Homeostasis and perpetual change

C. Domin & L. Medlin
College of Architecture and Landscape Architecture,
School of Architecture, University of Arizona, USA

Abstract

Historically, we have built to overpower nature with minimal concern for environmental impact. The Solar Energy Efficient Dwelling: SEEDpod prototype is intended to respond to and advantageously interact with the forces of nature and the unique characteristics of each project site. These include the **sun** – utilized to create electricity, heat water/air and provide day lighting; **water** – harvested for domestic needs and irrigation of edible plants and landscaping; and **air** – used for ventilation and maintaining a healthy environment. The SEEDpod provides a tool for engagement with specific microclimates and the natural environment of its location.

The arid Sonoran Desert, with limited vegetation, water resources and cloud cover has a climate characterized by a year round average diurnal temperature swing of 26°F. This variable condition enables the SEEDpod to employ an environmental control strategy in which the building envelope and surrounding vegetation form a "selective filter" that dynamically interacts with the surroundings.

Establishing a homeostatic relationship becomes the premise upon which we can begin to improve the design quality, efficiency and environmental responsiveness of residential construction. Balance is achieved in this energy efficient solar prototype by dynamically interacting with energy inputs and outputs in service of climatic stability. Air exchange, humidity and thermal control, interior and exterior lighting conditions and natural resource management are integral components that are continuously engaged in order to achieve a healthy, energy-efficient, and sustainably-built environment.

Keywords: ecological architecture, regional adaptation, performance based design, desert architecture, energy efficiency, materials research, thermal mass.

WIT Transactions on Ecology and the Environment, Vol 128, © 2010 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/ARC100031

1 Introduction

The challenge for the SEEDpod and the focus of this research is to provide an effective architecture/engineering solution to rising energy costs that balances passive and active building systems. A remedial engagement with the local environment provides further direction and clear inspiration for our performance-based design process. The resulting architecture sensibly integrates anticipatory strategies and multi-disciplinary design principles in order to provide a high quality of life for the inhabitants.

Figure 1: SEEDpod water wall and photovoltaic array [2].

"A thing is right..." Aldo Leopold wrote in his Sand County Almanac, "when it tends to preserve the beauty, integrity and stability" of the biotic community. Bio-cultural stability in the context of the built environment can be both dynamic and sustainable. Leopold then described the condition of homeostasis, as the maintained equilibrium in environments of perpetual change. This balanced condition is the premise that inspired our prototype dwelling and provided direction to the design and development process as we uncovered our solution for an efficient solar powered environmentally responsive dwelling [1].

2 Methodology

Research, testing and construction for the SEEDpod prototype desert dwelling was initiated and completed at the University of Arizona: College of Architecture and Landscape Architecture (CALA). During the two-year span of this project, the team integrated the expertise of numerous collaborators from Agriculture, Materials Science Engineering, Civil Engineering, Eller College of Management, Electrical and Computer Engineering, Optical Science, and Mechanical Engineering. Structural and systems engineering consulting was provided by Buro Happold: Los Angeles.

Four design studios including both graduate and undergraduate students in the School of Architecture were dedicated to research/analysis, project development, prototyping, and detailing. Construction took place in our materials laboratory over a period of twelve weeks, utilizing the assistance of master craftsman for direction, but completed almost entirely by students. The process began with an analysis of natural systems and adaptation strategies of both flora and fauna within the Sonoran Desert environment. Simple kinetic models were constructed based on this initial research, and a more complex building program/strategy began to take form in the subsequent studios.

Several building components were earmarked for their clear potential as interdisciplinary research projects. The structural system, thermal storage water wall, and self-regulating shade system became the design problems that were rigorously prototyped in our materials laboratory and became integral components of the final composition. Each of these components has applicability beyond the SEEDpod prototype, and the student design teams are in the technology transfer and patent review process. Comprehensive site testing is the next step in our evaluation sequence.

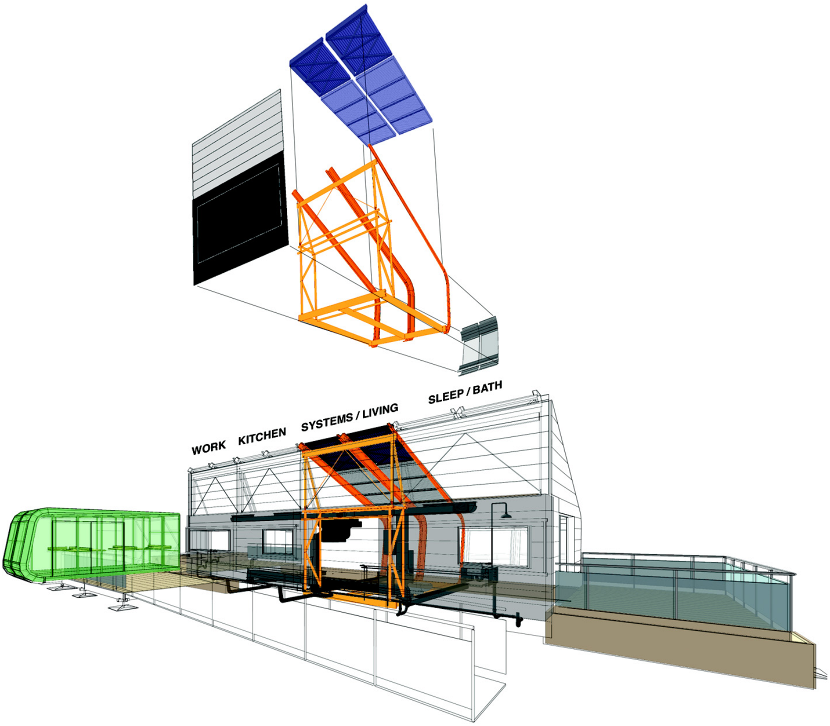

Figure 2: Exploded perspective illustration [3].

3 Components

3.1 Core/adaptable space

The SEEDpod consists of four modules with identical structural rib frames. Each module contains a utility core that provides the essential living components: kitchen, bathroom, workspace and systems (mechanical and electrical). The resultant continuous core frees the remaining floor plan for adaptable and flexible living space.

The essential living unit is composed of four modules with 800 square feet of interior space and an adjacent greenhouse. This one bedroom option contains a work area, kitchen/dining facilities, a systems module with associated living area, and a bathroom core with adjacent sleeping space. The modules are assembled end to end and the resultant continuous utility core amply serves the adjacent flexible, open-plan living space. Unit assembly proceeds along a logical path:

1. After the foundation rail system is installed and levelled. The first prefabricated module, with roof assembly in the compact shipping position, is hoisted into place and aligned on the rails
2. Module 2 is placed on the rails and the roof of module 1 is pivoted into position and fixed at the correct solar angle by securing the north clerestory frame to the top of the core module.
3. The sequence is repeated with the placement of modules 3 and 4.
4. After the roof is secured at module 4, the final foundation rails are installed and covered with the west and east exterior porous decking system.
5. The on-site installation of SEEDpod is completed by the addition of entry ramps, guardrails, landscape materials, water-harvesting elements, and the greenhouse.

The interior face of the core is wrapped continuously with a dense, waterproof composite material (Richlite) made of recyclable paper fibres from FSC-certified sources treated with resin, and pressed into rigid sheets. The exterior core and wall panels are clad with a zinc rain screen, which offers protection from the elements and an opportunity for cooling via air movement in the gap between the water-proofing membrane and the exterior cladding. The zinc material was chosen for its abundance, recyclability, and lasting performance qualities. Zinc is a highly malleable material allowing for the custom fabrication of the skin system in our materials laboratory.

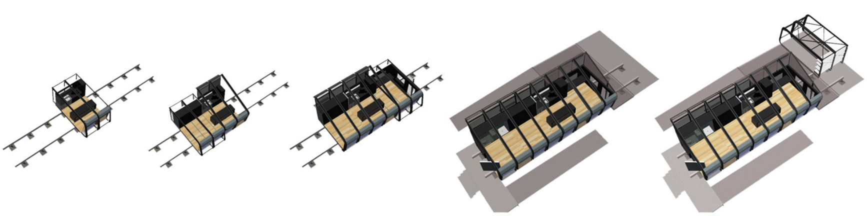

Figure 3: Assembly sequence illustration.

3.2 Systems

The exterior envelope is designed as a “selective filter” that can be operated to advantageously interact with the incident forces of nature and its climatic context. The majority of the optimally sloped (depending on location) south-facing roof is covered with a 9kW bifacial photovoltaic solar array that produces ample electricity for the entire dwelling.

The south-facing roof array produces grid tied electricity for dwelling functions and powers the entire environmental control system. The bifacial array allows the underside of each panel to absorb reflected light in the plenum space above the building’s white waterproofing membrane, significantly increasing electrical generation. Potential for ventilation and exhaust of hot air through the roof plenum will increase the collection efficiency of the photovoltaic panels. Additionally, above the core, a portion of the roof is dedicated to a highly efficient evacuated cylinder hot water assembly.

The building systems are designed in response to varying seasonal conditions and large diurnal temperature swings that exist in hot arid environments such as the Sonoran Desert. The mechanical systems of the SEEDpod incorporate a set of active and passive systems. The primary passive system utilizes “Stack Effect Ventilation.” Cool air is supplied at the base, near the pivot point of the house, and as the air warms it is allowed to flow out the peak of the clearstory through a set of operable windows.

The active heating and cooling strategy involves a series of ductless heat pump and air conditioning units. This compact system includes a condensing unit and three heat pumps. During the cooling cycle, the exterior condensing unit

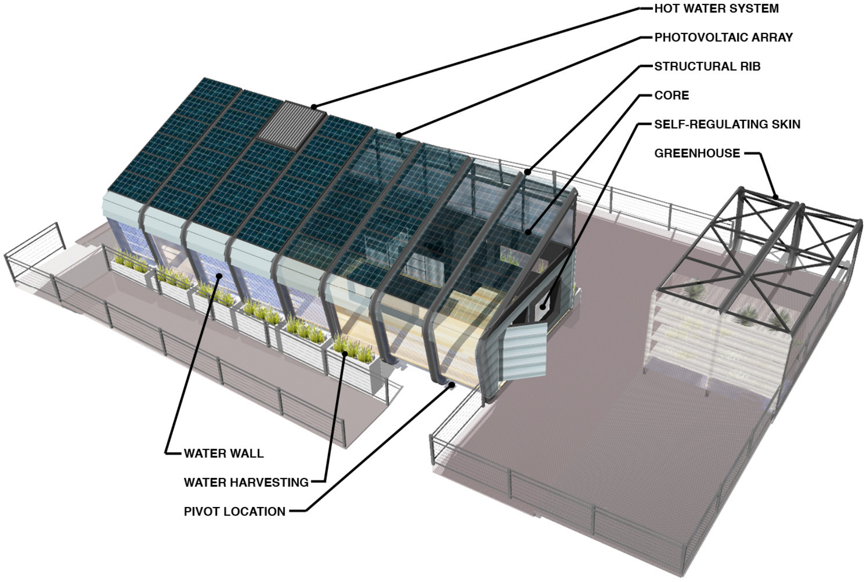

Figure 4: Systems illustration.

cools refrigerant and delivers it to fans incorporated in the indoor heat pumps. The heat pumps then supply cool air to the house. When heating is required the system works in reverse.

In Tucson, Arizona and other hot arid locations with low humidity and high diurnal temperature swings, the system can be frequently operated in a "vent only" mode or in off-position with full utilization of natural ventilation. Several control conditions were modelled by Buro Happold Consulting Engineers and will provide baseline information for on-site testing in the next phase of project development.

Summer - Day:
During daylight hours in a hot arid climate, the interior can be cooled by evaporation using low energy fans. Air is evacuated through the roof plenum reducing the cooling load on the space below and resultant air turbulence cools the solar panels above. Additionally, cool water introduced into the water wall tanks will absorb heat and reduce the cooling load.
Summer - Night:
During low humidity nights, cooling can be provided solely by cross ventilation entering through the lower opening in the southern wall. This can be supplemented with mechanical systems during extreme heat or high humidity.
Winter - Day:
During winter days, air warmed by the roof plenum can be drawn into the interiors during the day. Water wall collects and stores heat from the sun.
Winter - Night:
During the night, the heat collected in the south wall will be allowed to radiate into the space in order to supplement heating supplied by the mechanical system.

3.3 Structural rib system

Close collaboration with Buro Happold: Los Angeles allowed the team to benefit from digital form finding operations and optimization in the fabrication process. SEEDpod's structural system is made by laser cutting high-recycled content sheet steel, which is bent and folded to create a multifunctional form [4]. The deep structural profile allows for air movement in a plenum space that maximizes the efficiency of the photovoltaic array by cooling the underside of the panels, attached directly to the structure. The "V" shaped profile of the ribs facilitates drainage for water harvesting and expedites module-to-module connectivity.

The bent sheet steel structural ribs employ a system of tabbing for quality control purposes during the forming process. A series of strategic folds transforms a flat sheet of steel into a structurally optimized series of cantilevered ribs. These ribs are constructed with an integrated hinge located at the bottom of the southern wall. The resultant pivot action allows the team to change the angle of the roof and provide precise angle positioning in order to accommodate solar angles of incidence for any location. It can be adjusted during initial construction to any geographic location in relation to the optimal solar angle.

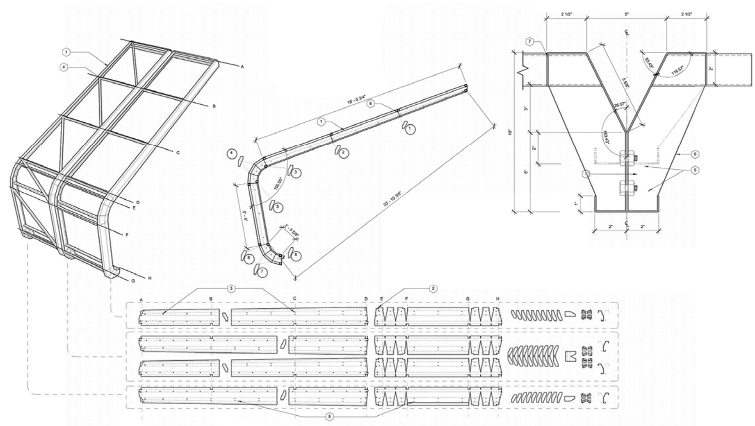

Figure 5: Structural rib construction drawing.

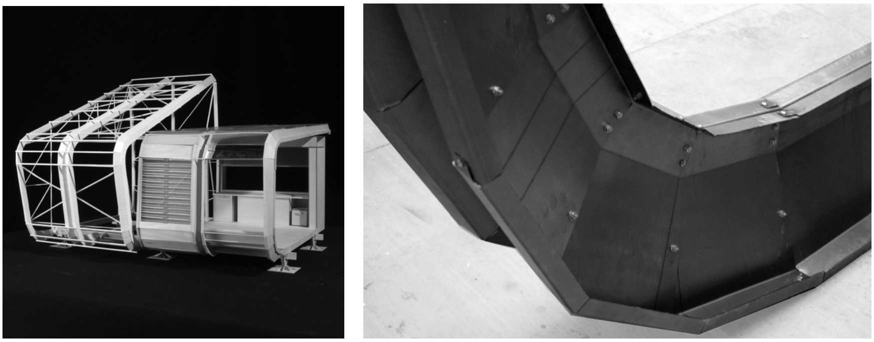

Figure 6: Structural rib model and joint prototype.

For ease of transport, the roof of the SEEDpod is lowered to rest on the top of the core module. Using a forklift or crane, rotating about a pin at the bottom of its south wall, it is raised to the optimum solar angle. It is then affixed in place by swinging in and connecting a triangular support frame at the north clerestory to the top of the SEEDpod core. The installation of insulated glazing at the clerestory completes the exterior weather-proofing system.

3.4 Water wall

The south wall consists of an insulated glass panel and a vacuum formed "water wall" made from recyclable PETE (polyethylene terephthalate) plastic sheets separated by a vented air space [5]. After arriving on site, the empty plastic tanks will be charged with a water-based solution drawn into the tanks via vacuum action. The water wall will absorb and hold the sun's heat during the day and then radiate toward the interior at night. Exterior shades will be closed to hold the heat in the space. In addition to winter heating, water cooled by taking advantage of the large diurnal temperature swing could be introduced into the tanks at night in the summer to absorb heat from the ambient air in the space the next day. An aesthetic benefit of the water wall is a constantly changing translucent pattern of daylight filtered and refracted through the undulating geometry of the tanks. At night, interior light gently illuminates the water and provides privacy for the occupants.

Between the exterior envelope and the internal water wall is a gap, allowing for air movement, which provides the ability to warm or cool air as it passes along the water wall. During the summer, the tanks will be filled with cool water, and shaded on the exterior side to resist the heat and keep the interior cool. In contrast, the tanks will be charged with warm water in the winter. The water, which has three times the thermal mass capacity of concrete or brick will absorb the sun's heat during the day and re-radiate it to the interior at night.

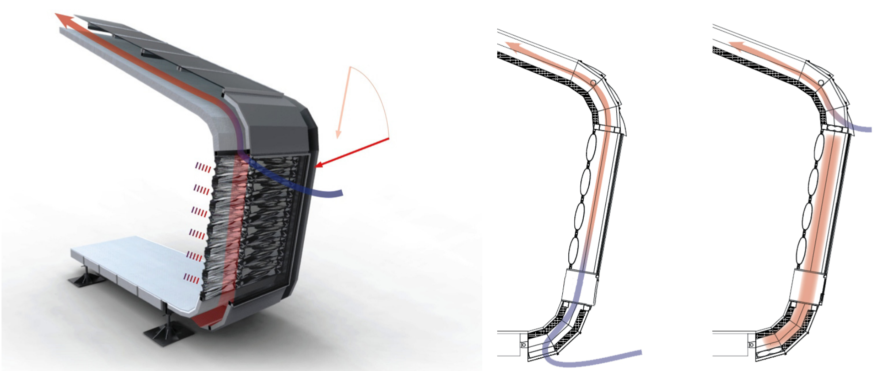

Figure 7: Water wall and air plenum illustrations.

Figure 8: SEEDpod interior with water wall and bath/system/kitchen core elements.

The ability to adjust the temperature of the water within the tanks makes the water wall a desirable element in a variety of climates. Further control is provided by the ability to open or close the south water wall and roof plenums separately, allowing them to be vented independently or together.

3.5 Self-regulating skin system

When the SEEDpod is placed on a desert location in Tucson, integrated site improvement components can be combined to create a benevolent micro-climate for the building and outdoor activity spaces. Ideally, this will be done in a way that preserves the natural equilibrium of the fragile desert ecology.

Landscape and hardscape will vary by location in order to soften the edges of the linear profile and allow the SEEDpod to integrate logically into specific ecosystems. The landscape area on the southern side of the dwelling becomes an important component of the water-harvesting system. Performance-based integrated vegetation will lead to increased building/site stability by passively utilizing the natural processes of evapotranspiration as an evaporative air conditioner and carbon dioxide filter. The greenhouse module is utilized for the growth of edible plants and performs a biofiltration function— the oxygenation, filtration and humidification of interior air.

Figure 9: SEEDpod self-regulating skin prototype.

Incorporated into the east wall assembly is a test panel for the self-regulating shade system, which opens and closes in response to changing thermal conditions and light levels. The self-regulated system prototype investigates elastic structures and materials in terms of mechanical and physical properties for the design of a bistable (capacitor) mechanism which is programmed to deform an aperture, complying with variable thermal loads and light, in order to provide shade and thermal comfort regulation between an exterior and interior space [6]. These systems would most benefit the dwelling on the east and west facades, where the thermal load is higher.

Figure 10: SEEDpod entry, greenhouse, waterwall.

With direct exposure to sunlight, the glazing assembly experiences a "miosis" function, or the constriction of light, based on thermal expansion properties of smart materials and programmatic structural arrangement. With no direct exposure to sunlight, the assembly experiences a "mydriasis" or dilation function, allowing for indirect light to penetrate into interior spaces based on the orientation and materials ability to recoil with lack of heat input.

4 Conclusion

The SEEDpod envelope is designed to selectively filter and interact with its local climatic context. It consists of a series of skin systems that protect the interior condition from varying environmental factors. These are the photovoltaic roof array, the south water wall, and the north, east and west wall assemblies, which have insulated panels and screened glazing systems. Within these walls, operable windows and doors can be positioned to facilitate cross ventilation. The primary objective of the SEEDpod is to provide a compact, highly efficient core dwelling that can advantageously interact with surrounding spaces and natural forces. The intention is to literally grow liveable interior and exterior spaces.

It has been the experience of the authors/architects that, in working with the residents of passive solar homes and observing interactions with their dwellings in response to natural climatic cycles, residents continually developed strategies to improve the dwelling's energy use efficiency. Similarly, it is our belief that living in the SEEDpod will give its inhabitants a homeostatic vessel, with which they can engage the local ecosystem and become more energy efficient, but also be able to understand and identify opportunities for advantageous interactions with sun, shade, air, water, and cultural and ecological systems within which they live.

Recognizing this, the next steps in the Seedpod's continuing development are to place it in a desert environment with a resident group, cultivate a landscape that utilizes native vegetation to create benevolent micro-environments surrounding the dwelling, and to monitor their experiences and the relative performance contribution of each of its elements or systems in response to changing environmental conditions over time. It is our goal that in this process the residents will be stimulated to steward preservation of the beauty, integrity and stability of the biome within which they dwell.

References

[1] Research, prototyping, and construction of the Solar Energy Efficient Dwelling was based on work initially proposed for the UASD grant proposal submitted to the United States Department of Energy: completed by Larry Medlin, Joseph Simmons, Dale Clifford, and Jason Vollen, 2007.

[2] All photography by Adam Strauss (undergraduate CALA student).

[3] Work completed by CALA students and faculty under direction of SEEDpod Principal Investigators Larry Medlin and Christopher Domin. Typical attribution at all illustrations and photographs.

[4] Principal Investigators Larry Medlin and Christopher Domin worked with Anton Toth (undergraduate CALA student) and Tom Reiner at Buro Happold: Los Angeles on the development, prototyping, and integration of the structural rib system into the SEEDpod prototype dwelling.

[5] Principal Investigators Larry Medlin and Christopher Domin worked with Eddie Hall (undergraduate student at CALA) an his capstone/thesis committee: Christopher Domin, Alvaro Malo, Beth Weinstein on the development, prototyping, and integration of the thermal water wall into the SEEDpod prototype dwelling.

[6] Principal Investigators Larry Medlin and Christopher Domin worked with Brent Vander Werf (graduate student at CALA) and his thesis committee: Alvaro Malo, Larry Medlin, Nancy Odegaard on the development, prototyping, and integration of the self-regulating skin system into the SEEDpod prototype dwelling.