70th International Astronautical Congress (IAC), Washington D.C., United States, 21-25 October 2019.

IAC-19,D3,1,7,x52547

Lunar Tourism: Catalyst for Jumpstarting a Cislunar Economy

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Abstract

The Moon is our closest celestial neighbor. Half a century ago, people made repeated visits there. Current technologies promise to bring cislunar travel to the masses for a fraction of the resources employed during the Apollo era. Private companies have been eyeing lunar tourism and some are making real progress toward providing that service. Some concepts developed in the ASTE527 Graduate Space Concepts Studio within the Department of Astronautical Engineering and in the Graduate Space Architecture Seminar in the School of Architecture are presented.

Keywords: Space Tourism, Commercial Space Activity, Lunar Tourism, Commercial Space Stations, Space Hotels

1. Introduction

The Moon is our closest celestial neighbor. Half a century ago, people made repeated visits there. Current technologies promise to bring cislunar travel to the masses for a fraction of the resources employed during the Apollo era. Private companies have been eyeing lunar tourism and some are making real progress toward providing that service. Some concepts developed in the ASTE527 Graduate Space Concepts Studio within the Department of Astronautical Engineering and in the Graduate Space Architecture Seminar in the School of Architecture are presented.

2. ASTE527 Graduate Space Concepts Synthesis Studio

ASTE527 all about creativity and ideation, the conception, birth or the origination of ideas. The area of investigation is complex space systems. Participants are taught to quickly create concepts and present them before a group of professionals and academics for review and feedback. These rapidly created ideas are referred to as Concept Architectures.

The core of the instruction is all about providing inspiration to create new products and processes. It is done primarily through engaging the studio with a variety of presentations by visiting guest lecturers who have created and continue to create innovative products. Debate and discussion are key to development and refinement of ideas.

Concept architectures are not optimized but help the architecture and the engineering student to appreciate the breadth of possibilities, start the discussion about future needs, propose alternative solutions to existing problems, and eventually enter the discussion of planners, if found worthwhile for further investigation. Graduate students from all disciplines of engineering, architecture, medicine and the law are encouraged to apply and participate in the studio. A basic appreciation of the sciences, space systems and the space environment are useful prerequisites for this course.

3. Topics discussed in the ASTE527 Studio

Options for concept architectures include but are not limited to :

•Space Transportation systems and their evolution
•Orbital debris mitigation systems
•On orbit assembly of large scientific platforms, modular stations/vehicles
•Solar Power Satellites
•Innovative communication satellite architectures
•Solar System Exploration strategies and human expeditions to the Moon, Mars and beyond
•**Space Tourism and Adventures**
•Recreational vehicles/facilities, advertising in space and other innovative ideas

Concept Architectures developed over the years in the ASTE527 Studio may be found at: https://sites.google.com/a/usc.edu/aste527/home

In this paper, some Space Tourism concept architectures developed in the ASTE527 Studio are presented.

4. ISS Co-orbiting Space Based Solar Power Satellite Hotels.[ISSCOSH]

A concept architecture is proposed to combine the buildup of Space Based Solar Power Satellites and low Earth orbiting hotels for space tourism. Since space based

solar power stations require large surface areas of photovoltaic arrays to convert solar energy into electricity, the idea is to assemble them as segments in LEO, at this orbiting hotel and then use a transfer vehicle to carry each segment to the geostationary orbital location for final integration and commission. By employing economic synergies of assembly depot and resort, and by building it close to ISS, it is thought that a viable commercial model may exist for such a concept to warrant further investigation.

The following visuals show the evolution of the ISSCOSH facility to support space tourism while building up SBSP capability.[Figure 1-5]

LEO orbiting hotels can be a catalyst, the springboard for lunar tourism, with space tourists spending time there to acclimatize to space environment before embarking on a longer cislunar tour.

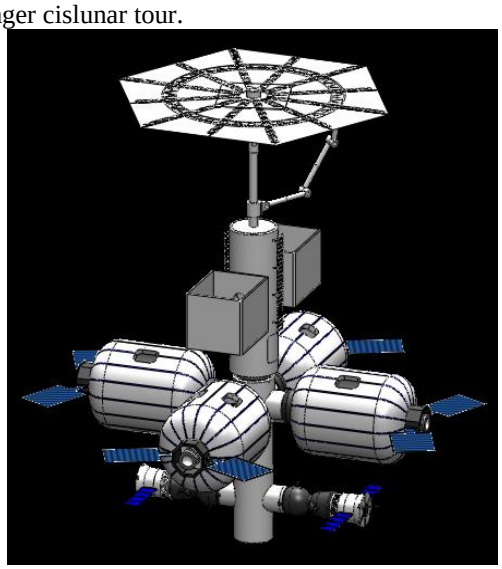


Figure 1. An inflatable cluster of habitats provide tourists and SBSP assembly crew habitation while EVA supervised assembly of SBSP segments happen above.[Zafarian,P.2010]

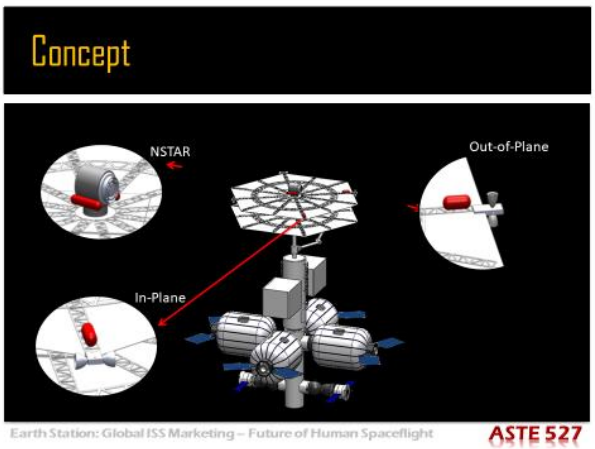


Figure 2. SBSP segments are assembled and fitted with ion engines to propel them to the desired GSO.

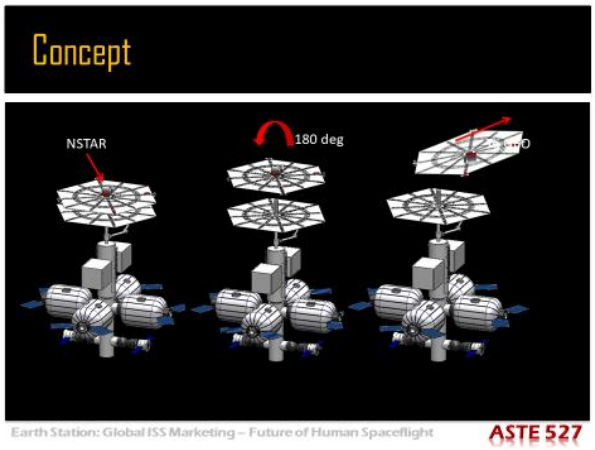


Figure 3. SBSP segment assembly and shipping to GSO.[Zafarian,P.2010]

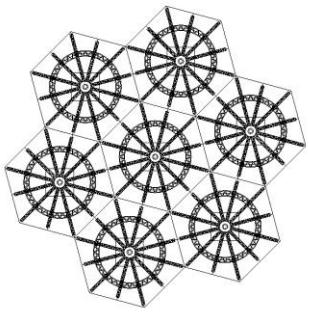


Figure 4. Multi-segment SBSP PV array assembly in GSO. Several of these will make up the SBSP power array. .[Zafarian,P.2010]

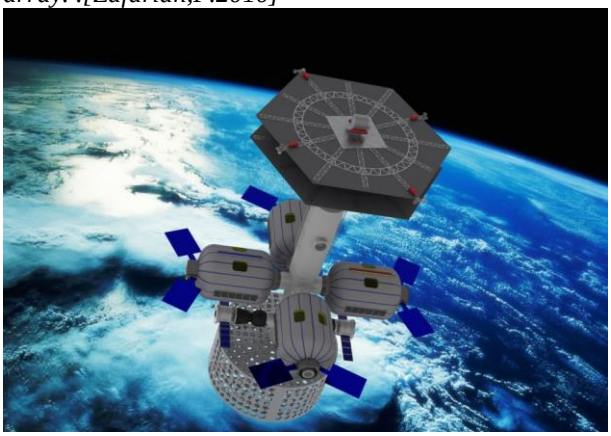


Figure 5. ISSCOSH hotel in LEO. Below the hab modules is the EVA cage where tourists can don spacesuits are float in free space with Earth view passing under them.ISSCOSH could be a catalyst for initiating lunar tourism[Zafarian,P.2010]

The entire *ISSCOSH* buildup and SBSP commission sequence may be seen in **Section 08 of the Evolution of ISS Part 2 – 2010** in the ASTE 527 archives at : https://sites.google.com/a/usc.edu/aste527/home

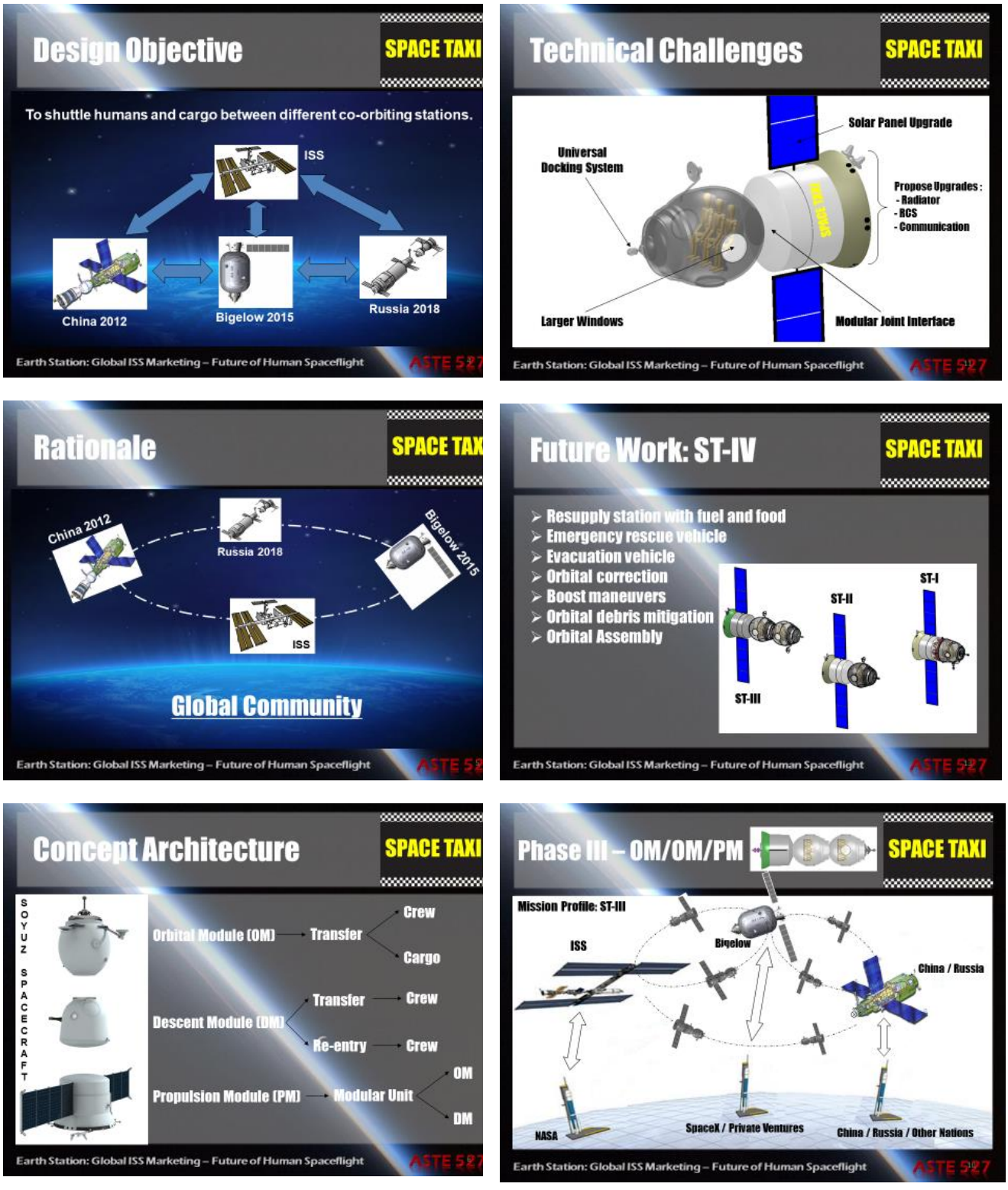


Figure 6 a,b,c. SPACETAXI proposes to use all existing and globally available space assets, especially crew capsules to move people from Earth to various Earth orbits to build a sturdy Earth-to-Orbit capability. SPACETAXI that can shuttle people to various stations in LEO and also help with lunar missions and crew emergency and abort and rescue support. .SPACETAXI concept could be a catalyst to initiate regular cislunar tourism as well.[Milanes,M., 2010]

The entire *SPACETAXI* buildup and commission sequence may be seen in Section 07 of the **Evolution of ISS Part 2 – 2010** in the ASTE 527 archives at : https://sites.google.com/a/usc.edu/aste527/home

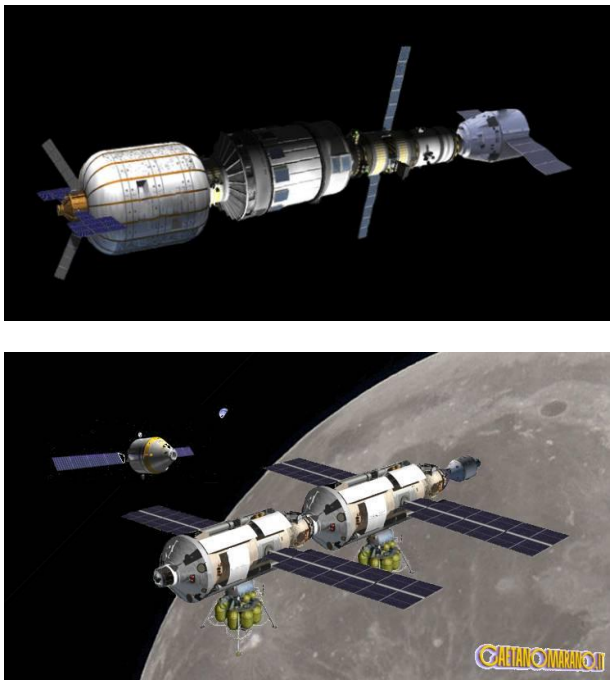


Figure 7. For All Mankind(FAM-1) Lunar Space Station proposes a lunar tour[Olsen, E., 2010]

The entire *For All Mankind(FAM-1) Lunar Space Station* concept architecture buildup and commission sequence may be seen in section 10 of the **Tipping Point - The Future of Astronaut Activity and Human Spaceflight** – 2014 in the ASTE 527 archives at : https://sites.google.com/a/usc.edu/aste527/home

In the 2015 ***LunaRevolution*** team project, a space tourism project called *MOBIUS Tours* was presented.

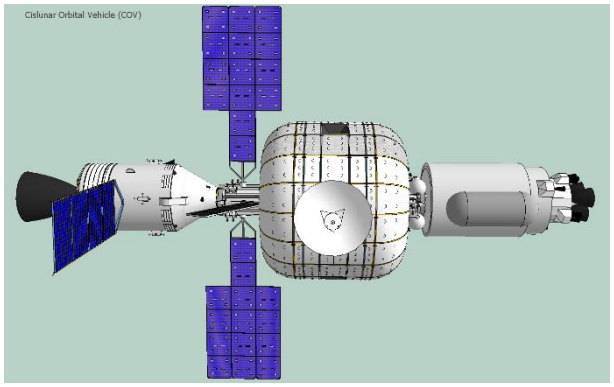


Figure 8. MOBIUS Tours employed supersynchronous orbit to bring tourists close to the Moon without orbiting.

This concept architecture involved using supersynchronous Earth orbit to apogee close to the Lagrangian point L1.

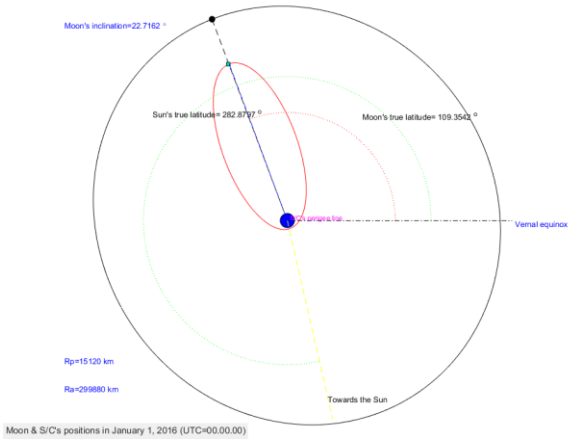


Figure 9. The MOBIUS Tours concept architecture picked a supersynchronous orbit that brought the spacecraft close to the L1 point but did not slip into the gravitational influence of the Moon, avoiding lunar orbit.[Lali, M., 2010]

The orbital period is such that tourists get to see the Moon up close but not fall under the influence of the lunar gravitational field. The concept architecture was presented in an AIAA paper and is archived at: https://arc.aiaa.org/doi/abs/10.2514/6.2016-5389.

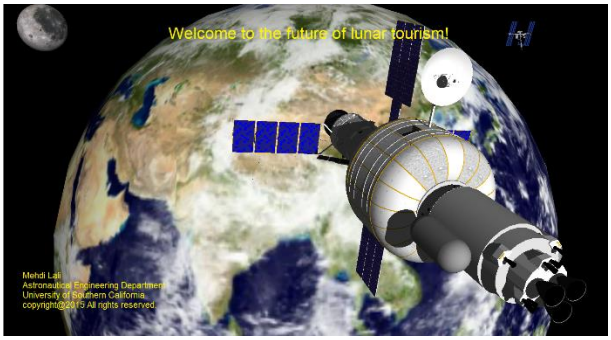


Figure 10. MOBIUS Tours on translunar Injection trajectory toward the Moon.[Lali. M, 2015]

The entire *MOBIUS Tours* concept architecture buildup and commission sequence may be seen in Section 08 of the **LunaRevolution-Role of the Moon in the Future of Human Space Activity – 2015** in the ASTE 527 archives at : https://sites.google.com/a/usc.edu/aste527/home

5. ISS as assembly node

A recurring theme in several ASTE527 studios have been using the ISS as an assembly and staging point for

various destinations including employing plane changes to achieve GSO, other inclined orbits. Though not in the ideal inclination to support lunar missions, ISS can still be a valuable way point for tourists to adjust to space and for many, to overcome the effects of space adaptation syndrome(SAS) commonly known as space sickness.

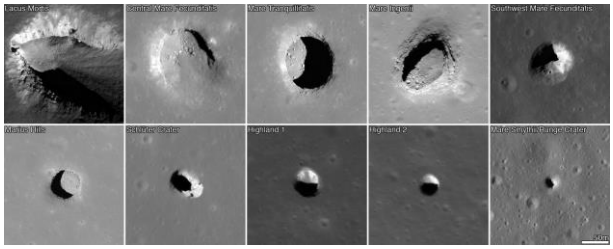


Figure 11. The discovery of pits and breaches on lunar the roofs of what appear to be lava tubes (referred to as "skylights") hold promise as entries into capacious volumes that could potentially serve as shelters to build permanent lunar settlements, safe from the harsh surface environment.[NASA LRO]

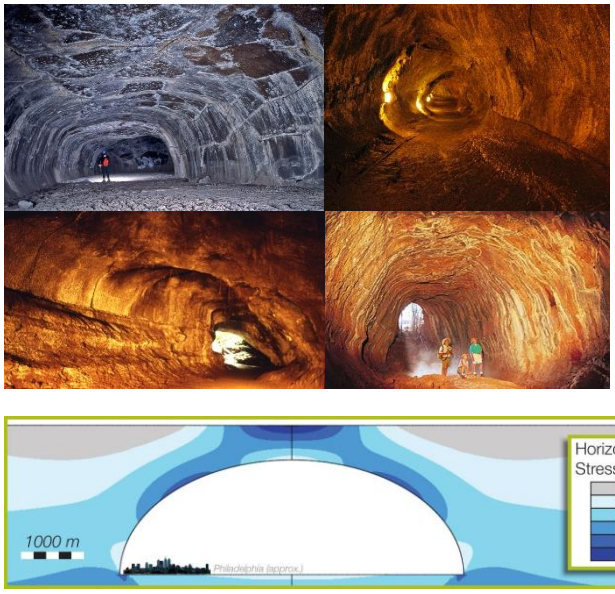


Figure 12a,b. Lava tubes on the Moon are expected to be much larger than those seen here on Earth, due to low gravity, some enough of house entire cities.

6. Mining, tunnelling and subsurface construction technologies

Mining, tunnelling and subsurface construction technologies are very capable and advanced equipment are used to build critical infrastructure under cities and sea floors here on Earth. The same technologies may be adopted for building extraterrestrial infrastructure on the Moon that can be used for tourism among other functions.[Figure 13]

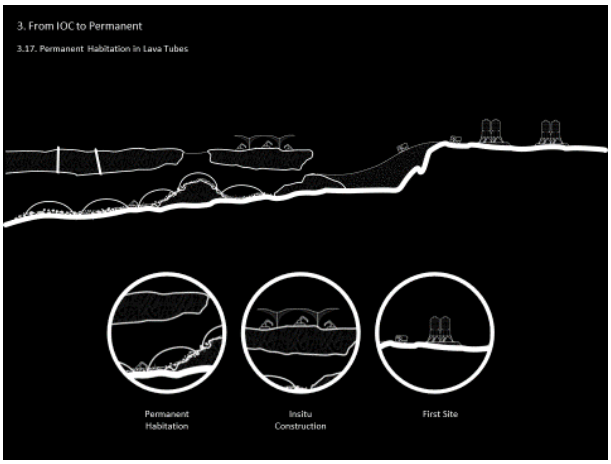


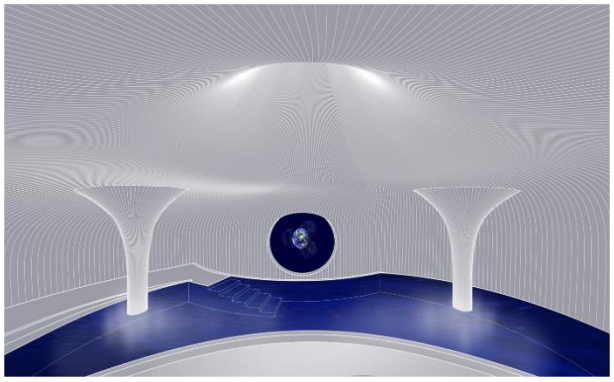
Figure 13. Advanced mining, tunnelling and subsurface construction technologies may be adopted to build permanent shelters in the interior of lunar lava tubes to house lunar tourists.[Vincent ITM]

Figure 14. Guniting is a well established method to stabilize underground structures by power guniting quick setting concrete over reinforcement to produce resilient structures like subway tunnels and hydro dam conduits.

Figure 15. The interior of lunar lava tubes, accessed through skylights hold promise for permanent habitats.

Figure 16. Once the lunar lava tube has been developed, it would be an ideal location for permanent habitation to house tourists as well.[Vincent, ITM 2016]

The entire presentation that also pondered how humans may adapt to partial gravity over an extended period may be accessed at Section 09 High Fidelity Partial Gravity Simulation in the **SeleneOption : High Fidelity Simulations and Analogs on the Moon-2016 :** https://sites.google.com/a/usc.edu/aste527/home



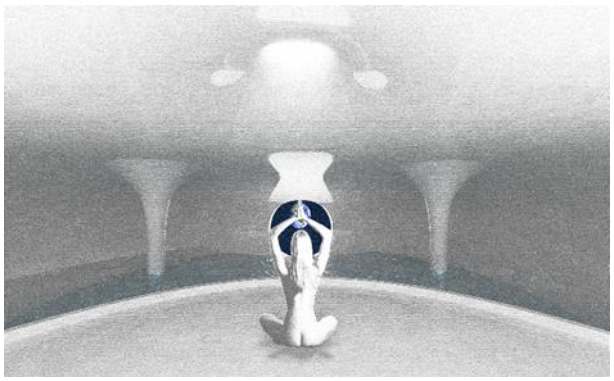


Figure 17a,b. Concept for a Lunar Bath and Spiritual Nexus in the Spring 2018 Space Architecture Seminar[Mungrueagsakul, P., 2018]

In the 2017 Renaissance Studio, the idea for a Sanctuary to experience the spiritual sublime was addressed. A concept architecture on the Moon that would be a space for tourists to contemplate and witness the awe of planet Earth from another celestial body[Figure 18a,b]. And this spiritual sensitivity was again reflected in the Spring 2018 Space Architecture Seminar when an idea for a Lunar Bath and Spiritual Nexus was presented.[Figure 17a,b]

Figure 18a,b. In the 2017 Fall ASTE527 Renaissance Studio, the idea for a Sanctuary to experience the spiritual sublime was addressed.[ESA]

In the Spring semester of 2012, graduate students attending the Space Architecture seminar in the USC School of Architecture presented various concepts for returning astronauts to the Moon. Lunar tourism was discussed. The Elevated Lunar Viewing and Information System{ELVIS) project proposed a way to bring tourists up close to the Apollo 11 site to experience the first lunar landing using ultra high resolution holographic rendition of Neil Armstrong and Buzz Aldrin stepping out of the real Eagle lunar module and making the first imprint of humanity's first footprints(bootprints really!) on an extraterrestrial surface. The concept suggested a way to take care not to disturb the historically important site by traversing the site from a cable car system with anchor towers placed several hundred yards from the site, and serviced by a tourist resort integrated in the architecture. Perched on a pressurized gondola, the ELVIS proposal concept would allow the tourist visitors to board the gondola at the resort and ride to the site to view the

hologram of the historic mission without ever touching the site.[Figure 19, a,b,c] The paper was presented at the 2012 AIAA Space Conference and Exposition in Long Beach, California. Details of this concept architecture may be accessed in the paper titled: **Architectural Concepts Employing Co-Robot Strategy and Contour Crafting Technologies for Lunar Settlement Infrastructure Development** and may be accessed at: https://arc.aiaa.org/doi/abs/10.2514/6.2012-5173.

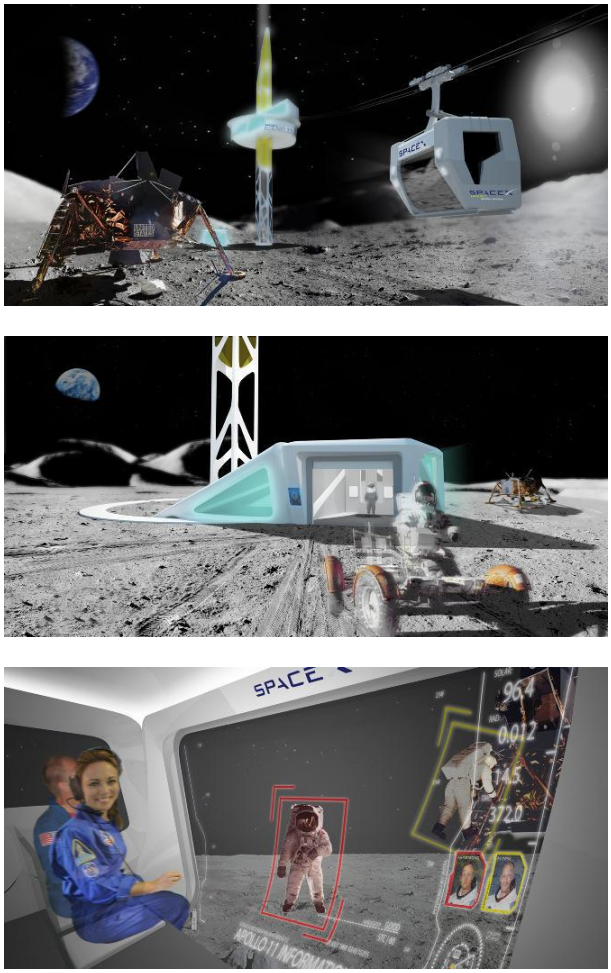


Figure 19. a,b,c. The Elevated Lunar Viewing and Information System(ELVIS) concept architecture proposed a way for lunar tourists to appreciate the historic Apollo 11 landing at the real site in the Sea of Tranquility without disturbing it by using a cable car and gondola system.(credit F.Sharpe)

Conclusion

Space tourism is approaching maturity as several private companies are readying their vehicles for the public to experience space. The ISS has had some citizen visitors to date and is ready to open doors to tourism. Private companies are making plans for lunar tourism as well. Concepts proposed in the ASTE527 Space Concepts Studio over the years as well as those from graduate students in Architecture School suggest that there are many possibilities to mature lunar tourism in the near term using existing or maturing technologies. Some elements described here could act as catalytic agents to accelerate human cislunar activities. Space Experience Tourism is perhaps the "low hanging fruit" that will spur on the development of a self-sustaining space economy in the near term, opening the doors to several other space applications that are waiting in the wing to make humanity a truly space faring species.

Acknowledgments

These concepts were generated in the ASTE527 Graduate Space Concepts Studio in The Department of Astronuatical Engineering within the Viterbi School of Engineering and the USC School of Architecture. We owe thanks for all the visiting lecturers, both from NASA and the industry as well as USC faculty, and industry professionals who engaged the studio. Special thanks to Viterbi Engineering school dean Yannis Yortos and Milton Curry, Dean of the USC Architecture School and Astronautical Engineering Chair Michael Gruntman and newly appointed Chair Dan Erwin for unwavering support of the studio, Special thanks to the Astronautical departmental staff for hospitality. Some of the work shown here was done by graduate Architecture students who shone their conceptual skills and visual talent through all the discussion and debates. Finally, thanks to the dedicated USC Distance Education Network staff that supports our remote students and were very effective in beaming in several lecturers and reviewers from NASA and industry across CONUS without whom we would lack the cutting edge that we so cherish in our graduate studio activities.