Home Spun: Water Harvesting Prefab Urban Housing

LAURA GAROFALO
University at Buffalo (SUNY)

OMAR KHAN
University at Buffalo (SUNY)

Home Spun is an urban housing prototype capable of harvesting water from precipitation and using it for heating, cooling and domestic consumption. It is composed of small (400sqft footprint), prefabricated two level houses that can be tightly clustered on existing building lots. These dwellings impose minimal stress on a city's services infrastructure while also reducing strain on the urban combined sewage and storm water disposal system. Using a variety of technologies including lightweight tape winding fabrication, parameterized parts that can be mass customized, thermally active surfaces, and integrated water processing through living machines, this easily deployable multi-dwelling housing type is designed specifically to address redevelopment of North American Rust Belt city downtowns. These sites provide unique challenges for new development including nonadjacent urban infill sites, limited services infrastructure and depleted populations. Home Spun proposes an alternative form of collective living that would be attractive to young professionals seeking community based sustainable living.

RUST BELT URBANISM

Due to the loss of manufacturing jobs, cities like Buffalo (New York), Cleveland (Ohio), Detroit (Michigan) and Hamilton (Ontario) have seen steady depopulation. This has caused urban fabric deterioration as dwellings fall to abandonment and eventually demolition. The results are pockmarked blocks with empty and underutilized lots that are not attractive for redevelopment either because they are too small or ill-configured for apartment buildings. Home Spun urban housing proposes an alternative urban typology that is mutable to nonadjacent city lots and capable of moderating the burden on existing services. The houses do so by capitalizing on local water harvesting from precipitation. Their form, manufacturing and integrated technologies provide the means to use this naturally available resource to service individual units' domestic use, heating and cooling while also becoming a conduit for developing mutual reliance between the units.

As cities in the rust belt pursue options to redevelop their downtowns to attract new businesses and young professionals, they will need to contend with the added burden this will place on the existing services infrastructure. To alleviate the increased load on the energy infrastructure, grid energy systems are already being developed to work with individual housing units. However, water systems have not been reconsidered and remain fully dependent on the existing infrastructure for both supply and waste. A sustainable and economically viable way to address this problem would require less city sourced water to be routed to new housing as well as less storm and sewage water to enter the city sewage system. This would place the onus of water supply and waste on the new development's architecture rather than the existing infrastructure. Housing would need to harvest and treat its water onsite.

REGIONAL HYDROLOGY AND THE BURDENS ON INFRASTURCTURE

Water is plentiful in the Great Lakes Basin with abundant ground water sources as well as accessible aquifers. The region holds 95% of the United States' surface water and receives 25 to 50 inches of precipitation a year. Although a gift in these times of global water shortage, this abundant precipitation overburdens outdated drainage systems that cause combined sewage overflow (CSO) into rivers and the lakes. When the service infrastructure was planned in these cities in the early 20th century, the majority of precipitation was retained onsite and eventually percolated into the groundwater and aquifers. The sewage outflow was also well accommodated, and continues to be adequately managed. However, due to the expansion of development to the suburbs and the road networks needed to connect these disparate areas, storm water runoff has grown exponentially and places an unmanageable burden on the existing sewage system.

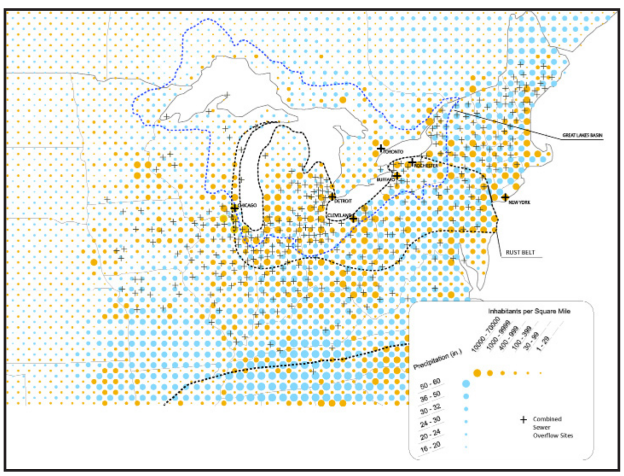

Figure 1: Percipitation and population in relation to combined storm and sewer system overflows in the eastern US

The EPA has mandated that communities reduce and ultimately eliminate CSO's to comply with the clean water act. The response has been to spend millions on expanding the existing sewage infrastructure by adding large scale temporary containment tanks that hold the water until it can be sent through the sewer system. Alternatively, both green infrastructure and engineered retention systems have also been popularized in many flood prone communities. These multifunction structures hold storm water during wet periods and allow it to eventually percolate into the ground. Landscape water treatment systems, like wetlands and shallow marshes, have regained popularity due to their effectiveness, low maintenance, and relative low cost.1 Working at multiple scales and varied climate conditions, these have proven effective in a variety of tasks. From slowly returning storm water into water bodies as shown by the highly urban biotopes of Berlin's Potsdammer Platz regenerative system by Atalier Dreiseitl2; to the treatment of grey and black water demonstrated by multiple vertical flow constructed wetlands found across the globe from China3, to Europe where they have been used to treat grey and black water for centuries4. In the US, wetland and shallow marsh systems are commonly used for the treatment of urban waste water focusing on runoff from public rights of way5, or smaller landscape interventions commonly used in public structures like educational facilities. These technologies are being employed by landscape architects, environmental services specialists, and urban planners.

THE ARCHITECTURE OF WATER HARVESTING

Architecture has addressed the problem of storm water infrequently, and then largely through grading and landscaping. In urban conditions, architects have followed the lead of landscape architects and engineers by integrating water retention through landscaping on site, or roofs, that occasionally include grey water recycling systems. The regenerative role is therefore relegated to the green (meaning landscape) infrastructure which fortifies the dichotomy between building and landscape in their capacity to manage water. The first sheds, while the second cleanses and perhaps replenishes the aquifer. Home Spun proposes a more active role from the architecture to harvest and manage water in conjunction with time tested urban landscape solutions such as living machines and small constructed wetland systems.

Using Buffalo, New York as a typical eastern Rust Belt city for the test site, the project explores the viability of water harvesting from precipitation. Located on the north coast of Lake Erie, Buffalo's precipitation levels are higher than the average of the Great Lakes basin due in part to the lake effect snow which often raises precipitation levels to 50 inches per year. Our analysis (figure 1) shows that, even in this water rich region, without the implementation of severe conservation measures, an urban lot could not support its own water needs even if it collected and used all the precipitation that fell within its property lines.

An average house (4 occupants and a 1,000 sqft footprint) could collect 30,000 gallons of precipitation (based on an average 30” of precipitation per year). However such a household consumes 153,000 gallons a year just with its interior water needs. Even if it was properly equipped, a household in the current system could not sustain its own water needs by gleaning precipitation. Meanwhile, the 30,000 gallons of precipitation are shed from the site directly into the combined storm water and sewage system where they increase the load on the treatment plants, and in severe situations cause the system to overflow. This results in an average of fifty yearly beach closings due to polluted water.

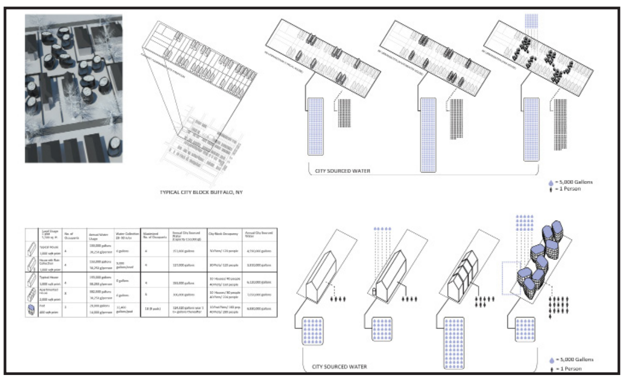

Figure 2: Comparative analysis of local precipitation and water usage in Buffalo, NY

The Home Spun houses, while not completely off the water grid, do provide a negligible increase to the city’s water resources because of their ability to conserve, collect, and reuse grey water. The new water equation begins with conservation through the implementation of efficient plumbing fixtures and composting toilets. In addition, each unit collects 12,500 gallons of precipitation on an average year. This is more than a third of the estimated water usage for each unit. The remaining two thirds would be recycled from grey water treated on the property through interior and exterior living machines and mechanical filters, and supplemented with city water in times of drought.

THE PERFORMATIVITY OF CLUSTERING

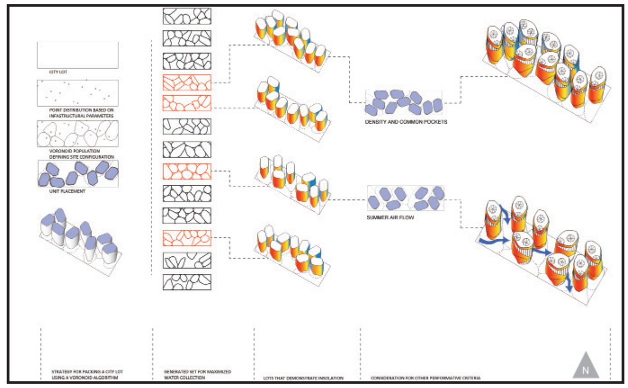

Figure 3: Performance linked strategies of unit

One of the consequences of urban depopulation has been the deterioration of the urban fabric. Large single family houses in which extended families with servants once lived have fallen to disuse, abandonment, arson or demolition. The resulting urban fabric is pockmarked with nonadjacent empty lots upon which it is neither economically viable to build another single family house nor are there adequate resources to build conventional multi-dwelling apartments. Home Spun houses exhibit a unique morphology that allows them to pack together in ad hoc ways (figure 3). This makes them ideally suited for difficult lots where flexibility in orientation is required. The housing’s site development strategy uses a voronoi packing algorithm to maximize the clustering of houses on adjacent and non adjacent lots. This provides a bottom up organization that develops new forms of circulation and micro neighborhoods within the urban block.

The packing organization also provides an efficiency of scale that allows for an effective reclamation of grey water. A single unit on the site does not produce the quantities of grey water necessary for treatment through living machines and artificial wetlands, but the volume of the full community makes this a viable option. The amount of precipitation that can be sourced from an average city lot would not be sufficient to supply a conventional US household. Upon such a lot, we propose to deploy 8 to 10 water harvesting homes. This large number of units may consume more water than is available through precipitation, but in return they provide efficiency in processing grey water that helps to fulfill the group's water needs. In addition, a landscape designed around the clustering flows in and out of the ground floor of each unit. Employing living machines and subsurface artificial wetlands that continue to function in the winter, it regenerates the grey-water for the community of units. It also contributes to the water cycle through both transpiration and percolation beyond the site boundary. This process provides for the remaining two thirds of a unit's needs, allowing the lot to function off the water network. The community of houses will use city water to begin their internally regulated water reclamation cycle as well as to compensate for conditions where precipitation proves inadequate. They will connect to its sewage outlet for minimal black- water removal. The process maintains water balance on the site and may even allow some of the water to flow into the aquifers.

The same principle permits the application of solar energy for both thermal heat gain and electrical production to all the units regardless of their distribution to solar access. The units are not only integrated to their environment, but responsive to each other making it possible to create micro climates within the lot. These in-between spaces can provide useful habitats for fauna and flora through the cold season. Through the interaction of the unit's thermal zones, air can be drawn through or blocked by these cavities.

ANATOMY OF THE HOME SPUN HOUSE

The Earthship house, developed by Michael Reynolds over thirty years ago, is an interesting model of sustainable living. In *The Natural House*, one of many guides on sustainable living, author Daniel Chiaras contends that the Earthship is"a demonstration of the wisdom of fitting in ... it reflects the knowledge that we humans are part of nature"6. As in the majority of these texts, the "natural house" tends to be an isolated, off the grid, rural or suburban construction that may evolve into a community of similar houses. But they seem to shun urban life. However, it would be more sustainable to look for a means of fitting into existing urban infrastructures, rather than expanding outside them. Regardless, there is much to learn from the Earthship. Like it, the Home Spun houses are defined by a living space, an environmental interface corridor7, massive cisterns and a relationship of these components to the sun (figure 4). They also have the ability to heat and cool themselves, and collect and process their own water. Waste management and electricity are also partially self-maintained.

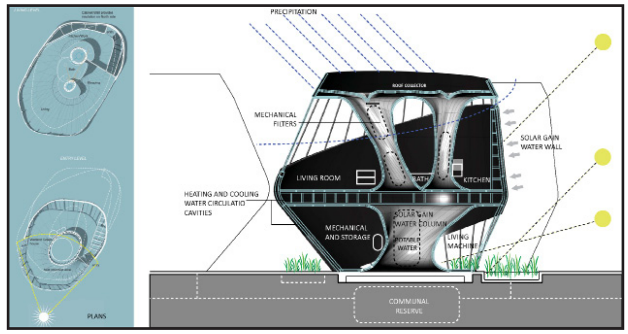

Figure 4: Unit hydrology and thermal heat gain systems

The two story house, occupied by a couple or roommates, collects rain and snow from its roof, melts it if needed, stores it in its structural columns, and treats it for all household needs. Both the skin and structural columns are water cavities that serve both thermal heat gain and domestic water use. On its first floor, it contains a portion of the communal grey water treatment facility and its own water storage and purification systems. A living machine processes grey water and the same cavities allow for water to be pumped back up for bathing and cooking.

The form and fabrication technology of the units intentionally privileges their role as water infrastructure rather than domestic interior. Both the interior structure and exterior skin are adapted to respond to water collection, storage, and distribution as well as the use of water as a thermal heat sink for heating and cooling the house. The thermal environment of these water based structures is tied to temperate to cool regions. Adjustments to the exterior envelope system are being explored to handle potential icing and ponding on the surface in a productive manner while preventing the formation of icicles.

Unlike the Earthship house, each unit cannot function as a self sufficient entity relying only on the environment around it. Due to both the site and climate constraints, the units rely on each other for thermal comfort and water resources. Its participation within a larger system highlights the unit's role in structuring a green urban infrastructure through an architectural proposal.

MANUFACTURING

Filament or tape winding fiber reinforced composite (FRC) will be used to fabricate the strong but lightweight housing components. The form of the house reflects the rotational shapes that would emerge out of such a manufacturing process. This choice of this material is twofold. First, a plastic is ideal to deal with water storage. Second, its lightweight allows for low energy consumption in its transportation as well as easy deployment onto the site. However, a significant problem with lightweight construction is its low heat retention. The houses address this problem by using the water they harvest to create the necessary thermal mass. Water, in addition to being a usable amenity in the houses, also insulates them.

Filament winding manufacturing technology has been traditionally used for manufacturing pipes and storage tanks. In comparison to steel reinforced concrete, fiber reinforced composite (FRC) tanks have been shown to be more sustainable for long term water containment.8 The FRC tanks out performed concrete tanks exhibiting lower greenhouse gas emissions, less solid waste production in manufacturing, less expenditure in energy resources in manufacturing and deployment, and even lower acidification. In both systems the bonding agents, the concrete and the resin, are the main drivers of solid waste and greenhouse gas emissions.9 These tests were conducted on low energy glass fiber from Owens Corning and polyester resin set through hand layup. The results would hold true for filament wound and tape wound thermoplastics as well.

The house's structure is developed from composite plastic pipes woven from straight lengths and 90 degree elbows. This cage acts as the scaffold around which the thermoplastic tape is wound, fusing with the pipes to create a very strong but lightweight construction. This completes a floor, structural interior columns, and ceiling. Then using hand lay-up techniques on the opposite side of the pipes, pockets are created that will conduit water for thermal heat gain in the cool seasons. An additional set of pipes is extended to the outer surface of the form, and an exterior FRC skin is applied in the same manner to complete the level. The same technique is used to manufacture the roof.

The prefabricated house parts are loaded on a flatbed truck and transported to the site. Using a small crane, they are installed on pre-poured foundations. Level 2 is mechanically connected to level 1 and the entire house is filled with city water to begin inhabitation. Each floor is delivered fully equipped and fitted for it's on and off the grid utilities hookups. The only amenities required from the city are an electric and sewage connection.

REDEFINING SHELTER THROUGH MICROCLIMATES

In *The Architecture of the Well-Tempered Environment*, Reyner Banham describes two modes for creating shelter.10 One, defined as a structural solution, builds enclosure through clearly defined material boundaries. The second, a power-operated solution, consumes materials to develop energy boundaries. Banham cites the tent as an exemplar of the first, with its clearly defined boundaries that provide a passive means for creating thermal comfort. For the second he cites fire and notes it as an active system whose boundaries are mutable and change in response to environmental factors.

Figure 5: Water harvesting community

In the Home Spun community of houses, the material boundaries of FRC separate one house from another and the outside. However, the water contained in the skin, can change the passive nature of the walls into active energy boundaries that are used to define thermal zones inside and outside the units. This allows for a performative dialogue to occur between the units through the space between them, developing micro-climates in each lot. This can provide a conducive environment for the growth of flora and fauna through the seasons including the dead of winter (figure 5). The lightweight shell becomes both a generator of environmental conditions as well as well as the arbiter of privacy. For example, in the winter, the envelope, structure, and water create concentric layers of radiant heat that transcend their boundary to the exterior environment and merge with the thermal bubble of the adjacent units. In each unit, the structure /skin system creates inner columns that perform as a central hearth now conditioned by water rather than fire. The hearth is equated with a central comfort zone, and in this case it can have diverse thermal functions. Depending on the occupant's needs the columns can heat through radiation or cool through absorption. The cool or warm water flows through the building skin creating the second layer of this thermal system. Inside, the occupant can occupy more or less sheltered thermal zones depending on the activity they are engaged in. A third thermal layer is provided by the adjacent units which are arranged to shade in the summer and radiate excess energy in the winter.

THE URBAN WATER CONTEXT

Water management as a generator of architectural form has primarily taken remote regions that lack access to potable water as their site11. Our goal in placing the Home Spun houses in urban sites was to interrogate the relationship between the water use, perception of urban water and sewage systems. The Home Spun house initiates a dialogue about how architecture, not just landscape, can help to mediate between the bodies of water adjacent to cities and the urban hardscape.

The water network is an amazing feat of engineering. It flows from aquifers, rivers and lakes through treatment facilities into our taps with little perceived effort. This is because the hydrological cycle is hidden from us. Even the systems that feed our homes are hidden behind our walls, in between the interior and the façade. Rather than exploring the abundant potential of retrofitting existing buildings with self sufficient water systems that find themselves hidden in attics or basements, in this project we aim to make the system part of our discussions of space making. Although the goal of the housing proposal is to help remediate the health of our water system, it recognizes that there are more efficient landscape infrastructures that address this problem. But these do not communicate the discrepancy between the water we use, the space we occupy, and the amount of water we can collect in relation to that space/use ratio. We contend that one's awareness of and engagement with the natural water cycles as well as the occupancy of the urban context changes when water use makes an impact on the physical enclosure rather than just the plumbing system.

In the Great Lakes Region many cities have suffered from urban shrinkage resulting in low density urbanism that inefficiently uses space. Municipalities looking to revitalize their urban cores face the constraints of their failing infrastructure which acts as a deterrent to re- densification. Meanwhile, existing structures get redeveloped with programs that require greater water resources and produce more sewage. Cities that propose to repopulate their downtowns without putting undue burden on existing infrastructure need to find alternative methods. Potentially acting as urban densifiers the Home Spun Houses can begin to positively add utility to underdeveloped and underutilized spaces even promoting the redevelopment of surrounding structures to feed their hydrological system. No longer a source of pollution, architecture can assist in improving the health of our shared surface water resources.

ENDNOTES

1 Helene Izembart and Bertrand Le Boudec, *Waterscapes: Using Plant Systems to Treat Wastewater,* ed. Gustavo Gili, (2003).

2 H. Dreiseitl, Dieter Grau, Karl Grau, eds., *Waterscapes: Planning, Building and Designing with Water,* (Basel: Birkhäuser , 2001), 44-49.

3 DWC Constructed wetlands. http://www.dwc-water.com/fileadmin/user_upload/images/PDF_Files/DWC_Constructed_wetlands_DWC_factsheet_english.pdf

4 Izembart, *Waterscapes*.

5 T.R. Schueler, *Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Mid-Atlantic Region,* (Washington, D.C., Metropolitan Washington Council of Governments, 1992)

6 Daniel Chiras, *The Natural House: A Complete Guide to Healthy, Energy-Efficient, Environmental Homes,* (Chelsea Green Publishers, 2000), 97.

7 The environmental interface corridor in an Earthship house is a glazed green space adjacent to the living quarters. It contains a plant based water filtration system for grey water and rainwater, and is capable of supplying the domestic needs of the household. It also contains the solar hot water system and batteries for the house's photovoltaic panels, as well as the bathroom.

8 E. Fekka, et al, "LCA Comparison of Two Aquarium Tank Systems: Fiber Reinforced Plastic and Concrete". Stanford University and Kreisler and Associates, http://www.kreysler.com/information/sustainability /resources/frp%20vs%20concrete.pdf.

9 Ibid., 3-4.

10 Reyner Banham, *The Architecture of the Well-tempered Environment,* (Chicago: University of Chicago Press, 1969), 18-44.

11 As representative of systems that are driven by their relation to their water systems, we can look

at two extreme cases, the low tech Earthship house proliferated across the south west by its inventor Michael Reynolds, and the speculative high tech Jellyfish house by IwamotoScott proposed for an island in San Francisco Bay. Both are engaged in a natural environment by preventing the houses from taxing it, but both follow the tradition of the remote self-sustainin anty-urban proposal.