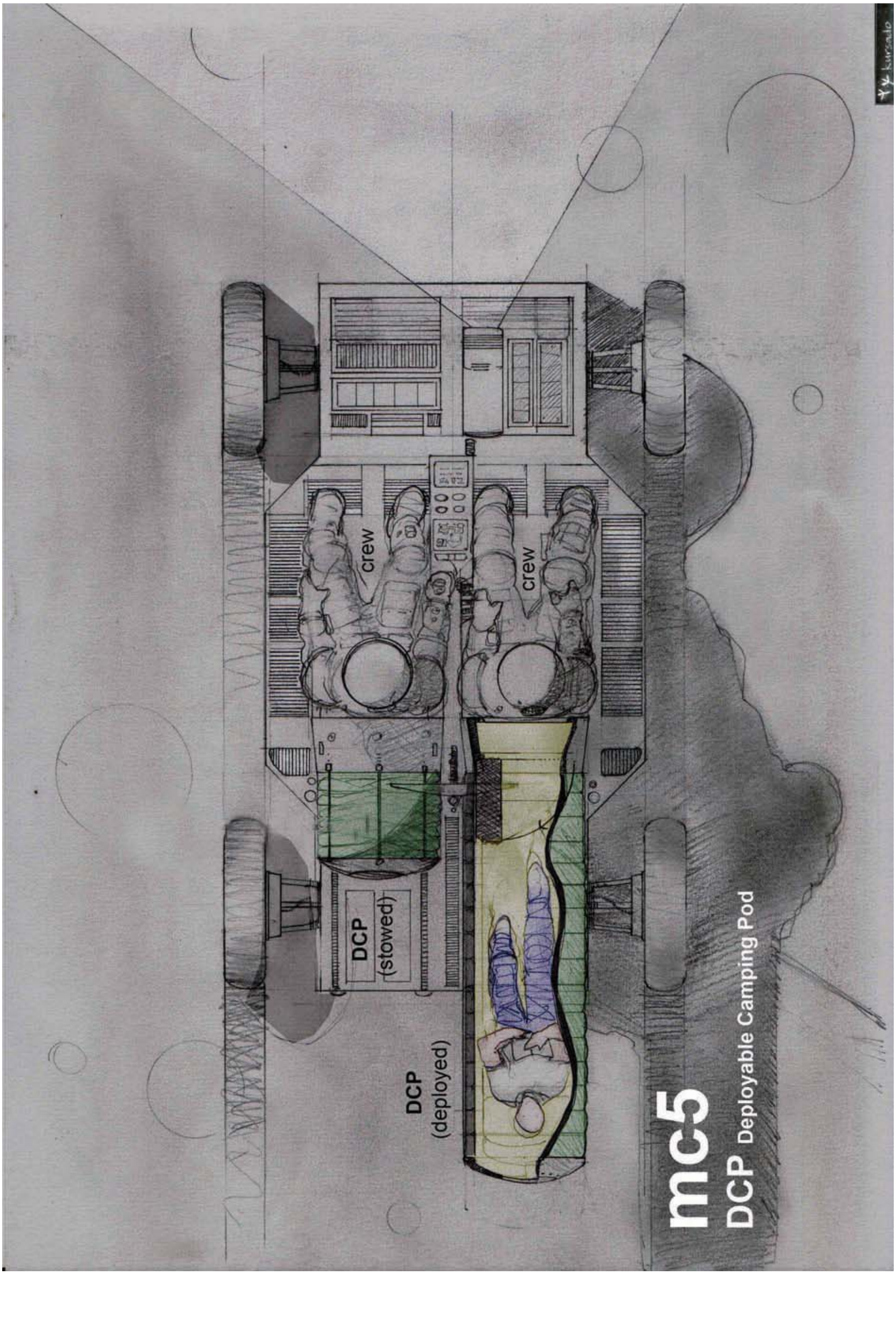


Figure 3-78: Scheme showing the main segments of a DCP in both layouts (Credit: Özdemir)

On the next page, Figure 3-79: DCP mounted on an unpressurized surface vehicle. The pods are seen in both configurations (Credit: Özdemir)

[52] The root segment of the DCP can also be considered as an extension of the backpack module of the spacesuit.


mc5
DCP Deployable Camping Pod
crew
crew
DCP
(stowed)
DCP
(deployed)

Compatible with DCP units, rear entry suits will be used by buggy crews. Based on the current Russian suit design, the rear entry suits provide practical ingress and egress without dismantling the suit into segments, like American spacesuits. Furthermore, rear entry suits are planned to be used in combination with suitport interfaces in the currently planned future planetary habitats.

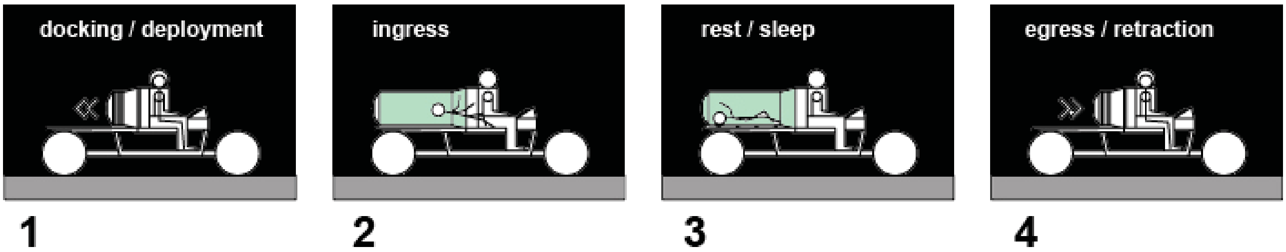


Figure 3-80: Operational sequence of DCP (Credit: Özdemir)

The typical operational use of the DCP, as depicted in Figure 3-80, is divided into the following steps:

1. Astronaut docks onto the DCP, which is attached to the seat back. DCP unit is pressurized and expanded to its full configuration. The pressure level of the DCP and the space suit are equalized. All systems of the DCP are activated. (e.g. air conditioning, lighting)

2. The hatches between the spacesuit and the DCP are opened, controlled by the astronaut, and the astronaut passes into the DCP.

3. The astronaut rests, relaxes, communicates and sleeps in the unit during the stay.

4. At the end of his / her stay, the astronaut passes back into the spacesuit. Upon closing of the hatches, the DCP, if it is not to be used again, is depressurized and retracted into the stowage position. The astronaut docks off from the DCP.

A variety of alternative uses can be configured for DCP units. One critical factor in this frame may be the compatibility with the rescue operations. The safety of crews and the missions can be enhanced by solid rescue operation plans.

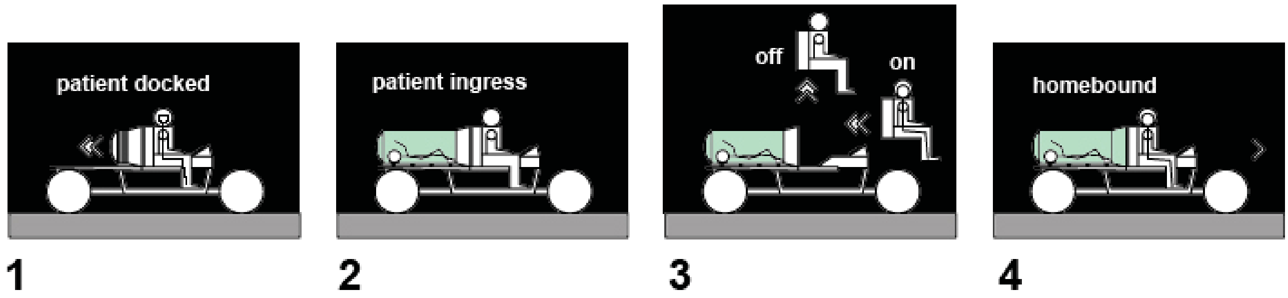


Figure 3-81: A DCP-based rescue operation scheme (Credit: Özdemir)

A rescue operation function is applicable using the DCP as a patient transport unit. The rescue operation is described, as seen in Figure 3-81, in the following steps:

1. The patient to be transported is suited and docked onto the DCP.

2. DCP is deployed and the patient passes into the DCP.

3. The hatches between the DCP and the suit are closed. The empty suit is removed by the buggy crew. The buggy crew takes the driving position.

4. The buggy crew drives the vehicle to the main surface base, where the patient will be treated.

This rescue / patient transport operation profile can only be applied when the patient is conscious and is able to pass into the DCP on his / her own. The most important advantage of this configuration is the ability to rescue two people by using just one suit for transport between the endangered habitat and the DCP equipped buggy.

As a result of the design transfer and the development process in the DCP case, a versatile on-board habitat unit is obtained. The surface crews are faced with long and exhausting EVAs during their missions. DCPs are thought to provide the crews an option to rest, relax and even to read a book or watch a film during their high-performance and dangerous missions. The DCP can enhance the surface excursion missions with camping at way-points, extending the exploration range of a buggy dramatically.

4 Results

The findings of the design research, presented in this PhD work can be classified under the following titles:

- **Capability of the proposed system to transfer designs from the terrestrial extreme environments to space environment**

The proposed design transfer method is applied to five different design cases, where inhabited planetary structures (i.e. Kopernikus 2 Station and an unpressurized lunar vehicle) were the host projects, serving as testbeds for the research work. The transfer method proved to provide appropriate concepts to be integrated into the host design projects. Design features from:

- Diving bells
- Temporary maintenance structures
- Free-fall lifeboats of ocean-going vessels
- Mono- / Diwheel vehicles
- Spatial layout of the military submarines
- Polar expedition habitats
- Container terminals
- Portable shelters

are transferred to the Kopernikus 2 Lunar Logistics Station and Unpressurized Lunar Surface vehicle design concepts. The transferred design features are adapted and integrated into the target designs, taking the lunar environment and the intended operational conditions into consideration. The adopted features brought significant design improvements from proven terrestrial extreme environment concepts, in regard to high levels of operational qualities (e.g. safe and fast evacuation of the crew in free-fall lifeboat vehicle design case)

Figure 4-1: The spatial aspects of military submarines provided valuable design features for the Kopernikus 2 Lunar Logistics Station in the research work. Image, depicting the recreational use of the wintergarten platform of a German U-boat by her crew. (Credit: Kaplan)

- **Systematic transfer of terrestrial designs , in order to construct a space structure design concept**

Using the proposed transfer process, a systematic approach to the design transfer issue in space infrastructure planning is intended and applied. Following the identification of the requirements and the target of transfers, a number of terrestrial role models are searched, found, evaluated and adapted to lunar environment using the same transfer structure. The systematic handling of the design transfer processes provided:

  - A high and stable level of design quality in all model cases, avoiding fluctuations in the overall integrity of the design concepts

  - Identification of all potential donor concepts from terrestrial extreme environments, leaving no unevaluated relevant role models behind

  - Transfer of all applicable features, provided by donor designs, enabling the author to use every terrestrial role model efficiently

The transfer processes, presented in this PhD work may have been done also singularly and using no methodical approach, however, the results would probably vary, in regard to their functional quality and integration into the target design concept.

- **Practicability of the proposed system as a design tool**

Throughout the entire research, presented in this PhD work, the proposed design transfer method was tested to see, if it could become a standard tool for designers, working on extreme environment design concepts. Standard processes and a clear procedure are thought to be the key factors for the method to be used practically by designers. When enhanced with a unified extreme environment database (see section 8), the transfer method can be easily integrated into the design work for planetary exploration infrastructure and other extreme environments.

- **Possibility of integrating space-based role model designs into the transfer process**

Although this work is focused on the design transfer processes from terrestrial extreme environments to space structures, the feasibility of using space-based role models as donor concepts for the transfer is also tested. The following design concepts that are developed for space use provided features to be used in the target concepts:

  - Soyuz crew capsule, with the focus on crew escape vehicle for the ISS use (see model case 2)

  - Personal Rescue Enclosure (PRE) of NASA, with the focus on crew escape option issue(see model case 2)

  - One-person space habitats (e.g. Collapsible Hyperbaric Chamber) (see model case 5)

The above mentioned design concepts enabled the author to identify and incorporate relevant aspects that need minimal adaptation, due to their space-based characters. This way, an option to use the proposed method for inter-space transfers is demonstrated. This option can help future work on the method for development into a design transfer system for all extreme environments.

- **Compatibility with student projects**

The use of the Kopernikus 2 Lunar Logistics Station, which is based on a design concept developed on the Lunar Base Design Workshop by a group of architecture and engineering students, represents the compatibility of the proposed transfer method with educational activities. The design transfer method is thought to be used also by students to improve their projects, while discovering more about the extreme environments through the transfer process.

- **Compatibility with planetary exploration infrastructure planning**

The last model case of the research segment demonstrates the use of the proposed design transfer method in the current planning work for the future planetary exploration infrastructure. The design process of a vehicle based one-person habitat for lunar surface crews is made using the proposed design transfer system. The terrestrial role models like temporary shelters, provided valuable transfer material, in regard to structural and operational issues. This design concept is presented to European Space Agency and has been registered as a product of the planetary exploration infrastructure design study. The proposed design transfer method proved to be compatible with the planning process for the future infrastructure on the Moon and Mars.

Having covered the observed benefits of the proposed design transfer system through the research work done, some deficiencies are also identified, namely:

- <u>Difficulties encountered during the literature search segment of the method</u>, concerning the access to all relevant terrestrial extreme environment design concept records in the literature. This problem is thought to be solved by the use of a database for extreme environment designs, to ensure the availability of all the knowledge possessed on the extreme environment design concepts.

- <u>Lack of standardized search tags,</u> which has a direct impact on the literature search segment. The possible solution is also incorporated in the use of a common database for extreme environment design concepts, where search criteria is standardized.

The future work, needed to be done to improve the proposed design transfer method into a system, which can be used as a design tool is explained in the next section in detail.

Figure 4-2: The bow segment of a nuclear submarine during transport to assembly facility through the streets of a small town. We need accessible and relevant design knowledge rather than common or garden architectural design references. Space is an extreme environment! (Credit: Getty Images)

5 Further work & Recommendations

A certain amount of work still has to be done, in order to bridge the gaps in the proposed design transfer method and improve it to a handy design tool to be used for the planning work for the space and other extreme environment structures. The recommendations for further work are listed below:

Construction of a common language / understanding of terms, criteria for all extreme environments:

In order to establish a universal design transfer system for extreme environment designers, standard terms, as components of a specific terminology have to be developed to define the situations, elements, concepts and techniques that are related to extreme environments. This terminology can serve as a basis for the search criteria to be used in a unified database of extreme environment designs. This way, all the designs that are developed for various extreme environments can be incorporated within a system, where the designers exploit all the available knowledge and experience related to human presence and activities in extreme environments.

Figure 5-1: Building an Igloo. Every piece of human knowledge on extreme environments has to be utilized for future extreme environment endeavours like space exploration. (Source: www.cbc.ca)

Extending the coverage of design transfer processes:

The entire research in this PhD work is focused on the development of a design transfer method, to transfer design concepts from terrestrial extreme environments to space structures. However, the proposed transfer method can be improved to a system that enables transfers between all kinds of extreme environments and in all directions, apart from terrestrial to space, like:

- Space to terrestrial
- Space to space
- Terrestrial to terrestrial

A similar evaluation and transfer process of role model designs is thought to be possible. The key factor to this type of use of the system is the availability of a extreme environment design database, providing access to concepts, developed by humans for extreme environments.

Furthermore, various configurations for a future design transfer system can be designed, which are suitable for specific fields of extreme environment operations. For instance, the system can be configured to produce peaceful extreme environment uses for military systems, by developing standard relations in the database structure.

A database concept as the future core of the system: E2D2 Extreme Environment Design Database

Having identified the importance of the literature search on extreme environment designs, the construction of a database of the designs that are developed for extreme environments is considered as the next step by the author in design transfer research. Replacing the literature search in various media in the proposed design transfer process, a database of extreme environment designs provide:

- Systematic and safe storage
- Efficient and fast retrieval

of the knowledge on extreme environment designs. This way, the proposed design transfer method can indeed be converted into a design tool for every planner and researcher. The construction and expansion of the database, respectively, can be configured as an educational research project, where students study and evaluate the extreme environment designs systematically, producing new records for the database.

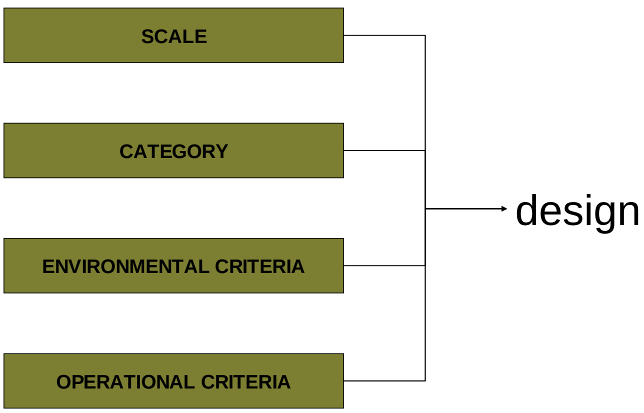


Figure 5-2: Each design is defined by a number of attributes in the database

E2D2 is aimed to be a structured collection of extreme environment design records, where each design has an info-card as an interface to users. The designs are to be tagged with specific categories and criteria that form a group of attributes. These are used to classify, store and retrieve the designs efficiently in the system. The main attribute groups, as seen in Figure 5-2, are as follows:

- Scale of the design identifies the overall scale of the design concept (i.e. element, system, technique)
- Category indicates the classification, in regard to the use of the design as well as the operation environment (e.g. military).
- Environmental criteria define the components of the operation environment of the design, in universal extreme environment values (e.g. pressure extreme, temperature extreme). Other than the previous attribute groups, environmental criteria have sub values for each.

As an example, when categorizing a nomad tent built for desert use, the operation environment has the following designation:

Environmental criteria 1: extreme temperature fluctuation
, considering the vast temperature changes between day and night in the desert

Frequency: day / night

Difference span: 30-60°

Environmental criteria 2: humidity extreme, in regard to the extreme dry environment

Value: Very low

- Operational criteria, similar to environmental section, defines the operational values of the design. These criteria may also have sub categories, as seen in the nomad tent example below:

Operational Criteria 1: mobility
, considering the transportability of tent structure by camels or light vehicles

Category: transport weight

Value: low

Operational Criteria 2: adaptability, in regard to use the material for other purposes (e.g. tent sheet as a floor insulation material)

Category: Multi-use character

Value: High

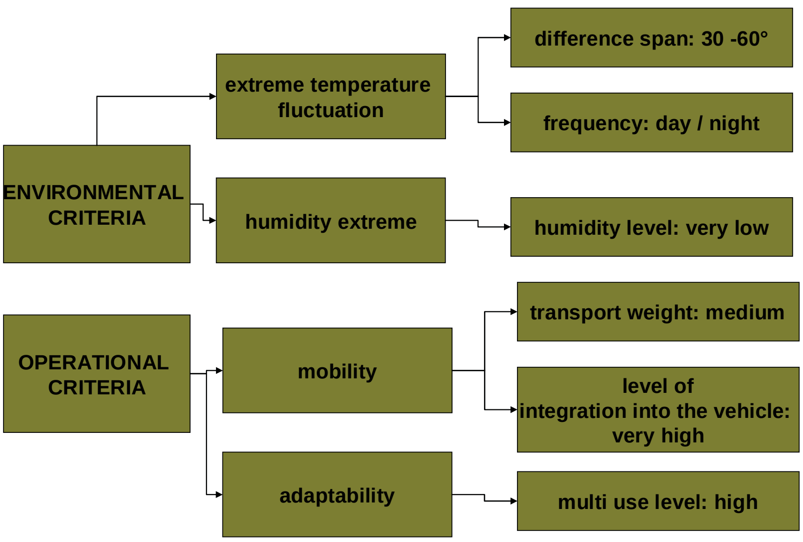


Figure 5-3: The attribute diagram for a nomad desert tent, depicting the environmental and the operational tags

The attribute groups, described above, are considered as the main designation tags for each extreme environment design in the database, E2D2. Using these tags, in other words the criteria, the extreme environment designs can be registered, classified and retrieved easily. Taking the networking of all attributes to each other in modern database structures into consideration, the user can make a custom search, typing in a self-defined composition of criteria.

The main interface of the designs to the user is the information card, where all designation values are integrated. The name, location, category, and operational / environmental criteria form the identity codes of the design role model. An explanatory image of the design, as well as a brief information text is placed on the card. Links for extended search are also provided via website links and references. A collection of E2D2 cards, related to the design cases of this PhD work can be seen in the Appendix section.

Figure 5-4: A possible prototype for the database cards. Using E2D2 cards, designers can easily overview a pallet of related extreme environment structures (Credit: Özdemir)

E2D2 can be constructed and extended as an educational network project. The database construction can be configured to become a joint effort, involving academic and professional design institutions, providing the students with important experience in cooperative studies, as well as new resources for the space and other extreme environment design development efforts.

Two main search options are identified for the effective use of E2D2. Depending on the conditions of the experience and knowledge of the user in extreme environment design, the appropriate search method can provide efficiency in the search & transfer process.

The detailed search method is the standard search application to be used in design processes. For the detailed E2D2 search, the operational and the environmental search criteria related to the target design have to be identified. These criteria are fed into the database search engine in order to find the relevant terrestrial extreme environment designs. The detailed search is the search method used when the designer applies the normal transfer process. This search method can be applied by any designer, also by the ones who have limited or no knowledge on terrestrial extreme environment structures.

Example: Free-fall lifeboat units of Kopernikus 2 Lunar Logistics Station

The literature search process of the model case 2, for the crew escape vehicle designs of the Kopernikus 2 Station can be replaced by a database search, made by "the detailed search" method. The search keywords, acquired from the initial evaluation of the target design segment are:

- Underwater habitat crew escape systems (e.g. submarine emergency evacuation)
- Surface vessel and off-shore platform crew escape systems
- Space station escape systems
- Mono- and diwheel mobility systems

These can be simplified down to a number of search criteria, for an efficient database search. The search is done in two segments, in regard to two different design aspects, as seen below:

- **Operational aspect**

Category: crew escape in all systems (e.g. military, utility etc.)

Character: Element and System

Operational criteria: Deployment

Category: Speed

Value : High

Environment: Underwater / Surface / Space

- **Mobility Aspect**

Category: Mobility

Character: Element and System

Environmental criteria: Operation medium

Category: Terrain

Value: Rough

Once fed into the database search interface, these criteria direct the system to produce the following role models[53] for evaluation and transfer:

- Free-fall lifeboats of ocean-going vessels
- ISS crew escape system
- PRE crew escape system
- Zorbing sphere
- Kugelpanzer

[53] Related database cards can be viewed in the appendix section.

The direct search method is suitable for designers with experience on extreme environment structures. In a direct search, the user provides directly the role model name of interest to reach extensive information. The direct search method is appropriate for design cases, where there is an intention for a specific group of designs, to use them in the process. The direct search skips the detailed identification of the target design segment and the relevant factors. Another use of this method may be for an enquiry on a specific category of extreme environment designs, which happens often in a typical design process.

Example: Container terminal system of Kopernikus 2 Lunar Logistics Station

Having identified the need to configure the container handling system of the Kopernikus 2 Lunar Logistics Station in model case 4, the terrestrial container terminals are identified as potential role models that can provide solid transfer material, in regard to container handling, transport and storage. Therefore, the direct search method is to be applied in this case using the following criteria:

Category: Container terminals

This way, the designer reaches directly the container terminal records, to study the relevant features of the role model of interest.

As a conclusion after having identified the present situation of the research and the future work to be done, the author would like to express his belief on the practicability of the presented transfer method for all extreme environment infrastructure planning activities.

6 Appendix

In this section, database card models are presented. These prototype models reflect the functioning principle of the future extreme environment design database (E2D2).

definition: confined-space unit for underwater operations

category: underwater – utility

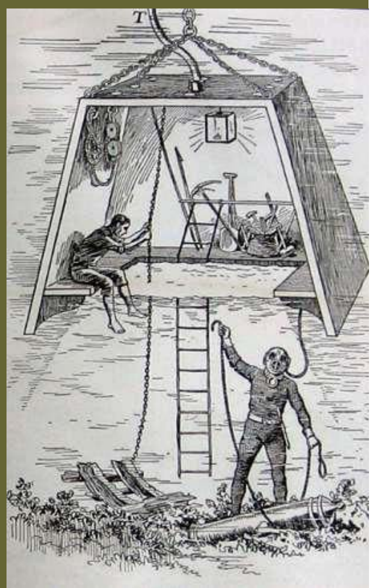
scale: element

literature links for extended search

operational criteria	**category**	**value**
deployment	speed	low
crew access	in action	low

environmental criteria	**category**	**value**
pressure extreme	underwater	very high

A diving bell is a cable-suspended airtight chamber, that is lowered underwater to operate as a base or a transport unit for underwater operations. Diving bells are designed and used systematically since 17.century. Diving-bells are constructions, that are closed at the top and the sides. The bottom is open. The air-pressure inside the bell is kept at the ambient water-pressure on the bottom of the bell, so that the inside is kept dry. Diving-bells in different forms and sizes have been used since ages to salvage cargoes and to fulfill underwater construction-works. To prevent floating up and capsizing, diving bells always have to be heavy, and can be used only when adequate lifting-capacity is available.



Diving Bell

definition: integrated rapid dispatch rescue boat

category: marine - rescue

scale: element

literature links for extended search

operational criteria	**category**	**value**
deployment	speed	high
efficiency	readiness	high

environmental criteria	**category**	**value**
operation medium	sea surface	rough

Free-fall lifeboats are integrated crew rescue systems, designed for ocean-going vessels. The fast and simple deployment system, easy access and robust structure of these units provide a high degree of reliability in emergency cases. Free-fall lifeboats are watertight structures and can sustain a specific number of inhabitants at emergency cases, with integrated life-support and communication measures.

Free-fall Rescue Boat

definition: deployable on-board rapid escape system

category: marine - rescue

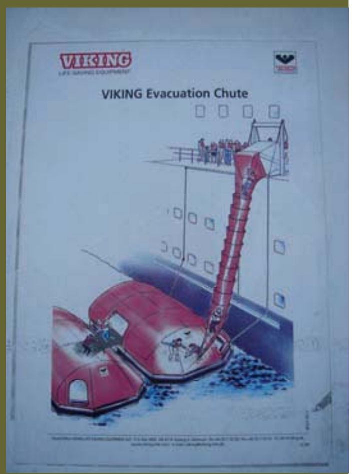
scale: element

literature links for extended search

operational criteria	category	value
deployment	speed	high
storage	compactness	high

environmental criteria	category	value
operation medium	sea surf.	rough
atmospheric extreme	wind	rough

Evacuation chute is an on-board integrated escape system for large vessels. The system is stowed on the decks in special casings, which are opened up in an emergency case and expand the membrane chute for evacuation. The practical storage, simplicity and the rapid deployment capability of the system are the main advantages of this concept.



Evacuation Chute

definition: one-man armoured vehicle

category: military – mobility

scale: element

literature links for extended search

operational criteria	**category**	**value**
mobility	efficiency	high
mechanics	complexity	low

environmental criteria	**category**	**value**
operation medium	terrain	rough

Kugelpanzer is a one-man armoured infantry vehicle design from WW II, designed to provide close battleground support during infantry attacks. One prototype was built, without armament,and a fully equipped vehicle never saw operation. The two wheels covering the whole flanks of the unit gives a redundant level of mobility, while keeping the mechanical complexitylevel considerably low.

Kugelpanzer

definition: recreational mobility unit

category : recreation - mobility

scale: element

literature links for extended search

operational criteria	category	value
mobility	complexity	very low
mechanics	complexity	very low
human factor	fun level	high

environmental criteria	category	value
operation medium	terrain	rough

The zorbing sphere is a double-hulled structure, with an inner sphere, acting as the passanger cabin. The passangers are strapped into place in the inner sphere, in order to prevent continous and uncontrolled rolling in the cabin. The zorbing sphere is just set free on an inclined and sometimes bumpy trackfor the action. It has no means of steering or proper self generated propulsion.

Zorbing Sphere

definition: diving suit

category: underwater-habitation

scale: element

literature links for extended search

operational criteria	category	value
visibility	direction	multi
structure	bulkiness	high

environmental criteria	category	value
pressure extreme	underwater	very high

Being one of the ancestors of contemporary hard shell diving suits, carmagnolle suit resembles the initial solutions to visibility and maneuverability problems of bulky hard shell diving suits. The multi vectoral viewports, covering the front segment of the helmet were thought to provide a wide angle of vision to the user. The whole suit looked like a body armour, in regard to the bulky structure and the integrated joints.

Carmagnolle diving suit

definition: using operation unit for sleeping during missions

category: military-habitation

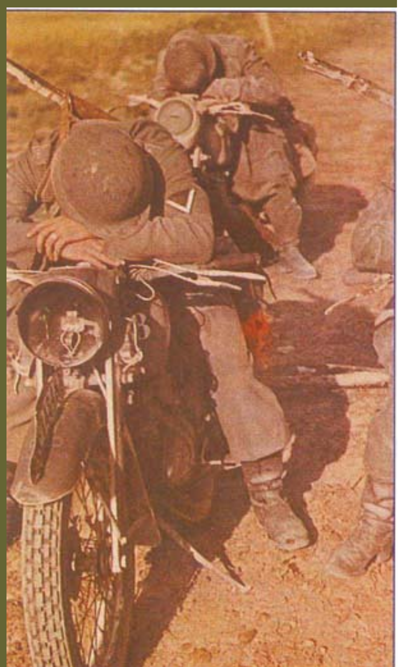
scale: technique

literature links for extended search

operational criteria	category	value
operational efficiency	readiness	very high

environmental criteria	category	value
temperature extreme	external	differing

Depending on their duties, daily routines and the environment, it is often a normal case that people use their vehicles as a temporary habitat / shelter. The mobility unit, the vehicle or a draft animal, can provide a shelter or help to build one, in case of sleeping during the ride, duty or operation. Staying in, on, under or near the mobility unit, the user keeps operational readiness level high and can exploit various systems of the unit (e.g. power, structural system.



Sleeping on the operation deck

definition: portable sleeping unit

category: outdoor – habitation

scale: element

Literature links for extended search

operational criteria	**category**	**value**
deployment	manual	low-speed
transport	weight	very low

environmental criteria	**category**	**value**
temperature extreme	external	low /high
atmospheric extreme	rain /wind	medium

Designed to be used in outdoor environments for camping, duties or in case of emergencies, the portable shelters provide their users an insulated sleeping place. Cocoon 4 is a sleeping pod, developed for motorbike campers, thought to be used for extended tours. The structure is completely insulated against temperature and atmospheric extremes.

Cocoon 4 Sleeping System

definition: portable sleeping unit

category: outdoor – habitation

scale: element

literature links for extended search

operational criteria	**category**	**value**
deployment	manual	low-speed
transport	weight	very low

environmental criteria	**category**	**value**
temperature extreme	external	very low
atmospheric extreme	wind/snow	high-speed

Mummy-type sleeping bags are designed for extreme sport fans, to be used in harsh mountain conditions, where temperature and atmospheric extremes can pose a high level of disturbance to the camping activities. These units can easily be carried in bacpacks and be deployed/retrieved instantly, on every type of terrain, providing the user a safe haven during resting hours.

Mummy-type sleeping bag

definition: portable unit for survival in extreme conditions

category: disaster relief-habitation

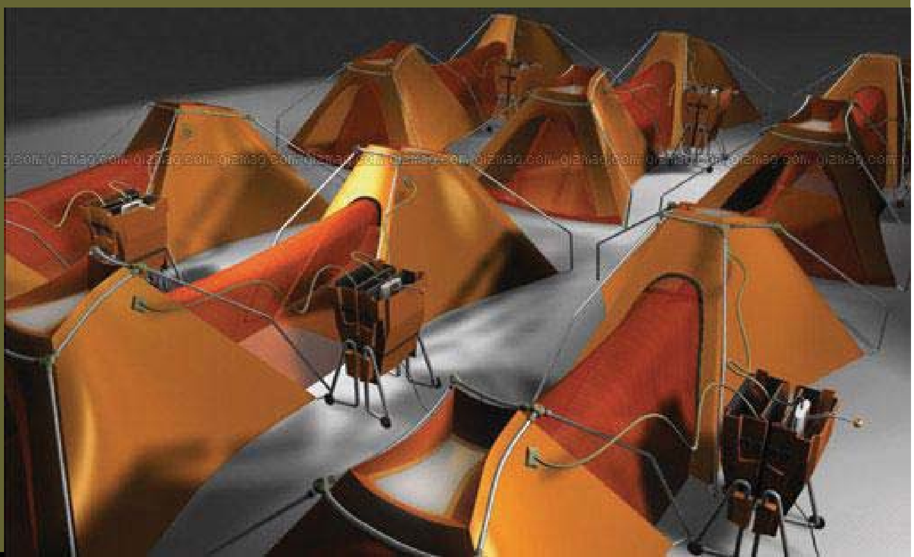
scale: element

literature links for extended search

operational criteria	**category**	**value**
self-sufficiency	ext. infrastructure	independent

environmental criteria	**category**	**value**
hazards	contamination	high
atmospheric extremes	rain	high speed

The Survival Pod is a waterproof shelter, a storage unit for first aid and food supplies, an emergency stretcher, a water purification unit and even a lifeboat in extreme situations. The compact, durable design from Euforia Design was inspired as a response to the devastating and recurring flood situation in Mozambique that leaves hundreds of thousands homeless and bereft of clean water, food and shelter



Portable survival pod

definition: terminal system for logistics

category: transport system

scale: system

literature links for extended search

operational criteria	**category**	**value**
autonomous operation	overall	high
efficiency	storage	very high

environmental criteria	**category**	**value**
atmospheric extreme	rain/ wind	medium speed

A container terminal is a facility where cargo containers are recepted, stored and transshipped between different transport vehicles, for onward transportation. Container terminals primarily serve as an interface between different modes of transportation, e.g. domestic rail or truck transportation and maritime transport. The transhipping of containers between loading, unloading and storage categorys require planning and precise operational coordination of bulky systems and equipment.

Container Terminal

definition: spatial arrangement of Type VII C German U-Boat

category: underwater – military – habitat

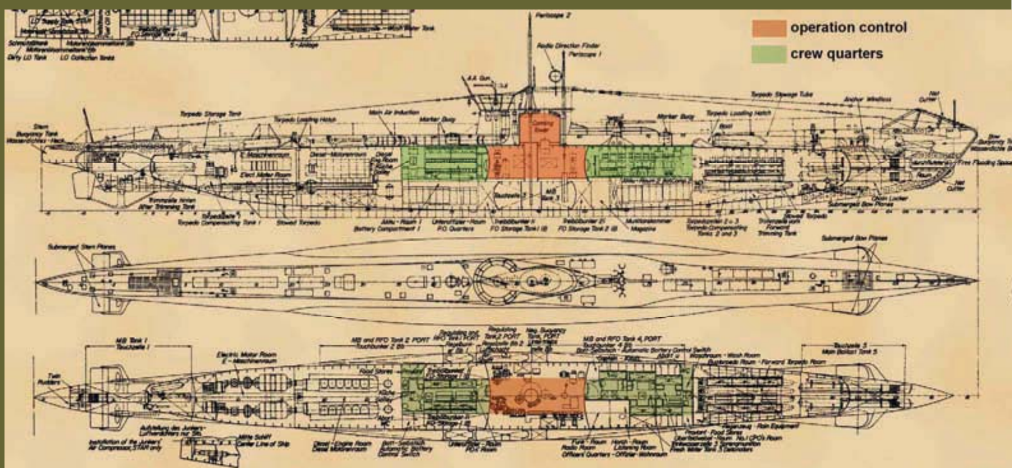
scale: system

literature links for extended search

operational criteria	category	value
layout	orientation	operational
human factors	habitation	low
efficiency	readiness	very high

environmental criteria	category	value
pressure extreme	external	very high

The crew quarters and the operational command & control spaces of type VIIC are arranged around the core of the system, the conning tower. The crew spaces diffuse into the utility areas, providing a high level of operational effectiveness while creating in a considerably distracted level of habitation quality.



U-Boot Type VII C _Spatial Configuration

definition: spatial arrangement of Astute class submarines

category: underwater – habitat

scale: system

literature links for extended search

operational criteria	**category**	**value**
layout	orientation	operational
human factors	habitation	high
efficiency	readiness	very high

environmental criteria	**category**	**value**
pressure extreme	external	very high

The spatial configuration of astute class submarines are dominated by a central area of operational command&control, extending to both ends of the vessel. The crew compartments are placed underneath the operational control area, isolated from utility spaces and providing the crew good conditions for habitation.

Astute Class Submarine _Spatial Configuration

definition: underwater vehicle for touristic trips

category:	touristic-underwater-excursion
scale:	element

literature links for extended search

operational criteria	**category**	**value**
visibility	direction	multi
human factors	comfort	high
	safety	high
	fun level	high

environmental criteria	**category**	**value**
pressure extreme	external	very high

Tourist submarines are submersible vessels, built for touristic underwater trips. A high level of safety , visibility and comfort are the cornerstones of a tourist submarine design.

Tourist Submarine

definition: definition

category: category

scale: scale

Literature links for extended search:

links

operational criteria	**category**	**value**
criteria	category	value

environmental criteria	**category**	**value**
criteria	category	value

text

image

Database Card Prototype

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List of Abbreviations

CHC	Collapsible Hyperbaric Chamber
DCP	Deployable Camping Pod
DMU	Deployable Maintenance Unit
ESA	European Space Agency
ISS	International Space Station
SMU	Surface Mobility Unit

9 Curriculum Vitae

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Research

2004 - Current	Participation in various space-related research projects as a member of Liquifer Systems Group, Austrian based cross disciplinary research team
2005	Participation in Moon-Mars Workshop, held at ESTEC Facility of ESA, as organiser
2003	Participation in the Aurora Student Contest of ESA, with asteroidal human settlement scenario “NOMADS”
2002	Participation in Lunar Base Design Workshop, held at ESTEC facility of ESA, as a member of the team “KOPERNIKUS”
1999 - Current	Extreme environment field experience as professional SCUBA diver and rescue team member

Professional

1997 - Current	Professional practice as architect in various offices in Istanbul and Vienna

Education

1998 - 2001	Masters Study at the Academy of Fine Arts, Istanbul. Master Thesis on Machine Aesthetics
1992 - 2001	Bachelor Study at the Academy of Fine Arts, Istanbul