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The Watershed House: A Water Harvesting Prototype for Vulnerable Communities

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ABSTRACT - *A potential answer to the call for a human right to sustainable and equitable housing, water access, and environmental justice may be found in the wings of a desert beetle. This paper presents a housing prototype integrating various water harvesting strategies and biomimetic solutions derived from the Namib beetle. An exploration of issues at the intersection of water access and equitable housing is presented through a literature review that demonstrates how housing conditions, access, and affordability are linked to a lack of infrastructural services, including water, which has subsequent health implications. The paper reviews both passive and active water harvesting opportunities for architectural integration. The paper concludes with a description of the prototype through a case study addressing the housing and water access needs of* colonias *communities in Texas, and sheds light on water access and housing affordability challenges, proposing architectural and policy strategies to address these issues. The speculative housing prototype integrates water harvesting solutions using a prefabricated kit of parts approach allowing for flexibility and adaptability across various communities where centralized infrastructure is technically or economically not feasible.*

Keywords: equity, health, housing, water access

Access to clean, reliable running water is essential for life and is a human right. It is linked to health, prosperity, and well-being. Similarly, access to affordable and safe housing affects our lives in myriad ways. For example, housing conditions can affect physical and mental health, overall quality of life, access to neighborhood services, including education, and access to economic opportunities. In the US in 1944, Franklin Roosevelt declared that “we have accepted, so to speak, a second Bill of Rights under which a new basis of security and prosperity can be established for all - regardless of station, race, or creed. Among these are…the right of every family to a decent home.” [1] Despite the declaration by Roosevelt, history has shown us that the legacy of systemic racism manifested through redlining, community disinvestment, zoning, and restrictive covenants resulted in many communities of color being excluded from access to safe and secure housing and the economic benefits of homeownership. In addition to grappling with the legacy of this systemic oppression (disinvested communities and environmental injustice), housing affordability is a significant issue in the US and worldwide. The National Low Income Housing Coalition stated that there is a “shortage of seven million rental homes affordable and available to extremely low-income renters whose household incomes are at or below the poverty guideline or 30% of their area median income.” [2]

The International Covenant on Economic, Social and Cultural Rights (ICESCR), which the United Nations oversees, declares a human right to adequate housing as consisting of:

(1) security of tenure,
(2) availability of services, materials, and infrastructure,
(3) affordability,
(4) accessibility,
(5) habitability,
(6) location, and
(7) cultural adequacy.[3]

While the US signed the ICESCR in 1977, the Federal Government has yet to ratify it.[4] The framework presented by the ICESCR situates housing as a human right instead of a commodity as it currently operates today. Adapting the framework of housing as a human right as a federal policy is essential. This human rights framework does not just address issues of affordability and habitability, but also issues that often do not get as much attention, such as availability of services, infrastructure, and cultural context.

The need to address the availability of services, materials, and infrastructure when studying water access and affordability issues in the US is paramount. Today, access to reliable and affordable water sources remains out of reach for many Americans, a situation exacerbated by the effects of climate change. A study by the US Water Alliance called *Closing the Water Access Gap in the United States* cited more than two million Americans living without running water and basic indoor plumbing and many more without sanitation.[5] In Addition, in 2019, more than 44,000,000 people were served by water systems that had health-based Safe Drinking Water Act violations.[6] In many communities in the US, people spend considerable time, effort, and finances retrieving water. Water scarcity and affordability affect some of the most vulnerable populations in the US. As noted by the report, “this is the reality for people living in the US – right here and right now. While the majority of Americans take high-quality drinking water and sanitation access for granted, millions of the most vulnerable people in the country – low-income people in rural areas, people of color, tribal communities, immigrants – have fallen through the cracks.” [7]

In addition to issues of tracking and measuring the water gap, the study found that “race is the strongest predictor of water and sanitation access.” [8] Specifically, the study found that lack of access to adequate plumbing was twice as probable in African-American and Latinx households than in White households and nineteen times more likely in Native American households.[9] The study also found that poverty significantly affects water access and water affordability. In addition to the quantitative metrics outlined in the *Closing the Water Access Gap* report, the report also investigated six regions through a qualitative lens. This qualitative assessment set out to understand the challenges faced by lack of water access in several communities that were representative of similar communities across the US and gives a human face to these issues. The report focused on six communities facing severe water access issues, including the Central Valley of California, the Navajo Nation, the Texas *colonias*, rural areas in the South, Appalachia, and Puerto Rico. These regions all have issues intersecting environmental justice, water access, and access to safe and affordable housing.

Similar to issues of equitable housing, lack of water access and sanitation in communities today dates back to historical discriminatory practices. Many communities of color historically did not receive adequate water and wastewater infrastructure when investments were being made in other parts of the nation. For example, the report notes,

> In the 1950s, Zanesville, Ohio, did not construct municipal water lines in African-American neighborhoods. In the 1960s, Roanoke, Virginia did not extend water and sanitation lines to neighboring Hollins, a majority African-American town. In California Central Valley, rural Latinx communities were discouraged from incorporating and therefore did not receive the same funding to build infrastructure that neighboring towns did.[10]

This initial lack of investment has compounded due to the decrease in federal funding for infrastructure, thereby placing pressure on states and local governments to address an ever-widening chasm with less available funding. The repercussions of these policies can be seen today in the current water and sanitation crisis that continues to threaten the health of communities across the country.
It is clear that access to housing and water are inextricably linked, and both

are steeped in racially discriminatory practices. Both housing and access to safe, reliable water have been affected by environmental racism. While some affected communities have access to piped water, discriminatory development practices have led to other water sanitation and health issues. For example, areas of the rural south in Mississippi and Louisiana are grappling with housing and water access issues, including the cancer alley of Louisiana, where water and air pollution have caused the highest cancer rate in the US (nearly fifty times the national average).[11]

In addition, access to clean water has hindered the ability to produce affordable housing. For example, in the California Central Valley, access to water has created a dearth of affordable housing development. Many unincorporated parts of the Central Valley experiencing a lack of infrastructure have resulted in the reluctance of developers to invest, causing housing production to fall below state goals.[12] In Texas *colonias* communities, local activists fight for water access, arguing that water access affects housing standards and is an environmental justice issue.[13] An understanding of the intersection of water scarcity and equitable housing sets the framework for investigating housing solutions that can address housing and water vulnerability issues. While policy change is necessary to address the multitudinous social, political, and economic issues wrapped up in infrastructure and housing challenges, there are also opportunities within the design profession for addressing these issues.

The following speculative project is grounded in the need for innovative solutions to water access and housing issues for the communities "for whom geographic, environmental or technical factors make centralized infrastructure prohibitively difficult to build and maintain." [14] The project proposes integrated solutions which address water access while providing opportunities for safe and reliable housing.
A kit of parts prototype utilizing a panelized wall system provides the framework for integrating various water harvesting technologies. This includes using the skin of the building to capture the roriferous qualities of the atmosphere as inspired by the Namib beetle. The system can also adapt to different vernacular and spatial-cultural housing typologies across various regions. An understanding of a systems-based approach was grounded in an in-depth analysis of various water harvesting solutions.

WATER HARVESTING SOLUTIONS

A range of potential water harvesting solutions can be integrated into housing typologies using a systems approach. These are:

(1) rainwater collection,
(2) biomimicry realized in fog and dew collection, and
(3) mechanical atmospheric water generation.

The field of biomimicry has been gaining traction in architecture, drawing on lessons learned from nature. The case of the Namib beetle is intriguing as it has adapted to the extreme climatic conditions of the Namib desert, one of the most arid regions of the world. The Namib beetle harnesses water from the environment through fog collection through the alternating hydrophilic and hydrophobic surfaces on its body, allowing for the condensation and channeling of water towards its mouth. Hydrophilic materials allow water to spread (i.e., they maximize contact with water, while hydrophobic materials repel water, causing droplets to form).[15]

These hydrophilic and hydrophobic surfaces are seen in many aspects of nature and combine to allow water collection and channeling. During this process, the beetle raises its textured elytra (wings) in the direction of the wind to siphon water from the air to feed itself.[16] The remarkable simplicity of how the Namib beetle operates has inspired the research and development field of atmospheric water generation, a scaled version of the anatomical approach to survival of a beetle that proposes to provide sustenance to water-scarce areas of the world. In addition to experiments with mesh,[17] numerous material scientists have been experimenting with various beetle-inspired surfaces exploring varying degrees of hydrophilic and hydrophobic properties.[18]

Other water harvesting strategies are derived from historical precedent. For example, rainwater collection strategies have been used for centuries across different cultures (e.g., Roman aqueducts, the terraced water systems of the Incas in Machu Picchu, the Islamic evocation of water in the Alhambra palace in Spain, and the stepped wells of India). These examples demonstrate water channeling through pipes or gutters and collection in cisterns for future use. In housing typologies, the roof becomes an ideal interface for rainwater collection.
Similarly, fog and dew collectors have been utilized historically. For example, archaeological remnants have shown these practices being utilized in Egypt and the Atacama Desert in South America, where stone walls were strategically placed to capture condensation that could be collected utilizing gravity.[19] Current fog and dew collectors tap into this knowledge base of historical precedent and rely on the condensation of water on mesh surfaces to produce water. Large infrastructural fog plants have been erected in arid and rural regions drawing on environmental conditions to harvest water.

The biomimetic water harvesting techniques used in atmospheric water generation are ripe for architectural integration, and several examples of innovative approaches from high to low tech have been explored. One example is the Warka Tower, implemented in rural African communities facing water access challenges. It utilizes the biomimetic principles derived from nature, such as the Namib beetle, for harvesting atmospheric water (rain, fog, and dew) through its surface and utilizes only gravity, condensation, and evaporation.[20] Its structure is derived from local materials and draws on the indigenous culture, making it easy to maintain and operate. According to the manufacturer, it aims to distribute between 40-80 L [10-20 gal.] of drinking water daily, but this depends on local meteorological conditions (i.e., adequate levels of fog and humidity).[21] Fog and dew collection materials vary based on location, but a combination of bamboo, polyester mesh, cable, and hemp rope are often used. Examples such as the Warka Tower point to opportunities for integrating such skin systems into building typologies.

The low-tech biomimetic notion of condensing water from the atmosphere has recently been commercialized into more sophisticated systems of mechanized Atmospheric Water Generators (AWG), which have been tested recently as a potential solution in drought-prone areas. Like fog and dew collectors, the AWG harvests water from the atmosphere through the natural process of condensation. AWGs function similarly to dehumidifiers, where the water is collected, passed through a water filtration system, and is ready for immediate potable use. There are various types of AWGs on the market, including refrigerant-based dehumidification and those relying on desiccant liquid.
Several tests have explored the potential of atmospheric water generation.[22] For example, solar-powered desiccant-based AWGs were able to generate 10.6 L [2.8 gal.] per day in ideal conditions when tested in Texas. It was able to function with relative humidity as low as 18%.[23] Researchers at UC Berkeley and MIT were able to generate 5.6 L [1.48 gal.] per day using a “metal-organic framework that captures water from the atmosphere at ambient conditions by using low grade heat from natural sunlight.” [24] This device was able to generate this in a test chamber at 20% humidity. Similarly, a study at Texas State University aimed to understand the cost/benefit of water generated using AWGs.

Using a refrigerant-based commercially available AWG in Texas over ten days, they found that water generated in this manner was more cost-effective at a breakeven point of seventy-two days compared to buying twelve oz. bottles of water. Results also showed a breakeven point of 1,259 days (three and a half years) compared to buying one gal. bottles of water.[25] It should be noted that this test did not account for the cost and time spent traveling to buy water and the varying efficiencies of AWGs based on climate conditions. The research into the area of AWGs, therefore, supports the synergistic combination of utilizing these systems with other water harvesting solutions architecturally. Given these water harvesting solutions, the aim is to address the right to dignified housing through the lens of water access while tapping into various technologies and policy opportunities. This goal is achieved by developing an efficient, high-performance home that folds several harvesting strategies into a prefabricated kit of parts envelope which can be assembled into a house with a “drinking skin.”

HOUSING THROUGH WATER ACCESS: THE WATERSHED HOME IN A TEXAS *COLONIA*

The strategy presented here uses a prefabricated kit of parts approach which formally responds to active and passive water capturing systems. Utilizing a kit of parts approach allows for flexibility and adaptability of wall systems. This adaptability meets the needs of various communities while addressing vernacular housing typologies and spatial and cultural ideas of domesticity. The focus was placed on the Texas *colonias*, one of the case studies from the *Closing the Water Access Gap* report. This case study focuses on opportunities for providing housing and water harvesting solutions that recognize the rich culture of the community, the informality and incrementality of the current housing typology, and the ways that the home has become not just a place of dwelling but also a place of economy and sustenance through home enterprises. As defined by the Texas Office of the Secretary of State, a *colonia* is a "residential area along the Texas-Mexico border that may lack some of the most basic living necessities such as potable water, septic or sewer systems, electricity, paved roads or safe and sanitary housing." [26]

Colonias communities also exist in Arizona, New Mexico, and California, but Texas has the largest number of *colonias* communities (2,294) and the largest number of people living in these communities (500,000).[27] Within these communities, 96% of the population identify as Latinx. The median household income is $29,928, with a 42% poverty rate and a 19.2% near poverty rate,[28] which is significantly above the national rate of 11.4%.[29] Income is primarily generated through the informal economy, with many residents subsisting through at-home enterprises, including car repair shops, fruit stalls, small bakeries, and small general stores.[30]

Many *colonias* communities grew rapidly due to the promise of affordable housing, homeownership, and an opportunity to realize the "American dream." However, many parsimonious developers never realized the promise of adequate housing and infrastructure to support this housing, such as paved roads, electricity, water, and sewage systems. This left many *colonias* communities on agriculturally unsuitable land, lots in floodplains, and many without access to essential services and substandard housing. Despite the disinvestment in many of these communities, there is a strong cultural sense of community, with neighbors and family members supporting those in need. As a result, homelessness is not a prevalent issue in *colonias* communities. Families in *colonias* without adequate infrastructure have to haul water by car, on foot or purchase trucked water. Many residents still buy gallons of potable water each month due to uncertainty about the safety of the trucked water. Even residents in *colonias* with piped water still face issues with safe drinking water due to the financial capacity needed to maintain treatment plants. Furthermore, the lack of legal plats makes it difficult to potentially install future infrastructure, which in turn affects the ability to produce affordable housing.

Even though water infrastructure has improved, safe, affordable housing is still difficult to obtain. The infrastructure improvement has made legal lots more expensive, and traditional loans may be difficult to obtain. With the expense of the lot, many residents do not have the financial means to invest in the home. Due to these constraints, some families build their houses over time as finances allow.[31] This pattern points to a method of resiliency relying on modularity, incrementality and informality of a housing typology that should not be ignored. Sometimes family members construct homes on the same lots to save money and share expenses, adding to the notions of temporality and a sense of community on the land. Therefore, the home in the *colonias* community is not thought of as a commodity as in other communities in our capitalist economy, but a place that provides a sense of stability and support to the *colonias* residents.

Colonias communities are dotted by a range of housing types with various housing conditions. These include "hybrid dwellings that are a combination of RV or trailer home with a wooden or cinder block addition, pier and beam homes, cinder block homes and standard brick or stucco homes on cement foundations." [32] Besides the hybrid RV homes, homes are single-story shotgun/ranch style homes. As noted, home-based enterprises are common, either occupying a portion of the home, as a separate structure attached to the home or coexisting on the parcel. Sometimes porch spaces are used as the infrastructure for these home-based enterprises.
It has been acknowledged that housing conditions also need to be improved in addition to addressing infrastructure issues. Several non-profit organizations have been working to improve housing conditions while aiding in affordable housing development. The Adult and Youth United Development Association (AYUDA) in El Paso County and the Community Development Corporation of Brownsville are examples of such organizations. In addition to rehabilitation and development of new *colonias* housing, many non-profits working in the area offer self-help construction programs and financial assistance for homeownership.[33]

The prototype presented here is situated within the context of a legacy of disinvestment, housing stability, and water access. The test case aims to meet the housing needs of residents while providing water access and operating within the system of non-profit organizations already working to drive change through programming in *colonias* communities. The prototype proposes a systems approach through a kit of parts of prefabricated wall elements with integrated water harvesting solutions. The kit of parts is made up primarily of a prefabricated, load-bearing bamboo core wall system (Bamcore) which eliminates 80% of studs and waste. Fixed to these prefabricated elements is a system of polyester mesh screens acting as fog and dew collectors which are channeled into troughs that subsequently connect to a collection tank for use within the home. This fog and dew collector screening system wraps the building like a skin, mimicking strategies deployed by the Namib Beetle and in the Warka Tower. Its simple attachment to the prefabricated wall system allows for adaptability, flexibility, and changes to the types of hydrophilic vs. hydrophobic textured screen material based on location and climatic conditions (Fig. 1).

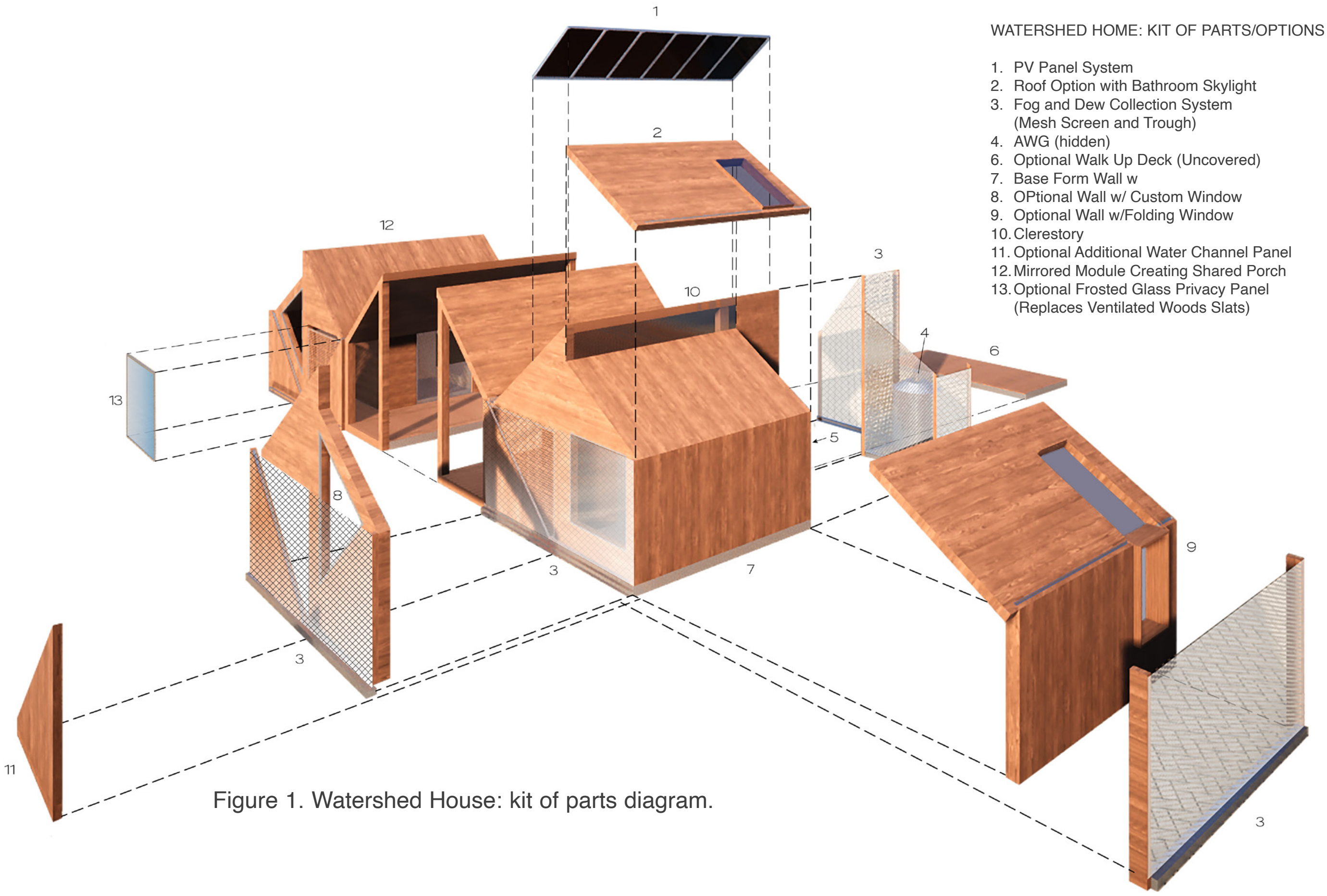

Figure 1. Watershed House: kit of parts diagram.

In addition, research on the Namib beetle and how it lifts its hind legs to raise its back informed opportunities to channel water in similar ways using a sawtooth pattern in the kit of parts (Fig. 2). Formally, sloped roof elements are used to channel rainwater but also help to frame porch spaces which in the Texas *colonias* are places of community engagement and extend the living space to the exterior (Fig. 2). The rainwater collection system ties the pitched roof to the design aesthetic of the home by extending the pitch to the ground, creating a continuous slope for the water to run down, and establishing a formal geometric language that plays on the local vernacular of *colonias* housing. The aesthetic aspect of the home is essential as it not only incorporates a cultural dimension into the equation but also provides dignified housing through the pursuit of beauty as inspired by nature, form, and light.

Lastly, AWG options are also available for climates that need additional water capturing support beyond the simple fog and dew collector and

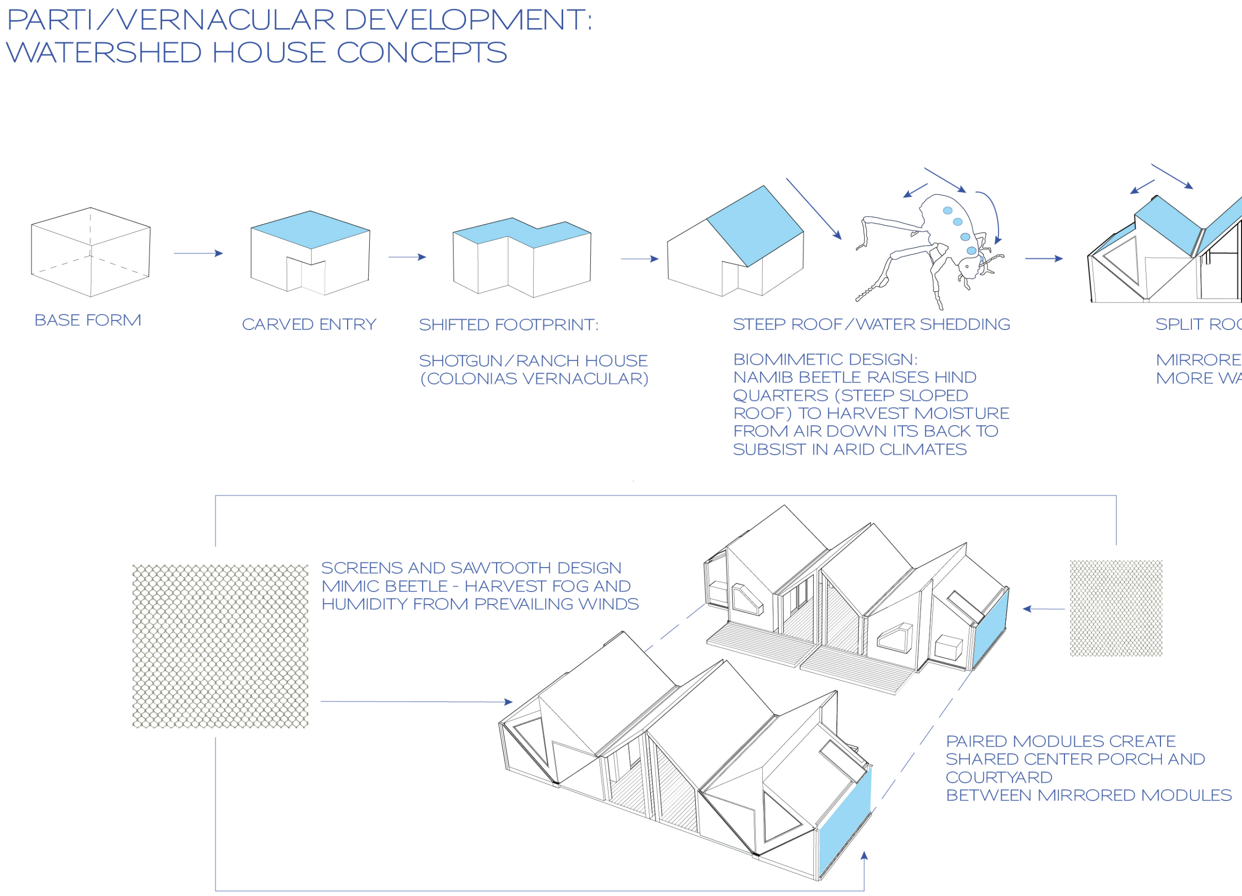

Figure 2. Watershed House: parti and vernacular development diagram.

rainwater harvesting strategies. While the current prototype presented explores the integration of a commercially available solar-powered desiccant AWG unit affixed to the prefabricated wall element, future research aims to understand how the components of the AWG can be pulled apart and be integrated more seamlessly into the wall section of the building so that the façade itself starts to act as an atmospheric water generator. The prototype also integrates a nine-cell panel PV system that provides power for the AWG. The synergistic interweaving of water harvesting strategies form the basis for the operation system of the house (Fig. 3).

These various systems come together in this case study test through a contextual awareness of the existing scales of the area while acknowledging the efficiency of microhomes. The prototype draws on notions of modularity and incrementality in the surrounding context. The prototype presented here is a well-lit finished 25.1 m^2 [270 sq. ft.] module plus covered deck space (for a total of 44.6 m^2 [480 sq. ft.]), which can be expanded through the connection of two modules to create larger homes (Fig 4). The resulting shape of two mirrored homes creates a unifying roof space in the porch area that touches the ground and suggests the notion of a “community under one roof” (Fig. 5).

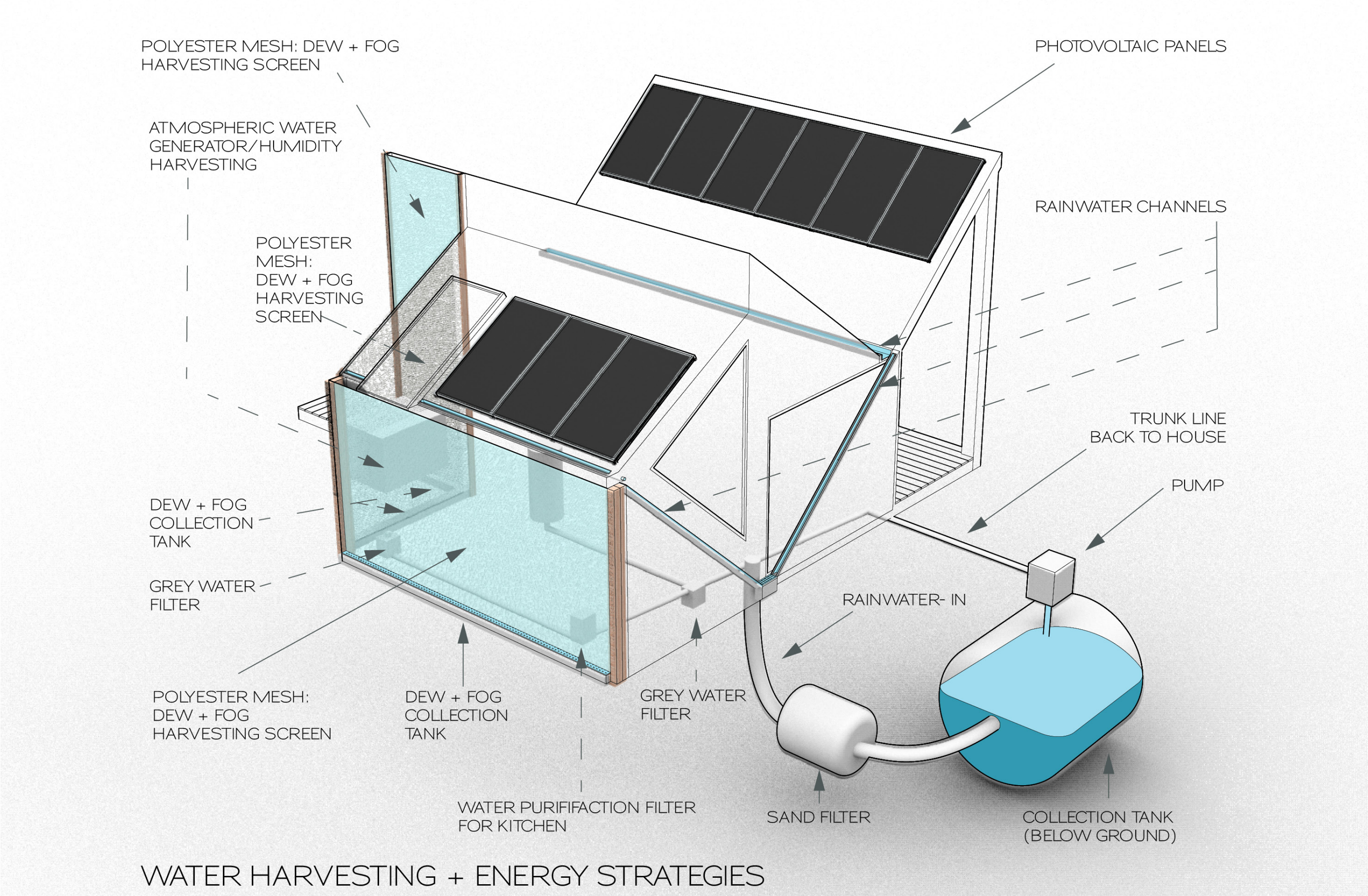

Figure 3. Watershed House: sustainability synergies diagram.

Figure 4. Watershed House: front elevation render.

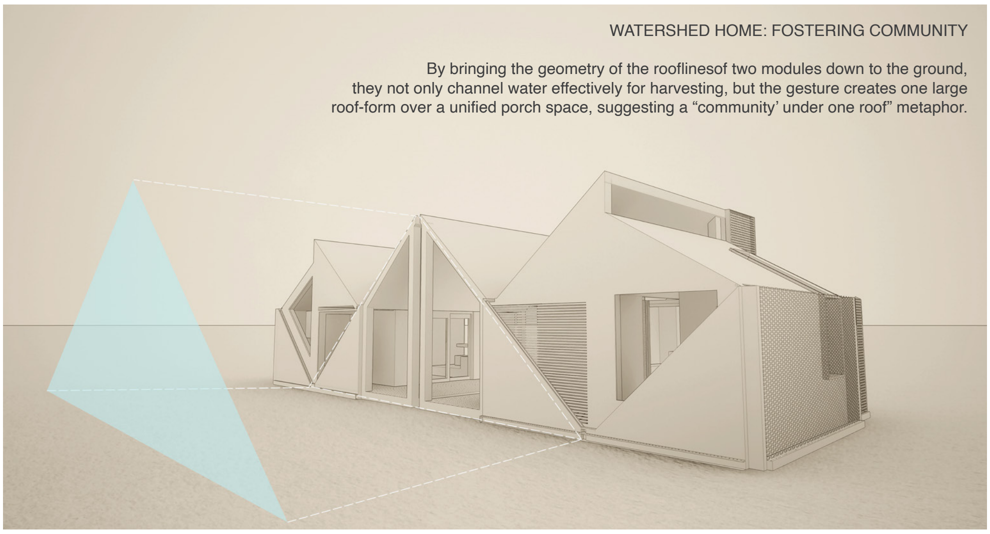

Figure 5. Watershed House: fostering community diagram.

Four modules can also be arranged to create a shared courtyard condition. This modularity allows for extended family living together but also provides privacy and shared porch spaces that operate as entryways. While each module can operate independently, the plan presented in this paper combines two modules to create a three-bedroom family unit (Figs. 6, 7). In this test case, there is also the opportunity to integrate a home-based enterprise through a window opening that can act as a walk-up kiosk

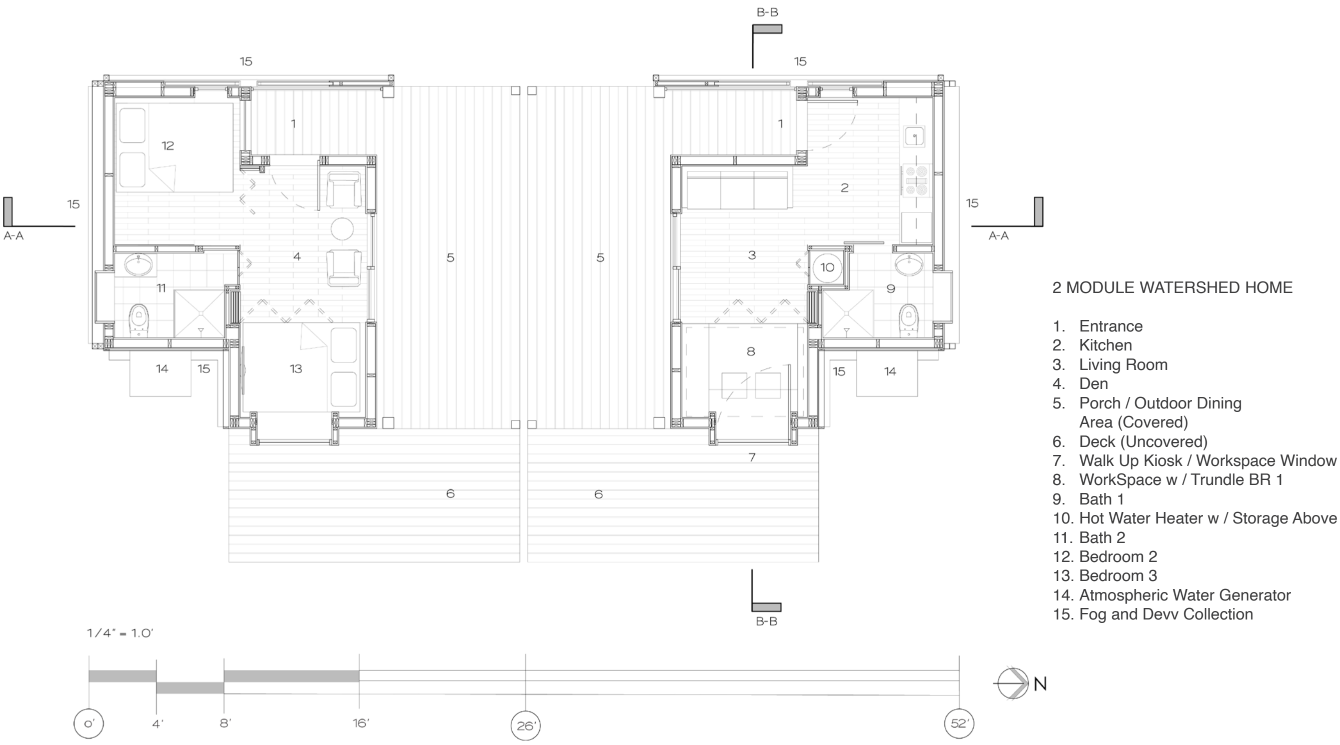

Figure 6. Watershed House: floor plan – expanded 3BR module.

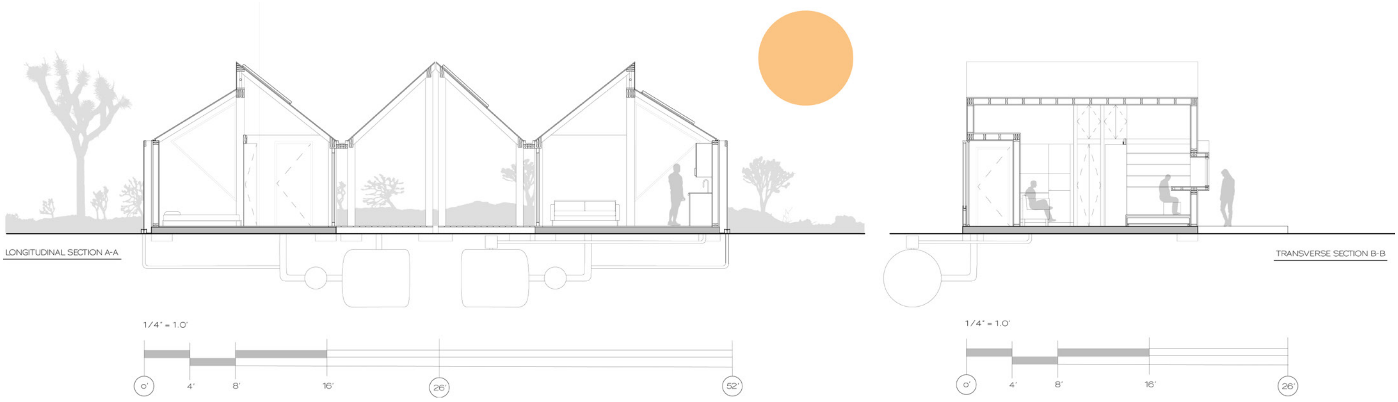

Figure 7. Watershed House: sections – 3 BR module.

(Figs. 7, 8). While this test case shows one iteration, it is envisioned that the prefabricated wall systems outlined in the kit of parts can be combined in different ways to suit different contexts and different spatial needs at different costs.

As described, the pitched roof, gutter system, fog and dew collector wrapper and AWG infrastructure all come together in a kit of parts to support active and passive water collection. In this self-contained system, water is collected from these various strategies and is filtered and stored in collection tanks for later use in the home. It is envisioned that the daily domestic routine of hauling water from external sources will be eliminated. New domestic routines, however, will take its place. While the residents would not have to harvest the water themselves, they would have to monitor levels (how much water was harvested) and maintain the system. Maintenance includes cleaning of gutters, filters and maintenance and cleaning of the fog and dew collector mesh. Such maintenance of these

Figure 8. Watershed House: walk up façade render.

low-tech systems can be part of a training program during construction. For example, in the Warka Tower precedent, residents were trained in the construction, operation and maintenance of the fog and dew and rainwater harvesting systems.[34] This maintenance will become part of the domestic ritual within these homes.

A feasibility analysis is currently underway, but current cost estimates put the cost of a single module home at approximately $123/sq. ft. [$11.5 m^2], including all water harvesting strategies and solar. Reductions in labor costs were made due to the easily erected nature of the Bamcore system, which could tap into existing self-help programs and job training to teach community members construction techniques. As with any other affordable housing development, we envision that innovations around creating a system of parts that integrate water harvesting strategies will also need to rely on government subsidy. In this specific case study, existing policy initiatives in Texas, such as tax rebates for rainwater harvesting and financial support systems set up by non-profits, provide programs that could support innovation around housing and water access. As the *Closing the Water Access Gap* report states, *colonias* communities where it will be challenging to supply shared infrastructure need “funding, guidance and regulatory support to develop alternatives to traditional systems.” [35] Examples include government policy and financing to support these innovations in housing and infrastructure at a household level and funding to help test and support alternatives to traditional modes of understanding water and housing access.

This guidance and regulatory support will also be necessary to support the framework in which the prototype will operate. While this infrastructural system is being proposed to address housing and water access issues, it is paramount to engage the end-user in a human-centered empathetic design approach. Therefore, this kit of parts approach should be operationalized through co-design strategies, where local non-profits, architects, and community members come together to understand how to incorporate these wall systems.

Figure 9. Watershed House: interior render.

CONCLUSION

This paper presented issues at the intersection of water access and housing affordability and an initial framework for approaching housing through the lens of water for communities where it will not be feasible to have centralized infrastructure. The idea of a systems-based approach to design that can be flexible and adapt to different situations is still in research and development. Future explorations include tests of the "drinking skin" through low-cost materials exploring weave patterns and mesh characteristics as well as the properties of other hydrophilic vs. hydrophobic materials. Other tests include investigating how this kit of parts can come together and adapt to different cultural and climatic contexts and housing typologies. Lastly, through partnerships, the aim is to construct mockups of various elements to test feasibility. While this work is ongoing, this paper outlines the importance of thinking of affordable housing through the lens of water access, as the two areas are inextricably linked. By addressing water access issues as a human right, one can simultaneously begin to address potential dignified solutions to a right to housing that weaves culture and technology. This final point is critical as we address environmental justice, resilience, and climate change issues in the pursuit of an equitable life for all.

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Credits

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