

## **LOW COST SUSTAINABLE HOUSING FOR TIJUANA, MEXICO**

**Submission for  
NCARB Prize for the Creative Integration of Practice and Education in the Academy**

### **ABSTRACT**

This project explores the development and integration of sustainable technologies for low-cost housing in Tijuana. This courses integrate design, construction and research in one project. Over the course of two academic years undergraduate and graduate students from five departments and two universities have worked together to develop and test a very low cost sustainable housing prototype for the people of Tijuana, Mexico. Students of all levels have participated in the design, construction or evaluation of the houses or its components. This process has been enriched by interactions with the community of Tijuana, the aid agency and reviewers from different universities and architecture and engineering firms that have provided input to the students.

The project emphasizes readily available materials and technologies that are appropriate for the cultural and economic conditions of Tijuana. These technologies include very inexpensive home-made systems that minimize the use of energy, water and materials to achieve human comfort with little energy consumption. The whole house has been built with less than \$1500 in materials. Affordable food production alternatives, and water and waste systems to protect public health are also incorporated in the design. The project explores the integration of specific technologies to examine their interdependency and reciprocal contributions. The project is ongoing and students are finishing a full-scale prototype of a house in which several low-cost sustainable systems are being monitored and tested.

## **1. THE PROBLEM**

Advanced sustainable technologies are incorporated into more buildings every day, but they are still out of reach of many low income families. Nevertheless many traditional societies learned to build with nature, basing their buildings on an intuitive knowledge of the environment and climate, and constructing buildings at a very low cost. In the development of this project we implemented strategies and systems based on Tijuana's local traditions and combining them with proven traditional principles of sustainability, but combining them with more advanced technologies that could be built at very low cost with local materials. A reduction in performance is acceptable if the cost reduction is so significant that these technologies are accessible to people that have no resources for conventional systems.

Tijuana, Mexico, located just 20 kilometers south of downtown San Diego, USA typifies the environmental and social challenges facing the border region between the United States and Mexico. In the 20 year period between 1985 and 2005, Tijuana's population grew by an estimated 145%, to well over 1.3 million people (CONAPO – *Consejo Nacional de Población*). Much of this growth is the result of trade agreements between Mexico and the United States, stimulating industrial expansion along the northern border region of Mexico. This substantial growth has tremendous consequences to the region, particularly in terms of providing adequate housing for migrants moving into the area to pursue employment opportunities. As a result, many informal settlements have emerged in the foothills of Tijuana, comprised largely of substandard housing, limited urban services such as water and sewer, and which have severely degraded the natural environment. Local residents have been quite resourceful in deriving shelter from readily available waste materials, such as tires, palettes, and garage doors. However, threats from criminal activity as well as natural hazards such as landslides, earthquakes and floods present tremendous challenges for this informal housing sector.

The climate of the Tijuana is moderated by the Pacific Ocean and does not have extreme winters or summers, but many winter nights reach freezing temperatures. Nevertheless, the houses in the *colonias* do not have heating systems or insulation, making the dwellings uncomfortable and dangerous, especially for the children and the elderly. Occupants complain of the cold at night and search for the warmest part of the house to sleep covering themselves in blankets and sweaters to try to keep warm.

## **2. THE PROPOSAL**

We worked with a U.S. non-profit organization whose mission is to serve the poor in Mexico, through an active home-building program, educational programs, and other community development activities. Their home-building program is effective in providing much needed shelter for residents of the communities in which they work. Chief advantages of their designs include their low cost (about \$4500 per house) as well as relative ease of construction, allowing unskilled volunteers to construct these units in a single day. However, the designs rely on imported, non-renewable materials that increase the expense, do not adequately consider heating and cooling needs, and do not address issues related to shelter that affect public health and quality of life, such as water, sanitation, growth, security, and food production. In short, there are more sustainable approaches than the current model that could enhance quality of life for the homeowners. Any truly viable solution, however, would need to operate under the conditions faced by housing relief organizations: it must be affordable, easy to construct and at the same time desirable for local residents. Student have developed a proposal that has been built, that is being tested and that could be implemented in lots in the Colonia "Nuevo Milenio".

The students' objective was to design and build a low cost sustainable housing prototype for the residents of the colonias in Tijuana. This house had to have very low construction and operating costs, providing thermally comfortable spaces and security for the residents. It also had to be easy to build using local materials and labor, so that both Corazon and the community could incorporate it in their construction program. This house would be site, climate and culturally specific but the principles and experience from this project could be implemented in other less developed countries. Students decided to focus on four main objectives: utilize local available materials, adapt to local topography, provide flexibility to the family's needs and passive heating and cooling.

### **2.1. Local Materials**

Materials from the site are incorporated in the project and they have earth and stone from their property for free, as a result of the grading process; materials from the site contain a lower embodied energy than processed materials; and being from the site, these materials acknowledge traditional building forms, which can be adapted into contemporary uses and forms, while connecting with the immediate environment. The soil from the grading process can be used in the papercrete bricks, while rock from the site grading can be used to fill gabion units used for both walls and retaining walls.

### **2.2. Adapting to Local Topography**

These home building program take place in several neighborhoods or "colonias" in Tijuana. Most of the lots in these colonias are located in very steep slopes with poor soil and a plethora of cobblestone-sized rocks. The soil is currently excavated into terraces and left exposed, sometimes to heights exceeding 2 meters and sometimes very close to the house or with the house precariously built above one of these terraces, creating extremely dangerous conditions. The very steep slopes in which the majority of the lots in the community are located would be considered unbuildable in many communities. The use of the gabion units provides a dual purpose: terracing of the site and wall structure that provides thermal mass. The retaining quality of the gabion units are adaptable to site specific considerations. These retaining walls provide a usable space for the occupants and also help improve the general neighborhood conditions of soil loss, slides, and massive erosion. The structures are designed for modularity and future expansion. Site orientation will be dependent upon the lot location and the prototype was designed with this in mind, thus adaptability is inherent.

Storm water runoff is a significant challenge in the community and should be addressed at the site scale. The use of rain catchment systems will reduce the need to mitigate some of the ambient rainfall. The rainwater can be collected, stored and directed to the landscape for irrigation via gravity. However, runoff from adjacent properties must be addressed.

An "extensive" green roof has been incorporated into the design to assist in mitigation of rainfall runoff. Landscaping with native vegetation and food production would take place in the courtyards defined by the buildings. By incorporating the production of food into the community a variety of positive effects can be realized. Fresh, nutrient rich, local produce can be grown onsite to incorporate diet diversity. Compost bins could also be placed in this courtyard space. The act of growing food within the community increases food security, saves money, and increases community pride. Minimal use of non-permeable surfaces assists in reducing runoff and keeping water on site. French drains uphill of the gabion wall

units can be used to direct water into holding pools for percolation. Excess water can be delivered to the parking area at the street level for additional percolation.

### 2.3. Flexibility and Growth

One of the main problems with the Corazon prototype and many affordable houses is their inflexibility and inability to grow. Our house is conceived as a unit with capacity to grow and evolve. The first stage is a simple “L” form with a multiuse space and a bathroom, while the final phase is a “U” form with living / dining room, kitchen and several bedrooms.

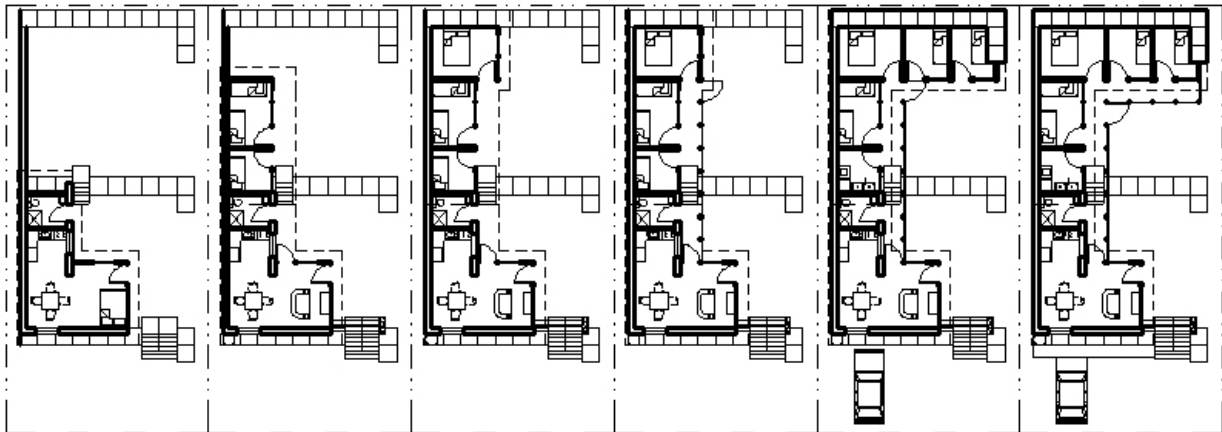


Figure 1: Growth of the house

### 2.4 Passive Heating and Cooling

Thermal comfort can be achieved almost every hour of the year with passive means. Passive solar heating is implemented in the winter and night ventilation with thermal mass is implemented in the summer. Concrete floors and gabion walls provide the mass needed for thermal storage. Several strategies to heat these materials are being tested in the winter of 2008. These include direct solar gain and hydronic systems with solar collectors. Additional windows are placed near the ceiling to further improve natural ventilation and daylighting. A jalousie system is proposed for the south façade that generates privacy and security while providing solar protection in the summer. Thermal simulations with energy modelling software indicate that passive heating and cooling systems provide thermal comfort inside the house. Preliminary indoor temperature measurements have also been done and will be ongoing to test different systems over the winter and summer of 08.

## 3. SUSTAINABLE SYSTEMS: DESIGN AND EVALUATION

One of the main objectives of these courses was to have students develop and test innovative, sustainable low cost systems. Some of these have been developed only to a conceptual stage, other systems have been tested with computer simulations, and other systems have been tested in the house itself. This process is ongoing and we expect the house to maintain its function as a laboratory for architecture, landscape architecture and regenerative studies students. Some of the systems that the students have developed are explained in the following paragraph.

### 3.1. Low Cost Green Roof

A low cost green roof has been implemented on the larger west-facing roof of our prototype in order to provide protection from the hot afternoon sun. On top of the wood

decking we placed an impermeable layer of plastic as a moisture barrier. "Cal Earth" bags (rice sack material) are filled with a growth medium which is a mixture of native soil and vermiculite (to reduce weight) and are placed on the roof in rows perpendicular to the slope of the roof. These bags are designed to store earth and are very inexpensive, lightweight, easy to transport, and biodegradable to sunlight. They allow water to pass through them while containing the growth medium. These bags can be easily transported onto the roof as well as providing a structure around the soil while allowing the roots to establish themselves. When positioned on the roof the top side of the bag was cut open and a variety of sedums and succulents native to Tijuana were planted. Additional local plants have grown in the roof. This green roof system is very inexpensive and its thickness can be adjusted from 3 to 10 inches. This allows for flexibility depending on the load that the roof can carry. Should one bag need to be replaced it is easy for it to be pulled out without having to replace the entire roof. In addition to the environmental benefits of green roofs, in this roof the soil is uninsulated and thermally coupled to the interior so that it can provide thermal mass for heat storage in the winter and act as a heat sink in the summer, when the buildings are night ventilated.

### **3.2. Low Cost Windows**

Windows are a delicate and sensitive part of a house system. They allow light into the space and have the potential to provide solar gain for the space during the daytime. However, poor window systems can cause large amounts of energy and heat to be lost during the night because of poor insulating qualities. Graduate students explored different window systems and materials that could be applied to the House and different solutions were tested in small building modules.

### **3.3. Papercrete Walls**

Papercrete is comprised of waste paper and cement. The material can be easily formed into blocks and used for the construction of walls and roofs. Tijuana generates a considerable amount of paper waste through its numerous manufacturing facilities, office use, and newspapers. Very little of this paper waste is recycled into additional post consumer products. Papercrete takes advantage of this abundant waste material that is used to build walls. Due to its 60% waste paper content, papercrete is relatively lightweight and boasts exceptional energy efficiency, R-3 per inch. Thus, a 10-12 inch thick wall can be expected to have an R-30 performance. Doors and windows can simply be cut out of a solid wall with a chainsaw.

### **3.4. Greywater System**

A simple and low cost greywater reuse system could be incorporated into the Tijuana House. For low volumes and immediate reuse, filters can be constructed of locally available, cheap materials like hay, wood shavings, and leaves. For larger flows, sand filters (with 55-gallon drums, masonry or barrels) can be used. In our proposed system, greywater is pumped on top of the sand filter, and then flows to the garden or a tank for future use in the home.

### **3.5. RainWater**

Any reused or low-cost tank of adequate size can be placed outside the house and used to collect rainwater. The development of a simple rainwater collection system would enable the residents to use potable water in the home. Rainwater can be pumped to the house, or gravity can be used in some cases to direct the water to interior fixtures. A simple pressure-tank can be installed to supply rainwater when required. When the tap is turned on, or the

toilet flushes, the pump is activated and gently pumps water through the plumbing system of the house.

### **3.6. Composting**

A compost pile is an excellent way to greatly minimize the amount of waste a household produces each year. Compost systems range from passive (setting the materials aside to rot on their own) to highly managed. Almost any organic material is appropriate for a compost pile. The Tijuana residents would need to find a level, well-drained area that receives adequate sunlight to properly start one.

### **3. PROJECT OUTLINE**

The project has been developed in phases that are closely connected to the activities. Much of the work has been done in elective courses in which students learned about social, technical, sustainable or economical issues.

ARC 499 Advanced Elective in Architectural design, Winter of 06. Students visited Tijuana, met with the community and the NGO and developed initial design proposals.

ARC 333 Energy Conservation. Spring of 06. Students developed the first series of systems for the house: radiant heating, mass walls, solar heaters, green roofs, variable insulation window. All of these systems were developed with local materials and technologies. Students built prototypes of the systems and inserted them in the house.

ARC 499 Advanced Architectural Elective, Spring 06. Students developed construction documents and began building the house with ARC 333 students.

ARC 341 Construction, Spring 06. Several second year students volunteered to work in the construction of the house.

RS 599, Fall 06, Winter 07, Spring 07. Students developed and tested in test cells some of the systems, while continuing with construction.

ARC 499 Winter 08. Students tested some of the systems designed and installed by previous students and developed, built and installed additional systems. Construction of the house finalized.

ARCH 692ab, Fall 07 & Spring 08. Students developed and tested windows and green roofs in small cells and in the prototype.

### **4. EDUCATIONAL BENEFITS**

The house has become an experimental laboratory in which students from different departments and universities have designed, built and tested systems over the course of several courses in two years. Analysis has been in various forms: computer simulations, experiments in small test cells, and by evaluating the systems in the house itself. By participating in this project the students benefit in many forms: a) Because they are part of a larger project, they can learn more than if they simply participated in a typical quarter or semester project. The student is exposed to activities that he/she would not usually develop in a week or a semester. b) The students are able to test the performance of their designs in a real building and for real clients. Because of time constraints students typically do not have time to develop an idea to the level in which it can be thoroughly tested. This project provided

opportunity for testing which provided immediate feedback and improved their learning. Students learn much from the results of the analysis of their ideas. C) Usually, as students become more capable, their projects become proportionally more comprehensive and difficult and students become progressively more skillful at making diagrams of shape and layout with increasing degrees of showiness, but not always with a deeper understanding of how the thing really works. For the students to have a more thorough understanding of sustainable design concepts, they have to go into more depth in their resolution, increasing the precision of the results. This project provided the perfect setting so that they learned how to solve problems with more precision and a finer level of detail, while being exposed to a wider range of design and analysis tools.

Students prepared and/or presented technical papers with their work in professional or scientific conferences, thus completing the full cycle of design, construction, analysis, testing, peer review and dissemination.

Since the house is in a different country with a different culture, the students are exposed to new conditions and challenges to which they would otherwise not be exposed, increasing their learning experience exponentially.

## **5. IMPACT ON PRACTICE AND THE COMMUNITY**

This project has had an impact on the education of the students that have participated in this project, on the community and on the practitioners that have been involved in the project. These students together with other students have also done work for the community in other courses directed by Faculty in this project. In these courses the students also designed and built several projects in Tijuana that directly benefited the community, which actively participated in these projects. Because so many of our students are involved in work with the community, they respect and appreciate their work. The practitioners that have participated in the project have also discovered that it is possible to develop alternative very simple low cost sustainable systems. Even though building codes make many of these solutions more difficult to implement in the United States it has helped open the mind of these engineers and architects, showing them that there are other possibilities that can be developed.

## **6. CONCLUSION**

This project demonstrates that students can benefit immensely when they are part of a long term project in which they must develop and test ideas for clients and communities in need in challenging conditions. We expect that their findings will be disseminated to residents so that they can implement the changes themselves without having to hire builders or specialists. Students rise to the challenge and learn, but at the same time they also give and learn to continue giving, which is something that is even more valuable.