Inquiry: The University of Arkansas Undergraduate Research Journal

Volume 3 Article 6

Fall 2002

Marsport Deployable Greenhouse

Iova Dineva
University of Arkansas, Fayetteville

Recommended Citation

Dineva, Iova (2002) "Marsport Deployable Greenhouse," *Inquiry: The University of Arkansas Undergraduate Research Journal*: Vol. 3 , Article 6.
Available at: http://scholarworks.uark.edu/inquiry/vol3/iss1/6

MARSPORT DEPLOYABLE GREENHOUSE

Iova Dineva
Department of Architecture

Faculty Mentor: Dr. Jerry Wall
Professor of Architecture

Abstract:

To sustain a Mars exploration team, NASA's reference mission IV includes a greenhouse facility requirement to supplement the crew's food supply. This research project explores strategies for building, delivering, deploying, operating, and maintaining a greenhouse as a supplemental structure for the Mars environment. The MarsPort Deployable Greenhouse (MDG) addresses the issues of atmosphere, sunlight, energy, deployment mechanism, water and nutrients, crop collection, modular development for expansion, research module for Mars experimentation, and crew recreation.

Heaven on Mars:

The planet Mars has been tantalizing mankind since the dawn of time. The Red Planet has been given attributes that range from a mankind-welcoming place to a deadly force and trap for explorers. In 1998 NASA refined the Mars Design Reference Mission (DRM)[1], which will enable humanity to finally set foot on the mysterious planet. In preparation of such a prolonged mission many innovations are put in use.

The given problem:

The Reference Mission v 3.0 defines the requirements and strategies for executing human exploration on Mars. Although DRM specifies the use of non-perishable food supply reserves as a means for executing the near 900-day mission segments, it also indicates the possible development of regenerative life-support systems, including food production *in situ*. In search of creative solutions, NASA commissioned the 2002 MarsPort Engineering Design Student Competition, establishing a set of requirements for a greenhouse structure. As a result of an independent study at the University of Arkansas School of Architecture, this paper presents a theoretical response to the competition based on application of known materials and adoption of existing design strategies. The design adheres to the NASA requirements to explore strategies for building, delivering, deploying, operating, and maintaining a greenhouse as a supplemental structure for the Mars environment, but it also augments the given program by introducing the requirement of human habitation.

The MarsPort Deployable Greenhouse (MDG) engages issues of atmosphere, sunlight, energy, deployment mechanism, water and nutrients, crop collection, modular development for expansion, research module for Mars experimentation, and crew recreation. These issues were considered equally for their technical and architectural value and priorities.

Multiple studies have been conducted in universities and various agencies across the globe, from state-supported institutions (Utah State University, University of Florida, Purdue University) to private agencies and groups (the Moon Society Artemis Project, the Mars Society, etc.) to NASA and her contractors. Most of these projects are highly specialized in a certain area and lack continuity and overall integration of the issues. Building on architectural education, this proposal utilized research publications by these specialists to synthesize a more comprehensive view of the problem. The design strategy linked solutions of structural integrity with deployable delivery, Mars native chemistries with a sustainable Earth ecosystem, and last, but not least, human comfort with efficient mixed-use of facilities.

Traditionally in the development of a life-supporting mechanism like the MarsPort, practicality of the systems, robust mechanics, and maximum utilization are given priority over the architectural, aesthetic or psychological effect of the environment. The MarsPort will be stationed on the planet surface for a prolonged period of time (the projected life-span for the MDG is twenty years; the crew stay is 600 days), so it must be equipped with possible technologies to utilize native resources for fuel and building materials, and certainly the opportunity for linear surface expansion of the complex. Thus, the MarsPort does not have the size limits and confinements of space stations or transportation crafts, and it presents the opportunity for expanding the engineering side of design to take into account the human variables.

Based on a belief that there is little human satisfaction derived from living in a 'tin can', it can be concluded that prolonged missions like the Mars project call for special care for the provision of privacy, exercise, and a relaxing environment. While ideally this can be achieved in a specialized module apart from the main surface habitation and laboratory, the efficiency of all systems should be augmented by designing particularly Earth-recalling spaces such as the MDG to serve the double role of functional element and dwelling-place where people can regenerate their physical and psychological condition.

Work methods:

In an effort to maintain a wide margin of ideas built upon existing practical research on the subject, the theoretical findings of this document generated a catalogue of possible solutions for each issue of the overall problem (atmosphere maintenance, light, heat and energy, vegetation, deployable structure and methods of construction) and described the basic advantages and disadvantages of each system. During this phase of the project there was no attempt to present conclusive evidence for one system over another. Limitations on time, funding and equipment made it impossible to develop functional prototypes for each solution and test them for satisfactory performance in structural integrity, deployment mechanism, and vegetation sustainability.

The project consisted of several phases: data collection, preliminary design, development of construction strategies and sample prototype design. Phase One provided the basic knowledge of life-support systems, requirements for growth of vegetation in extreme conditions, parameters for crew necessities and comfort and the initial parameters for structural design. Phase Two developed the preliminary design of several schemes ranging in programmatic layout from a fully automated utility device to a leisurely garden that doubles as crew quarters. At this point the selection and design of general lighting and plant-growing systems was included. Phase Three focused mainly on the development of construction methods for each scheme, inclusive of installation, execution, and support techniques. Phase Four was the design of a sample structure utilizing the schemes that were determined to be most appropriate. Strategies were considered for the physical linkage of the MDG to the main MarsPort complex, for clustering of multiple greenhouses as a system of multi-function modules, and for integration of the life-support systems between the main complex and the MDG.

Issues and Proposal Summary:

The MarsPort Deployable Greenhouse presents a set of requirements, which, although closely related to greenhouses on Earth, also make the structure radically different from traditional greenhouses. The term greenhouse is loosely used as meaning an enclosed space for growth of vegetation. Besides the main requirement as a vegetation growth chamber requiring certain atmospheric, energy, nutrition and storage needs, the MDG also has to include provision for protection from the harsh environment of Mars and for the possible utilization of native resources for sustainability, thus minimizing the dependency on Earth-imported material. Although it will depend on highly scientific support mechanisms as does everything else of human origin on Mars; the intent of the design is to detach the MDG as much as possible from the feeling of a laboratory and to make it similar to a peaceful garden.

Atmosphere maintenance:

The specified atmosphere can be maintained through the use of a commercially available system for close monitoring of air chemistry. Such systems can control every aspect of the atmosphere: chemical makeup (amount of different gases and water vapor), relative humidity, and temperature. Air quality can be tailored to the vegetable crops in the greenhouse at any given time.

An initial amount of Earth life-supporting substances will be shipped with the MDG. A sample system is designed that efficiently stores, uses, and supplants imported material that cannot be easily extracted from the Mars environment. The most important elements are *oxygen* (produced and consumed by the plants, oxygen can be introduced into crew quarters for breathing or into a biochemical reactor for breakdown of other substances by oxidation), *carbon dioxide* (used by the vegetation for photosynthesis, carbon dioxide can be introduced directly from the Martian atmosphere which is 95% CO_2), and *nitrogen* (used by the vegetation as nitrite or ammonium only, nitrogen can be extracted from the Martian atmosphere as gas (2.7%) and fixated by bacteria or chemical processes). By-products of the greenhouse such as ethylene gas and water vapor can be removed in the air-monitoring systems and routed to other services for utilization.

Light, heat and energy:

A major concern of the design is meeting the energy requirements for the greenhouse. NASA prescribes the minimum requirements to be 125 – 50 W/m^2 for at least 12 hours per day, with a temperature range of 10-30 degrees Celsius. The fact that Mars' iridescence is 589.2 W/m^2 means that a 21% transparency of the enclosure will be adequate to produce the mid-day intensity required. Few materials can maintain this level of transparency and still keep a high R value (resistance to heat transfer). Furthermore, transparent materials that are flexible on Earth, therefore ideal for a deployable tensile structure, loose such qualities in the cold Martian climate (as low as -140 degrees Celsius)[3].

A more viable solution is an opaque enclosure that satisfies the requirements for structural integrity, deployment, and heat-transfer isolation in which the lighting can be achieved through a system of light-collecting devices (focusing lenses, mirrors, sun-tracking apparatuses), distribution devices (fiber optics, mirrors), and conservation devices (photothermic/photovoltaic plates, batteries) that maximize the light collection and utilization levels for both natural and artificial lighting (Figure 1).

Temperature in the MDG must be maintained between 10-30 degrees Celsius. Part of the heat requirement will be satisfied from the natural operation of the equipment – lamps, pump engines, biochemical reactor – all of which emit heat in their normal mode of operation. Provided there are adequate energy sources, the temperature can be further supplemented by the previously discussed air system.

Energy for the MDG may be harnessed *in situ* with photovoltaic/photothermic systems, other natural systems like wind or geothermal energy, or the air system may be plugged into the main power grid of the complex, utilizing either fuel cells with (ideally) native materials or the two nuclear power plants prescribed in the DRM.

Vegetation:

NASA studies have shown that the ALS (Advances Life Support) greenhouse can fully meet the dietary needs of one adult with 12 m^2 of planting trays. The MDG is designed to produce 25% of the needed food for the crew; therefore, for design purposes, $3m^2$ planting space per person is allocated. As the NASA brief and DRM specify crew size of 6, $18m^2$ is the minimum required planting space.

The most efficient growth system[4] is hydroponics – either static medium (inert "soil" for root support and aeration) or NFT (Nutrient Film Technique, a shallow channel) with a slow moving solution of nutrients that washes the plants' roots (Figure 2). Hydroponics requires a system of reservoirs for the nutrient solution and a monitoring mechanism for nutrient content. One of the major advantages is that the system can optimize the nutrient content for any of the desired crops. Systems for collection, primary preparation, and storage of the foods produced may include both human and robot labor. If the greenhouse is dispatched to arrive before the crew, it would be beneficial if it were designed to be self-deploying and fully automated so that an initial amount of food would be ready for consumption at crew landing. A selection of foods with a high harvest index is desired for optimizing dietary supplements.

The Utah State University Crop Physiology Lab has developed a series of dwarf cultivars – tomatoes, rice, and wheat. Such space-efficient plants mean a more compact planting area in the enclosure, thus allowing for a more liberal allocation of space for human activities not directly related to the operation of the greenhouse.

Deployable structure and methods of construction:

The discussed technological requirements produce the need for a mechanical core that houses all the equipment and storage units needed for the operation of the greenhouse. In architectural terms this translates into a separation of systems into the mechanics core, the enclosure, and the planting space. The plant-trays and the enclosure system can become the deployable portion of the structure, backed-up by a rigid mechanical core that contains all the necessary materials and machinery for deploying and operating the MDG during transit. For space efficiency during transit and operation, geometrical forms that optimize the ratio between internal space and enclosure surface are desirable, therefore cylindrical or near-spherical forms are desirable.

There are multiple ways to handle the deploying systems. They can generally be separated into three categories – inflatable, telescoping, and smart-materials derivations. Some of the options available include air-supported structure and enclosure, inflatable structure and tensile enclosure, tensile enclosure and telescoping structure, telescoping sliced rigid shells, rigid telescoping enclosure, smart material sheets corresponding to open-closed situation under different amounts of agitation, and programmable or propelled resins on a rigid skeleton structure (Figure 3).

The designed sample prototype focused mainly on the cylindrical 'backbone' version of the system with inflatable enclosure and ribs filled with foam, which has the necessary rigidity after curing to provide the compression strength needed by the structure (Figure 4). All life-support systems are enclosed within the mechanics bay in the center of the developed torus, while the fiber optic light distribution system, the enclosure, and the plant trays are integrated into an inflatable skin and structure. Depending on the size of the crew, the area and height of the torus may be modulated for efficiency and comfort.

Crew life:

While the MDG is primarily a utility building, it also provides a unique opportunity to introduce a node for crew interaction that is not easily achievable in any other part of the MarsPort. It provides an option for mimicking a piece of Earth for private use as a garden for relaxation or solitude or for another mode of working that is different from the crews' highly scientific everyday life.

In the worst-case scenario of the mission window 2007-2009, transit time for the crew is 180 days, with a surface stay in the order of 600 days, which means about three years in the exclusive company of five crewmates without the certainty of returning to Earth. While acquired discipline, training, and everyday work will be a constant protection from the tension among crew members and between the crew and mission control, the addition of a purely low-speed and low-stress environment with edible and decorative vegetation should be able to provide for necessary privacy and humane ambiance.

Work Value:

In conclusion, this research focused on obtaining and cataloging information and design ideas and collating them into a useful document to serve as a starting point for prototype development of the MDG. While my background in botany, engineering, chemistry and psychology is limited, this project allowed me to gather the basic information needed to design a prototype structure for a Martian greenhouse. This project can also serve as a base for future student projects and build upon the University of Arkansas relationship with NASA[5]. I maintain a great interest in the subject of space exploration and design for human comfort in sterile environments, and my intention is to continue research with prototypes of the proposed deployable structures for use in a wider sphere of human habitation.

This project has proved to me the need of architectural design for any and all human environments, and iterated the importance of close integration between technology and design. Extreme environments call for extreme strategies. While on Earth many aspects of the architectural design are taken for granted (sunlight, openings, access, and sustainability), design for environments like that on Mars take on the character of ultimate problem-solving and can easily slip into the realm of engineering. An extraordinary need for enclosure, and yet openness to the outside world, is manifested by the pioneers that go out in space to learn as much as they can; yet they must physically isolate themselves from their subject just to be able to perform a basic human action – to breathe.

References:

Advanced technologies for human support in space. NASA MarsPort 2002. http://www.tsgc.utexas.edu/marsport

The Case for Mars – International Conference for the Exploration and Colonization of Mars. http://spot.colorado.edu/~marscase/home.html

Mars Design Reference Mission v. 3.0 http://spaceflight.nasa.gov/mars/reference/hem/hem2.html

Mars fact sheet. http://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html

Endnotes:

[1] Mars Design Reference Mission v.3.0/1998

[2] Mars Fact Sheet

[3] For example vinyl sheets, 89% transparent and highly elastic at normal temperature, become brittle at –58 degrees Celsius

[4] As far as the density and speed of growth is concerned, as well as the amount of growth labor and collection. The most labor-intensive part is the seeding stage, which can be automated. On Earth with NFT lettuce can give between 9-12 harvest per year.

[5] My former professor Ted Krueger established a successful dialogue between the School of Architecture and NASA. Professor Jerry Wall is continuing his efforts.

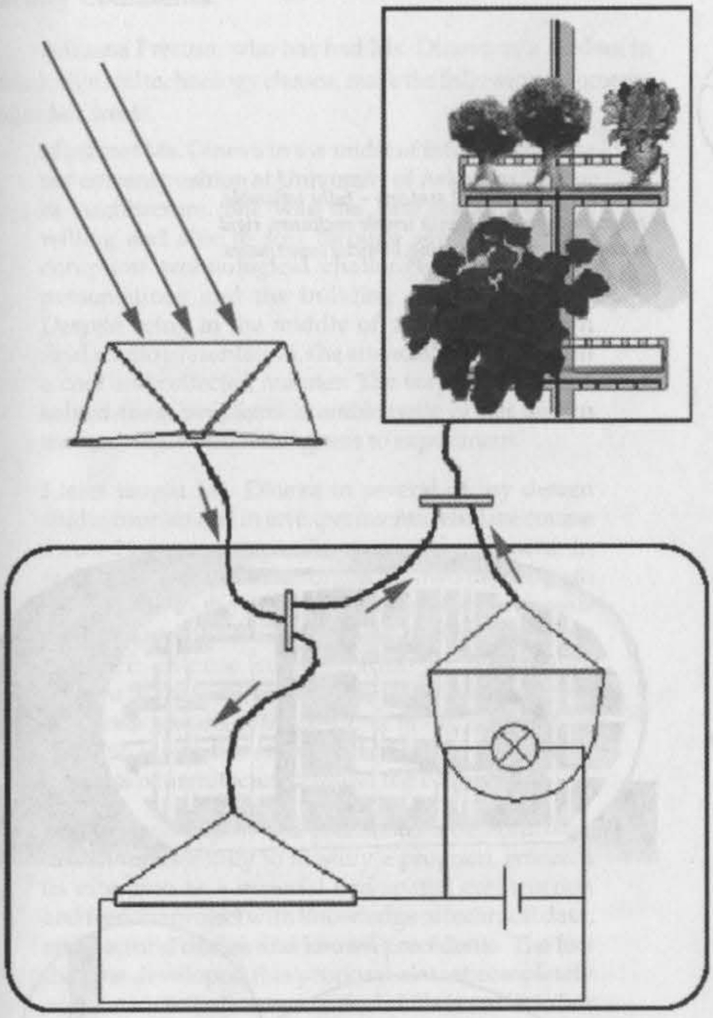

Figure 1 - Lighting system - collected sunlight is tunneled through fiber optic cables to the plants, excess is piped to photovoltaic plates; the produced electricity is stored in batteries and used to supplement the lighting when necessary. The electric light is distributed through the same piping system as the natural light.

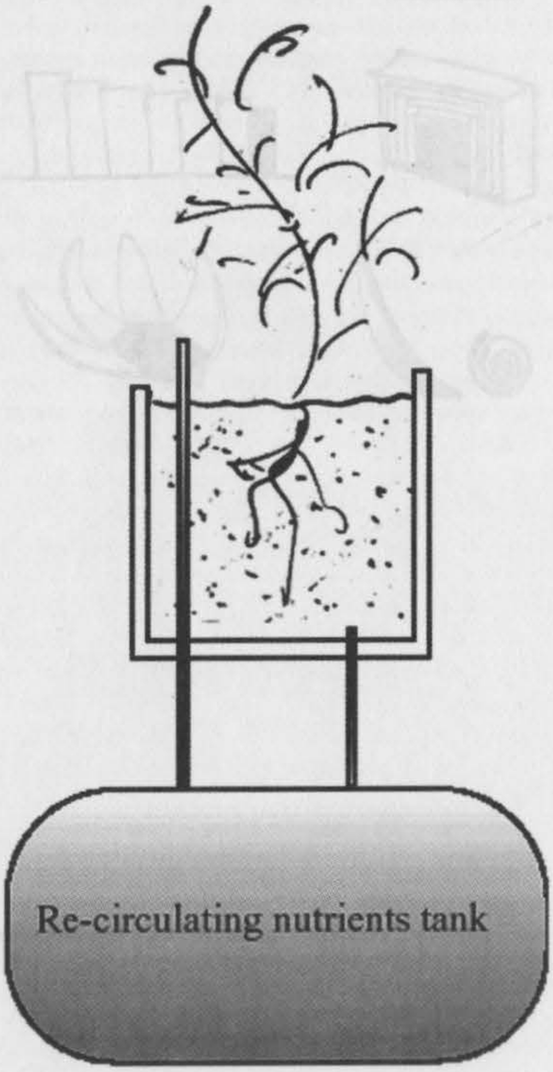

Figure 2 - Hydroponics diagram

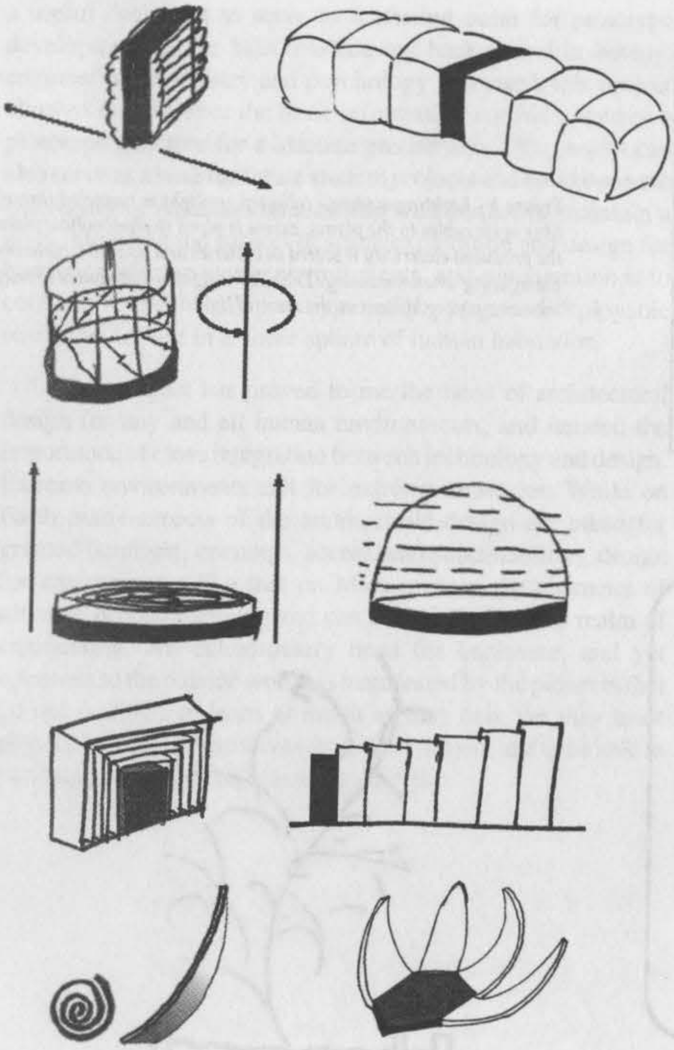

Figure 3 - Structural systems – fully inflatable, telescoping structure with tensile enclosure, rigid sliced shell, rigid telescoping, bi-metal smart plates.

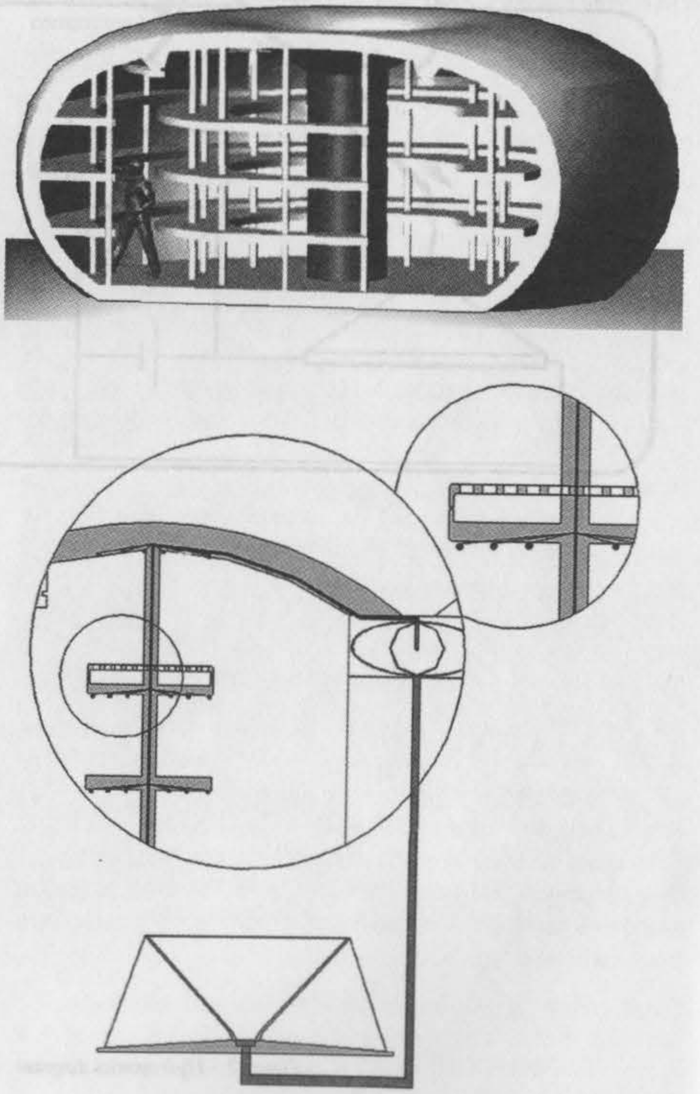

Figure 4 - a. An MDG prototype – (functionalism preferred)
b. Integration of deployable systems

Faculty Comments:

Julianna Preston, who has had Ms. Dineva as a student in both design and technology classes, made the following comments about her work:

> I first met Ms. Dineva in the midst of interviewing for my current position at University of Arkansas School of Architecture. She was the lone student/expert willing and able to sort through several layers of computer technological challenges between my presentations and the building network system. Despite being in the middle of preparing her own final studio presentation, she attended to my needs in a cool and collected manner. The way in which she solved these problems is emblematic of her design method, rigor and willingness to experiment.
>
> I later taught Ms. Dineva in several of my design studio courses and in an experimental elective course focused on computer technology and ornament. In each of these courses she forged her own unique path in response to the course objectives. Her proposals have consistently stood out among her fellow students for their intense consideration of technology (structural, material, geometry) and for their numerous iterations toward refinement. It is my observation that this is not the norm in this school or in other students of architecture around the country.
>
> The work on deployable greenhouses demonstrates Ms. Dineva's ability to identify a program, research its extension as a material and spatial construction and feed the project with knowledge of technical data, architectural design and known precedents. The fact that she developed this proposal almost completely on her own initiative and critical skills is credit to her enthusiasm, drive and professional attitude.

Ms. Dineva's faculty mentor, Jerry Wall, had this to say about her:

> Iova Dineva is an excellent student, creative designer, exhaustive researcher, and responsible leader. As her faculty mentor I knew that she always gives her best effort. She has been extremely helpful with our NASA research on exercise equipment for zero gravity. She was instrumental in preparations for the exhibit of "Work surfaces in space," in Zurich, Switzerland. Ms. Dineva is definitely one of the top students in the School of Architecture. I support her wholeheartedly.