JOURNAL OF UNDERGRADUATE RESEARCH

Earthship Architecture in Punta Cana

Gabriela Villalobos
University of Florida

Faculty mentor: Jocelyn Widmer, Texas A&M University

Abstract

Earthship, developed by Michael Reynolds in the 1970s, is an experimental architectural design that seeks sustainable housing. This movement is known for using passive solar methods, earth sheltered facades, and recycled materials for building. This paper explores the possibility of applying this architecture that was originally developed in North America, in the tropical areas of the Dominican Republic. The eastern area of the Dominican Republic, Punta Cana, is the home of a growing informal population due to the booming service sector's demand to support tourism development. Earthship architecture focuses on small scale homes satisfying the need for multi-family and single-family housing in the area; however, Earthship was designed for dryer climates that go through considerable seasonal temperature changes. Extensive research shows that to accommodate Earthship homes in Punta Cana is unadvised. Building a thermal wall has not had significant benefits on climates with little daily temperature changes. Making an earth-berm building would make the humidity overwhelming, and the transparent south facade would overheat the inside spaces.

Background

The eastern area of the Dominican Republic is home to one of the Caribbean's most luxurious tourism destinations (Punta Cana), but it is also home to a growing informal population due to the increased demands in the construction and service sectors to support this tourism development. As a result, there are several informal urban areas in the region where people have migrated from all over the island of Hispaniola to have access to robust employment opportunities. The housing stock to support this informal population is split between multi-family and single-family dwelling units. Ecocycle is a recycling business in the region that specializes in sorting and selling solid waste generated by the massive tourism industry in the Punta Cana region. They could provide the necessary recycled material to build Earthship.

History of Earthship

Earthship architecture was born in the 1970s after architect Michael Reynolds felt un-satisfaction with modern building designs. As a consequence, he started a new movement in Taos, New Mexico, based on sustainable living and green design. Reynolds focused on three important ideas when creating Earthship. First, he wanted the buildings to be sustainable. Sustainability meant to build houses using local and recycled materials for the structures and facades, but also, for the buildings to function sustainably. Secondly, Reynold wanted to create houses that could work independently from the grid by relying solely on natural energy sources. Thirdly, Reynolds strived for creating a method of building that anyone could do themselves. Some criticized these ideas as radical, but with them, Reynolds created a movement with green design techniques that got their category as "Earthship" homes.

It took Reynolds twenty years to polish his sustainable architectural designs. In the end, six core design concepts were born (Reynolds, 2008). The first core concept utilizes passive architectural design techniques to harness the sun's energy for heating and cooling spaces. The second is the use of natural resources to produce electricity on-site. The third concept is to create houses with built-in wastewater treatment. The fourth is the use of available materials, including recycled materials, to build the facade and structure of the houses. Concept five is to implement techniques that allow the gathering of rainwater and utilized it in practical means. The sixth and final concept is creating a means for the occupants to produce some of their food on site. These six fundamental design principles became the characterizations for Earthship architecture, and they are still implemented by Earthship builders to this day (Kinney & Dodge, 2015).

Earthship Architecture

Controlling the temperature inside of a building is essential for sustainable architecture. It makes buildings more energy efficient by reducing the amount of power they would otherwise need to maintain a comfortable inside temperature. Earthship architecture accomplishes this with multiple design techniques, but its most well-known is building the houses with the northern facade as an earth berm (Figure 1). Having the north façade earth sheltered, allows successful insulation of the buildings to maintain a constant indoor temperature.

In comparison, the southern facade is usually made of a glass wall or windows that maximizes the natural light in and simultaneously allows the thermal energy from the sun to penetrate the building. During the winter, the heat from the direct sunlight helps maintain the interior spaces warm. This passive architecture technique harnesses the thermal power of the sun for the use of the occupants. The ingenuity of these solar designs is meant to provide Earthship homes with independence from electricity and fossil fuels to heat or cool a space.

Figure 1. Wannee, E (Photographer). (2009, September 4) *Earth ship in Zwolle* [digital image]. Retrieved from https://commons.wikimedia.org/wiki/File:Earthship_Zwolle.jpg

Earthship reuses old tires and integrates them into the facades of its buildings. The tires are packed with earth, mud, or concrete to create 300 pound building blocks. When stacked, their strength and wide dimensions build the load bearing walls of the house. The combination of the tire's rubber with the packed earth inside creates a wall with thermal mass properties. These walls store solar heat during the day and release it at night as the outside temperature drops. Thermal mass maintains interior temperatures locations that experience extreme temperature changes during 24 hour periods. Earthship uses these walls to enclose the buildings from east, west, and north by integrating them with the earth sheltering systems. The sunlight penetrating through the translucent south facade hits the thermal mass walls and flooring. The directionality of the light assists the gathering of heat to release it at night (Earthship Biotecture, n.d.).

Figure 2. Kamp, Y (Photographer). (1999, January 10*) Earthship built by Angel and Yvonne Kamp in South Africa* [digital image]. Retrieved from https://commons.wikimedia.org/wiki/File:Kamp%27s_Earthship.png

Michael Reynolds also incorporated other unorthodox materials in his designs, such as aluminum cans and recycled glass bottles. These artifacts are not imperative to the performance of Earthship homes. However, their aesthetic appearance has become the signature of this movement as it attests to the promise of reusing trash. (Earthship Biotecture, n. d.). Reynolds reused glass bottles by embedding them in concrete, mud, or adobe and arranging them in rows according to color. Many compare them to stained glass as the bottles filter sunlight and illuminate the interior with patterns and colors. The metal can arrays are situated in rows inside the walls and are used to create a similar aesthetic appearance, but instead of letting light through, they reflect it. These materials create a play with light and color in the building's facades by either letting it through or reflecting it, granting a significant experience to anyone inside, but at the same time acting as a symbol of what these houses are about: sustainability and recycling.

Figure 3. Parkins, J (Photographer). (2015, May 21) [digital image]. Retrieved from https://www.flickr.com/photos/132649838@N04/17898234946

Earthship performs sustainably not only by controlling the temperature of the building with its facades but also by harvesting water for the use of tenants. Architects employ curves and slopes in the design of the roofs to redirect and gather rainwater water to be used by the household. The materials that compose the roofs are chosen to allow water to move through uninterrupted. Commonly, they are made of metal roofing, cement plaster coated with acrylic, or rubber as EPDM. The shape of the roof leads the water to a natural filter that then conducts the water to a cistern. Earthship architecture usually integrates the cistern within the earth berm structure to keep the water insulated and at a comfortable temperature. (Reysa, n.d). The water is then distributed to a pump and another filter system to clean it further before it goes to a solar water heater and a pressure tank. This water is then used for dishes, sink, bathrooms, and laundry. After the tenants use the water, an additional system composed of plants and roots re-filter the water to use it to flush the toilets. (Earthship Biotecture, n.d.).

Cabeza de Toro, Punta Cana

The Dominican Republic growing semi-urban population could benefit from Earthship architecture. Tourism in the northeastern region of the Dominican Republic is continuously growing, creating an expansion in local towns as the need for service is prominent. Cabeza de Toro, a small community, located next to the hotel Be Live Gran Punta Cana, is an example of this enlargement of a small town. The housing stock to support this informal population is split between multi-family and single-family dwelling units. Earthship architecture specializes in family homes of relatively the same size.

In Cabeza de Toro, there is a substantial difference between the buildings of the informal settlements and the luxurious resorts and hotels (Figure 4). The latter was built for financially comfortable tourists that are looking for a place to spend their vacation. These resorts are pre-planned and designed by costly architects to provide excellent services to visitors. The rooms in these locations include air conditioning, adjacent swimming pools, and connections to the beach for recreation and leisure. In comparison, people in Cabeza del Toro perceive the sea as one of their primary methods to make a profit. Fishing is one of the main markets that drive the economy in the town. Housing in the area and buildings for these local businesses are the opposite of what the average tourist experiences in resorts and hotels. These buildings are primarily built of concrete blocks, few with added stucco and paint (Figure 5), while the roofs are made of corrugated metal or tropical palm leaves (Figure 6). The roofs are held by either the concrete walls or irregular tree trunks that work as informal columns (Figure 4). The people have also used old wood planks to cover damage the buildings have gone through (Figure 7). Moreover, air conditioning is a luxury that only a few can afford; therefore, the building must provide shade and thermal comfort.

Figure 4. Contrast between a local building in the front, and a tourist destination in the back. Cabeza del Toro, Punta Cana, Dominica Republic. June, 2018.

Figure 5. Successful restaurant in the area built with concrete blocks walls. Cabeza del Toro, Punta Cana, Dominica Republic. June, 2018.

Figure 6. One of the local "Pescaderia" or seafood markets that drive the economy of the area. Cabeza del Toro, Punta Cana, Dominica Republic. June, 2018.

Figure 7. A building that houses a private "Pescaderia" or a seafood market, and a restaurant located at the seafront. Cabeza del Toro, Punta Cana, Dominica Republic. June, 2018.

Climate

The climate of Punta Cana is reasonably constant throughout the year. According to the National Oceanic and Atmospheric Administration (NOAA), from November to April, the colder months of the year, the lower temperatures range from 70° to 73° Fahrenheit (F); while the higher temperatures range from 84°F to 87°F. The warmest months of the year are not very different. From May to October, the lowest temperatures range from 74° to 76° and the highest from 87°F to 90°F ("National Centers for Environmental Information," n.d.). According to World Weather and Climate Information, the annual average humidity of Punta Cana is of 82% with January being the most humid time of the year and March the least ("Average monthly humidity," 2019)The climate of Punta Cana falls into the Tropical Climate classification for its high temperatures and humidity levels, a climate very different from the climate of where Michael Reynolds developed his Earthship ideas.

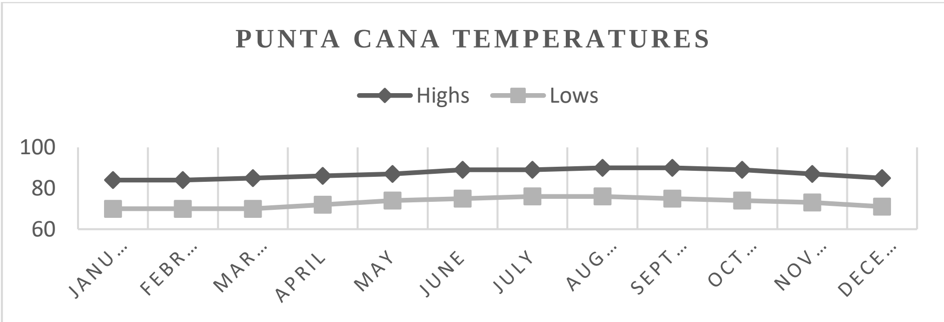

Figure 10. Average of lower and higher temperatures of Punta Cana each month of the year

Investigating Thermal Comfort in Earthship Architecture

An experiment by Nathanael J. Kruis and Matthew K. Heun from Calvin College used engineering computer models to assess the thermal comfort of Earthship houses in different climates. They used a traditional Earthship home as their basis. This home had three well-insulated walls that used old tires as their structure and a southern facing window to let sunlight and thermal energy inside. The experiment first evaluated the R-value of the walls to assess their insulation properties. The total R-value of the tire walls was of 25 $ft^{2}\ h°F/Btu$, providing high insulation, while the southern window had a low R-value of 0.48 $ft^{2}\ h°F/Btu$, being a poor insulator. The analysis concluded that with warm outside temperatures, there is no need for intensive thermal envelopes such as the ones from Earthship. The thermal enveloped was designed by Reynolds to maintain the warm while winter stroke, therefore in places where the temperature is continuously warm yearlong is unnecessary (Kruis & Heun, 2007).

Priestman also used modeling to forecast the thermal performance of an Earthship building in Taos, New Mexico. Summer temperatures in this area are as high as 86°F - 87°F, around the average high temperature of Punta Cana. According to the analysis, the house in the summer overheats and needs a new system, such as air conditioning, to be able to cool the space (Priestman, 2014). In the book "Hacking the Earthship, In Search of an Earth Shelter That Works for Every Body," author Rachel Preston Printz states that Earthship overheats nine months a year in climates that contain seasonal changes. The southern glass facades let too much direct sunlight in and the reduced insulation rate of glass allows thermal heat to enter the building overheating the interior spaces. Earth tubes and roof venting have been developed by the Earthship movement to provide ventilation and free the excessive heat in houses; however, these techniques are not successful in environments with high humidity rates (Prinz, 2015).

Archina, an architecture firm that focuses on sustainable design, states that when building Earthship houses, one must always choose a location with 60% humidity or less. If the humidity rate on the site exceeds this amount, the building would be set up for failure ("Solving The Earthship Enigma," n.d.). The signature design principle of Earthship architecture is earth sheltering buildings, but this feature also affects the humidity levels of the interior spaces. Research published in the third volume of Tunneling and Underground Space Technology compared the inside and outside humidity levels of an earth-sheltered home. During the winter, when the outside relative humidity was of 65.1%, the inside humidity levels increased the small amount of 1.9%; on the other hand, during the summer, when the outside relative humidity was of 69.8%, the inside humidity reached 79.7%, which is 9.9% higher.

In comparison, the researchers tested other buildings in the area that were not Earthship and found out that the interior humidity decreased during the summer instead of increasing (Woong Lee & Yeul Shon, 1988). The rise of humidity levels that occurs when earth sheltering a building is a significant disadvantage in hot, humid climates. Higher relative humidity negatively affects human comfort; the recommended relative humidity of interior spaces is 30% to 70% (Tsutsumi, Tanabe, Harigaya, Iguchi, & Nakamura, 2007). If higher, it intercepts the evaporation of sweat and prevents the human body to regulate internal temperature and cooling itself down (Ashrafian, 2011). Additionally, high interior levels of humidity can be harmful to tenants as they allow the interior wall surfaces to accumulate water and facilitate the reproduction of molds and algae (Prinz, 2015).

The massive tire walls that Earthship uses as a core to build houses have thermal properties of gaining heat during the warmest times of the day and releasing it when cold strikes. The thermal fluctuation is useful in climates with significant daily temperature differences fluctuations such as the northern regions of the United States. The temperature on Punta Cana, on the other hand, does not drop below 70°F yearlong. A comfortable temperature for an average person ranges between 68°F to 72°F; therefore, there is no need to warm the space at night. A study done by the MIT Concrete Sustainability Hub indicates that thermal mass benefits a building mostly in the winter. Furthermore, it discovered that in hot, humid climates, the thermal benefit is minimal (Ghattas, Ulm, & Ledwith, 2013).

Conclusion

The Earthship architecture movement claims that it can be employed in every climate providing thermal comfort by passive means without the need for fossil fuels. However, extensive research has shown that it is not effective in warm and humid tropical climates as the one of Punta Cana. The average temperature of Punta Cana is 80°F and does not drop lower than 73°F in the winter. The intensive thermal envelope of Earthship has an impractical function in climates like this. The walls made of tires that build the structure have thermal mass properties that gather heat during the day to release it in the cold of night; yet, the nights in Punta Cana are not uncomfortably cold. These thermal mass walls would be detrimental to the inside temperature of the house as they will be releasing the heat of the day when the temperature inside is rather comfortable.

Additionally, the southern facing window that Earthship implements have caused buildings to overheat in places where the summer temperature resembles that of Punta Cana. Having a translucent facade for the thermal heat of the sun is only beneficial with a building that suffers from significant cold winters. In the climate of Punta Cana, it prejudices the building by overheating the interior instead of allowing it to cool. Vents that come from the ground and provide cool air have been proposed to counter the issue of overheating in these buildings. However, this solution is not recommended in places with high humidity levels such as that of Punta Cana. The earth sheltering techniques that Earthship is so known for worsening humidity inside the buildings. Earth releases more moisture into the interior spaces intensifying the lack of thermal comfort and allowing for mold and algae to grow in surfaces. Earthship has virtuous sustainable principles and a moral vision for building. Its design principles have shown that passive techniques can be useful; however, it is not the best option for the humid tropical climate of Punta Cana.

References

Ashrafian, T. (2011). Human Comfort in Underground Buildings. In *5th SASTech*. Mashhad.

Average monthly humidity in Punta Cana, Dominican Republic. (n.d.). Retrieved from https://weather-and-climate.com/average-monthly-Humidity-perc,punta-cana,Dominican-Republic

Earthship Biotecture. (n.d.). Design Principles. Retrieved from https://www.earthshipglobal.com/design-principles.

Ghattas, R., Ulm, F., & Ledwith, A. (2013). Mapping Thermal Mass Benefit. CSHub. Retrieved from https://cshub.mit.edu/sites/default/files/documents/ThermalMassBenefit_v10_13_0920.pdf.

Hacking the Earthship. (n.d.). Earthship Glass Block and Bottle Walls. Retrieved from http://hackingtheearthship.blogspot.com/2015/01/glass-block-and-bottle-walls.html

Kamp, Y. (n.d.). Earthship built by Angel and Yvonne Kamp in South Africa [Digital image]. Retrieved March 20, 2019, from https://commons.wikimedia.org/wiki/File:Kamp's_Earthship.png

Kinney D, Dodge D. (2015). How We Built Our Own Earthship. *Natural Life*, 45-49.

Kruis, N. J., & Heun, M. K. (2007). *Analysis of the Performance of Earthship Housing in Various Global Climates*. ASME 2007 Energy Sustainability Conference. doi:10.1115/es2007-36030

National Centers for Environmental Information. (n.d.). Retrieved from https://www.ncdc.noaa.gov/

Parkins, J. (n.d.). [Glass bottles inside wall]. Retrieved March 20, 2019, from https://www.flickr.com/photos/132649838@N04/17898234946

Priestman, M. H. (2014). Earthship Architecture: Post occupancy evaluation, thermal performance & life cycle assessment (Unpublished master's thesis). The University of Adelaide.

Prinz, R. P. (2015). Hacking the earthship: In search of an earth-shelter that works for everybody. Albuquerque, NM: Archinia Press.

Reynolds, M. (2008). Journey. Taos, NM: Earthship Biotecture.

Reysa, G. (n.d.). Earthship Water System. Retrieved from https://www.builditsolar.com/Projects/SolarHomes/Earthship/Visit/WaterSystem.htm

Solving The Earthship Enigma. (n.d.). Retrieved from https://archinia.com/earthships/solving-earthship-enigma.

Tsutsumi, H., Tanabe, S., Harigaya, J., Iguchi, Y., & Nakamura, G. (2007). Effect of humidity on human comfort and productivity after step changes from warm and humid environment. *Building and Environment*, *42*(12), 4034-4042. doi:10.1016/j.buildenv.2006.06.037

Wannee, E. (2009, September 4). [Earth ship in Zwolle]. Retrieved March 20, 2019, from https://commons.wikimedia.org/wiki/File:Earthship_Zwolle.jpg

Woong Lee, S., & Yeul Shon, J. (1988). The thermal environment in an earth-sheltered home in Korea. *Tunnelling and Underground Space Technology*, *3*(4), 409-416. doi:10.1016/0886-7798(88)90013-