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DESIGNING SUSTAINABLE MOON BASE 3D ENVIRONMENT AS AN INTERACTIVE LEARNING TOOL

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This paper presents an on-going project that Sasakawa International Center for Space Architecture (SICSA) graduate students and staff have been working with support of the Houston Museum of Natural Science (HMNS) since September 2010. The project aims to create a 3D Moon settlement environment for the HMNS's Discovery Dome program. HMNS uses full-dome video of the solar system, earth science topics and the human body to take students on learning adventures. Discovery Domes are completely immersive domed planetariums that utilize digital technology and can be installed in fixed facilities or in mobile, inflatable domes. The Houston Museum of Natural Science built the first digital fixed dome in 1998 and the first portable one in 2003 and has been delivering the domes, which can bring lessons about the universe even to remote places on Earth, to 75 locations on six continents since then.

The 3D interactive model of a sustainable Moon base for 80 people will be used as a learning tool at middle schools to ignite students' interest in science and technology and help them to explore challenges and opportunities that space exploration offers. The students will be able to navigate through the whole settlement, walk into facilities and see how people may live on Earth's only natural satellite in the future. They will learn about the importance of sustainability in remote environments using a Moon base as an example. Subjects that students will be able to explore and discuss later in their classrooms with teachers include:

1. Closed loop life support systems;
2. Environmental challenges that people will face living on the Moon;
3. Sustainable design issues and concerns;
4. Human factors;
5. Advanced technologies.

This paper will describe the project and SICSA graduate students' involvement in identifying the way the design can lead middle school kids to learn more about science and help to understand important aspects of space disciplines. The paper will also discuss challenges and advantages of using digital technology for educational purposes and emphasize importance of bringing a "wow" factor into classrooms of all levels.

I. PROJECT BACKGROUND AND RESOURCES

The project was conceived by the Houston Museum of Natural Science (HMNS) and Sasakawa International Center for Space Architecture (SICSA) in 2010 and was sponsored by the museum. Project goals and requirements were determined by Carolyn Sumners, the HMNS Vice President for Astronomy and the Physical Sciences. Overall design concept, base layout and assets were designed by SICSA's graduate students with technical support from the HMNS animation staff.

In 2010-2011 and 2011-2012 academic years, SICSA's architecture graduate students worked to develop models for a Moon colony of 80 people. Students worked under the direction of Dr. Sumners at HMNS and SICSA faculty. The settlement concept had to focus on a multi-national effort in the distant future, recognizing importance of the colony's sustainability and economic feasibility.

I.I "Discovery Dome" at HMNS

The museum installed the first full dome projection system in the United States in its Burke Baker Planetarium in the fall of 1998. The first full dome video was just 10 minutes production but demonstrated important advantages of the new technology. More shows were produced since then. In June of 2012, the Burke Baker Planetarium was listed second of the six planetariums you should visit this summer by Geeksugar.com.

Over a million visitors have seen video productions in the Burke Baker Planetarium since the dome projection system was installed. Full-dome still images produced by the astronaut Scott Parazynski with a fisheye camera on the International Space Station were put in a show by the planetarium animation staff. In collaboration with the Immersive Earth project at Rice University, HMNS invented the portable digital theater (Discovery Dome) in the fall of 2003 and reaches over

80,000 students with its inflatable domes each year. (Figure 1) In a 3D-like environment students can better immerse into the surroundings and become engaged in close to real life experience. (Figure 2) Adding interactivity to this experience is a next logical step in the evolution of learning process in general and the Discovery Dome project as a part of it.[1]

Fig. 1: HMNS Discovery Dome inflated.

Fig. 2: Discovery Dome “We Choose Space” show.

I.II SICSA Program at the University of Houston

The Sasakawa International Center for Space Architecture (SICSA), an organization which is part of the Gerald D. Hines College of Architecture, undertakes comprehensive research and design associated with facilities and structures to support operations in low Earth Orbit, during Earth-planetary transfers, on the surfaces of the Moon and Mars and extreme environments on Earth.

SICSA brings more than 30 years of internationally recognized experience in habitat research, planning, and design for space and extreme environments. These include orbital and planetary space facilities, polar research stations, offshore and underwater accommodations, and shelters for populations impacted by natural and man-made disasters. Such settings typically impose logistic transport challenges for people, equipment and supplies; present severe facility construction and operational constraints; demand careful attention to habitability, performance and safety under isolated, confined conditions; and heavily rely upon all practical means to optimize sustainable, energy-efficient, ecologically-responsible strategies. SISCA sponsors the world's only Master of Science in Space Architecture program. A central priority is to explore and apply sustainable design and living approaches that can prevent unnecessary extreme living conditions from occurring everywhere on our planet.

II. PROJECT REQUIREMENTS AND GOALS

The HMNS planetarium recent space related shows proved that even the most exciting work that did not get any negative comment does not gain much of public attention and people in general lose their interest in space. In order to bring it back and also to spark interest to space in young generations the museum conducted an extensive interviewing of public and teachers. The most common request was TO MAKE IT REAL.

SICSA was asked to create an interactive game environment that would help teachers to explain their students the essence of science and engineering and to make them accept the idea that space is part of their life today and may become even more so tomorrow. The digital environment was created using 3DStudioMax, Rhinoceros 4.0 and AutoCAD 2012. The game sequence was created using Unity3D 3.0 software.

II.I Location

There are several factors that help to determine an appropriate settlement location on a celestial body:

1. Relation and proximity to the sun and landing site;
2. Type of terrain, type of soil and its composition;
3. Communication availability with earth and surface units;
4. Mobility of the landing units;
5. Availability of power resources;
6. ISRU ability;
7. Geologic diversity.

After considering all the above factors and availability of data it was decided that Skackleton crater in Moon’s South Pole (Figure 3) is the most appropriate location that can also provide:

1. Maximum of solar energy availability;
2. Proximity to possible ice water resources;
3. Usage of existing relief as a partial natural radiation shielding.

II.II Settlement Requirements

The museum coordinators in coordination with SICSA faculty set a list of requirements for the settlement and facilities design to comply; these recommendations and requirements were based on the vision what a successful show or the game product has to offer to its users. It was decided that a future moon settlement has to:

1. Serve 80+ people;
2. Be self-sufficient and sustainable;
3. Provide benefits and profitable outcome to Earth;
4. Expandable (growth possibilities);
5. Provide means to fulfil all aspects of life for inhabitants.

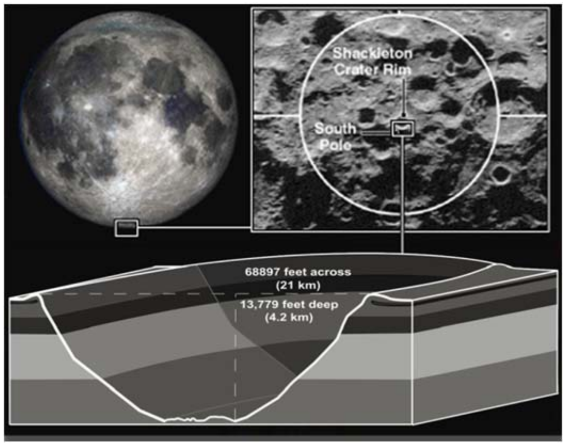


Fig. 3: Shackleton crater location and data.

III. CONCEPT AND STORYBOARD DEVELOPMENT

SICSA's graduate students who worked on the project came to the Master of Science – Space Architecture program from different backgrounds which enabled them to cover the design of diverse elements for future living and working on the Moon. The concept development started from developing a storyboard of what the middle school students would be interested to learn and in parallel working on project programming. The design program was based on lifestyles and activities of future colony habitants.

To satisfy project goals and museum requests it was first discussed and determined what such a settlement would be able to produce to support itself and make its existence beneficial for mission sponsors from Earth. Science opportunities are obvious although they may not pay back investments right away and have to be supported by other businesses. One of the evident options is building solar array farms and producing energy for the settlement and back to Earth. Another prospect would include oxygen and fuel production.

Planning operation strategies to achieve science and production goals helped students to understand and design a general settlement layout where all functions are related and to create a logical pathway through the settlement for future users to explore the environment as they navigate from module to module and from activity to activity. (Figure 4)

During the process of site planning graduate students learned constraints and requirements for designing habitable spaces in the extremely harsh moon environment where no developed or at least some existing infrastructure is present and where all initial elements have to be brought from Earth and comply with stringent volume and mass restrictions of a spacecraft payload.

Middle school students and other users of the game would arrive to the landing site, walk through the receiving module/initial habitat, check-in and get on a rover to drive to the habitat site where they will be dispersed to different modules depending on their mission agenda and purpose of the trip. They can visit solar plant, radio telescope, aquaponics lab, medical and exercising facility or relax in the entertainment module.

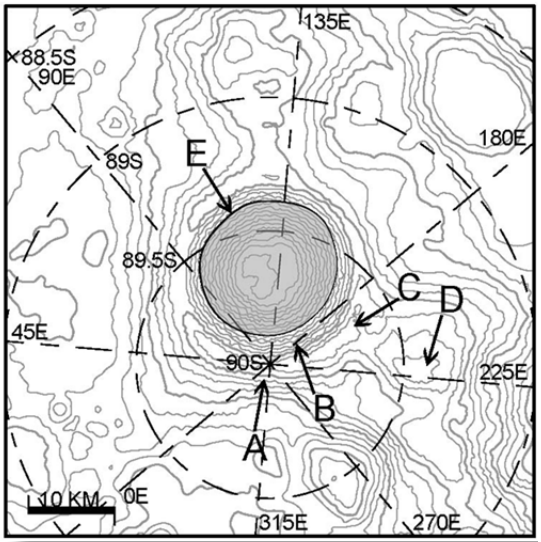


Fig. 4: Site layout where: (A) Landing site; (B) Habitat site; (C) Solar array farm One; (D) Solar array farm Two; (E) Line of perpetual darkness inside Shackleton crater.

IV. LEARNING ASPECTS AND CHALLENGES

The interactive environment created by graduate students at SICSA had to address several key learning aspects that would be later discussed in the class with teachers. To meet those requirements the project objectives were focused on implementing into design the following:

1. Sustainability;
2. In-situ resource utilization (ISRU);
3. Closed-loop systems;
4. Harsh environment and safety;
5. Human factors.

Importance of base sustainability cannot be underestimated and may be achieved through maximizing ISRU, closed-loop life support systems and recycling of most of resources brought from Earth. Students will have to identify those aspects and maybe propose more options to achieve maximum of sustainability of the base.

The middle school students will learn about regolith elements composition, how they can be used for human needs and what utilization processes will require. ISRU would include utilising ice that is found on the moon surface, power produced by the solar array plants and possible Helium-3 and spacecraft fuel production.

Water recycling and other close-loop systems are well-known and have been used on the International Space Station (ISS) and previous space stations for years. The learning aspect of importance of close-loop systems was emphasized in the design by maximizing utilization of such systems for human life support and food production.

Human safety is the biggest concern for any crewed space exploration missions. Learning about environmental hazards present on the Moon students will discover connecting points between different science disciplines. They will study how the moon environment will affect a human body, what health concerns will have to be addressed during long periods of staying on the Moon and how it can be done.

All the learning aspects had to be incorporated into the game environment so that game players will be moving from place to place following the mission agenda and figuring out modules and facilities functions. This required a well-organized approach and structured procedure. (Figure 5)

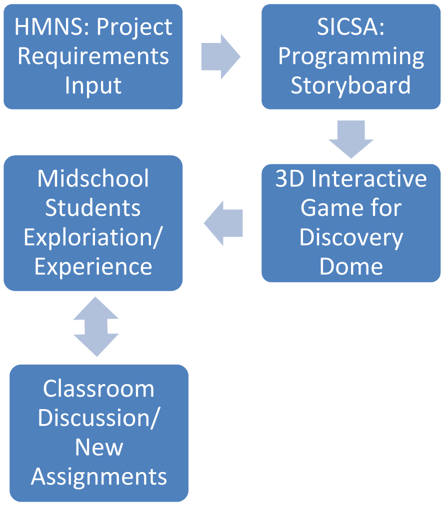


Fig.5: Moon Base project development and operations flow chart.

Another challenge we faced during the work on the game settings and development of exploration strategy was defining how players will interact with the environment and levels of interaction. It was decided that a class will delegate "driving" duty to one person and he or she will be responsible for navigating through the base to points of interest or to accomplish a mission. Later on the mission results will be discussed in the classroom with teachers and another student will be chosen to redo the work or become a driver for a new assignment.

V. DESCRIPTION OF SETTLEMENT ELEMENTS

All necessary elements and facilities of the base were defined by the graduate students and SICSA's faculty in the program. The overall design complied with the main goal of the project of creating a real life experience to help children to understand and rely themselves to space exploration and life in space in general. The project had to include all key elements of what a successful and sustainable living and working in space would be.

It was also decided that the utilization of proven and up-to-date technology has to be maximized in the design approach. An ISS conventional module was used as a core element for habitats and working facilities. Inflatable structures (donuts) deployable from the hard shell core elements added extra volume and real estate that will be necessary for comfortable long-term human presence on the moon surface. (Figure 6)

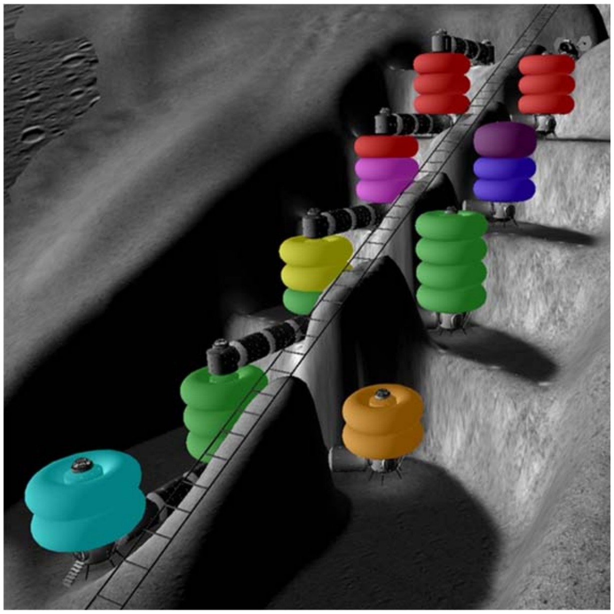


Fig. 6: Base functional elements. 🟥 Crew quarters; ■ Dining; 🟦 Fitness; 🟪 Recreational; 🟨 Medical; 🟩 Aquaponics; 🟧 Research; ■ Command Control.
Design by SICSA's students David Ladewig and Thomas Hockenberry.

V.I Landing Site

Students' exploration experience of the Moon starts from the landing site and "Welcome" module. Several non-pressurized rovers are parked next to the welcome module and ready to bring newcomers to their headquarters and habitats. There are also pressurized "Hoppers" – rovers for long-range exploration missions that can serve as short-term habitats if necessary. Students will "get" on a rover and start driving down from the crater's rim towards the settlement. (Figures 7 and 8)

The Landing site is equipped with an independent power supply and has an ascent module ready to take off in case of emergency. Students will learn why the landing and launch site has to be located away from major activities, what functions it will have to serve and provide, and what equipment is necessary there.

Fig. 7: Entry level and unpressurized rovers.

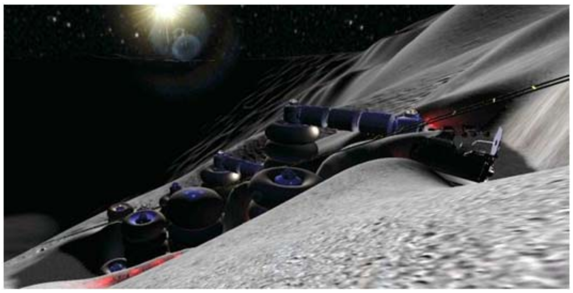


Fig. 8: View down to the base from the rim of the crater. Design by SICSA's students David Ladewig and Thomas Hockenberry.

V.II Crew Quarters

Housing modules of the base included several important functions. Mid-schools students will be asked to think what those functions are and prompt to suggest how they can be resolved in the lunar remote environment.

Living, consumables, equipment requirements etc. – all of it has to be addressed in the design approach. In the proposed base inflatable structures in addition to hard shell conventional modules are proposed to house all necessary functions. Inflatable structures deployed from core modules after they are positioned on the surface, will offer extra area and volume benefits and afford additional spaces for extended number of habitants and their activities. (Figure 9) All major communications and utilities run through a hard shell core. Living quarters can present independent living accommodations for families and single occupants without compromising privacy.

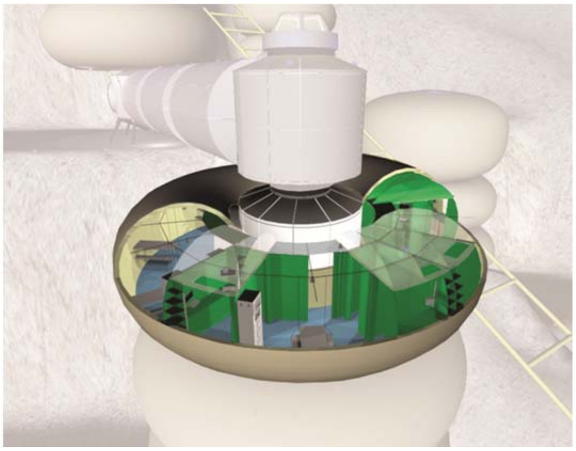


Fig. 9: Living quarters. Design by SICSA's student Thomas Hockenberry.

V.III Supporting Facilities

Aquaponics

Moon base food supply is based on aquaponics sustainable food production system. Aquaponics food production is a combination of a traditional fish rising and hydroponics crops growing where both parts provide resources for each other.[2, 3] Hydroponics growing beds are located in inflatable torus-shaped structures of a multi-storey labs facility and connected to fish tanks positioned in the central core. (Figure 10)

Students will learn about eco-systems dependability and closed-loop systems requirements by following the food chain from fish to plants and back and by discovering how plants and fish by-products can be utilised and used for community's benefits. They will also discuss in the class later on amounts of food production required for the base everyday support and required size of aquaponics lab to support that demand.

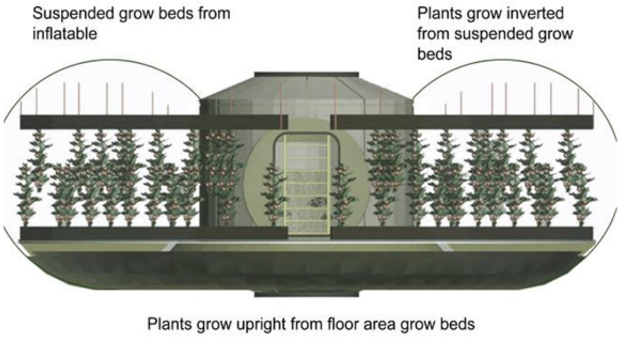
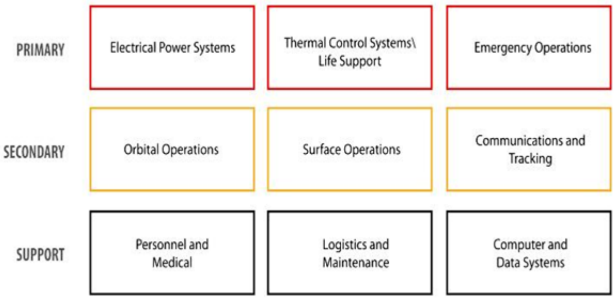


Fig. 10: Side elevation of hydroponics lab. Design by SICSA's grad student Nima Cheraghpour.

Command Control and Research Labs

Users/students will investigate what specific functions a lunar settlement's command control center should perform and how they have to be connected or related. Students will discover that command control operators will have to monitor surface operations, both automated and manned; communicate with Earth and travelling spaceships, satellites, ISRU facilities, take care of emergencies and more. (Figures 11 and 12) Students can enter a cupola on top of the stack of inflatable donuts and look around to see the settlement, lunar surface and ISRU plants.



PRIMARY	Electrical Power Systems	Thermal Control Systems\ Life Support	Emergency Operations
SECONDARY	Orbital Operations	Surface Operations	Communications and Tracking
SUPPORT	Personnel and Medical	Logistics and Maintenance	Computer and Data Systems

Fig. 11: Command control center functional areas of monitoring and control.

Fig. 12: Interior arrangements of the command control floor. Design by SICSA's grad student Stacy Henze.

Depending on research requirements, base research labs are located in inflatable or in hard shell modules. They placed away from the living quarters and close to the command control center for easier operations and safety reasons.

Fitness and Medical Facilities

Living in a 1/6 of Earth gravity environment will require all habitants of the colony to exercise every day. Lightweight structures are used to separate and support different activities in partial gravity. (Figure 13)

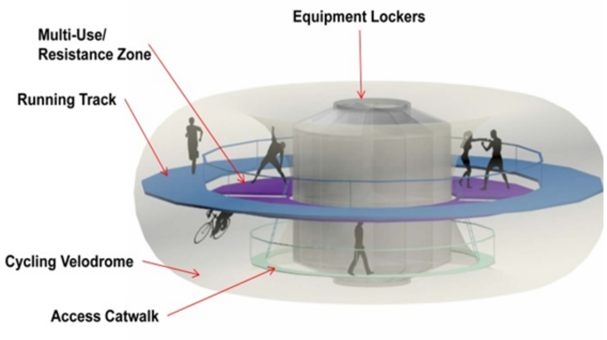


Fig. 13: Free-form fitness facility. Design by SICSA's grad student David Ladewig.

What sports can be played in partial-gravity? How it affects regular sport activities that we have on Earth? What new sports can be discovered on the Moon? Students may be asked such questions during the game or in the classroom afterwards.

How different living on the Moon will be? Would people get sick or injured there? Probably, students will walk into medical inflatable facility and see how a small hospital might be arranged there.

Recreational and Dining

Long periods of time away from familiar Earth surroundings and lifestyle may cause people to feel more lonely and depressed and less motivated.[4] They will miss things common to Earth life, such as movie nights or dancing or just getting away to nature. SICSA students offered a multipurpose recreational inflatable module where interior volume may be transformed into different places depending on requirement or/and activity. (Figure 14)

What else can be offered there? What would people like to do in their leisure time? The recreational center would stimulate creative thinking and could be a place where the form of recreation is only limited by one's imagination.

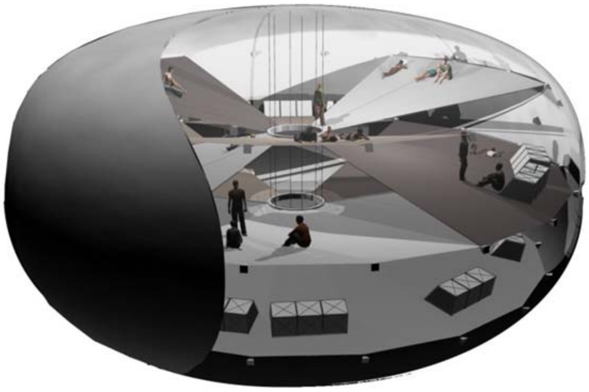


Fig. 14: Transformable floor system of the recreational module. Design by SICSA's grad student Zhu Chen.

Dining can be also part of entertainment and plays very important social role in the community. Graduate students offer using the same transformable floor system to re-arrange place into a nice dining area where people can share their time, exchange news and have a nice meal at the same time. (Figure 15)

Food sources can be harvested from aquaponics facilities with some additions brought from Earth. It may be possible to grow more food locally and depend less from Earth? Students can be asked to suggest other ways to make the settlement more sustainable and effective.

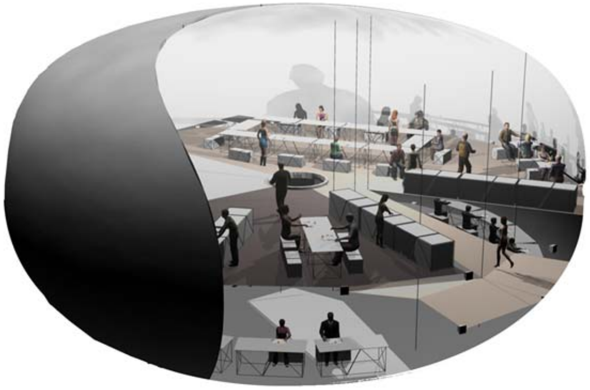


Fig. 15: Dining module. Design by SICSA's grad student Zhu Chen.

VI. CONCLUSIONS

There has been already many papers written and presentations made about the benefits of using games as learning tools. Those benefits are pretty obvious although not that easily achievable. Attractiveness of using games for teaching lays in their entertainment quality but unfortunately sometimes they lose it as soon as learning quality increases.[5] During SICSA's work on the Moon base interactive environment project faculty and graduate students tried to create a game environment that would almost seamlessly instigate students/users to learn about moon and space as he or she will be moving through discovering settlement's elements. There is also an important distinction between the discussed game concept and usual teaching games – it focuses not particularly on development of certain skills but on inspiring young kids and induce their curiosity to learn more about science and engineering.

The development of the project was also a part of SICSA MS-Space Architecture program where graduate students had to conduct extensive research on sustainability, engineering, science and economy prior and during the design development. The "reality" of the design was one of the priorities and had been verified by HMNS representatives and NASA ISC professionals throughout the whole process. Another essential aspect of graduate students building a 3D interactive model was that they worked from "inside" of the built environment. The graduate students could test their design solutions by "walking and riding" through the spaces they created and could relate themselves to the place in a better way. The last was also one of the objectives given by the museum: creating an effect of presence and involvement. Working for real users – middleschool kids and teachers – brought more energy to the class adding professional office atmosphere. Overall, the whole experience of working on the project was very beneficial for SICSA graduate students as well.

There are considerable differences in education techniques based on gaming: learning by playing or teaching by using games.[6] A teacher can not be substituted by technology but technology can be used by an educator as a perfect teaching tool. Adapting the game 3D environment to Discovery Dome makes this tool even more effective in teaching and adds amusement factor into the learning process.

The Moon Base interactive game environment targets to bridge the gap between Space and Earth. It teaches students to look at space exploration not only as a unique and exclusive endeavour but as an everyday activity and one of the building blocks of their future.

REFERENCES

1. Houston Museum of Natural Science. (n.d.). *HMNS website*. Retrieved July 31, 2012, from http://www.hmns.org/index.php?option=com_content&view=article&id=262&Itemid=279
2. Wikipedia. (2012, July 28). Retrieved July 31, 2012, from http://en.wikipedia.org/wiki/Aquaponics
3. J. E. Rakocy, M. P., (2006). Recirculating aquaculture tank production systems: aquaponics—integrating fish and plant culture. *Southern Regional Aquaculture Center*, Publication No.454.
4. L. Baroff, O. Bannova, (2012, October). A realistic vision of the mars expedition: how many people must go? *Proceedings of International Astronautical Congress 62*, IAC-11-E5.1.7.
5. R. V. Eck, (2006, March/April). It's not just the digital natives who are restless. *EDUCAUSEreview*, pp. 17-30.
6. K.Kiili, (2005, Agust). Content creation challenges and flow experience in educational games: The IT-Emperor case. *The Internet and Higher Education*, 183-198.