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Space and the City: Lessons from the Future

M.Thangavelu[1]*, D.Cong[2], C.Derman[3], M.B.Gamble[4], Y.Godhani[5], A.S.Kantak[6], S.Lee[7], V.G.Lahoti[8], W.Lin[9], S.Nashine[10], C.A.Reonisto[11], J.Rutledge[12],

[1]Conductor, ASTE527 Space Concept Studio, Department of Astronautical Engineering & Lecturer & Graduate Thesis Adviser School of Architecture & [2-12] Graduate Student Arch599 Graduate Space Architecture Seminar, the School of Architecture, University of Southern California, Los Angeles, California 90089 mthangav@usc.edu

* Corresponding Author

Abstract

Studies from the 2019 Spring USC Graduate Architecture seminar will show how our cosmopolitan cities, urban and suburban landscapes and dwellings are already using space assets including crew on orbiting space stations and allied technologies to monitor, inform and enhance quality of life. Orbiting spacecraft also help predict, alert and even prevent hazards, both natural and manmade, from affecting populations adversely. Human spaceflight systems can help Future City habitation. Future cities and their amenities including active adaptive and agile response systems are proposed.

Keywords: SmartCity, Human Space Activity, Space Technology, FutureCity, GroundScrapers, Ecological footprint

1. Introduction

As the Smart City paradigm takes hold across new metropolises and potential human habitation zones around the globe, human space activity continues to pioneer innovation in agile, responsive building sys-tems and their evolution, transforming habitats and surroundings to suit needs of occupants as well as adapting to both dynamic and gradual changes with minimal imposition on the natural environment that we call ecological footprint. [Figure 1]

Figure 1. Future City designs employ Smart City paradigms space technologies and processes to provide citizens and dwellers a more productive and safe environment while reducing ecological footprint.

Frugal use and recycling of consumables like air and water, performant building materials, energy efficiency and systems that respond with agility to environmental changes are hallmarks of human spacecraft and start-to-end space mission manifest management.

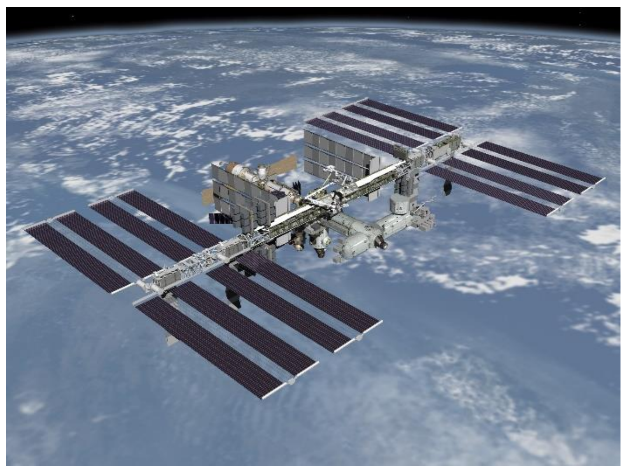


Figure 2. The International Space Station sets an example for minimal ecological footprint by operating on Smart City paradigm including clean renewable solar power and air and water recycling

The International Space Station (ISS) is a fine example of a unique, off-the-grid Earth-orbiting dwelling. ISS has been orbiting the Earth for nearly 20 years in the extreme environment of space, primarily dependent on solar power for energy. For the past decade, the ISS has also been recycling her atmosphere and more than 90% of water used by her occupants. A crew of six continue to spend an inordinate amount of time on housekeeping functions. Ways to reduce crew time for facility maintenance, without impacting mission productivity or sacrificing safety have become a top priority.

Extending our reach into space, a lunar orbiting station is being developed by NASA with another advanced layer of efficient systems to cope with this crew time consuming deficiency. It is called system autonomy.[Figure 3]

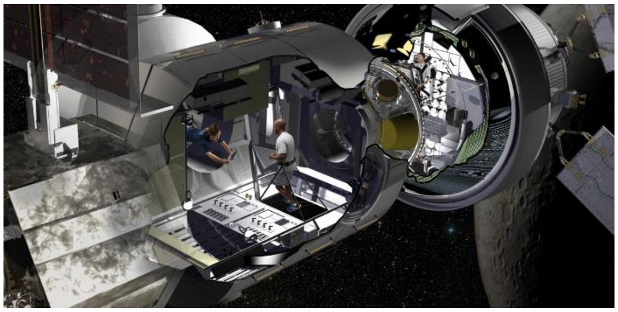


Figure 3. Extending our reach into space, a lunar orbiting station is being developed by NASA with another advanced layer of efficient systems to cope with this crew time consuming facility maintenance activity. It is called system autonomy.

Several parallels exist between the Smart City tenets and space system autonomy. How to preserve sense of place and enhance quality of life in cities that are rapidly evolving to absorb the migration of rural population? Space activity & technologies hold clues that offer solutions to Future City needs & development. [Figure 4]

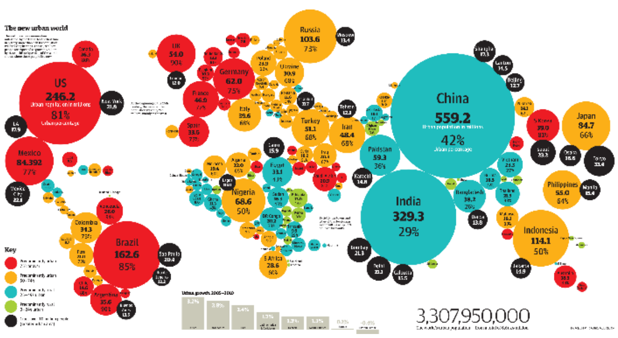


Figure 4. 3-4 million people move into cities every week. Rural to City population migration is causing tremendous strain on already overcrowded cities and space technologies may offer some ways to mitigate and enhance future city needs and experience.

Space activity informs. It lays out, in stark contrast, graphic images of the state of our biosphere, majestic and pristine portraits of nature, as it is as well as humanity's forays, and warns us about the consequences of climate change, all in real time. Human space activity in particular, reminds us of our species fragility and the ecological balance vital to sustain life.

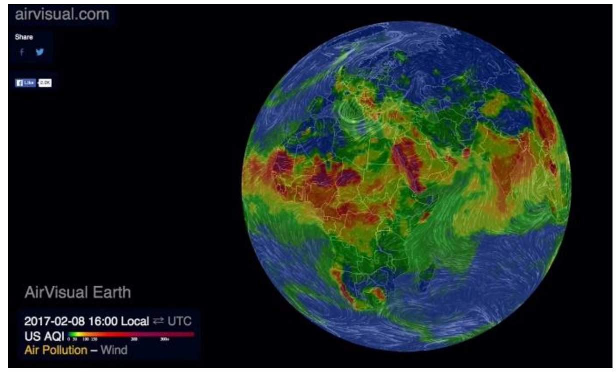


Figure 5. Satellite imagery shows deterioration of air quality that transcends national boundaries and geography

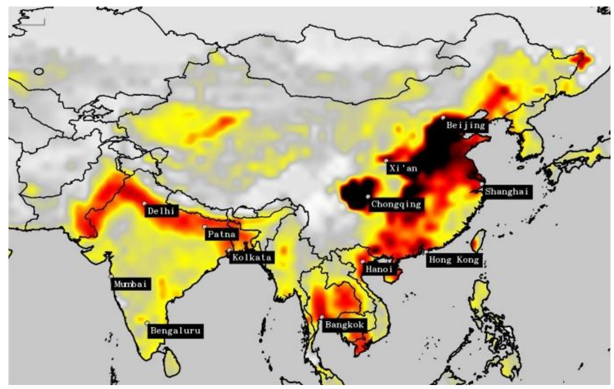


Figure 6. Air quality deterioration is related to economic development as seen in this satellite image of China and India.

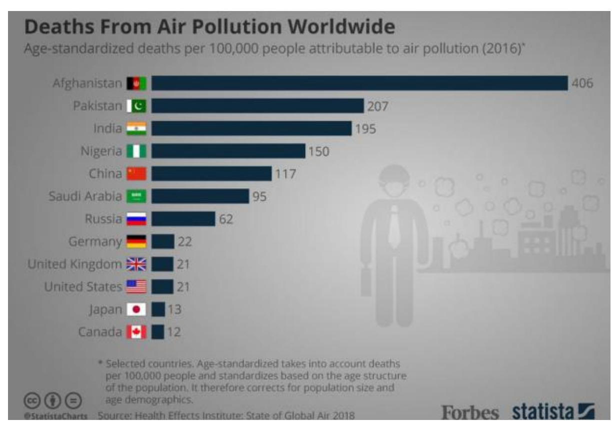


Figure 7. Air quality affects health and wellbeing of the population.

It is global in scope by necessity, cosmopolitan in nature by design, and inspires diverse communities, transcending geographic, national and economic boundaries, to address issues, anticipate problems, and work together to preserve and protect our environment.

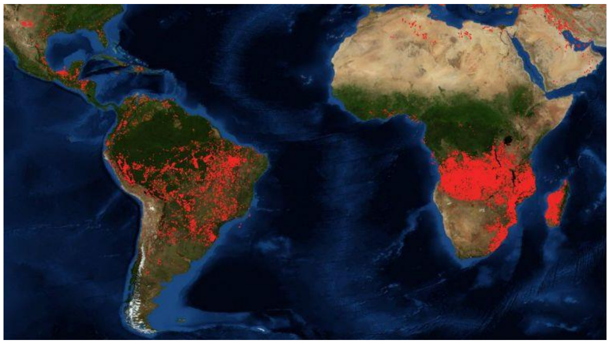
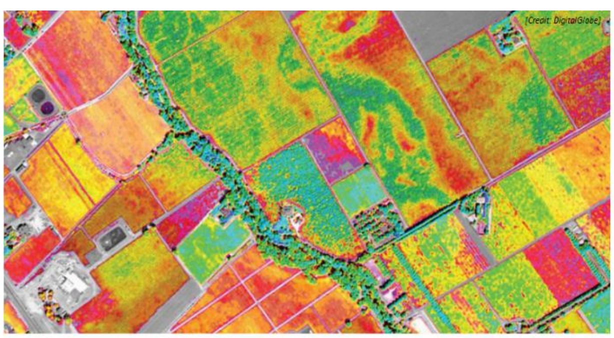


Figure 8. Satellite imagery shows global extent of wildfires in South America and Africa in 2019. Such data can be used to monitor, warn populations and also prevent the hazard nature poses to humanity.

Figure 9. Accurate forecasts of extreme weather and surface hazards are possible using space based assets and timely warning help to preserve life and property.



Satellite imagery used for precision agriculture, green areas show healthy crops, red shows unhealthy crops

Figure 10. Remote sensing from space based satellites provide farmers with accurate prediction of crop well being and yield, and also provide real time data on threats including disease burdens.

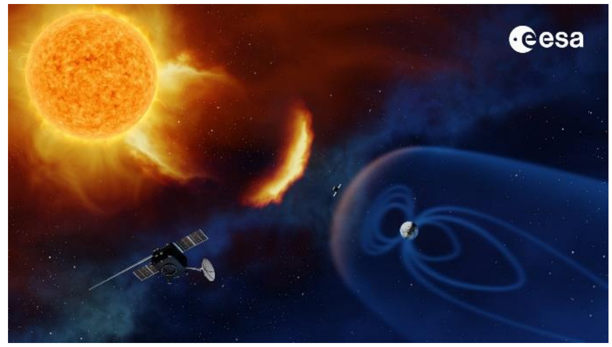


Figure 11. Space weather affects Earth weather. Solar storms affect continental electrical power grid network and timely warning helps prepare energy providers to take action.

2. Space Age Technologies Shaping Future City

Space based solar power

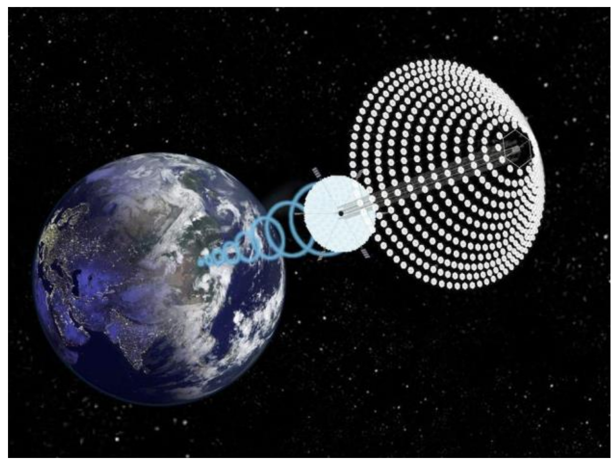


Figure 12. Solar energy harvested in space, converted into microwave energy and beamed to rectenna receivers on Earth can provide clean, carbon neutral power to cities. By steering the power beam, it is possible to provide power to various locations on Earth as base-load demand dictates, in a flexible manner.

Figure 13. Los Angeles Sepulveda basin could be the rectenna farm for a space based power satellite system

Figure 14. Tengger Desert Solar Park in China generates over 1500MW from photovoltaic arrays and occupies 3.4% of the desert region around the inner Mongolia Autonomous region.

Current megascale photovoltaic farms are already feeding 1000s of megawatts of power into the CONUS and global grid. [Figure 14] Several more operational systems on this scale are being planned around the sunbelt, both in the US and around the world.

Figure 15. Crescent Dunes Solar Energy Project is a 110MW solar thermal power plant that uses molten salt for heat exchange and a reservoir to store excess energy that can help to provide stable base load to the Nevada grid without the need for electric storage batteries.

3. Compact Nuclear Power

Recent developments in nuclear fission technology, especially the KRUSTY reactor testbed developed by the KILOPOWER program at NASA and space qualified in May of 2018 hold much promise. Such reactors may pave the way for small, 3-10kWh off-the-grid, safe, carbon neutral power generation that can be deployed quickly and serviced and maintained efficiently, without the need for specialized tools or personnel on hand. Such systems make versatile applications possible for a range of dwellings of all kinds and scalability. [Figure 16]

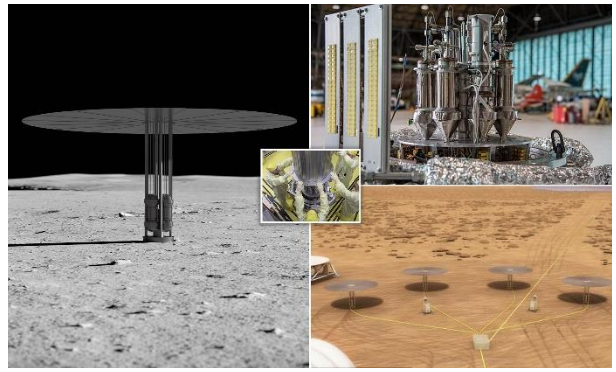


Figure 16. NASA recently space qualified a low power nuclear fission power plant that can continually sustain 3-4 kW of power making it ideal for early lunar settlement needs. With simple operation mode, minimal maintenance requirements and built in safety, such systems could be scaled to power homes and factories making off-the-grid infrastructures viable.

4. The Internet and the World Wide Web

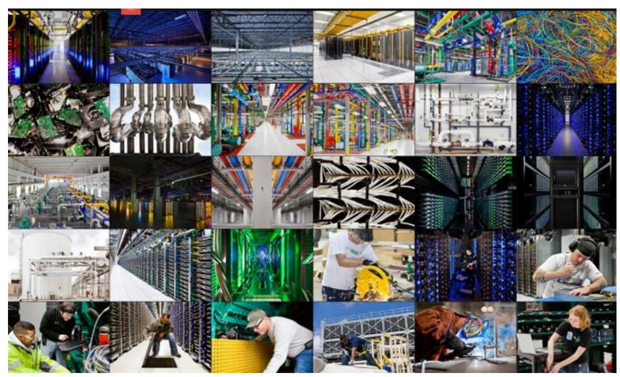


Figure 17. The internet and the world wide web and the proliferation of servers around the world have matured to such a level that data throughput is sufficient to use for a variety of real time interaction application.

Space Based Satellite Internet

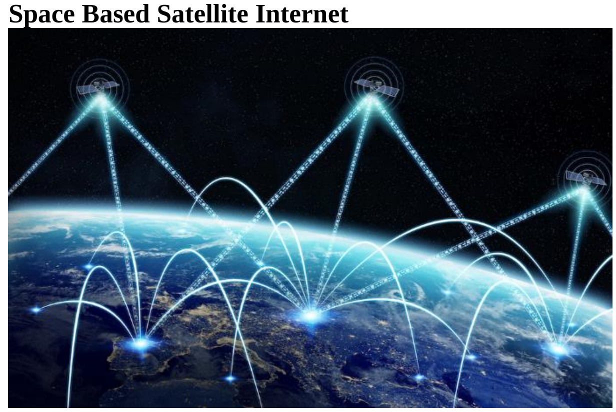


Figure 18. Space based internet makes IoT ubiquitous

Figure 19. Applications like telesurgery become possible with the arrival of wideband, high throughput data systems that allow real time high resolution video streaming while providing enough data throughput for applications like precision robotics with high resolution visualization and AR and VR layers, and haptic feedback as well as teamwork hook-ups in telemedicine

5. 5G and the arrival of Internet of Things(IOT)

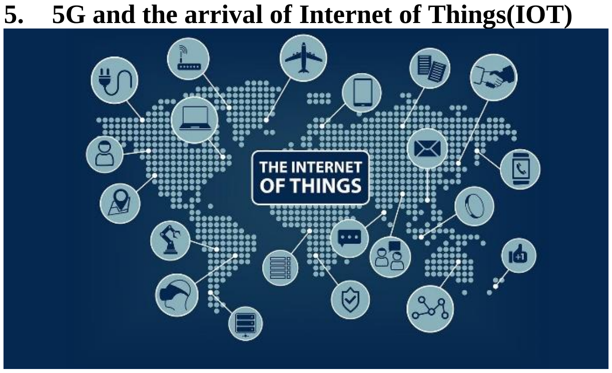


Figure 20. High data throughput capability of the internet, coupled with electronic sensors built into diverse elements that make up the city infrastructure allow for very efficient and timely monitoring, anomaly resolution and allocation of resources, as needed, to make Future City a safe and vibrant environment.

Augmented, Virtual and Mixed Reality Environment

Figure 21. VR AR and MR allow new modes of abstraction and information manipulation that can be useful to synthesize creative solutions to complex problem like logistics traffic management, security and safety that arise in Future City management and evolution. VR can also provide positive artificial ambience to enhance well being and productivity for people in alien or isolated and uncomfortable settings.

6. Optical Laser Communications

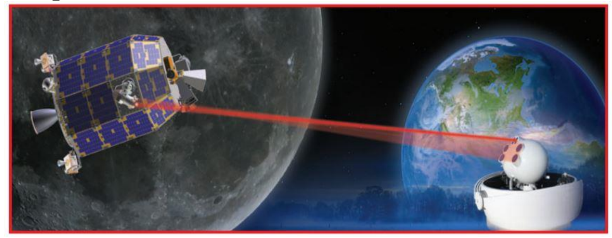


Figure 22. Optical Laser Communications allow much more data throughput at far better efficiency and has been tested and verified between the Earth and the Moon during the LADEE mission with the LLCD payload. Terrestrial, secure, high bandwidth IoT become possible with laser communication links.

7. Robotic Construction and 3D Printing

Building construction and transformation of cityscape are a normal and progressive activity that all cities engage in as they evolve to provide more amenities, and in many cases, expand to accept a growing population. Building construction and rehabilitation is also one of the leading causes for accidents that cause fatalities and injuries of workers. Advanced robotic systems are gradually replacing human workers in risky building operations.
Extravehicular space activity has always been risky and several systems are being commissioned or being planned to remove the astronaut crew from hazardous tasks. USC has been at the forefront of this activity. Especially in advanced robotic construction systems for extraterrestrial habitation and allied infrastructure establishment. Contour Crafting is a technology that is looking into terrestrial applications as well.

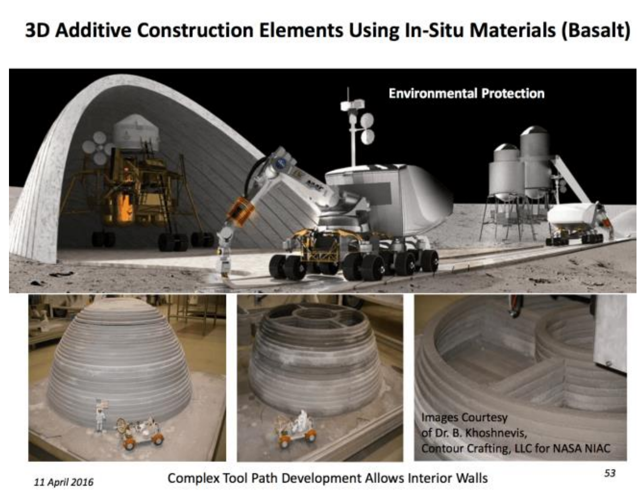


Figure 22: Robotic Construction removes the astronaut from the hazards of associated extravehicular activity.

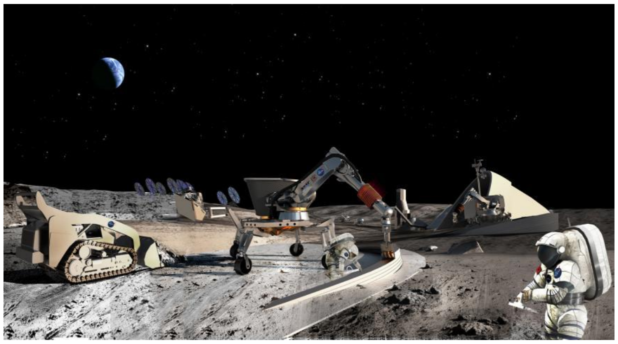


Figure 23: Contour Crafting technology, a form of additive manufacturing, proposes to use local materials to build structures on the extraterrestrial surface.

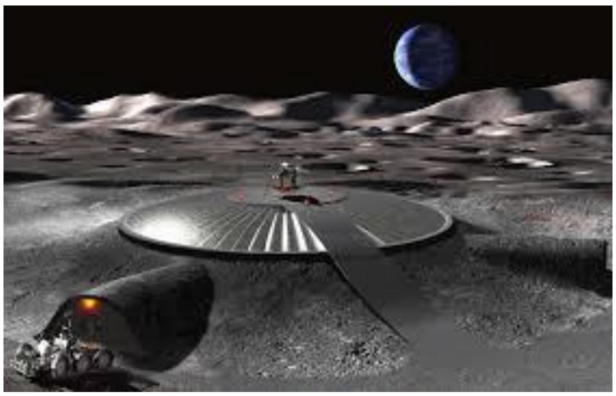


Figure 24. Robotic Additive manufacturing methods could be used to build critical extraterrestrial infrastructure like landing pads to eliminate debris production during lander operations.

8. Underground Habitation

Extraterrestrial surfaces like the Moon or Mars pose extreme hazards including micrometeoritic bombardment, large and abrupt diurnal temperature swings and exposure to radiation. Recently discovered breaches in the roofs of lava tubes suggest that they may be ideal for siting permanent habitats away from the harsh extraterrestrial environment.

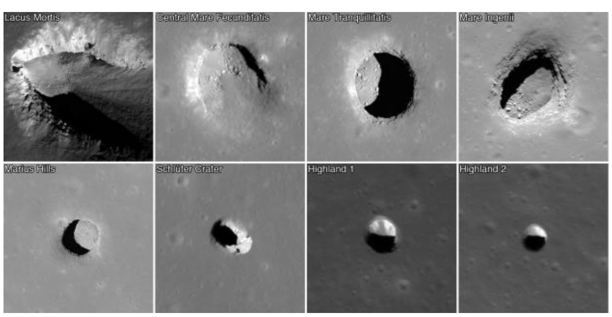


Figure 25. Recently discovered breaches in the roofs of lava tubes suggest that they may be ideal for siting permanent habitats away from the harsh extraterrestrial environment.

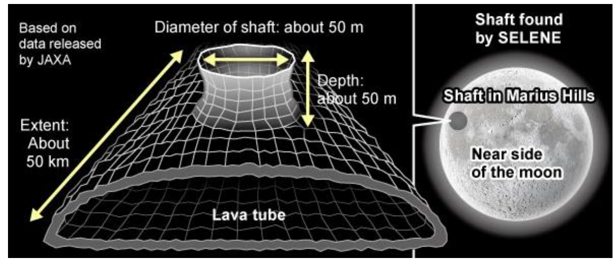


Figure 26. Lunar lava tubes are estimated to be much more capacious than those found on Earth.

Figure 27a,b,c. Elevators and cable cars may be used to lower robotic construction equipment into lava tubes to build permanent lunar habitats

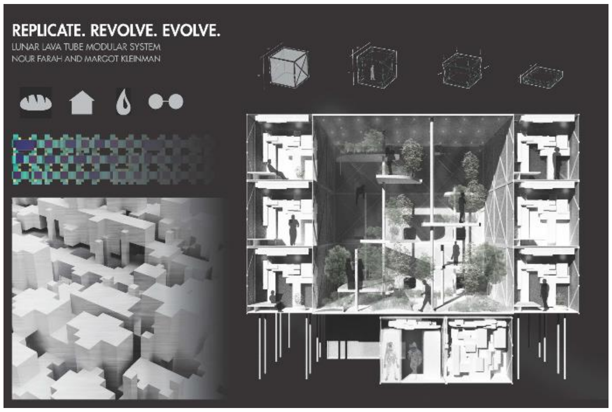


Figure 28. Interior of a modular lunar lava tube habitat

Advantages of Underground Dwellings

Humans have survived and thrived in underground dwellings from the earliest periods, predating civilization. In fact, people live in such structures today. Subsurface habitats offer several advantages over structures erected on the Earth surface. As we aspire to build skyward, we must also look for options downward. Advances in Mining Drilling and Tunnelling technologies allow rapid excavation and burrowing, shoring and buttressing of expansive underground volumes that can be stabilized and built up to provide useful spaces for living, working and even housing factories and manufacturing facilities. [Figure 29-30]

Figure 29. Advanced tunnelling technology can create expansive volumes deep below existing cityscapes

Figure 30. Washington DC Metro is an example of a subsurface structure that as served the city well for decades and continues to evolve with miles of new tunnels.

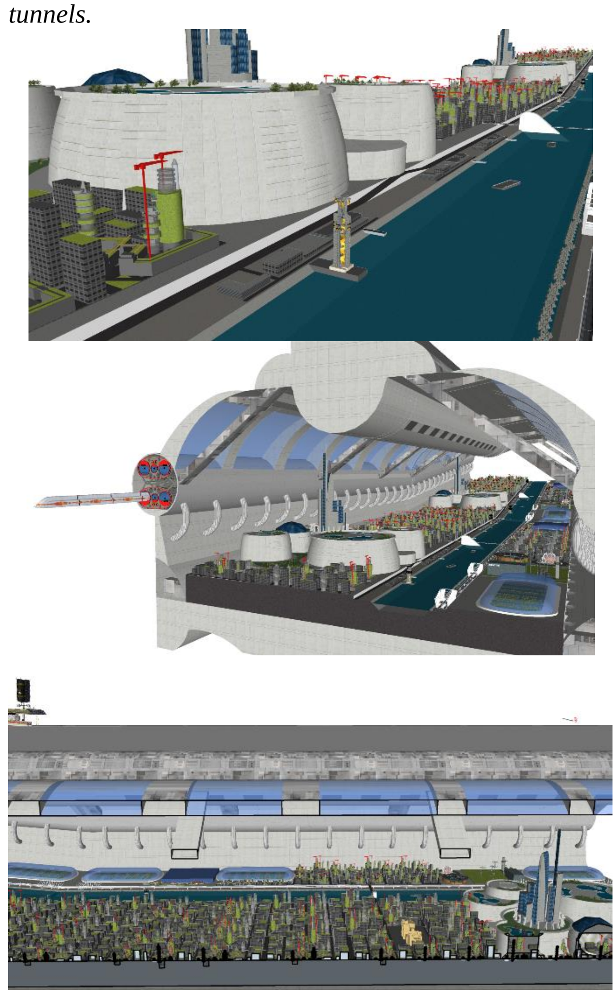


Figure 31 a, b, c. Subsurface MoonBai city infrastructure proposed for the densification of New Mumbai metropolis attempts to weave the surface elements with the underground, even below the sea floor

Effluents are easily processed and waste management better controlled and confined while underground.

Underground dwelling advantages include 3-4X increase in urban city population density, much reduced vehicular pollution, high energy efficiency and protection from adverse surface phenomena, especially extreme weather. For most part, structures built underground are more stable during earthquakes, and are immune to harsh transient surface conditions as posed during heatwaves, floods, tornadoes, fires and rapid changes caused by inclement weather like storms and blizzards. Submerged dwelling technologies may also protect existing coastline cities from abandonment due to sea level rise and associated ocean encroachment effects.

Faced with the effects of Climate Change and the accelerating migration of rural populations into cities and megalopolises around the globe, and drawing precedents that indicate cities and centers that pack higher populations generally perform better economically, the Arch599 Spring 2019 graduate seminar participants decided to explore underground habitation as one way to accept urban density increase without increasing surface spread, which conventional city evolution paradigm follows.

Compacting the physical city footprint by building habitation downward and below ground, we expect several other advantages including rapid decrease in particulate atmospheric pollution caused by local vehicular transportation and logistics, more citizen contact and real time feedback of performance to city management as well as quicker response to resolving anomalies.

The current Smart City paradigm along with state of the art space and allied technologies may offer some lessons as we strive to evolve a more efficient, interactive, responsive and humane experience that is Future City.

9. Rapid Suborbital Space Transport

An important paradigm shift in space transportation underway promises to have serious ramifications for the future of civilian commercial passenger transport between global hubs of commercial activity. The arrival of reusable rockets will drastically reduce travel time between megalopolises across the globe. Transitioning from aircraft to jetliners has such an impact in the 20th century. Reusable suborbital rockets may soon be able to service antipodal locations in a fraction of the time it takes jetliners today.[Figure 32] And southern California is poised to take the lead in this revolution with Spacex of Hawthorne, CA and Virgin Galactic of Mojave, CA spearheading the effort. Blue Origin. also based on the western seaboard of the United States in the city of Kent, WA is also working on reusable rocketships that will be capable of swift global transport. In some ways, the foundation elements of Future City are already in place with clean renewable energy, swift global data servers and transport systems.

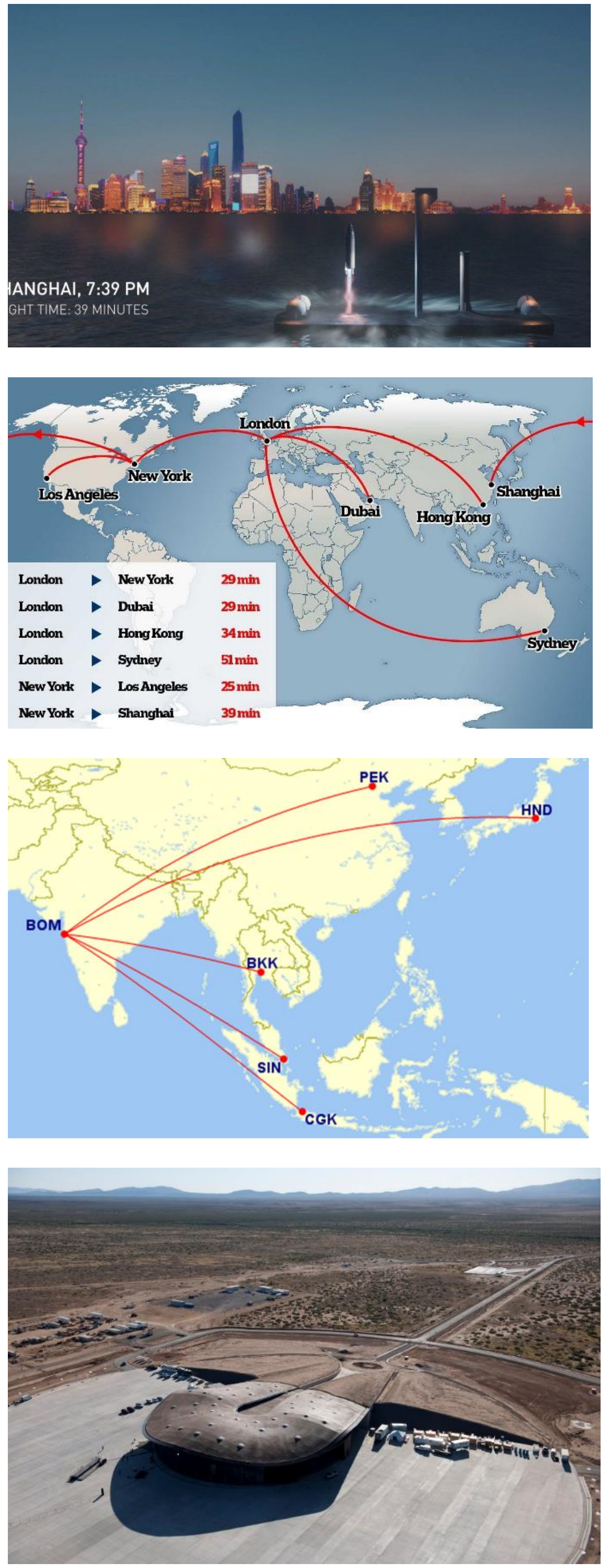


Figure 32 a,b,c,d. Reusable Suborbital rockets are already laying the groundwork for rapid travel between various global destinations in a fraction of the time jetimers take today and spaceports are commissioned.

Space and the City Finals participants and reviewers

Advanced Food Technology

NASA has a very active Space Food Systems group under the Human Health and Performance Directorate that is continually evolving better nutrition for astronauts. Providing fresh food produced in compact, electrically lit and controlled plant nutrient food chambers are being developed on the International Space Station and developmental studies are underway in remote research stations like the Antarctica and South Pole Stations. The University of Arizona Controlled Environment Agriculture Center(CEAC) and Utah State University are among the leading educational centers working on intensive cultivation and several industrial facilities are already producing high quality fresh food for the consumer. Many of the advanced processes are already finding application in dense urban regions.[Figure 33]

Figure 33. The U of A CEAC biorgenerative lunarbase greenhouse produces food and revitalizes atmosphere.

Conclusion

Human space activity makes us more aware of our surroundings and refines our sensitivities. As the global population grows, so does the need for more resources and their efficient management. By applying useful and appropriate technologies and processes of current and proposed human space activities and allied technologies, it is possible to create more synergetic relationships between the manmade and natural environments using principles of human space activity as a guide.

Acknowledgement

The Arch 599 Space and the City seminar was a 3 unit graduate elective offered in the School of Architecture in the Spring of 2019. The aim of the course was to appreciate the role of space technologies and investigate future possibilities in the design and evolution of daily operations of modern "smart" cities. We would like to thank all the faculty and visiting lecturers who contributed and the Dean of USC Architecture School Milton Curry and Dean of USC Viterbi School of Engineering Yannis Yortsos for bringing the disciplines together to imagine and create synergetic products for our collective future. Thanks to Wes Jones, Director of the Graduate Program in Architecture, who is instrumental in promoting and supporting new insights in architecture education, and to Doug Noble, Marc Schiler, Goetz Schierle and Karen Kensek for their support. Special thanks to Jane Ilger and administrative staff, and to our able teaching assistant John Rutledge who helped to make the course mechanics run smooth. Last of all, thanks to an enthusiastic and diverse group of graduate students from all over the globe who exemplify and reflect the true diversity and strength of USC.

- *E Pluribus Unum*