The Outer Space Also Needs Architects

Dr. Sudarshan Krishnan, University of Illinois at Urbana - Champaign

Sudarshan Krishnan specializes in the area of lightweight structures. His current research focuses on the structural design and stability behavior of cable-strut systems and transformable structures. He teaches courses on the planning, analysis and design of structural systems. As an architect and structural designer, he has worked on a range of projects that included houses, hospitals, recreation centers, institutional buildings, and conservation of historic buildings/monuments.

Professor Sudarshan is an active member of Working Group-6: Tensile and Membrane Structures, and Working Group-15: Structural Morphology, of the International Association of Shell and Spatial Structures (IASS). He serves on the Aerospace Division's Space Engineering and Construction Technical Committee of the American Society of Civil Engineers (ASCE), and the ASCE/ACI-421 Reinforced Concrete Slabs Committee. He is the past Program Chair of the Architectural Engineering Division of the American Society for Engineering Education (ASEE). He is also a member of the Structural Stability Research Council (SSRC).

From 2004-2007, Professor Sudarshan served on the faculty of the School of Architecture and ENSAV-Versailles Study Abroad Program (2004-06) in France. He was a recipient of the School of Architecture's "Excellence in Teaching Award," the College of Fine and Applied Arts' "Faculty Award for Excellence in Teaching," and has been consistently listed on the "UIUC List of Teachers Ranked as Excellent/Outstanding by their Students" for 16 different architecture and civil engineering courses. His research and teaching at the University of Illinois were recognized in the Big Ten Network's (BTN) "Stories of Innovation, Impact and Inspiration."

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Abstract

Conventional architecture and architectural engineering pedagogy deals with design of buildings and systems for earth-specific functions, spans and load demands. Architecture curriculum has required educators to constantly transform and innovate their course offerings to meet the changing trends and rapid technological advancements. The discourse about space exploration and colonization have placed a creative onus on educators who have traditionally taught design for earth conditions alone. While terrestrial structures are typically designed for service conditions and region-specific severe conditions, outer space structures in contrast are designed for unique extreme conditions such as zero or microgravity, gamma radiation, high temperature fluctuations, and micrometeoroid impacts. Planetary soil (or regolith) characteristics also present unique challenges that are very different from soil problems on earth.

For a long time, work related to space exploration and design were confined to scientists and engineers. However, the challenges faced are multi-disciplinary and require expertise from several fields such as aerospace engineering, structural engineering, environmental engineering, psychology, urban planning, architecture and design. Architecture firms such as SEArch, Diller Scofidio + Renfro, Foster + Partners, and Bjarke Ingels, and offices of Skidmore Owings and Merrill (SOM) and Thornton Tomasetti are engaged in planning and design of structures for Mars and Moon.

In this spirit, knowledge of outer space architecture (OSA) and engineering will certainly provide the foundations, skills, knowledge, and design sensibility that architecture students can build upon in their careers. There may be more graduating architects in future working for space agencies or offices dedicated to outer space designs. But, what exactly should this body of knowledge contain and how should it be delivered? This paper discusses how OSA can be offered as a specialization and/or a joint degree in architecture and architectural engineering programs.

Key Words: architecture, outer space architecture, architectural engineering, terrestrial architecture, extreme conditions, design studio, seminar, deployable structures, inflatable structures, Moon, lunar, Mars.

Introduction

Planet earth never ceases to awe and intrigue humans. Despite many centuries of trying to understand the planet's workings, and designing to comply with natural constraints, we only realize that there is so much more to know. Architects and engineers have done well to understand the major governing principles in order to design in compliance with natural laws and forces. Now, consider another planetary body and planet – Moon and Mars. One can only imagine the knowledge base that needs to be developed in order to design and construct structures that adequately respond to the unique planetary conditions. NASA and other space agencies have worked to build this knowledge base for decades using samples of rocks obtained from Moon and extrapolating to get a broader understanding. This is an arduous mission owing to the fact that we not have the same constant contact as we do with the phenomena on earth.

There is no doubt that the space age was responsible for many inventions that people on earth still benefit from. The idea of making compact forms of large items was one of them. Putting this in context of architectural, structural and mechanical engineering, the design of foldable structures that can transform from packaged to expanded geometry when launched into space led to the popularity of retractable and deployable structures. The concept has been applied to different scales in terrestrial architecture. There is still much to be discovered in terms of new applications, new mechanisms, long spans, limiting spans, etc. Indubitably, designing for outer space is a specialized field and much allied to terrestrial architecture and engineering.

A partial list of universities that have dedicated courses/studios or degree programs in outer-space architecture (OSA) in the United States include: Cal Poly Pomona, Colorado School of Mines, Pratt Institute, MichiganTech, Oklahoma State University, University of Houston, University of Southern California, and the University of Maryland. In Europe, The International Space University and the École nationale supérieure d'architecture de Strasbourg in France, Vienna University of Technology in Austria, and Lund University in Sweden are some of the well-known institutions that offer education in OSA (Hauplik-Meusburger and Bannova, 2016a).

SATC (2014) provides a succinct overview of OSA, what outer space architects do, and how OSA and terrestrial architecture are related in terms of design for extreme environments. Howe et al. (2002) comprehensively addressed how terrestrial architectural education can be augmented to include space architectural design. The overlaps, omissions and a framework for university education were laid out. Duerk (2004) laid out an elaborate year long program in aerospace architecture with a detailed day-to day-activity listing. The myriad of topics, useful questions to be addressed and the vast resources under each topic is just the kind of information that an aspirant of OSA would seek. Doule (2010) proposed a Universal Architecture Curriculum that combined topics in outer space and terrestrial architecture to benefit both disciplines.

Architecture curriculum is rapidly evolving due to advancements in fabrication technologies and blurring of disciplinary boundaries. The scope for space architecture within terrestrial architectural curriculum has only gained more valence. In this spirit, the education of future space architects and engineers may be best achieved by infusing existing architecture and architectural engineering (AE) programs with a degree or specialization in OSA. This paper provides the motivation and importance of integrating OSA in architecture and AE curricula. The author expects to supplement this paper in future with academic projects, teaching methodologies, assessment methods, student learning and outcome, among other insights.

Framework for specialization in Outer Space Architecture (OSA)

“Space Architecture is the theory and practice of designing and building inhabited environments in outer space” (Space Architecture Workshop, 2002). OSA has considerably different program requirements, constraints, and loading conditions when compared with terrestrial architecture. This significant departure would require changes in conventional pedagogy and practices. However, the governing and guiding principles for both architectural and structural design are still applicable. It may be a challenging endeavor but nonetheless an experience that can be used for design of structures in extreme environments on earth as well. It is reasonable that architecture and AE students of today be given the requisite knowledge in their programs in order to pursue this alternate but allied career.

A typical architecture curriculum includes design studios and courses on history, theory, structures, technology, and other building science courses. A typical AE body of knowledge includes design studios and courses on structural, electrical, mechanical systems, and construction management. The focus is primarily on buildings for terrestrial conditions. Seldom do courses delve into design for extreme conditions on earth, not to mention about architecture and engineering for outer space.

Many schools have a joint Master of Architecture (M.Arch) and a Master of Science in Architectural Studies (MS AS). M.Arch is usually a two year professional program for students holding a Bachelor of Architecture (B.Arch) or a similar degree in architecture recognized by the National Architectural Accrediting Board (NAAB). The degree architecture students who upon graduation work in firms and pursue NCARB licensure. The MS in AS degree is usually a one year program and not accredited by the National Architecture Accrediting Board (NAAB) (UI, 2020). The MS degree would be for students who want to specialize in particular areas, in this case OSA to obtain both breadth and depth in the area. The degree requirements would include a series of required courses in OSA and elective courses in allied field which would be determined in consultation with the student’s Program Advisor. The proposed joint degree option would allow students to obtain two degrees in a condensed time span while maintaining the integrity and rigor of both programs.

Graduates of the MS OSA program would have the education to become licensed (terrestrial) architects with extensive knowledge of OSA and/or licensed space architects with extensive knowledge of terrestrial design. This is assuming that there is a licensing or certification board for OSA. An architectural engineering (AE) program with an Outer Space Architecture and Engineering (OSA+E) specialization would be accredited by the Accreditation Board for Engineering and Technology (ABET).

Universities that start such programs may expect to see early recognition due to the relevance and uniqueness of the program. There would be a need for architecture and engineering faculty with interest and inclination for collaborative endeavors to make this happen. With time, the OSA and OSA+E programs would be expected to grow in the number of full-time permanent faculty. The proposed joint degree programs would allow students to pursue their goals to meet the requirements of the M.Arch degree and receive recognition for specializing in OSA. Having this unique knowledge set would be a valuable asset in today's integrated design and construction industry that constantly seeks individuals who can bring architectural values and creative problem-solving skills to solve engineering problems in complex building structures.

Learning objectives

Exercises or projects on designing for unique extreme environments would enhance design thinking considering new and unforeseen factors. In fact, such exercises bring a sense of reality to projects that is not possible when you design with fewer and milder constraints. Through designs for outer space, students would learn about design for similar extreme environments and conditions on earth. The knowledge they take away may shape their life and careers in humanitarian architecture such as disaster-relief structures, pop-up clinics, among others. Students will learn about:

(1) Space architects, space engineers and their projects in collaboration with space agencies.
(2) Principal design challenges of microgravity and partial gravity, cosmic radiation, micrometeoroids, lunar dust, and extreme temperatures.
(3) Design for extreme environments which will be useful for designing for extreme environments on earth as well.
(4) Human factors in extreme environments.
(5) Local materials and suitable structural systems and concepts for space.
(6) Survival, well-being, and space medicine.

An OSA specialization in an architecture or AE program may be best offered as a combination of design studios and seminars. The teaching model would be based on intensive research on: planetary conditions, relevant architectural applications, structural systems and materials suitable for construction, construction technologies and self-deployment techniques. Highlighting the differences in environmental conditions when compared to earth would help comprehend the challenges involved. Similarly, emphasizing precedents of built and unbuilt projects would give a sense of design thinking and approaches.

Seminar

A seminar course as outlined in Table 1 would focus on learning the design process for outer space habitats in particular. During the first six weeks, students would learn about planetary environments, in-situ conditions, infrastructure planning and transportation. Topics related to human factors, health and well-being, and energy efficiency of structures will be researched. Weeks 7-12 would focus on habitats. Through the years, there have been many designs developed for outer space habitats, the International Space Station being the best example of an orbiting habitat. The questions about living and working in space and the structures that support the activities are fundamental for any successful mission – short or long-term (Hauplik-Meusburger, and Bannova, 2016b). Habitat designs depend on planetary destinations and mission duration. Long-term space missions such as a human mission to Mars would be a challenge from economical, technological, and human endurance points-of-view. Of priority in such missions becomes human factors in design. Architectural and technical program requirements will be worked out. For a deployable structural system, focus will be on geometric design, connection detailing, and packaging efficiency that can be best experimented through digital parametric modeling. For inflatables, creation of multi-performance materials and inflatable shapes would be fundamental. Study of space-saving foldable furniture and integrating them with the structures would be simultaneously examined. Weeks 13-15 will build on the earlier weeks and focus more on the technical aspects of structural, optimization, and reliability analyses. Table-top prototypes will be made for an intuitive understanding of motion of parts, expansion and packaging of the designed forms.

Table 1 Sample outline for a seminar course on outer space habitat design

Week No.	Topic
1	Study of extreme environments and planetary conditions (Earth, Moon and Mars)
2	Infrastructure planning and transportation
3	Potential sites and in-situ resources
4	Health, well-being, safety, and comfort
5	Energy efficiency of structures
6	Overview of outer space structures and habitat case studies (built and unbuilt)
7 - 12	Habitat Design A. Habitat types and program requirements B. Deployable structures i. Geometric design and connection detailing ii. Optimal structures: packaging efficiency and reliable deployability iii. Digital modeling C. Inflatable systems i. Inflatable materials and their properties ii. Optimal shapes iii. Foldable interior fixtures
13-15	Advanced analysis and design A. Deployment and reliability analyses (digital and physical models) B. Structural analysis and optimization C. Design prototyping and testing

Design Studio

Design studios form the core of architecture programs and are enhanced by lecture-based technical courses. Relevant projects include: design of habitats, space-stations, infrastructure design, space antennas, and solar sails. Designing for conditions that are far different from earth and unique based on planetary conditions present a significant challenge to conventional wisdom. To name a few: micro or zero gravity, low pressures or vacuum, extreme thermal changes, soil conditions, radiation, and micrometeorite attacks are different constraints. Some projects may require more emphasis on structural systems. An integrated design + structures studio may be considered for such projects. The studio may explore transformable and inflatable structures using self-optimizing materials and autonomous construction in extreme environments.

An architectural design studio would broaden the inquiry of various building types for outer space. Several aspects need to be addressed, namely:

(1) Planetary conditions and site characteristics – What characteristics are common and unique between the various planetary bodies?
(2) Specific design response – How can we design for specific planetary conditions?
(3) Materials – What materials are suitable for specific planetary conditions? What in-situ materials can be used for construction purposes?
(4) Responsive and adaptive design - How would habitats respond and adapt to unpredictable and dangerous new conditions?
(5) Design optimization – How can structures be made as light and adaptive as possible?
(6) Transportation – Can habitats be constructed with in-situ planetary materials? If inflatables are used, they would be transported from earth and have to be considered in aircraft payload.
(7) Erection – How can habitat deployment be made autonomous, i.e., without the need for human effort?
(8) Reliability – How reliable is the deployment methodology or inflatable design?

Graduate programs with a design thesis option may lend themselves better for a project on OSA. An integrated design + structures thesis may extend architectural design to include study of specific topics such as: (1) geometric design and connection detailing of deployable structures, (2) strength and stiffness of deployed structures, and (3) packaging efficiency and deployment reliability, to name a few.

Needless to say, the learning curve will be steep as architects will simultaneously learn about outer space conditions to a good detail while conceiving of new designs that address unique planetary conditions. This situation can be alleviated in the initial years by faculty collaboration with scientists and professionals in space agencies who can provide the essential foundational knowledge. With the constraints and design criteria established, students may focus on the aforementioned eight aspects of design.

Conclusions

(1) Outer space architecture (OSA) intrinsically is an interdisciplinary field. Knowledge from terrestrial architecture, design, materials science, engineering, health/medicine, and human factors inform outer space designs. Considering the direct influence of several disciplines, it is only prudent to incorporate outer space design education in some format in architecture and architectural engineering curricula.

(2) A concentration or specialization in OSA would help promote interest in this field and also prepare students for future architecture that would rely on many concepts developed for outer space structures. This would also prepare students aspiring to pursue advanced research or practice as a space architect or engineer.

(3) In the case a specialization is not viable, architecture and architectural engineering programs should try to offer courses on OSA with the aim to develop architects for the future and not just to meet present needs.

(4) Through integrate outer space design + structures studios, students would learn to design for harsh environments. They would recognize how precision in geometry and perfection in construction are essential for coherent movement of parts and foldability of deployable structures. "Learning by making" would be an essential component.

(5) The outcome and deliverables from design studio projects, theses, and seminars may help in the development of design guidelines for OSA.

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