POSITION PAPER ON

THE ROLE OF SPACE ARCHITECTURE IN THE 21st CENTURY

International Academy of Astronautics

The International Academy of Astronautics (IAA), a non governmental organization recognized by the United Nations, was founded in 1960. The purposes of the IAA are to foster the development of astronautics for peaceful purposes, to recognize individuals who have distinguished themselves in areas related to astronautics, and to provide a program through which the membership can contribute to international endeavors and cooperation in the advancement of aerospace activities.

Position Paper on The Architecture of Space: Tools For Space Development In The
21st Century
Edited by:
Printed by
Code ISBN/EAN
International Academy of Astronautics
6 rue Galilee, BP 1268-16
75766 Paris Cedex 16, France
Cover Photo / Illustration: NASA

International Academy of Astronautics

Position Paper
On
The Role of Space Architecture
In the 21st Century

Table of Contents

Introduction

For about a half century, humans have ventured into space. What began as nationalistic adventurism evolved to footsteps on the Moon, sustained operations in Earth orbit, and inchoate space passenger travel. Humankind has now begun to inhabit the alien environment of space – a place of altered weight, hard vacuum, extreme temperatures, and lethal radiation, but also a place of novel sensations, breathtaking views, and expanding frontiers of knowledge, experience, and being.

Designing for this new human domain is what the field of Space Architecture is all about. *Space Architecture is the theory and practice of designing and building the human environment in outer space. It is a unique discipline by combining attention to technical systems, human needs for working and living, and human reactions to the natural and built environments. It is simultaneously technical, pragmatic, humanistic, and artistic.*

Progress in human space flight has brought long-duration missions, large-volume complexes, multi-cultural crews, non-specialists, and paying tourists. During some shuttle visits, ten people have occupied the International Space Station at one time. Many considerations familiar to terrestrial architects – productivity, privacy, assembly, aesthetics, place identity, sensations, view, mood, safety, utilities, and adaptive use, to name just some – are increasingly relevant to the design of habitable environments for outer space. In addition, living in space brings into sharp focus some new considerations increasingly important to architecture on Earth: sustainability, material recycling, regenerable life support. So Space Architecture is a two-way bridge to a better future, connecting how we have lived with how we can in the future, via how we must in space.

Understandably then, Space Architecture is an ascendant topic among some professional societies (American Institute of Aeronautics and Astronautics, Society of Automotive Engineers International Conference on Environmental Systems, American Society of Civil Engineers) and some universities (University of Houston Sasakawa International Center for Space Architecture, Lund University, Technical University of Vienna, Southern California Institute of Architecture). The International Academy of Astronautics' Commission VI formed a Space Architecture Study Group (SASG) in October 2005 to recommend international and Academy actions in this area. This paper is the result. Its goal is to bring attention to importance of reflecting all aspects of human being throughout space structures design process and to encourage the industry to involve professionals from diverse disciplines into design development at its early stages.

- The Academy recommends that organizations and projects undertaking the design of human accommodations in outer space specifically engage the professional contributions of space architects.

The SASG elected to focus on "Tools for the 21st Century," meaning the *development of new theories, methods, and forms of engagement among professional disciplines to advance the field of Space Architecture in the quest for better, more effective, and more ennobling human environments in space.* The SASG capitalized on the individual interests of its members to develop recommendations in four diverse aspects of Space Architecture: human/system interaction (**Human Factors**), terrestrial facilities that model mission conditions (**Space Mission Simulators**), humanistic expression (**Art**), and training that integrates the other topics to prepare future generations of space architects and to introduce space architecture discipline and its aspects to engineers (**Education**). The Academy commits these recommendations as illustrative of the breadth of topics addressed by Space Architecture, and hopes future Academy study groups will take up additional topics, such as Habitable Space Structures, Integration of Life Support Systems, Interior Design for Reduced Gravity, Application of In Situ Materials, or Commercial Space Systems and Facilities.

Human Factors

New and advanced space missions will impose new kinds of interactions: crew members and passengers with one another, with their tools, with Earth-based operators and supporters, and with their environments. Future crews will rely on higher levels of system autonomy, be more reliant on in situ improvisation and problem solving in conditions where it will not be possible to predict and rehearse every contingency. Future generations of spacecraft habitats must enable new partnerships among people, standardized hardware and intelligent machines (e.g., on-board computers and robots) to reduce maintenance overhead and automate routine tasks and operations.

- The Academy recommends Space Architecture be developed as a powerful tool to achieve a seamless amalgam of environments, tasks, people, machines and operations.

Human drivers for architectural design are usefully parsed into four domains: the biological (including life support), the ergonomic (including human-machine interaction), the psychological (including human reactions to isolated, confined, and hazardous environments), and the sociological (including how people interact with each other in extreme circumstances).

- The Academy recommends Space Architecture design projects attend explicitly to drivers from the four domains: biological, ergonomic, psychological, and sociological.

Space Architecture is an embryonic field; to date all spacefaring scenarios center around small government or private “mission crews” each having a specific, bounded purpose. A second type of human-in-space scenario – “passengers” – characterized by leisure or business travelers without professional in-flight duties or extensive pre-flight screening or training, is now emerging. A third type – “settlers” – can be reasonably projected to emerge late in the 21st century, who will make space their permanent homestead. These three types of spacefaring populations require distinct architecture solutions, as the scale and complexity of their biological, ergonomic, psychological, and sociological drivers vary considerably.

- The Academy recommends that research elucidate differences among space mission populations comprising crews, space passengers, and space settlers, and determine how they drive an evolutionary progression of Space Architecture in the coming decades.

To date there are no significant supporting examples of implemented space architecture that has been optimized for populations other than mission crews; spacefarers so far have been either (1) government mission crews; (2) one paying passenger temporarily mixed in with such crews; or (3) suborbital flight-test crews. The next types of populations are likely to be (1) mixtures of more than one paying passenger at a time, e.g., on the ISS; and (2) suborbital flights of small groups of paying passengers. Current work in the private sector to design suborbital vehicles and flight experiences for such tourist groups (e.g., Virgin Galactic, Rocketplane) is anticipated to begin driving out architectural differences, such as large windows and visibility from all seats.

Space Mission Simulators

Space mission simulators are facilities for testing one or more aspects of potential space missions in a controlled, measurable, and repeatable way, as the missions, mission systems, and crew training are still under development. The goal of using simulators is to uncover issues before the actual mission, thereby reducing risk, cost, and uninformed design choices. Simulators have been used since the earliest days of space travel.

However, there is no easy way to access and compare data from past simulation campaigns. Considering the resurgence of interest in human missions to the Moon, Mars, asteroids and beyond, an online, comprehensive database archiving simulator projects from around the world – past, present, and future – would be highly useful.

- The Academy recommends an Online Global Simulator Database be created to aggregate and archive simulation data from international partners engaged in Earth-based human space mission simulations.

Simulators designed under strong budgetary and programmatic constraints often focus narrowly on a few research objectives, which sacrifices overall simulator architecture and operations fidelity. The interactions among systems and sub-systems, which lead to many real-world failures, thus remain largely unstudied, leaving gaps in understanding that may be costly.

- The Academy recommends that entities conducting Earth-based human space mission simulations set high standards for architectural, operational, environmental and psychological fidelity.

Space mission simulators can be broadly classified into two kinds: partial and full mission simulators. “Partial simulators” focus on certain aspects of a mission (e.g., life support system interactions), while “full mission simulators” take an integrated approach to simulating the entire mission: e.g., launch, transit, landing on a planet or other celestial body, surface stay, ascent from the planetary surface, transit back to Earth, and landing on Earth. To simulate long-duration planetary missions, a stay that fully interfaces with surface exploration systems and tasks (e.g., live field geology) is key.

- The Academy encourages space agencies to develop full-mission simulators to prepare for long-duration missions to the Moon, Mars, asteroids and beyond.

Mission crews can be expected to become more multinational in the future. Through analysis of past simulations and space missions, crew dynamics has emerged as critical to successful functioning and morale, and also heavily dependent on crew composition. Yet the only truly international space mission simulation ever conducted was in 1999, during an isolation campaign at the Institute for Bio-Medical Problems (IBMP) in Moscow, called the Simulation of Flight of International Crew on Space Station

(SFINCSS). The crew composition, comprising Russian, German, Japanese, Austrian, and Canadian crew members, was somewhat reflective of ISS crews. The SFINCSS campaign demonstrated that the clash of languages, as well as cultural and gender differences, could make cohabitation stressful to the point of walkouts and violence. Simulations using cross-cultural and cross-gender crews are indispensable for researching such issues.

- The Academy recommends future simulations take into account real-life mission scenarios in terms of representative crew size and composition.

Habitat design can influence crew behavior and performance, and therefore mission success. Well-designed habitats provide countermeasures to mission stressors. Simulators can help obtain valuable insight into habitat design parameters such as layout, habitable volume, windows, lighting, and color. Such parameters can be varied in response to findings from successive simulation campaigns or even during a single campaign.

- The Academy recommends that habitat design be integrated into the overall research agenda of human space mission simulations.

Supporting Examples

The ISEMSI-90, EXEMSI-92 and HUBES-94 isolation studies conducted by the European Space Agency (ESA) were exemplary. The experimental protocol of ISEMSI-90, EXEMSI-92, and HUBES-94 confined crews in closed habitats, varying simulator architecture (i.e., four, two, and one main chamber(s) respectively); crew size (i.e., six, four, and three respectively); and duration of the simulation campaign (i.e., 28, 60, and 135 days respectively).

The NASA Extreme Environment Mission Operations (NEEMO) simulator is currently operational using the Aquarius underwater facility off the Florida coast. China and India are contemplating long-duration human missions, so they too will likely conduct Earth-based simulations. Since future missions to the Moon and beyond are likely to have international crews and systems, it is important for the various entities engaged in Earth-based simulations to find ways to meet, interact, and share research activities and experiences.

ESA and the IBMP plan to initiate a new series of long-duration space mission simulations called “Mars 500,” leading up to a final, unprecedented, long-duration Mars mission simulation of nearly 520 days. This will involve a crew of six living and working in a complex of six interconnected, hermetically-sealed modules in a Moscow laboratory. The Mars 500 campaign will extensively model a complete mission (e.g., interplanetary transit and surface stay duration, surface exploration activities, communication lags, autonomous crew decision-making, rationed consumables). Planned mission phase durations are 250 days for the outbound leg, 30 days for surface operations, and another 240 days for the return leg.

Art

At the beginning of the 21st Century, a unique opportunity exists for qualified artists to contribute to the world’s space programs. Creative artists can become integral, productive, and important contributors to interdisciplinary space mission design teams working to improve the human condition as we venture forth from our home planet.

Artists may offer alternative perspectives and imaginative solutions to design challenges faced by space architects and engineers. For example, artists introduced to new technologies and materials may devise innovative ways to incorporate these into human space environments in ways not conceived by space architects or engineers. This is best done by integrating artists into design teams from the beginning of projects.

- The Academy recommends integrating artists into space project teams from the earliest phases of the project lifecycle.

Interdisciplinary art – produced through collaboration with space architects, scientists, engineers, and psychologists – moves beyond simplistic views of art as merely decorative, aesthetic, or provocative “add-ons.” For art in human space environments, technology and science become “starting point” tools artists can utilize. In this paradigm, artistic concerns extend beyond aesthetics: (1) art that adapts to its environment (e.g., work/living spaces that are electronically modifiable by the user, or personalized electronic images utilizing flat-screen technology); (2) art that enhances or is capable of altering mood and environment (e.g., through the use of 3-D or binaural sound to create aural environments similar to Earth, or use of color, pattern, and light relevant to psychological states).

- The Academy recommends establishing a paradigm for art utilized in human space projects that focuses on art as a core factor enabling mission success, rather than as aesthetic afterthought.

Finding artists qualified to work within interdisciplinary teams who design the human environment in outer space presents a challenge. Success requires more than the mere desire to participate. Defining roles that artists can play in human space projects and the nature of possible contributions can help clarify expectations.

As with all space project team members, it is important for artists to be appropriately qualified. Selection criteria should consider previous work, the artist’s credo, and formal training. A review panel comprising experienced artists, space architects, engineers, and managers could support the selection process.

- The Academy recommends developing a process template for human space project teams to identify and select artists.

Preparing artists to support human space projects may require formal training through university and college programs. Space architects and engineers acting as mentors may also assist in providing artists with basic understanding of human factors, health and safety issues for living and working in extreme environments, and design approval requirements. They may also play a role determining feasibility and applicability of artists’ concepts, and assist artists with concept implementation and integration. Certification could be accomplished via certified curricula in universities and colleges or through space agencies.

- The Academy recommends that certification curricula be established by universities and colleges to facilitate adequate, specialized training of artists desiring to participate on human space project teams.

Supporting Examples

During a meeting taking place at NASA Ames Research Center, a Human Factors discussion was going on about color schemes for the International Space Station (ISS). In the next room, a team of engineers was proposing bare metal and plastic walls to save the weight of paint. An artist's aesthetics-based solution to these seemingly irreconcilable differences between the two groups addressed the needs of both. When the amount of paint to cover the interior surfaces of a space habitat is calculated, a pattern may be designed where some part of the surfaces will be painted, leaving other surfaces bare. The result is both avoidance of some paint weight and a surface treatment that could help induce a positive psychological state for occupants. Based on Luscher's color research, the choice of color could enhance this effect.

In micro-gravity, orientation within a habitat continues to be a concern for crew. The ISS currently uses color and endcone closeout shape to provide spatial orientation cues. An artist has proposed the use of 3-D or binaural sound for orientation onboard spacecraft or ISS (more information at: http://en.wikipedia.org/wiki/Binaural_recording). Crew would receive binaural sound orientation cues through headsets worn during mission assignments. 3-D or binaural sound, light, color, and imagery can be used to modify the interior space to suit a wide range of conditions and personal needs of the individuals.

Windows are a serious structural design challenge for space habitats. An artist's solution to this dilemma is to consider "virtual" windows as an alternative to actual viewports. With flat-screen technologies, relatively thin virtual windows could be installed in various locations throughout space habitats. Such virtual windows could be "tuned" to meet a variety of needs for both individuals and groups. Coupling 3-D sound with virtual-window imagery could provide a powerful sensory experience for viewers (e.g., the experience of looking out the window while riding on a train – the audio component, provided by headphones, could create directional sound such as the tracks below, signal crossings from outside, and even other trains passing in the opposite direction.

Artists, by joining human space project teams at their inception, can work in conjunction with space architects, scientists, engineers, and psychologists to help create innovative, positive space habitation solutions in both expected and unexpected ways.

Education

Education is particularly important for new fields. In the case of Space Architecture, the SASG recognizes two core needs: (1) educating the aerospace community about the architect's process and role within the enterprise; and (2) educating space architects and associated specialists about constraints, conditions, and priorities unique to human space systems.

These needs can be addressed, respectively, by two key educational tools for the 21st century: (1) introducing the Space Architecture discipline into space system engineering curricula; and (2) developing Space Architecture as a distinct, complete training curriculum.

New generations of professionals with a Space Architecture background, by offering their inherently integrative design approach to all types of space structures and facilities, can help shift professional focus from just engineering-driven transportation systems and "sortie" missions to permanent offworld human presence. Although architectural and engineering approaches share some similarities in solving problems, they also have significant differences. Architectural training teaches young professionals to operate at all scales from the "overall picture" down to the smallest details; to provide directive intention – not just analysis – to design opportunities, to address the relationship between human behavior and the built environment, and to interact with many diverse fields and disciplines throughout the project lifecycle.

Introducing the architect's approach into engineering programs at universities could be done via a series of "Space Architecture Issues and Concerns" courses. Topics of focus would include human factors and ergonomics, extreme-environments constraints and influences, and psycho-social factors.

- The Academy recommends that the field of Space Architecture become integrated into aerospace curricula through required courses.

Undergraduate and postgraduate students can be a source of creative potential for large, multilateral space projects.

- The Academy suggests that space companies involve Space Architecture students in their design process to anticipate and accommodate international, interdisciplinary, and inter-institutional cooperation at all design stages.

The increasingly multinational nature of space exploration, as well as continuing trends toward undergraduate curricula standards (i.e., the Bologna Process in the E.U.), make it advisable for students to acquire experience with full-scale international collaboration via their required and elective projects and undergraduate research. The Academy can be instrumental in providing this international perspective by hosting on-line, teleconference, and physical-meeting discussions toward this end.

- The Academy recommends that collaborative, international student projects with a Space Architecture component be a required component of aerospace education curricula.

A number of student and young-professional space design contests in recent years have demonstrated advantages as a tool for stimulating students and encouraging them to proffer their designs in a competitive environment.

- The Academy endorses international Space Architecture student contests as a productive way to emphasize multidisciplinary and system-design approaches, and views Academy conferences as appropriate venues to promote such contests.

The SASG believes there is strong potential for the Academy to directly promote Space Architecture undergraduate and postgraduate education development.

- The Academy supports distribution and promotion of Space Architecture educational projects and students' work through Academy networks, Acta Astronautica, and related internet sites.

Supporting Examples

In the summer of 2002, an international Lunar Base Design Workshop (LBDW) was hosted at the European Space Agency's ESTEC Center in the Netherlands. The lead organizers and managers of the workshop were a team of international space architects. Space experts from Europe and the United States were invited to give lectures and coach the students. Nearly 50 graduate and undergraduate students from 16 European nations worked in six multidisciplinary teams. The primary workshop objective was to highlight the importance of involving space architects in the design of future habitats, and showcase the innovative nature of multidisciplinary collaboration. It was a two-week, full-time workshop followed by another six weeks of work by the architecture students from TU-Vienna, Austria. The results were presented at ESA-ESTEC and at the architecture department of TU-Vienna, Austria. Some of the planetary base designs generated during the workshop can be seen at http://www.esa.int/esaMI/Aurora/SEMIDI1A6BD_1.html.

The Sasakawa International Center for Space Architecture (SICSA) at the University of Houston supports the world's only Master of Science in Space Architecture program. Founded in 1987 with a $3M endowment gift provided by the Japan Shipbuilding Industry Foundation, SICSA's central mission is to plan and implement programs to advance peaceful and beneficial uses of space and space technology on Earth and beyond. Many SICSA activities address extreme terrestrial environments. Established in 2003, the M.S. in Space Architecture program responds to the interests of aerospace engineers, social scientists, and other specialists employed at NASA and associated organizations who wish to broaden their career foundation and opportunities. Most attend the program on a part-time basis while working. http://sicsa.uh.edu/

Houston-based SPACEHAB, Inc. collaborated with SICSA to develop the Concept Development and Assessment Study of Lunar Exploration Systems in the 2004-2005 academic year, to support a proposal to NASA in 2005. http://findarticles.com/p/articles/mi_m0EIN/is_2004_Nov_29/ai_n7579493

Under contract to NASA Ames Research Center, Donna P. Duerk, Professor of Architecture at California Polytechnic State University, developed a Curriculum for Aerospace Architecture (With Emphasis on Lunar Base and Habitat Studies) published in September 2004. This curriculum comprises a year-long study for architecture students in masters or fifth-year undergraduate programs, as an option for the capstone experience. The first edition of the curriculum is intended as the foundation for enrichment as others add their own emphases and areas of special expertise. The curriculum structure follows Bloom's 1956 "taxonomy of educational objectives for the cognitive domain." The curriculum takes the form of a framework of objectives, study guides for each objective, a workshop, and a possible schedule for organizing the year's study to develop a specific Space Architecture project to the design-development phase. http://www.spacearchitect.org/pubs/NASA-CR-2004-212820.pdf

The Robert A. and Virginia Heinlein Prize Trust supported the young researchers' "Flight into the Future" Contest in 2007-08 to encourage innovative activities in space commercial utilization. http://www.heinleincontest.info/index_.htm

At Lund and Chalmers Universities in Sweden, students conduct elective, one-semester courses each autumn and spring, for graduating-year architectural and industrial design students. This STAR Design program includes fieldwork at NASA

Johnson Space Center in Houston, TX, that involves research and design of habitats for the Moon and Mars, as well as for orbital facilities. http://www.ark3.lth.se/

MOON CAPITAL Competition 2010, an international design challenge was organized and sponsored by AIAA, Boston Society of Architects, Draper Laboratory, Google Lunar X PRIZE, Space Architecture Technical Committee and The Boston Center for the Arts in the summer of 2010. It aimed to expand the possibilities for the future of design by asking participants to explore the concept of a moon habitat that will include both living and working in addition to collecting the most provocative visions for new Lunar possibilities. http://www.shiftboston.org/competitions.html

Conclusions

The purpose of this study was to identify professional disciplines as *tools* that should collaborate and interact with each other in order to achieve comprehensive and balanced design solutions that would satisfy human needs during space flight and might be applied to diverse space missions. The study attempted to demonstrate importance of addressing all types of human activities at earlier stages of space structures design rather than adapting existing engineering solutions to various human needs and incorporating them into final design product. That is especially important for planning long-term missions to farther destinations than Low Earth Orbit practices with demographically, culturally and professionally diverse habitants onboard of spacecrafts. There are no “small” issues in designing facilities for dangerous and extremely expensive missions to Moon, Mars, asteroids and other destinations. That applies to technical and human sides of design equally.

The Academy entrusts the recommendations described in this report as examples of the extensive range of topics addressed by Space Architecture, and encourages upcoming Academy study groups to continue exploring additional topics, such as Habitable Space Structures, Integration of Life Support Systems, Interior Design for Reduced Gravity, Application of In Situ Materials, or Commercial Space Systems and Facilities.

The proposed recommendations from four chosen topics are summarized below:

1. **Human Factors Module:**

   a. The Academy recommends that organizations and projects undertaking the design of human accommodations in outer space specifically engage the professional contributions of space architects.

   b. The Academy recommends Space Architecture be developed as a powerful tool to achieve a seamless amalgam of environments, tasks, people, machines and operations.

   c. The Academy recommends Space Architecture design projects attend explicitly to drivers from the four domains: biological, ergonomic, psychological, and sociological.

   d. The Academy recommends that research elucidate differences among space mission populations comprising crews, space passengers, and space settlers, and determine how they drive an evolutionary progression of Space Architecture in the coming decades.

2. Space Missions Simulators Module:

a. The Academy recommends an Online Global Simulator Database be created to aggregate and archive simulation data from international partners engaged in Earth-based human space mission simulations.

b. The Academy recommends that entities conducting Earth-based human space mission simulations set high standards for architectural, operational, environmental and psychological fidelity.

c. The Academy encourages space agencies to develop full-mission simulators to prepare for long-duration missions to the Moon, Mars, and beyond.

d. The Academy recommends future simulations take into account real-life mission scenarios in terms of representative crew size and composition.

e. The Academy recommends that habitat design be integrated into the overall research agenda of human space mission simulations.

3. Art Module:

a. The Academy recommends integrating artists into space project teams from the earliest phases of the project lifecycle.

b. The Academy recommends establishing a paradigm for art utilized in human space projects that focuses on art as a core factor enabling mission success, rather than as aesthetic afterthought.

c. The Academy recommends developing a process template for human space project teams to identify and select artists.

4. Education Module:

a. The Academy recommends that the field of Space Architecture become integrated into aerospace curricula through required courses.

b. The Academy suggests that space companies involve Space Architecture students in their design process to anticipate and accommodate international, interdisciplinary, and inter-institutional cooperation at all design stages.

c. The Academy recommends that collaborative, international student projects with a Space Architecture component be a required component of aerospace education curricula.

d. The Academy endorses international Space Architecture student contests as a productive way to emphasize multidisciplinary and system-design approaches, and views Academy conferences as appropriate venues to promote such contests.

e. The Academy supports distribution and promotion of Space Architecture educational projects and students' work through Academy networks, Acta Astronautica, and related internet sites.

Bibliography

Armstrong R., Space Architecture, *Architectural Design* 70:2. John Wiley & Sons, ISBN: 978-0-471-86438-7. June 2000.

Avduyevski V.S., Uspenski G.R., *Space Industry*, 2nd ed., Moscow, Mashinostroenie, 1989 (in Russian).

Ball J.R., Evans, C.H., *Safe Passage: Astronaut Care for Exploration Missions*, Washington, DC, National Academy Press, 2001.

Baranov V. M., (Editor), *Simulation of Extended Isolation: Advances and Problems*, Institute for Biomedical Problems, SLOVO, Moscow, 2001.

Bechtel, R.B. "On To Mars!" in Bechtel, R.B., Churchman, A., (editors), *Handbook of Environmental Psychology*. p676-685, Wiley, New York, 2002.

Bonting S. L., *Advances in Space Biology and Medicine*, Volume 3, 1993, ISBN 1-55938-410-7 and Volume 5, 1996, ISBN 1-55938-970-2, Jai Press Inc., Stamford Connecticut, USA.

Clar R., "Space Flight Dolphin: An Art-and-Technology Payload for the Space Shuttle," *Leonardo*, 26:4, 293-296, 1993.

Cohen, M. M., Habitat Distinctions: Planetary versus Interplanetary Architecture. AIAA 96-4467, Space Programs and Technologies Conference, Huntsville, Alabama, USA, 24-26 September 1996. Reston, Virginia, USA, American Institute of Aeronautics and Astronautics.

Dubois K., "Dance And Weightlessness: Dancers' Training and Adaptation Problems in Microgravity," *Leonardo*, 27:1, 57-64, 1992.

Duerk, D. P., *Curriculum for Aerospace Architecture with Emphasis on Lunar Base and Habitat Studies*. NASA CR-2004-212820. Moffett Field, California, USA, September 2004, Ames Research Center, National Aeronautics and Space Administration.

Golovanov Y. K., *Architecture of Weightlessness*. Moscow, Mashinostroenie, 1978 (in Russian).

ESTEC, "REGLISSE: Review of European Ground Laboratories and Infrastructures for Sciences and Support Exploration", *Technical Note 2: Ideal Facility for Psychological Research*, ESTEC Ref.: TOS-MCT/2001/3021/In/CL.

Fukuhara T., *Space Dance, Someday in the Universe with Tetsuro Fukuhara*, Japan Aerospace Exploration Agency, Tokyo, Japan, 2004 (Japanese Only).

Gifford R., Lacombe C. "The Habitability of Spacecraft: Assessments of a Virtual Reality Simulation of the ISS Across Cultural, Personality, and Individual Differences," report to the Canadian Space Agency, 2006.

Harrison, A.A., Clearwater, Y.A., McKay, C.P., *From Antarctica to Outer Space: Life in Isolation and Confinement*. Springer, New York, 1991.

Howe A. S., and Sherwood B. (editors), *Out of This World: The New Field of Space Architecture*. American Institute of Aeronautics and Astronautics, 2009. ISBN: 978-1-56347-982-3.

Koelle, H. H., *Lunar Base Facilities Development & Operation*. Berlin, Germany, 2000, Institut für Luft- und Raumfahrt, Technische Universität Berlin.

Koelle, H. H., *A Preliminary Concept and Life-Cycle Analysis of a Lunar Settlement*. Berlin, Germany, 1996, Institut für Luft- und Raumfahrt, Technische Universität Berlin.

Krichevski S. V., Space Activity: Methodological, Historical, Social Aspects. Moscow, RAGS, 2007 (in Russian).

Lane H. W., Sauer R. L., Feeback D. L. (Editors), *Isolation: NASA Experiments in Closed-Environment Living: Advanced Human Life Support Enclosed System*, American Astronautical Society Science and Technology Series, Vol.104, San Diego, CA.

Larson W. J., Pranke L. K., *Human Spaceflight: Mission Analysis and Design*. The McGraw-Hill Companies, Inc., 1999.

Meister D., *Conceptual Aspects of Human Factors*, The Johns Hopkins University Press, Baltimore, 1989.

Millennium Charter: Fundamental Principles of Space Architecture, developed and signed by 46 attendees of the Space Architecture Workshop, 12 October, 2002, Houston, TX, USA. http://www.spacearchitect.org/

NASA, *Get Away Special: The First Ten Years*. NASA Goddard Space Flight Center, Greenbelt, Md., USA, 1989.

Palinkas L.A., "The Psychology of Isolated and Confined Environments," *American Psychologist*, 58:353-363, 2003.

Poynter J., *The Human Experiment: Two Years and Twenty Minutes Inside Biosphere 2*, Perseus Publishing, August 2006, ISBN-13: 9781560257752.

Ransom S., et al., "Definition Study of a Facility for Integrated Planetary Exploration Simulation (FIPES)", Executive Summary Report: LSGFIPES-SR-2006, ESA-ESTEC Contract No. 19397/05/NL/SFe, October 2006.

Sandal, G.M., "Psychosocial Issues in Space: Future Challenges," *Gravitational Space Biology Bulletin*, 14:47-54, 2001.

SICSA Space Architecture Seminar Lecture Series. Sasakawa International Center for Space Architecture, Houston, Texas, 2006.
http://sicsa.uh.edu/index.php?option=com_docman&task=cat_view&gid=32&Itemid=59

Stuster, J., *Bold Endeavors: Lessons from Polar and Space Exploration*, Naval Institute Press, Annapolis, MD, 1996.

Suedfeld P., Steel G.D., "The Environmental Psychology of Capsule Habitats," *Annual Review of Psychology*, 51:237-253, 2000.

Vaernes R. J., Baranov V. M., Demin Y. P., Stepanov V. A., "HUBES Executive Summary", Norwegian Underwater Technology Center (NUTEC), Institute for Biomedical Problems (IBMP)-Moscow, NUTEC Report 10-95, ISBN 82-7280-385-2.

Vogler, A., "The Universal House – An Outlook to Space-Age Housing," in M. Eekhout (ed.), *Concept House: Towards Customised Industrial Housing* (p. 77-87). 1st Concept House Symposium, Delft, The Netherlands, 22 June 2005, Faculty of Architecture, Delft University of Technology.

Vogler A., Jørgensen J., "Windows to the World, Doors to Space: The Psychology of Space Architecture," *Leonardo*, 38:5 390-399, 2005.Whitmore M., McQuilken, M.L., Woolford, B.J., "Habitability and Performance Issues for Long Duration Space Flights," *Human Performance in Extreme Environments*, 3:1, 64-74, 1998.

Wichman, H.A., Behavioral Health and Implications of Civilian Spaceflight," *Aviation, Space and Environmental Medicine*, 76(6), Section II, Supplement: B164-B178.

Members of the Study Group

Oleg Alifanov (SG proposer, M, Russia)

Olga Bannova (co-chair, Education Module leader, CM, USA)

Ivan Bekey (M, USA)

Larry Bell (USA)

Haym Benaroya (M, USA)

Jim Burke (USA)

Maijinn Chen (USA)

Richard Clar (SG proposer, Art Module leader, M, France)

Al Harrison (editor, Human Factors Module leader, USA)

Jesper Jorgensen (Denmark)

Jim Lowe (Canada)

Susmita Mohanty (Simulators Module leader, CM, India)

Dmitry Payson (Education Module leader, CM, Russia)

Jerome Pearson (M, USA)

David Raitt (M, UK)

Brent Sherwood (secretary and editor, Human Factors Module leader, USA)

Jack Stuster (USA)

Peter Suedfeld (CM, Canada)

Peter Swan (M, USA)

Nikolai Tolyarenko (co-chair, M, Russia)

Larry Toups (USA)

David Wong (co-secretary, UK)

Participating Contributors

Scott Howe (USA)

Barbara Imhof (Austria)

Gregory Scott (USA)

Al Wunderlich (USA)

Mark Zaballa (Spain)