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Viral Design: Conceptual Contributions to Architectural Attributes of Space Station Design

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This paper highlights a conceptual space architecture design project that was approached by advanced students of architecture. Two primary considerations of the project are discussed including: 1) the viral conceptual design contributions to the field of space architecture and 2) the educational value of space architecture to students of architecture. The notion of viral design is such that conceptual contributions are made from non-expert designers outside the professional norm and disseminate into the general discussion of space tourism and economically viable space station design. Viral design in this case is adapted from the concept of viral marketing where ideas spread on their own. The benefit to the space architecture community however lies beyond the fostered dissemination of these particular designs. The idea is that the conceptual designs would be fleshed out and revised by autonomous contributors supporting the effort. In this case, the initial contributions come from architectural design students who have schematically developed station designs with the larger goal that they provoke professionals actually working in the field. The design project itself primarily approached three concerns including: economic viability, human accommodation and construction feasibility. The students were guided with expertise in terms of engineering from outside professional consultants, but approached most design problems initially from an architectural perspective. Such an approach breaks the norm of a typical systems or trade analysis approach to confronting space architecture design problems. The second primary consideration of the project lies in the educational value of exposing students of architecture to problems of space architecture. Space architecture is an ideal test bed to explore many of the basic interfaces which concern humans in an optimized way. The design problem presented three principal areas of educational value including: 1) developing equilibrium between practical and livable concerns, 2) prioritizing spatial efficiency and optimization as well as 3) managing a mass balance of resources needed for sustaining life. All three of these issues are extremely important in their application to space architecture and are directly translatable to terrestrial applications of architectural design.

Nomenclature

GEO = Geostationary Orbit
ISRU = In Situ Resource Utilization
ISS = International Space Station
JPL = NASA's Jet Propulsion Laboratory, Pasadena, CA
LEO = Low Earth Orbit
NEO = Near Earth Orbit

I. Introduction

The focus of this project was a design studio that allowed architecture students to make contributions to the conceptual design for alternative means of an Economically Viable Space Station (EVSS). The premise of the approach is that space tourism in LEO is optimistically viewed as an inevitable near-future reality. Currently several private companies are realistically pursuing low-Earth orbit commercial space station projects that may come to fruition in the near future. The design project investigated and integrated current commercial space tourism precedent and proposals. Ten examples by architecture students are highlighted whereby programmatic scenarios were created within the context of a space architecture design studio and applied to space making at various scales. Heavy emphasis was placed on the individual programming Conceptual development hinged on developing and programming an idea to make an orbital station economically workable. Economic viability was in this case defined as a space station that could be economically profitable and the ideas ranged from tourism to commerce.

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A. The Value of Viral Conceptual Contributions

The notion of viral design in this case is adapted from the concept of viral marketing where ideas spread on their own. As in marketing, viral phenomenon does not just happen, and is typically dependent upon three things: 1) Key influencer relationships 2) An open-eared sharing community, and 3) Paid (or earned) media. The first step in this process is to document the design ideas that came about in the context of this studio via this paper itself and to disseminate it to professionals actually working in the field. The second is to have an open-eared community which certainly exists within the spacearchitecture.org member community and in particular within the context of the Space Architecture Technical Committee (SATC). The third step is fostered through disseminating the designs to a larger audience via the internet and also through public exhibits. The hope then is that the benefit to the space architecture community lies beyond the viral exposure; that such conceptual designs will eventually vetted by professionals and is eventually developed to generate further concepts in overlapping forums.

The initial contributions described in this paper come from 4th and 5th year architectural design students in a 5 year professional program combined with a few graduate students. The students all have demonstrated competence in core architectural courses. Most of these students had little or no knowledge in space architecture or space tourism prior to the course and a moderate fact-finding phase was initiated at the beginning of the course to supplement this knowledge gap. The intent of this initial investigation was to integrate the lessons learned from past work in space architecture as well as to construct an informed foundation upon which to design. The design process was also supplemented with guest lecturers and in-class critiques from professionals working in the field of Space Architecture. The precedent fact-finding phase is discussed further in Section C below.

All of the projects were well documented with the understanding that dissemination is important to the viral goal.. Aside from having a number of experts serving as critics at the final review, the entire process was documented on the web. There was a central website dedicated to the studio which was linked to team blogs which documented the process development of each project as it developed. These blogs serve as a sort of digital sketch-pad for the students which made process dissemination between students very transparent as well. Although the final presentations were in the form of Power Point slides, they were supplemented with large print posters. The final posters were required to document all aspects of each design in an inclusive manner for easy dissemination.

B. Contextual Precedent

As these were architecture students with little or no base knowledge in space architecture, there were three weeks at the beginning of the semester devoted to increasing their exposure to the field. It was understood that the value of such a studio hinged on the foundations, and it was therefore a goal that the designs be as well informed as possible within the limited time constraints. The initial phase was primarily a review of literature as a fact-finding process which included both technical papers and online articles. This review covered precedent in the area of space tourism and current commercial space tourism proposals as well as the ISS, and numerous space habitation projects which included orbital as well as mars and lunar proposals, and Terrestrial analogues were also documented which included cruise ships and other maritime designs as well as Antarctic habitation design. Additional fact-finding was done in the area of space construction with a focus on robotic construction. The literature was generally organized into 5 categories including 1) Space Habitation 2) Space Tourism 3) The International Space Station 4) Interaction/Robotic Construction and 5) Sustainability/Biomimetics. An abbreviated list of the readings is included in the bibliography.

As there were 22 students in the class, each student was assigned three technical papers to review and was required to create a PowerPoint presentation. This strategy allowed us to cover almost 70 papers and articles in three weeks with roundtable presentation sessions. The additional benefit of this method is that each article or technical paper covered was put online on the course website with the accompanying 5 minute PowerPoint presentation to be easily accessed by the students throughout the term as they developed their designs. The scope of fact-finding was quite large and it was found that often the students would access a particular summary of a paper as a means of recalling a technical paper relevant to a particular design issue.

The intent of this initial investigation was tointegrate the lessons learned from past work in space architecture as well as to construct an informed foundation upon which to design. As the students are earning a professional degree in architecture they did not have particular areas of specialty but they did all have various backgrounds and areas of interest. As this was an optional topic design studio, all of the students did register for the course because they had a stated interest in the area of space architecture and felt that such a design project could contribute to their overall architectural education. The studio presented three principal areas of educational value including: 1) developing equilibrium between practical and livable concerns, 2) prioritizing spatial efficiency and optimization as well as 3) managing a mass balance of resources needed for sustaining life. All three of these issues are extremely important in their application to space architecture and are directly translatable to terrestrial applications of architectural design.

Three weeks is very little time to cover the immense knowledge base needed for designing for space but it was vital for informing the students of the realistic considerations needed for such a design task.

The students also received lectures from individuals/technologists etc. working at JPL and went on a tour of the facilities.

II. Design Problem

A. Project Overview

The design project had three primary considerations including: economic viability, human accommodation and construction feasibility. Economic viability was in this case defined as a space station that could be economically profitable. All of the space station designs were developed for LEO to include commercial passenger travel, leading to resort destinations and associated services; with a few associated projects in NEO and GEO which included commercial business travel, leading to construction projects such as Satellite Power Stations. All of the projects required programming for crews onsite as well as a variety of services to support tourism. Initial and predicted growth scenarios of occupancy were developed individually for each project. Human accommodation was developed utilizing an approach with prioritized humanistic concerns over practical concerns. Humanistic concerns are defined in this context as livable concerns which include environmental contextual interactions as well as sociological and psychological concerns. In the end, the goal was to find a balance between practical and livable concerns. The students were aware that human factors are often discussed and addressed in real concept designs for space architecture but often are not prioritized in a way that allow them to make it into final designs due to constraints. Typically, designing for sustaining life is necessarily prioritized over livability design in space architecture, and it was the need to integrate the pragmatic considerations of space architecture that took the greatest amount of effort from the students.

Numerous issues related to space design were necessarily considered including: gravity, atmospheric pressure, radiation shielding, micrometeoroid and orbital debris (MMOD) protection, propulsion, electrical power, avionics, environmental control and life support systems as well as the mass balance of resources and waste required for accommodating human life in space. Although the degree of competence in dealing with these issues varied widely, it was important that they were considered in each project. Construction feasibility was approached in most cases by means of utilizing systems of discrete assemblies that could be pre-fabricated and then assembled robotically with human support in space. Physical models demonstrated actual robotics, structure and in some cases, the materials. Issues of kinetic engineering were therefore also developed in most projects. Students developed scaled prototypes of their systems that successfully demonstrated the robotic aspects of the project related to construction as well as those which were integrated into the designs to optimize the energy performance of the structures.

Students worked either individually or in teams of two to produce complete schematic designs including the development and a construction/ fabrication concept.

B. Performance Parameters of the Design Problem

The design project had three primary considerations including: economic viability, human accommodation and construction feasibility. The design project was presented in such a way that students were provided a framework with which to develop a conceptual idea for an economically viable space station. This framework consisted of a Base Program which could be elaborated upon relative to the specific program of each design:

Dock / Terminal

- Berthing/docking systems, Node (transition element), Logistic supply, Storage

Core/ Common

• Communications, Administration / Information, Lounge, Dining, Cleansing, Medical, Retention

Tourism Facilities

• Recreation, Education, Short-term hotel rooms, Long term staff / Researcher rooms, Cleansing

Research Facilities

• Laboratories, Conference / Meeting spaces, Offices

Systems Design

- Mechanical / Thermal system, Infrastructure/ Power Conversion and storage, Radiation shielding, Debris protection, Propulsion, Water storage and conversion (black and grey water), Waste and recycling (mass balance of resources)

In addition to the Base Program, students were required to develop a conceptual idea for their station based upon economic viability. The concept of the design was developed through satisfying an Architectural Strategy and a Strategy for Construction and Phasing.

Architectural Strategy

- Programming of all areas and strategy for circulation
- A conceptual scenario for visitors including: short and long-term guests, staff, and researchers
- Approach / docking

Construction and Phasing

- Phased growth
- Construction and fabrication

C. Design Proposals

Conceptual development hinged on imagining an idea for an economically viable space station. Economic viability was, defined as a space station that could be economically profitable. In the end a few of the ideas relative to economics were strong and others did not lend much to the discussion of programming an economically workable commercial orbital station principally because they were too unfeasible from a technical standpoint. Several of those that are not feasible are still however included below for their architectural contributions so space station design. Students developed vastly different ideas in this area, some of which may show promise and others which were imaginative but not technically feasible. Although it was possible to design a project that hinged solely on tourism, most of the projects utilized a multi-purpose approach to economic viability. While tourism needed to be functionally separated in many of the design proposals, the multi-purposing of the stations was considered to be an imperative approach to all of the designs. The premise put forth to the students was that tourism alone would not be economically workable and that it should be coupled with additional programmatic considerations. As both hotel tourism facilities and research facilities had to be designed, issues of sociology and psychology came up frequently as paramount concerns. The benefit of exploring these concerns lies in the fact that they were also highly engineered spaces and there was therefore a necessary balance of livable considerations that involved many tectonic issues primarily with respect to spatial efficiency. Understanding how to balance such concerns translates well to designing many terrestrial architectural design projects where issues of building operational efficiency are prioritized. Lastly, understanding building operational efficiency and material reductions are key to the industry of architecture which is increasingly growing aware of its' environmental responsibilities. Taking lessons from the field of Space Architecture is an ideal venue for understanding how to optimize the mass balance of resources required sustaining life.

There were ten projects in total. As put forth in the program brief, all of the programs began with a minimally functional scenario that was built upon through expansion. The project ideas by the students are summarized below with an accompanying graphic presentation in the Appendix::

1. *Space Track: A Zero-Gravity Sports and Research Complex*

This program will provide the foundation for an extreme zero-g athletic and recreational experience stadium that will be supported by revenue from broadcasting contracts, advertising, and corporate sponsorship. The programming of the space station includes three phases including: 1) Research 2) Recreation and 3) the professional sports facility described below. The initial phase primarily centered on research facilities for human propulsion techniques as well as the effects of zero gravity on the human body and health. Phase 2 was primarily a resort/recreational component which included additional facilities for zero gravity sports experiences as well as the use of propulsion techniques by test groups of recreational visitors. It also included zero gravity game development as well as a health center that includes physical therapy and a spa. The third phase includes the professional sports arena as well as the completion of the research facilities. Plans for additional phasing of the space station include continuing research as well as an entertainment campus. At this point, Phase 1 would be converted to a hotel and retail and additional tourist dining facilities as well as leased long-term housing.

The largest incentive to the public to travel from earth into space is the effect of zero or low gravity. Therefore, the best experience to have in space is one in which the people can experience and witness various physical feats and manipulations of a zero gravity environment.

Sport has long been a worldwide form of leisure, exercise, civic pride and entrepreneurship. Today, professional sports players have a glorified celebrity status and the public's enthusiasm for these heroes has produced a multi-billion dollar industry. The enterprise of sports in space will yield completely new fields of competitive activities, performance gear, material technology and promotional items. Not only will the world view space sports via media on earth, but during the new frontier of space travel the public will also have the capability to journey into space to see live competitions. The demand for a sports facility and arena in space is fueled by pro space sport athletes, space sport fans and the experience of practicing the space sports that will be seen on television. The "Space Track" is a space sports arena and hotel which is a venue for professional games as well as a facility which will allow the general public and hotel residents to have similar gravitational experiences as the professional players.

The students created a matrix of various zero gravity maneuvers which fed into the actual design of the spaces. In the end the station design included three main sporting facilities including a stationary field, a rotating field and a racetrack tube.

2. *SCRAP: satellite capturing, remediation, and processing*

SCRAP captures defunct satellites and debris in low earth orbit to remove excess space junk. Once captured, the junk is recycled into raw materials for additions made onto the station. Often when manmade orbiting objects grow old or are damaged they are simply left to continue on their path around the earth in LEO. These items along with other orbital debris are informally called space junk. Such items can cause anything from inconveniently expensive, to catastrophic damage to other space craft. The amount of space junk has reached a critical level and needs to be removed. This project will not only function as a tourist and research facility, but will also collect and recycle defunct satellites, rocket boosters and other orbital debris. The space junk would be separated and then used selectively on the fabrication of the station. The proposed strategy will cut down on the amount of finished materials and components that would need to be sent from earth. The recycling program will help boast the station economically by recycling thousands of pounds of materials in space. This material can be used then to add to the station. In a section of Space Law enforced by the United Nations, every country is responsible for the damage that their satellite causes to any other country’s property even if they no longer have control over it. Therefore, countries could pay for the station to remove their defunct satellites so they do not cause damage to any other property.

3. *UnEarth: Asteroid Mining Station*

This project is not technically feasible but presents an interesting architectural concept of an infrastructural hexagonal grid for inflatable modules which is highlighted in Section D below. The design proposal is for a station that would serve as a home base and processing center for a near-Earth asteroid mining program. This project takes advantage of the resources that are available on near-earth asteroids. Eventually the station will serve as a home base for a comprehensive asteroid mining program. Initially the only programmatic element that will be appended to the core hotel and research program will be a small station that will serve as host for the first small drones that will be sent to mine asteroid water ice. The drones would be sent out to collect ice and return to the station for processing. An electrolyzing station and refinery would be housed in the station to process the water brought back by the drones. In addition to water ice, valuable metal ores such as iron as well as nickel and platinum are available on near-Earth asteroids. The ability to mine such resources would require advanced drones and processing facilities so this ability would be phased in after the water ice program has been proven to be successful. A docking station for the new, larger drones would be in the form of a holding cell outside of the core station facility because the raw materials would not need environmental protection. A facility to process such materials would also need to be added in this second phase and this would begin to initiate the self-manufacturing capabilities of the station.

Once established, this system would be self-sustaining and self perpetuating. The material mined could return and be used to make more drones for more mining and expand the existing facilities. The majority of the material would additionally be sold to other stations and facilities in space either in their raw form or as manufactured products.

4. *Space Broadcasting Studios*

Acting as a strong component in accelerating space passenger travel, the Space Broadcasting Studios (SBS) is dedicated to the exploration and promotion of outer space as a new medium for Film, the Performing Arts, and Sports. Understanding the importance of informing the public of new and exciting discoveries, SBS is committed to bringing Space Research, Film, and the Performing Arts to people throughout the world. Owned and operated by a large media and broadcasting organization, SBS is a facility that aims to discover the untapped potential of outer space in the form of cinematography and the performing arts. In addition, the SBS is a platform for science and research. Hosting a broadcasting station the SBS is able to easily disseminate cutting edge technology discovered on the station.

The SBS will develop in three essential phases. Phase 1 is the establishment of the film research and broadcasting platform. This initial phase lays down the foundation for proper filming, research and broadcasting from space. After obtaining a world audience, the SBS moves into Phase 2 of its development. The performing arts sector will programmatically grow out of the first phase of the film and research platform. Simultaneously, the hotel and tourism platform of the SBS will begin during this phase. Closely following the establishment of the performing arts, hotel and tourism portion will be the addition of Phase 3 which includes sports and recreation facilities. All three phases will be developed with supporting programs that facilitate fundamental needs such as power generation, nutrition development, hygiene and waste facilities health and safety as well as security.

5. *Invert Planet*

Invert Planet explores the experiential realm of micro and zero gravity with variable experimental and experiential areas. This project tries to answer the question, “What will space architecture be like once it becomes reliable and cost effective enough for everyone?” This project hinges on the idea of creating a rotating ring about a central core that can produce various degrees of gravitational forces. This scheme rests on a core that contains all of the infrastructural components for a station that can expand via arms that extend linearly around three radial rings. The two outer rings are static relative to the core while the center ring has the capacity to rotate and induce gravitational forces. The phasing for this project begins with the initial tourism and research components that are constructed in the form of a core facility. Once the first two rings are complete a modularized construction strategy is put into effect whereby hotel rooms and research facilities are moved out of the central core to the radial arms extending from the core and the core is repurposed for large facilities that can handle the increased mass balance of life on the station.

6. *Space Ark*

The Space Arc is a genetic back-up bank for all life forms on Earth. In the case of mass extinctions on earth, or with the destruction of Earth altogether, the genetic space bank could send genes back to earth for the reproduction of the deceased species. The Arc could also be used to generate food supplies, animals, etc, on a planetary colony.

We live in an ever changing world where the future of species on earth is fragile and uncertain. Countries from around the world could send to the ARC the genetic DNA of humans, microorganisms, animals, plants, etc. If desired then genetic replicas could be sent back down to earth to reproduce what was once lost. Once the station expands to phase 2, additional copies of the arc will be constructed and attached in different locations acting as a back-up to the main bank. On earth there are several well known gene banks and many of these have taken on an architectural strategy of self-preservation. Space is seen in this proposal as an ideal environment for such a facility in being well suited for the requirements necessary to securely sustain a range of genes at very low temperatures. Although the operation and cost of construction of such an arc would be very high it would be financed through the optimism of a protected future. In the phases of the gene bank’s development, little human oversight will be required for the operation. The initial phase would include a small research facility with the gene bank and living quarters for staff and researchers. With time the station is envisioned to become a permanently colonized tourism and research facility that is programmatically separated from the functions of the gene bank. The station as a whole would create a network of data sharing and research development related to genetics within a zero gravity environment.

7. *Voyeuristic Research of Comparability*

The primary objectives of the Space Station and Earth components are to further educate the public in the research that is taking place and to create future prospects for both funding and space tourism. The objective is voyeuristically exploring the capabilities of multi atmospheric research in space and Earth. The core driver in this station lies in exploring the capabilities of research in space versus research on Earth. Various types of research would be carried out on the station including medicine, life sciences, physical sciences, astronomy and medicine. The station would allocate spaces for multiple research labs accompanied by a sister research center located on Earth. As well as the research facilities, the terrestrial sister station will include a museum and an interactive replica of the space lab. The museum will showcase various elements of space exploration with the goal of educating the public in research that is taking place on the station in order to create future prospects for both funding and tourism.

Such a scenario facilitates the secondary driver behind the concept of the station which is focused on the dissemination of the research projects. By allowing public viewers on Earth to visually be tangibly connected to the research facilities while the research is being conducted, the station will help to fuel the larger goal of increasing public enthusiasm for space exploration and colonization.

8. *AstroLab-Medical Research in Space*

The purpose of AstroLab is to observe the behavior of pathogens in microgravity and develop new drugs and vaccines and develop ways and technologies to allow humans to adapt for future space travel and colonization. This project hinges on space as being an ideal place for the study of pathogens whereby organism growth in the microgravity environment elicits unique interactions in biological systems that do not occur on Earth. The time, money and resources expended in terrestrial drug development could be minimized by using a process which identifies promising agents or drug candidates earlier in the development pipeline for quicker testing to evaluate downstream. The drug industry is one of the most profitable industries on earth. This station would be developed as a shared research facility that would be privately owned and operated by the drug companies. The initial phase of the station would primarily be that of pathogen research facilities with infrastructural support and housing for the researchers and staff. After the research facilities have been developed the station would expand to include a variety of tourism facilities including short and long-term hotel rooms and associated recreational spaces.

Two of the projects were developed for a future where there are numerous tourist Space Stations in LEO and served as infrastructural projects for a large population. These two projects are described briefly below:

9. *Recycling and Production Hub*

Recycling of waste and extra materials will occur simultaneously with the production of food and oxygen. At the same time a research component will provide the facility for further improving the system. The project will ultimately have a relatively slow phasing structure. It is proposed that construction begin immediately and finish along with future stations to integrate itself seamlessly.

The idea of living in space is understood as the extension of our society beyond the limits of our atmosphere. This project serves to create a facility that can support multiple simultaneous ecosystems. The necessity of waste management as a species is seen as crucial to the success of inhabiting space. In light of the extreme cost of transporting anything to the station, this station serves as a closed system of perpetual production. The recycling of waste and the manufacturing of food and materials will occur simultaneously on the station. The station will serve to produce both food and oxygen to be sold to other orbiting space stations. Also included in the station is a research facility primarily centered on the task of improving the efficiency of the station from a holistic standpoint. The phasing of the project is that it begins as only large enough to serve a small number of orbiting station and evolves both in size and efficiency to serve a great number of orbiting stations as they come into existence.

10. LEO Spaceport

The Spaceport is the orbital counterpart to terrestrial based space travel. It establishes the necessary transportation infrastructure to sustain space tourism in L.E.O. for passengers, crew, and cargo. The station includes terminals for travel to and from Earth, Inter-Station transit, and eventually outer orbit excursions. The infrastructure is determined primarily by the requirements of daily life in space. One vital component is transportation both to and from Earth. Space tourism has the capability to become the next mega industry, potentially generating enormous annual revenue. Safe, reliable and cost effective transportation will become essential. Currently several private companies are developing just such terrestrial launch vehicles and facilities however the industry will inevitably grow as the economic viability becomes more certain. Space shuttles are so valuable to the industry that maximizing efficiency and minimizing down time are critical to profitability. In addition to tourist transportation, a large shipping industry will also need to develop. Supplies such as water, oxygen, fuel, and other necessary components required to sustain life will continually need to be transported into space, As more industries develop and orbital space stations come into existence, so too will the demands for transportation,

A spaceport in orbit is seen in this proposal as an essential counterpart to a terrestrial spaceport. The primary function of this station will be to assist in the transfer of tourists and shuttles arriving from and departing to Earth. As apace tourism becomes a reality, the market will become saturated with competition and innovation. A spaceport in orbit can open up the possibility for developers to build their own space hotels without having to also build their own spaceships and relevant transportation facilities. Likewise aeronautical companies can focus solely on transportation. The station will also provide transportation for guests between various orbiting hotels and research facilities. As a network of orbital space stations are created, inner-station travel will grow into a new industry. In addition, the space port would also serve as a middle destination for tourists or researchers who are headed to the Moon, Mars or other destinations outside of LEO. It will serve as the gateway for space and will become a symbolic place that is the functional and experiential hub of the budding space tourism industry.

D. Construction and Fabrication Development

The construction objective of the approach was to create designs that are minimally functional with the capability for evolving additional functionality and expansion. In addition to the tectonic objectives of understanding the fabrication techniques, there are several architectural objectives that this area explored including: 1) to serve as a vehicle for developing strategies for fabrication and how individual parts of a collective system could be assembled 2) to demonstrate how individual modules and components work in terms of forming structures and figuring out how to move them around, and3) to demonstrate possibilities of space manufacturing. For lack of a better reference the payload bay of the current space shuttle (15 ft by 60 ft (4.6 m by 18.3 m)) was used as a reference for scale in determining component sizes. In most cases, scenarios for construction were highly automated with robotic construction with on-site human oversight and management. The idea behind this phasing strategy in all projects was that when enough of the station had been constructed it could then be inhabited and continues to expand as needed. As put forth in the program brief, all of the programs began with a minimally functional scenario that was built upon through expansion. This notion had implications on developing construction strategies that could easily allow for expansion. Students were required to schematically diagram their larger architectural strategy for fabrication and construction as well as how it can deal with water, air, atmospheric pressure and shielding. The ideas for construction varied but most were that of a “kit-of-parts” approach whereby panels and other components were shipped and then assembled and then sealed manually. Two sample projects are shown below where notable strategies were used in terms of fabrication. In the first case (unEARTH) an automated system is incorporated into the expansion of the complex. The bulk of the construction is done by a 3-d printing mechanism using mostly materials procured from the mining of asteroids. Initially the mechanism is used to create rigid cylindrical structures that come together in the shape of a hexagon. These hexagons (which primarily serve as circulation corridors) became the infrastructural grid for inflatable modules which made up the spaces of the station. All of the negative space would also be considered within the printed walls including electrical and plumbing conduits similar to common terrestrial concrete core-slab construction. Within the module space, the panels which serve as partition walls inside of the inflatable are also printed to serve as anchors for the expandable membrane. The membrane is also anchored to the hexagonal structural grid by means of rails on the exterior of the cylindrical structure. Once the interior of the hexagon is fully enclosed, the walls of the infrastructural hexagonal grid can be penetrated to allow access to the larger inflatable spaces.

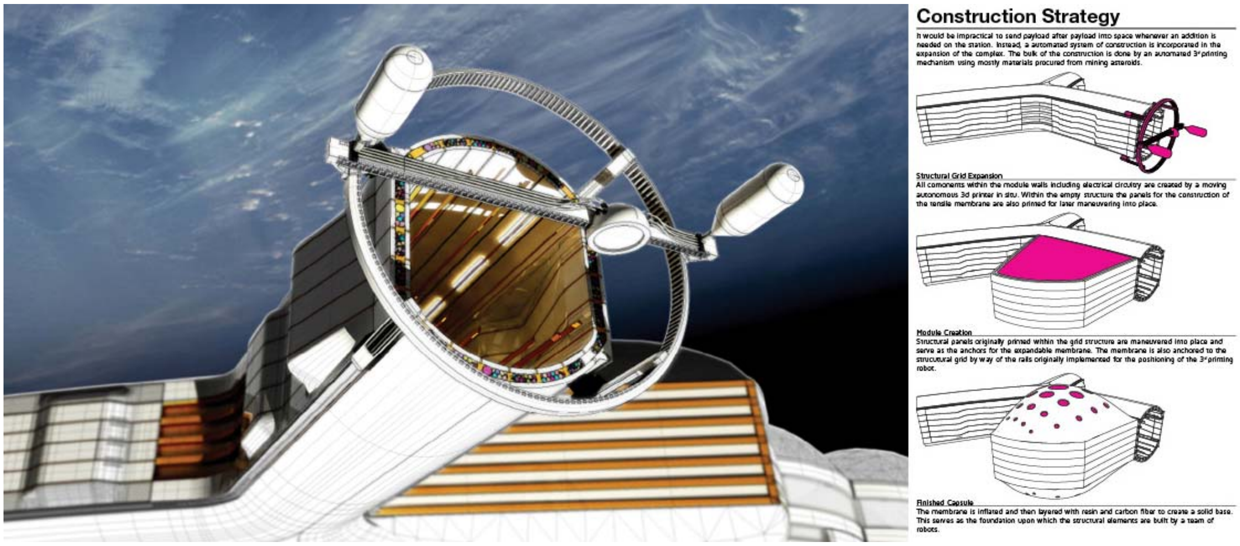

Figure 1. Construction Schematic. Using 3-d printing combined with inflatable habitation modules.

In the second approach (SCRAP) shown below the approach was to have a fabrication base which would partially manufacture and assemble floors of the station adjacent to the base and then push out from the base to expand the station. The majority of the raw materials would come from the collection of "space junk" (which is the primary function of the station). The space junk would be melted down to a raw metal to be used in the electron beam freeform (EBF3) which is an existing fabrication machine which uses an electron beam to melt metals and build almost any object layer-by-layer with a process similar to standard 3-d printing devices. The use of this fabrication technique will cut down on the amount of finished materials and components that would need to be sent from earth.

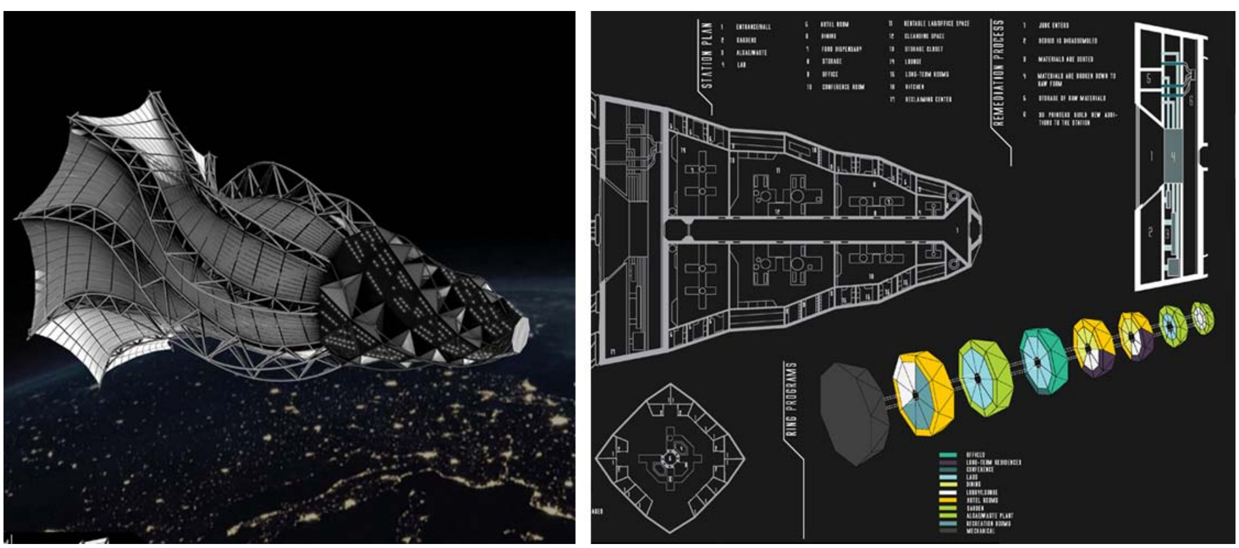

Figure 2. Construction Schematic. Using partial manufacture and assembly from a base which expanded outward.

From a construction standpoint there are many lessons from robotic construction techniques that can be applicable to terrestrial architectural problems including: higher safety, uniform quality, improving the work environment, eliminating complains, increasing productivity and efficiency with reduced costs. As the students familiarized themselves with such construction systems through the readings, and schematically applied them to the projects, they sought out ways to apply them to systems that make up architectural space.

In terms of assembly, students looked at several types of existing robotic fabrication techniques and developed prototype models of their assembly strategy using model parts and robotic prototyping kits. Many of the students prototyped conceptual physical models which could help explain the kinetic aspects of their system of construction. Several of the projects such as the “MethaFly” created models of complex geometries with a 3-d printer at a small scale to visually represent their intentions in a physical form. The prototypes successfully demonstrated various strategies for mechanical design. Typically the scale of the model was based on the size of the microchip, battery, and mechanical parts that had to fit within each module. The architectural students’ schematic robotic explorations were limited by the current possibilities of manufacturing and of the inherent physical mechanics. The robotics was developed within the context of the course and included an overview with tutorials of Arduino which is an open-source electronic prototyping platform allowing to create interactive electronic objects. This allowed them to develop a cursory understanding of basic electronics, and circuitry and the ability to apply a number of different sensors to their models.

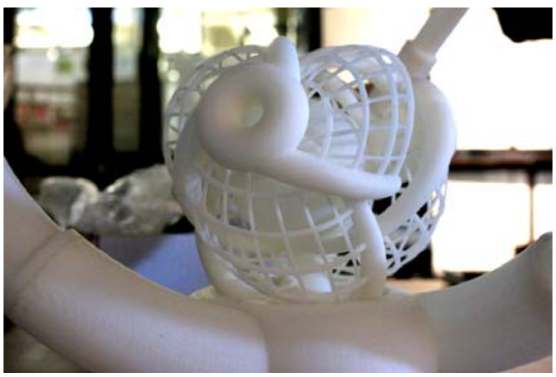

Figure 3. Most students printed 3-d models of the complex geometrical aspects of their designs.

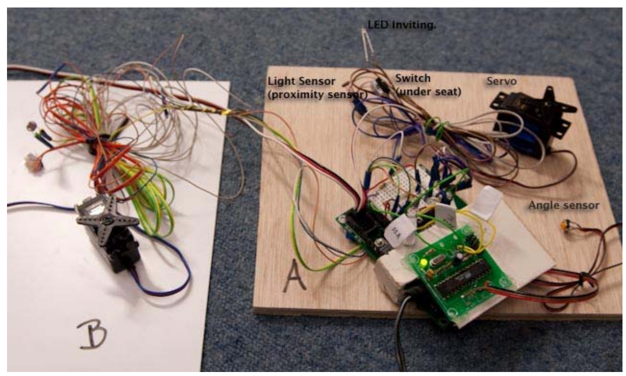

Figure 4. Typical Robotic Components. Students used the Arduino developer kit and various sensors and actuators to create simple prototypes of aspects of their construction strategies.

III. Conclusions

This project examines the value of a conceptual space architecture design project carried out by advanced students of architecture. Two primary contributions were made through the project: 1) the viral conceptual design contributions to the field of space architecture and 2) the educational value of space architecture to students of architecture. The design project had three primary considerations including: economic viability, human accommodation and construction feasibility. Each of these areas was developed into a holistic design that was built upon an original conceptual idea. The students utilized a design process that prioritized humanistic concerns over pragmatic problem solving. . Such an approach breaks the norm of a typical systems or trade analysis approach to confronting space architecture design problems. The second primary consideration of the project lies in the educational value of exposing students of architecture to problems of space architecture. Space architecture is an ideal test bed to explore many of the basic interfaces which concern humans in an optimized way. The design problem presented three principal areas of educational value including: 1) developing equilibrium between practical and livable concerns, 2) prioritizing spatial efficiency and optimization as well as 3) managing a mass balance of resources needed for sustaining life. All three of these issues are extremely important in their application to space architecture and are directly translatable to terrestrial applications of architectural design. A large part of the educational value then resides in the ability to “bring home” the ideas exposed in this design project to a new way of thinking about approaching terrestrial architecture.

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Appendix

Graphical representations of eleven of the design projects are included below in the following order:

- Space Track: Zero-Gravity Sports and Research Complex
- SCRAP: Satellite Capturing, Remediation, and Processing

- UnEarth: Asteroid Mining Station
- Space Broadcasting Studios
- Invert Planet Gravitational Research Facility
- Space Ark: Medical Research Facility
- Voyeuristic Research of Comparability
- AstroLab-Medical Research in Space
- Recycling and Production Hub
- LEO Spaceport
- Methalab: Methane Mining and Processing Facility

Figure 5. Space Track: Zero-Gravity Sports and Research Complex

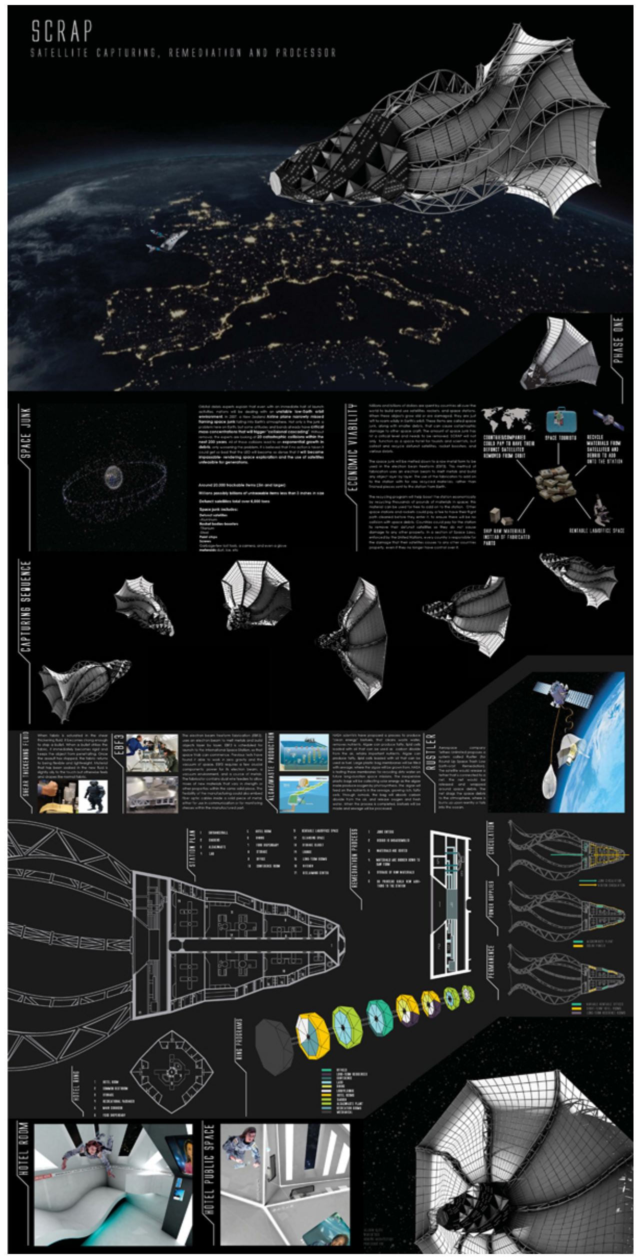

Figure 6. SCRAP: Satellite Capturing, Remediation, and Processing

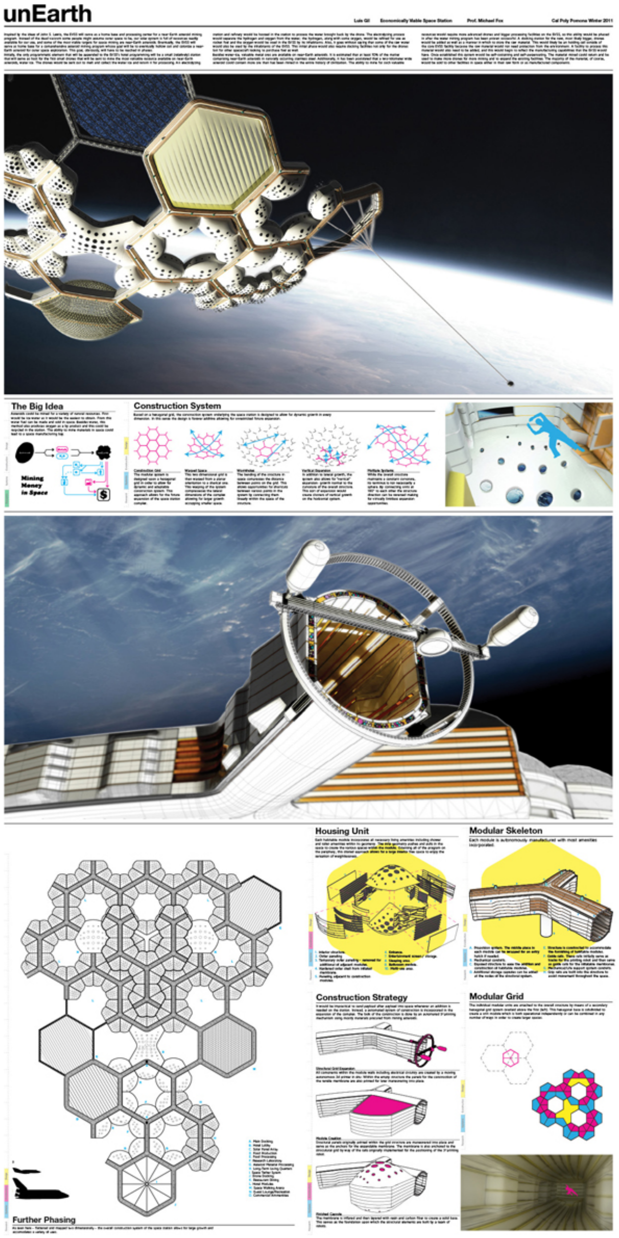

Figure 7. UnEarth: Asteroid Mining Station

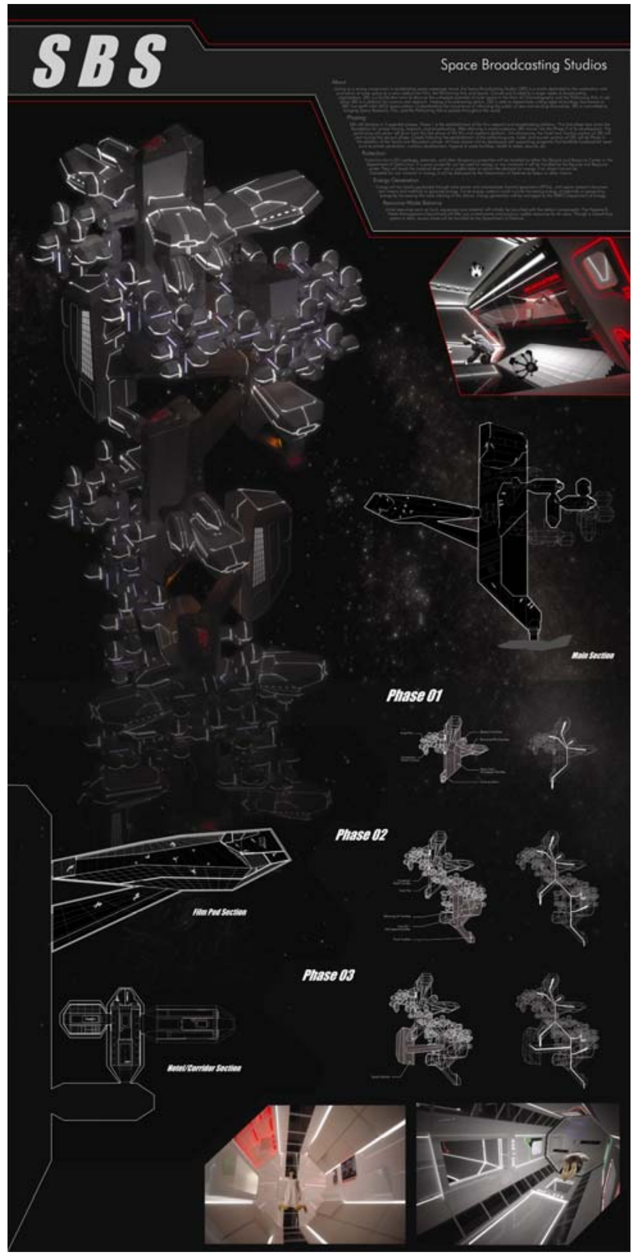

Figure 8. Space Broadcasting Studios

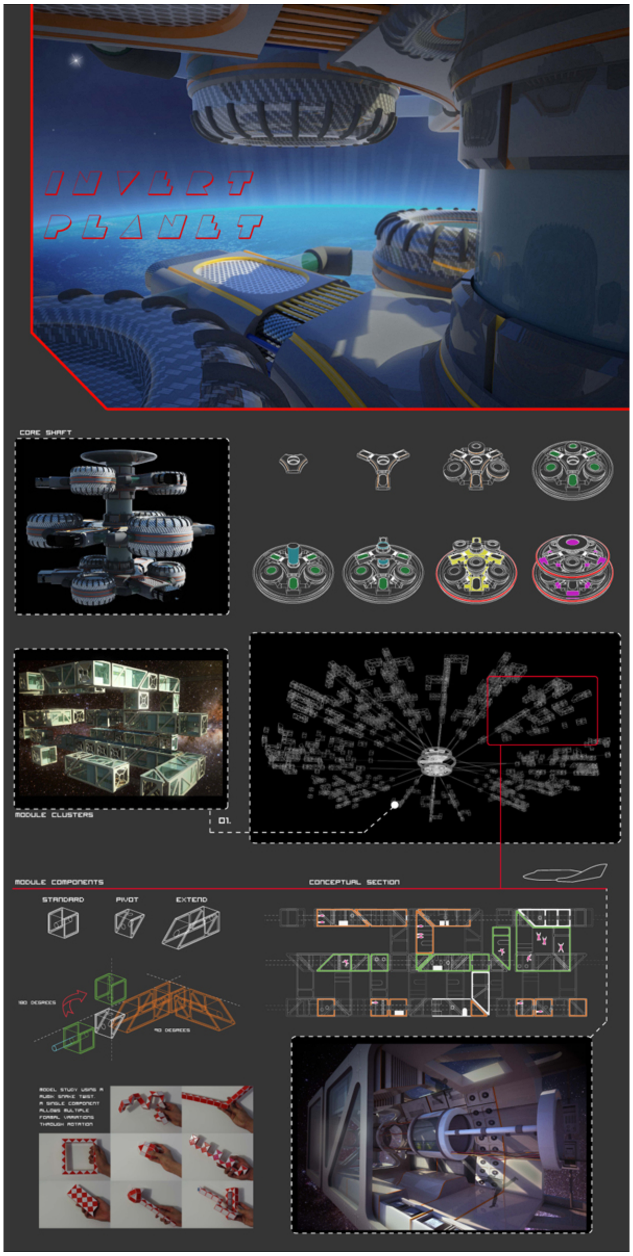

Figure 9. Invert Planet: Gravitational Research Facility

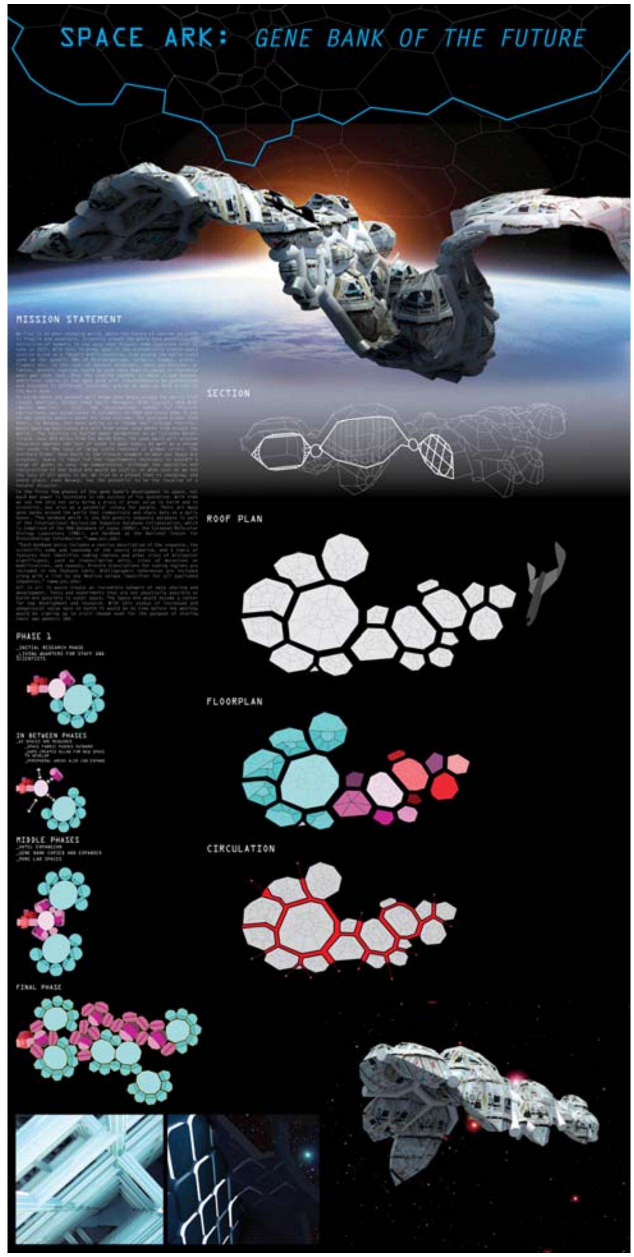

Figure 10. Space Ark: Medical Research Facility

Figure 11. Voyeuristic Research of Comparability

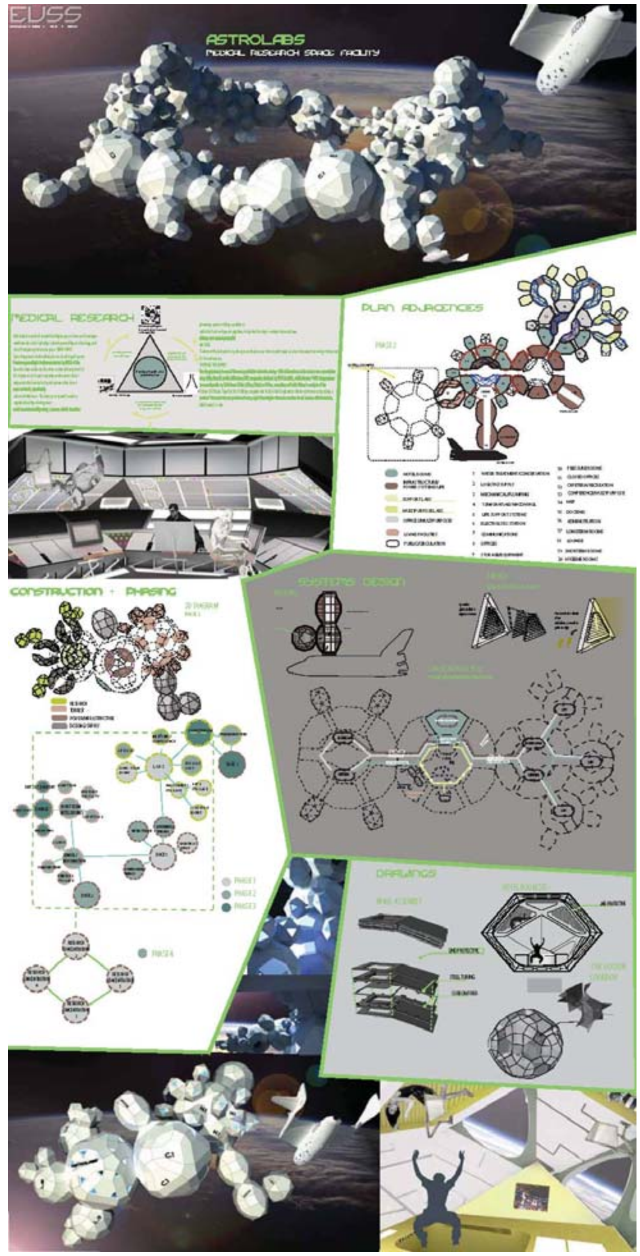

Figure 12. AstroLab-Medical Research in Space

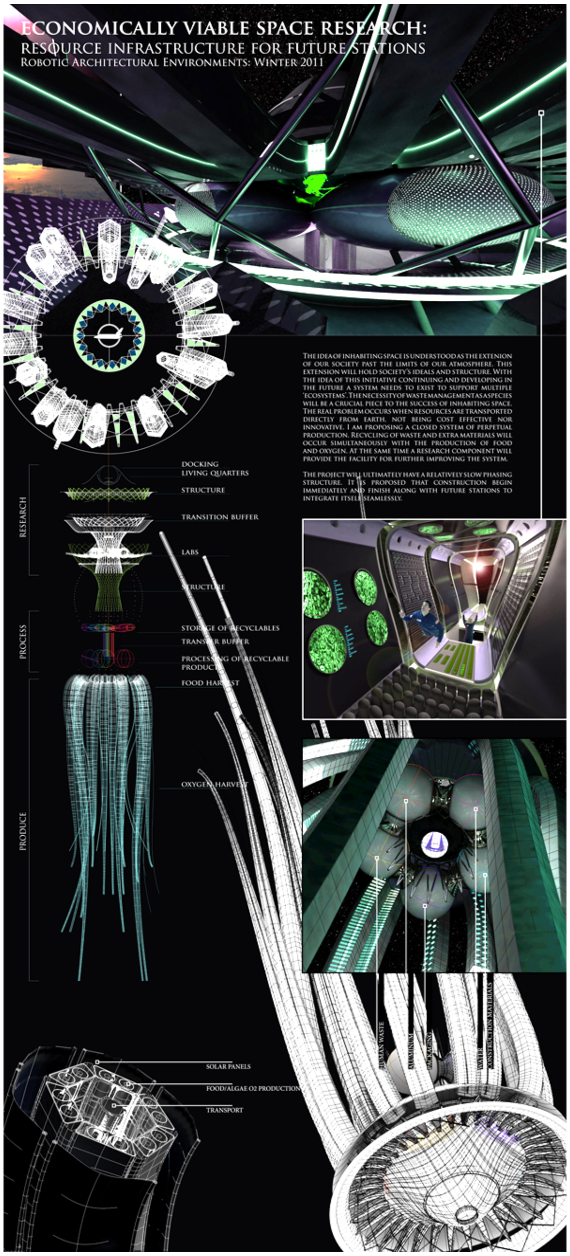

Figure 13. Recycling and Production Hub

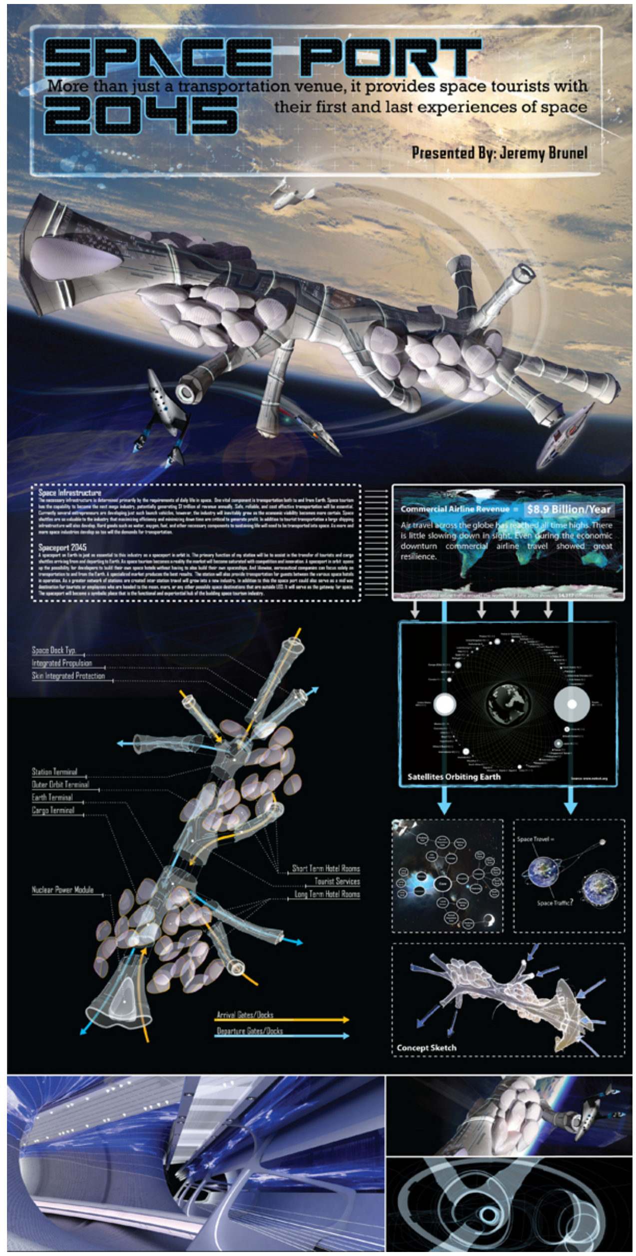

Figure 14. LEO Spaceport