Unprocessed regolith—lunar soil—can be used to construct superadobe/superblock structures and infrastructures. It can also be melted, using solar rays, to form ceramic structures.

Lunar and Terrestrial Sustainable Building Technology in the New Millennium

An Interview with Architect Nader Khalili

by Madhu Thangavelu

Due to growing interest in sustainable building, University of Southern California faculty member Madhu Thangavelu recently met with Nader Khalili to discuss Khalili's role, as an architect and inventor, in the development of innovative materials and methods of construction.

Madhu Thangavelu: After having specialized in the design of high rises in the 1970s, you turned your attention to the research and development of ceramics and superadobe/superblock building technologies based on indigenous Middle-Eastern building traditions. What prompted you to propose the use of these technologies for lunar and planetary construction to NASA?

Nader Khalili: When I left my high-rise architectural design practice, I set out on a five-year journey through the Persian deserts to explore the potential of clay as a building material that could be used to house the Earth's masses—there were then 800 million people in the world without adequate shelter; that number is now 1.2 billion. In those deserts, there are no resources except earth. Trees are too precious to cut, and constructing walls provides more shade and consumes less water. During those five years, I integrated my knowledge of high-rise and prefabricated building technologies with thousands of years of accumulated human knowledge about earth architecture and ceramics. This synthesis of high-rise and traditional earth building methods resulted in the new technologies of ceramic and superadobe/superblock construction.

I faced some new challenges in 1984 when I was among those invited to the first NASA-sponsored symposium, "Lunar Bases and Space Activities of the 21st Century," held at the National Academy of Sciences in Washington, D.C., to propose new technologies for possible use in the construction of lunar bases, but the fundamental problems were very similar. There are even fewer resources on the moon than in our deserts, and the climate is much harsher. There was not known to be any water then, and there is no atmosphere; therefore, there is no oxygen to fuel the fire needed to manufacture ceramics. The moon's surface temperature range varies from 261°F (127°C) to -279°F (-173°C), and the potential effects of solar particle radiation and meteorite impact had to be considered. Yet on the moon—as on earth and, indeed, throughout the solar system—timeless materials and principles exist. An understanding of the concept of the unity of the elements makes the use of these materials and principles in the integration of tradition and technology with the laws of nature possible at many levels of microcosm and macrocosm.

My paper "Magma, Ceramic and Fused Adobe Structures Generated In Situ," described the timeless architectural forms of the arch, the vault and the dome; their structural principles; and the possibility of constructing them by transforming lunar dust/regolith into liquid magma using solar fire to cast the buildings. It also introduced the concept of a building material I then called "Velcro adobe," which is now referred to as superadobe/superblock, which was referred to in the *Journal of Aerospace Engineering* with these words:

> *Two main materials and methods utilizations of moon dust for shielding or generating structures are in the forms of automated or manually packed soil covering, or Velcro adobe, and fused lunar adobe. Soil packing covering in flexible dry-adhering containers (Velcro adobe) will utilize unprocessed regolith for both structures and shielding. Packed Velcro adobe in flexible containers can be used to construct structures using corbels, dry-packs*

and leaning arches. In single- and double-curvature compression shells, the dry-adhering containers' texture will allow the tightness of consecutive rows, in the case of a vault, or rings in a dome, to hold up the structures in space during construction. Neither type of structure needs centering or form-work. Velcro adobe can be used in conjunction with other, more conventional, structures, mainly for shielding purposes.

My vision was seconded by the editor of the NASA-published monograph of that symposium, who wrote:

The first humans to live and work on the moon will be supported by an advanced technology. Yet the basic incompatibility of human physiology with the environment will limit flexibility of response to challenges of everyday existence. Our tools will be very sophisticated, but our actual resources will be limited initially. In many ways, the development of a lunar economic and social infrastructure will require the kind of adaptability and innovation seen in successful enterprises in the Third World. For this reason, Khalili's perspective on lunar architecture provides an interesting and thought-provoking contrast to "orthodox" scenarios.

An hour after that presentation, I was invited to Los Alamos National Laboratory as a scientist (they had no category for architect) to present my ideas and interact with the scientists for several days, which I did in 1985.

Thangavelu: The idea that we will use extremely advanced space technologies to arrive at the moon and then immediately resort to indigenous materials and age-old ways of building up infrastructure is both fascinating and humbling. What are your thoughts on space exploration and the lessons and impact of this activity on humanity?

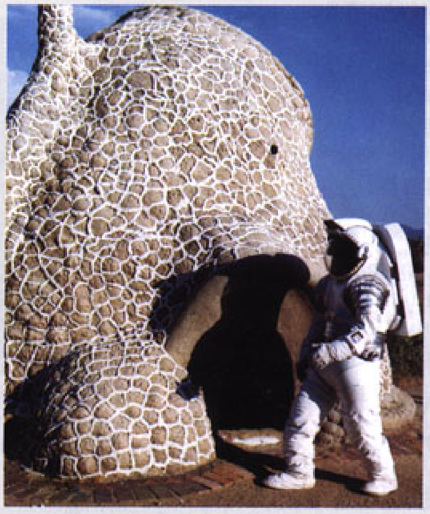
Khalili: My thoughts are best expressed in my original paper, in which I wrote:

All heavenly bodies are like human bodies: marvels of creation in the highest forms of technology, yet filled with poetry and spirituality. Everything we need to build is in us, and in the place. We must sail into the cosmos not only with zero-defect spaceships, but in ones filled with inspiration, not merely carrying a databank, but also carrying a sense of unity integrating us with our past and future aspirations. It is good to remember that what we may ultimately reach in space may be the space within.

Thangavelu: What was the tangible result of these presentations and research?

Khalili: Subsequent to my visit to Los Alamos, at a presentation in a Princeton Space Studies Institute/NASA symposium, I was invited by McDonnell Douglas Space Systems to become part of a research team. They offered me the use

Hesperia Museum and Nature Center utilizes 91 percent in-situ materials to construct stabilized superadobe/superblock coils, with both pumping and manual systems.



The "Mars One" prototype employed in-situ unstabilized earthen material for construction and testing. Its reptile texture is the result of terrestrial demonstration of a random pattern finish.

Cal-Earth Institute's "Earth One" prototype structure was constructed and tested using unstabilized superadobe/superblock walls. Cal-Earth prototypes are also used as grounds for space suit maneuvering and documentary research.

Superadobe/superblock coils under construction, demonstrating pumping method.

of their large solar energy concentrator in Southern California in order to develop and test magma structures using lunar regolith simulant, and we conducted several tests. As detailed in my paper, the solar energy easily melted and fused the regolith to the extent where we could create magma structures, ceramics, fused adobe and even magma fibers for potential reinforcing. I spent a few years pursuing Los Alamos, McDonnell Douglas and NASA with proposals and feasibility studies. In one meeting of top McDonnell Douglas management, when they were gearing up for a multimillion dollar proposal to NASA, I voiced my opinion that we could construct a life-sized lunar base in Death Valley for a fraction of the proposed cost of the feasibility study. Of course, this didn't go over well.

I finally decided to start Cal-Earth Institute in California's Mojave Desert to demonstrate these technologies independent of the aerospace industry and NASA. Our main focus at Cal-Earth was to construct full-scale prototypes and put them to the test in a harsh environment and seismically active zone to validate our work. It was time to leave behind the feasibility studies and actually put our buildings through the grueling stress tests of local and national codes via the local Hesperia Building Department and ICBO review. Fortunately, along the way we found open-minded individuals who, while not accepting of any compromise, have been brave enough to assist us in taking steps to benefit the future of the nation and of the world.

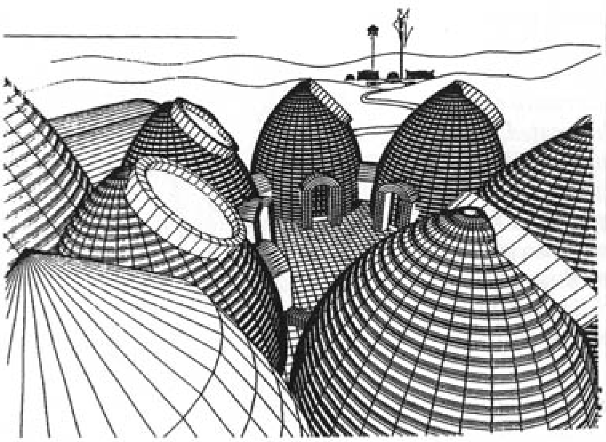


Figure 1 – Hesperia Museum and Nature Center courtyard clustered with skylights angled for high solar gain. Lunar and Planetary Institute, Houston, technical report #98-01, 1998.

We built and tested prototype shell structures of superadobe/superblock using unprocessed desert sand. We used the same timeless principles and materials in harmony with nature, but now applied rational engineering analysis. We worked as a team with P.J. Vittore, Ltd., which has extensive experience in large-span, thin-shell structural engineering (see the September/October issue of *Building Standards*™ for a jointly written article).

Thangavelu: What came out of the Cal-Earth prototypes?

Khalili: The Cal-Earth prototypes generated support from a wide range of individuals and organizations, world media attention, some projects and good community relationships, while operating on a shoestring budget thanks to the efforts of highly dedicated professionals and volunteers.

As the research and testing program developed, so did our working relationship with the Hesperia Building Department, the City of Hesperia, and the local community. In the September/October issue of *Building Standards*, Hesperia's building official, Tom Harp, wrote, "When architect Nader Khalili first proposed constructing buildings made of earth-filled sandbags, stacked in domes, the building department was skeptical to say the least." However, after the years of structural analysis and prototype testing, he reported, "Our skepticism had long since vanished, as we had seen this type of building meet and exceed the testing of rational analysis as required by our code."

The Hesperia Recreation and Park District (HRPD) commissioned us to design the Hesperia Museum and Nature Center, not only as a project but also to demonstrate the environmental and educational benefits of these technologies. It is now under construction. Later, the HRPD and the city offered a 20-acre site to NASA for its Lunar Habitat program.

The Earth One typology was developed for super-adobe/superblock housing, of which a standard three-bedroom, two-car garage model home was permitted and is currently under construction for the mainstream marketplace.

Other benefit projects are in different phases of construction around the world. Still functioning excellently are flood and erosion control systems prototypes at Hesperia Lake, where the lake's edge is lined by using the pumped superblock system, in which coils are pumped at a rate of 15 feet (4572 mm) per minute.

Thangavelu: Has there been more interest terrestrially?

Khalili: There is so much need, globally, for these technologies and for the many other ideas that are locked away under different patents by big organizations. We have dedicated our patent to those in need of assistance, as the result of disasters. The United Nations (UN) has now partnered their branch United Nations Institute for Training and Research with us, and together we are developing a program for training in response to natural disasters, emergencies and for reconstruction efforts. The United Nations Industrial Development Organization and United Nations High Commissioner for Refugees built 14 prototypes in the Persian Gulf area after Operation Desert Storm. A few statistics from the World Disaster Report of the International Federation of the Red Cross will tell you just how great the need is for such programs. For example, more major natural disasters occurred in 1998 than in any other year on record; forty of the 50 fastest-growing cities are located in the highest earthquake zones; environmental refugees account for 58 percent of refugees worldwide; and the UN estimates that 80 percent of the world's population will live in developing countries by 2025. The costs in the U.S. alone between 1991 and 1997 of flooding, tornados and hurricanes was over $100 billion.

Thangavelu: What would be the advantage of expanding the use of this technology in the U.S.?

Khalili: The advantages are numerous, but first, let me ask you: Is it reasonable for a technologically advanced nation like the U.S. to rebuild disaster regions with the same disaster-prone types of structures? Is it logical to invest billions of dollars of materials and energy in another doomed community by rebuilding the same structures on the flimsy foundation of what has already been torn to shreds by a hurricane, reduced to rubble by an earthquake or turned to ashes by fire? We must never forget that it is not the hurricane, earthquake or fire that causes the disaster, it is mainly the man-made structures and infrastructures.

It is high time we utilize those timeless structural principles that work in harmony with the laws of aerodynamics, fire resistance, compression, gravity and monolithic response. The spin-off technologies from designing for the moon and Mars have proven able to weather extreme environments and natural disasters. The materials are fireproof and the aerodynamic forms naturally ride through hurricanes and tornados and resist earthquakes. Simple sandbags have been used to resist flooding for centuries, and now the technology exists for using on-site material not only for building homes and public buildings, but also for flood and erosion control. The U.S. could lead the way in developing and implementing these sustainable technologies that address the urgent needs of this new millennium.

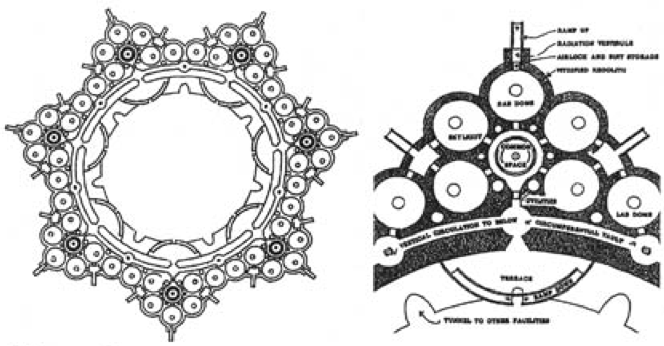


Figure 2 – Lunar base design using domed clusters at a crater's edge for passive utilization of sun/shade zone. From a 1989 Journal of Aerospace Engineering paper by Khalili.

Thangavelu: What measure should we take to foster these technologies?

Khalili: First, the *International Building Code*™ should take into account the projected 80 percent of the world's population who will be living in developing countries in the next 25 years and will be unable to afford highly manufactured building materials or timber. Any international code that omits technologies appropriate for these regions will be inapplicable internationally. Perhaps a totally different type of code, such as the performance code, will open the avenue to relevant building technologies, which can in turn create future business and technological improvement opportunities for the U.S.

If existing codes do not allow for entry of new ideas, then some basic rethinking should go into code structures. Do we really want to look back on this millennium and say: "How stubbornly our engineers and officials fought for untenable precepts embodied in inherently unstable structures, and how blindly we followed because our lives were swept up on a wave of panic, financial gain, insurance, tradition and resistance to change?"

Watching the former Soviet Union fragment, we can be thankful that the U.S. still retains the flexibility to grow and adapt to today's needs and still has institutions that can nurture freedom and the pioneering spirit into relevant and useful new products and methods.

Thangavelu: What would be the impact of this new technology on building manufacturers' products, the job market and the mainstream?

Khalili: The computer industry was at first feared because it might eliminate great numbers of clerical jobs; however, once invested in, it created a giant industry. Likewise, the earth, ceramic, straw bale and alternative building industry in general has the potential of opening totally new business horizons and job opportunities. It will allow us, in the best American tradition of moving forward with new ideas, to create flourishing businesses with wiser resource management both nationally and globally.

America's economic base is increasingly shifting from products to services and information, and the offspring of these technologies will produce environmentally friendly wealth.

Thangavelu: What potential opportunities do these technologies offer?

Khalili: The new millennium is offering great opportunities for creative solutions to pressing demands for sustainable building materials, technologies, design and regulatory practices. The accelerating increase in global population and natural and man-made disasters are wake-up calls to a wiser utilization of renewable resources. Development of advanced technologies, with an integrated focus on human and global needs, can be the main source of these creative solutions. It may take a long time to go through the system; meanwhile we can depend on the good old American entrepreneur to take a look at Cal-Earth's web site (*www.calearth.org*), take the next plane to Hesperia, California, and recognize the potential for turning the disasters of the last millennium into the fortunes of the new one. ■

Nader Khalili, California architect and author, is the innovator of the Geltaftan Earth-and-Fire System known as "ceramic houses," and is founder and director of the Cal-Earth Institute in Hesperia, California.

Madhu Thangavelu is an adjunct faculty member of the University of Southern California School of Architecture and Department of Aerospace Engineering in the School of Engineering. Thangavelu is also the co-author of the recently published book The Moon: Resources, Future Development and Colonization *(John Wiley and Sons) and is the vice-chairman for education of the Los Angeles section of the American Institute of Aeronautics and Astronautics. Thangavelu was first captivated by Khalili's ideas at the inaugural session of the International Space University, held at the Massachusetts Institute of Technology in 1988, and has been following and assisting in the activities of Cal-Earth Institute since.*

PUBLICATIONS REFERRED TO

"Magma, Ceramic, and Fused Adobe Structures Generated In-Situ," paper by Nader Khalili; presented at the first NASA sponsored symposium in 1984; published in the monograph *Lunar Bases and Space Activities of the 21st Century*; edited by W.W. Mendell; Lunar and Planetary Institute; 1985.

"Lunar Structures Generated and Shielded with On-Site Material," paper by Nader Khalili (awarded by the American Society of Civil Engineers - Aerospace Division); *Journal of Aerospace Engineering*; July 1989.