A Very Low Cost Sustainable Housing Prototype for Tijuana, Mexico

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ABSTRACT: A low cost sustainable housing prototype for Tijuana, Mexico was designed and is under construction by faculty and students of Architecture and Regenerative Studies, in the grounds of the Lyle Center for Regenerative Studies at Cal Poly Pomona in Southern California. This prototype emphasizes local materials and technology appropriate for the cultural and economic conditions of the community in Tijuana. These technologies include very inexpensive home-made solar heating systems that minimize the use of energy, water and materials to achieve human comfort with little energy consumption. Addressing security concerns of residents, exploring 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. Principles in this project could later be adapted to other less developed countries. The project is ongoing and thermal performance of the different systems will be monitored beginning in the late Fall of 2006.

Keywords: sustainable architecture, affordable housing, developing country passive solar.

1. INTRODUCTION

Sustainable technologies are being 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 collaborating with nature, basing their buildings on an intuitive knowledge of the environment and climate, constructing buildings at a very low cost. In the development of this project we implemented strategies and systems based on proven traditional principles of sustainability, combining them with more advanced technologies that could be built at very low cost with local materials, providing adequate thermal comfort while being sustainable. A significant reduction in performance would be acceptable if the cost reduction is significant even with a reduction in performance.

This research project explores the development and integration of low cost technologies in a very low cost housing project for Tijuana. This paper presents the initial design concepts of the prototype that will be further developed and tested with the construction of a full scale building in the spring of 2006 in the Lyle Center for Regenerative Studies at Cal Poly Pomona. Teams of students are working together to develop these systems using local materials and technologies. Systems tested include low cost insulating assemblies, low cost windows, low cost insulating walls and thermal mass components.

2. TIJUANA

2.1 The city of Tijuana

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 (Fig. 1). 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, few urban services such as water and sewer, and a severely degraded natural environment (Fig. 2). Local residents have been quite resourceful in deriving shelter from readily available waste materials, such as tires, palettes, and garage doors (Fig. 3). However, threats from criminal activity as well as natural hazards such as landslides, earthquakes and floods present tremendous challenges for this informal housing sector.

Figure 1: Tijuana, Mexico

Figure 2: Colonia Nuevo Milenio, Tijuana

Figure 3: Colonia Nuevo Milenio, Tijuana

2.2 Climate of Tijuana

The climate of the Tijuana is temperate, moderated by the Pacific Ocean without extreme winters or summers. Maximum average summer and winter temperatures are 30.3 C and 22.7 C and minimum average summer and winter temperatures are 18.4 C and 5 C. Relative humidity is used between 50 and 65%. Furthermore many winter nights have very clear skies, increasing radiant losses from the building to the night sky. Interior temperatures at night follow exterior temperatures quite closely, easily reaching freezing or close to freezing interior temperatures during many winter nights. Nevertheless, practically none of the houses in the colonias have heating system or insulation. This is not only uncomfortable for the dwellers, but also dangerous, especially for children and the elderly. Occupants complain of the cold at night and do not necessarily sleep in the bedroom but rather search for the warmest part of the house and use many blankets and sweaters to try to keep warm during the night.

An analysis of hourly temperatures using climate data for San Diego, just a few miles north, indicates that thermal comfort can be achieved inside a building during almost every hour of the year using passive means (Fig. 4). Passive solar heating could be implemented in the winter and night ventilation with thermal mass or daytime ventilation could be implemented in the summer. So even if temperatures in the winter and summer are out of the comfort zone it is still possible to achieve thermal comfort inside the building using passive means.

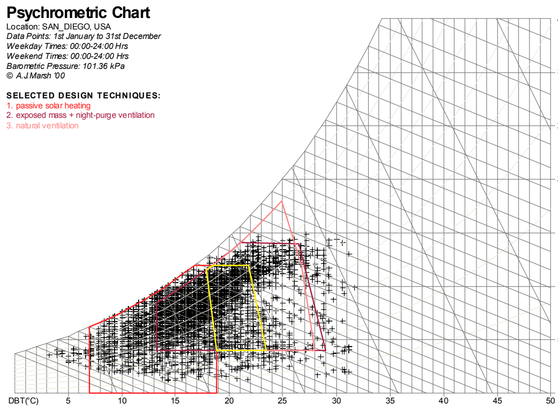

Figure 4: Hourly temperature and relative humidity

3. THE PROJECT

3.1 Habitat 21

Habitat 21, the project for sustainable settlements at the John T. Lyle Center for Regenerative Studies at Cal Poly Pomona is currently conducting a long-range study to improve housing options in impoverished neighborhoods in Tijuana. These neighborhoods are served by Corazón, a U.S. non-profit organization whose mission is to effectively serve the poor in Mexico, through an active home-building program, educational programs, and other community development activities. Many similar organizations exist around the world, focusing on providing safe and affordable housing in similar economic and social conditions. Corazón's 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 Corazón and other housing relief organizations: it must be affordable, easy to construct and at the same time desirable for local residents. We are designing a proposal that could be implemented in lots in the neighborhood or Colonia "Nuevo Milenio" (Fig. 5).

Figure 5: Colonia Nuevo Milenio

4. DESIGN PROPOSAL

Five students and three faculty worked together to develop two design proposals during the winter quarter of 2006. The students worked in two teams, each developing one project. Both teams had the same basic goals, to develop affordable sustainable housing for low income families of Tijuana. Because of space limitations we will concentrate on only one of these projects.

4.1 Prototype Design

The goal of this project is to create low cost sustainable housing for the residents of Tijuana. The house should have very low construction and operating costs, provide conditioned spaces year round, provide security for the residents and should be easy to build using local materials and labor, while integrating indoor and outdoor spaces to offer greater usability of the individual sites.

Because of the complexity of sustainability issues the students in this team proposed to focus on three main objectives: local sustainable building materials, use of passive heating and cooling systems, adaptation to local topography and site restrictions.

The project evolves from an "L" form to a "U" shaped building that maximizes surface to the south, while permitting cross ventilation through the spaces as needed. Simple elements, textures and natural materials are used to give a feeling of "home" to the building. Three gabion walls that can be adjusted help to regulate the topography. Even though these gabion walls might seem high (fig 7) they can be adjusted to different heights depending on the slope making it possible to build in these steep and very dangerous slopes. Compare to figs 3 and 4.

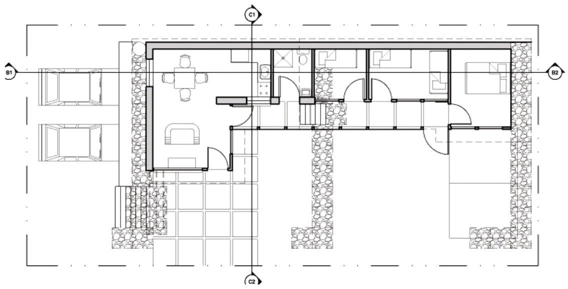

Figure 6: Plan phase 2

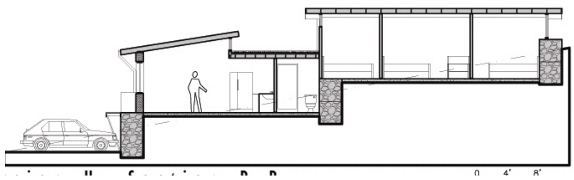

Figure 7: Section phase 2

4.2. Flexibility and Growth

One of the main problems with the Corazon prototype and many affordable houses is their inflexibility and inability to grow. The house is conceived as a unit with capacity to grow and evolve. The initial stage is a small unit with less than 30 square meters with a multiple living-sleep space, bath and laundry. This unit can evolve and grow up to a house with five bedrooms, living room, dining room, kitchen, laundry room, backyard, front yard and internal patio, porch and a place to park the car if they have one. This way anybody could build as much as he/she needs and can afford.

The initial site work for the whole house should be done first so as to establish the foundation for the whole house. This might mean slightly higher initial costs, but which will be compensated with the flexibility and capacity to grow that the house acquires.

The house can grow in many stages and can achieve the final stages of growth through many different paths. 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 of different sizes. One of several possible paths to achieve the final phase is presented in figure 11.

Prior to the construction of the building, grading, gabion retaining wall construction, drainage swales and earth bag walls can be constructed by the community. This requires very little outside resources, because much of the materials come from the site itself. Next, the building's slab on grade foundation system can be poured.

The fist phase of the house is 29.75 m^2 and includes a kitchen, sleeping area and bath. The construction consists of gabion units, earth walls and lightweight framing (Fig 8). Depending on the location of these walls, either lightweight or heavy mass components would be used. A loft is above the kitchen/bathroom area and can be used for sleeping or storage.

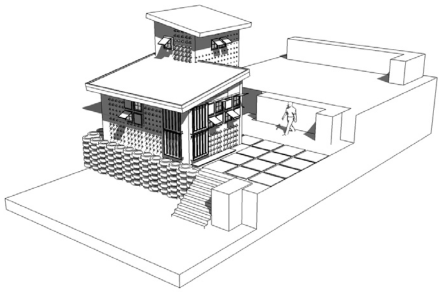

Figure 8: Phase I

In the second phase additional sleeping pods that are approximately 2.44 m x 3.05 m area added as the family grows and has more resources (Fig 10). The sleeping pods use the gabion units for walls, earth wall and wood framing.

These sleeping pods can be arranged in two versions: either creating two "L" shaped buildings, or creating one "U" shaped building (Figs 9 and 10). These configurations depend on the site, neighbor relations, and most importantly, input from the occupants. By scheduling the development in phases, the construction work can be done in a short amount of time, while construction costs are also minimized.

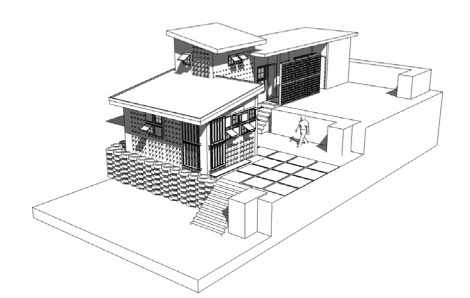

Figure 9: Phase II variant A

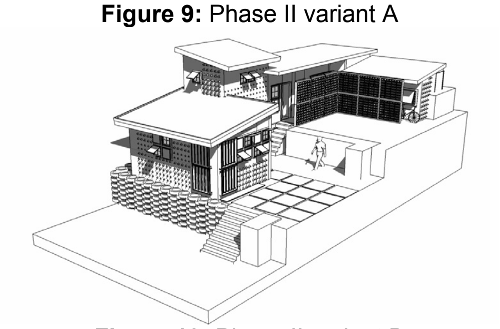

Figure 10: Phase II variant B

4.3 Landscaping and Green Roofs

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.

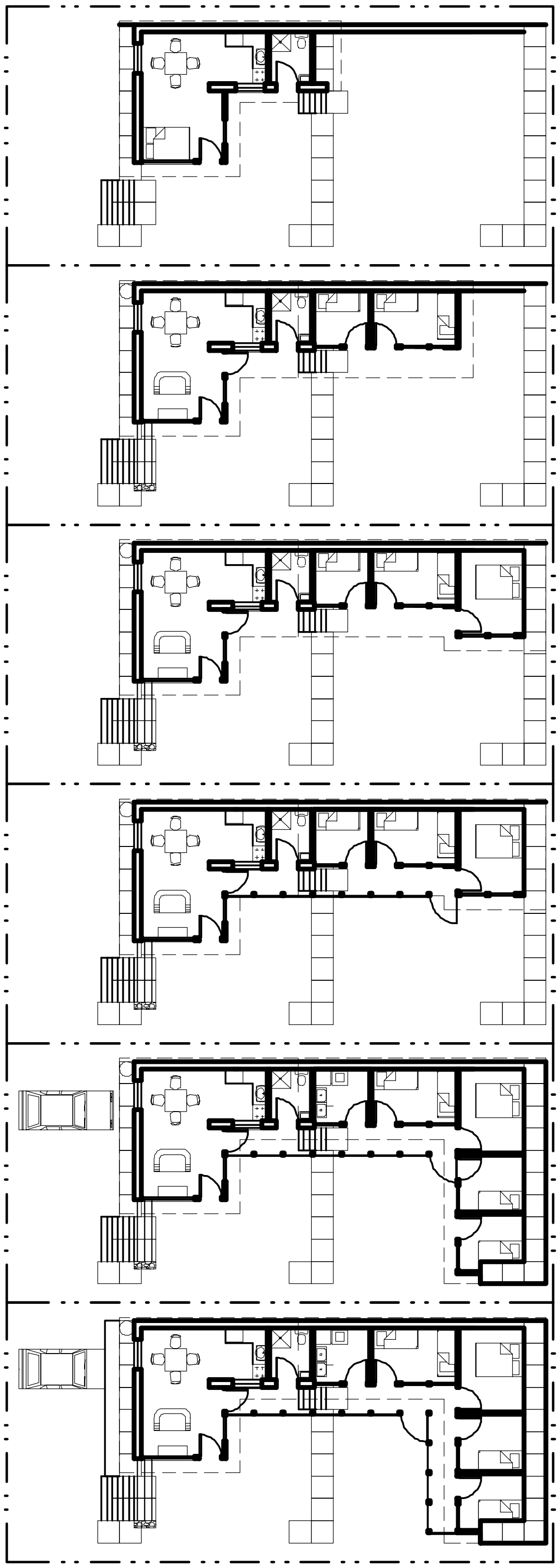

Figure 11: Growth from "L" to "U"

An "extensive" green roof has been incorporated into the design to assist in mitigation of rainfall runoff while providing improved heating and cooling performance and an increased roof life expectancy due to reduced UV exposure. An extensive type green roof is proposed rather than an intensive green roof to minimize structure costs.

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.

4.4. Local Materials

Corazon's home building program takes 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.

It is important to use materials from the site. There are several advantages in this: since they own the property they do not have to pay to buy or remove the materials, instead they are readily available 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 generated from the grading process can be used to build the walls of the structures, while rock also from the site grading can be used to fill gabion units used for both walls and retaining walls. Instead of relying on the structural integrity of the soil, the soil is placed in bags and compacted. Plaster is then used to encase the bags – a system developed and popularized by Nadir Khalili. The gabion units are comprised of rocks placed into square wire "baskets" measuring approximately one cubic meter. These are then stacked and tied together to act as retaining walls. The interior could also be plastered, much like the earth bag walls.

4.5 Adapting to Local Topography

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.

Figure 12: Construction of the prototype

4.6 Passive Heating and Cooling

As can be seen from the psychrometric chart, (Fig 4) a greater emphasis needs to be placed on passive heating in the winter, while ventilation, which can be either during the night or during the day can be used in the summer.

Materials with high thermal capacity are used to store heat in the winter or act as heat sinks in the summer. Concrete floors and earth bag walls provide the mass needed for thermal storage. Several strategies to heat these materials in the winter will be tested, including simple direct solar gain, solar air heaters integrated in the lightweight south walls and hydronic systems with solar collectors to heat the water.

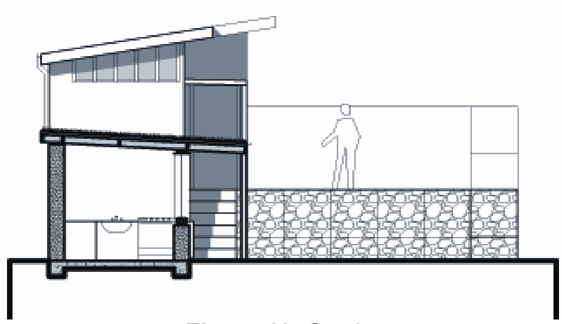

Figure 13: Section

Operable windows are also placed along the southern and eastern façade, providing natural light, ventilation, and solar gain in the morning, and in the case of the southern elevation, during the whole day in the winter. Additional windows provide radiation during the early afternoon in the winter. Many of the windows are also placed near the ceiling to further improve natural ventilation and daylighting (Fig 13).

A jalousie system is constructed in the south façade that generates privacy and security while providing solar protection in the summer. Additional illumination is provided by the windows above this system that spread light further inside the space (Fig. 14).

Figure 14: South Elevation Phase II

Thermal simulations were done with HEED, Home Energy Efficient Design, a user-friendly energy design tool developed at the department of Architecture at UCLA. Simulations were done using an EPW meteorological file for San Diego.

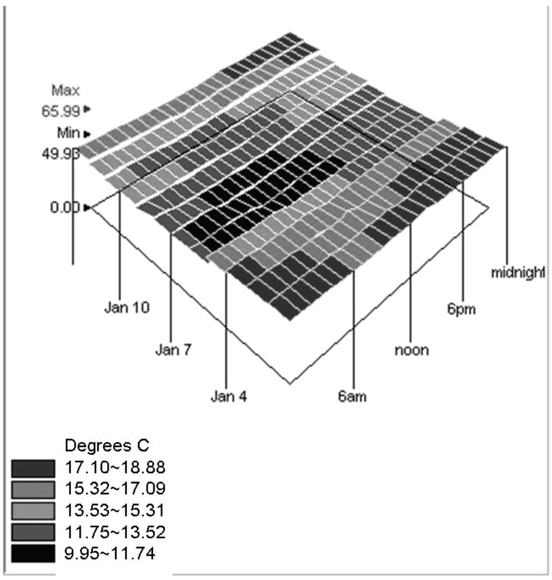

Figure 15: Thermal simulation for twelve winter days

Twelve warm days in the summer and twelve cold days in the winter were analyzed. The indoor temperatures in the winter ranged from 10 to 19 C (Fig 15) while in the summer they ranged from 23 to 28 C (Fig 16). These simulations only account for heating provided by direct passive solar gain through the windows and do not account for additional systems that could be implemented in the buildings, such as the hydronic heating system. Nevertheless, even though indoor temperatures in the winter night can be out of the comfort zone, they are much higher than the temperatures recorded in several of these houses in the winter of 2006.

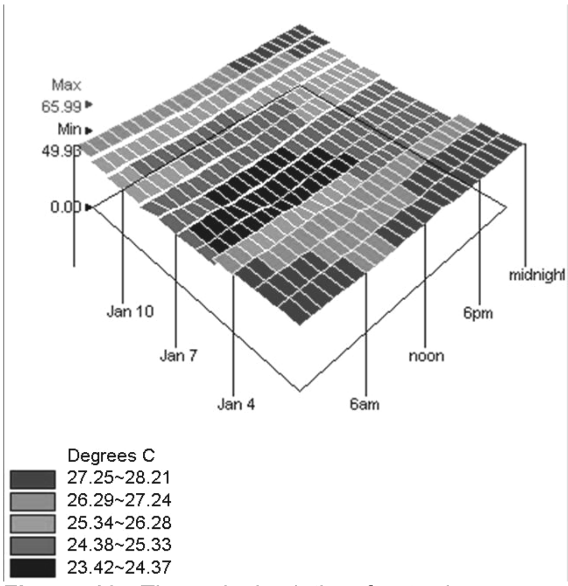

Figure 16: Thermal simulation for twelve summer days

5. CONCLUSION

It is possible to design very low cost sustainable house for developing countries adapted to local conditions and culture. More detailed results will be presented in the conference presentation and in further papers on the project.

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