Prefabricated Recovery: Post-Disaster Housing Component Production and Delivery

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Introduction

The impact of natural disasters on communities worldwide has made disaster relief and subsequent community rehabilitation demand a response from the design fields. Issues raised by Hurricane Katrina and the Indian Ocean tsunamis, for instance, have clearly articulated the need for quick response in providing well-designed, temporary housing that will allow displaced residents to return to their communities. Focusing on the events following Hurricane Katrina, this paper recognizes the need for sustainable and rapidly deployable post-disaster housing, and investigates current relief-housing fabrication and delivery efforts in the U.S. Using a proposal for high-density multi-family waterfront dwelling as a vehicle (Figure 1), it goes on to investigate fabrication and deployment alternatives that are responsive to ecological and human needs.

Current Relief-housing Fabrication and Delivery Efforts

Katrina had devastating effects on Louisiana, destroying entire neighborhoods and temporarily displacing between six hundred thousand and one million residents. On the Friday after the storm 1000 people were bused out every hour, and many of them have not returned to live in the city. One year after Katrina, only 2/3 of the debris had been cleaned up, half the homes still had no electricity, and many homes were unoccupiable. Three years later the U.S. Census Bureau estimates that the city's population is 75% of what it was before the storm, which puts a great strain on a recovering city.

The Federal Emergency Management Agency (FEMA) led disaster recovery efforts and attempted to mitigate the housing crisis by deploying travel trailers to the state. The majority of these trailers were manufactured for this post-disaster situation. Though the trailers were implemented to accommodate residents for up to 18 months (as limited by government legislation), FEMA statistics showed that over 76,000 households were receiving temporary housing more than 18 months beyond the date that Katrina made landfall. Katrina was an extreme example, but more recent disasters have met similar problems. The relief effort continues to experience shortcomings in housing quality and delivery, governmental preparedness, and volunteer organization.

Disaster relief policies have been scrutinized in recent publications, and housing units and timeliness of relief efforts are commonly implicated as significantly frustrating components of disaster relief and recovery. A Government Accountability Office (GAO) document from 2007, entitled "Disaster Housing: Implementation of FEMA's Alternative Housing Pilot Program Provides Lessons for Improving Future Competitions," highlights community resistance to the use of travel trailers for extended temporary
housing.” This document reports that “uncertainty with respect to neighborhood and community recovery and individual and community resistance to the use of travel trailers for extended temporary housing challenged the effectiveness of FEMA’s traditional housing options.” These reports call for governmental policy changes regarding disaster housing, and temporary housing design that is humane and inhabitable without the stigma elicited by ubiquitous “travel trailers.” Hurricane Katrina illustrated the need for rapid deployment, but also for long-term disaster recovery housing that could offer new sustainable models of single-family homes and community design.

**Delivery Efforts:**

In 2007, the U.S. (GAO) produced a Report to Congressional Addressees entitled “Disaster Assistance: Better Planning Needed for Housing Victims of Catastrophic Disasters.” The report examines the “extent to which [government] organizations had plans for providing sheltering and housing” after hurricanes Katrina and Rita. In doing so it calls for governmental policy changes in planning efforts for providing emergency housing and better coordination of the agencies contributing to relief efforts. Efforts to address short-term, post-disaster housing have also been underway, and they often address the requirement to be delivered rapidly to disaster-stricken regions.

Relief housing can be delivered as soon as sites are cleared of debris. In the case of Katrina it took up to six months to clear some sites. The devastation caused by Katrina in New Orleans presented an extreme case, and projected clean-up times for most hurricanes averages about 100 days. Once sites were cleared, people applied for a FEMA trailers, but they could get one only if they had electricity, sewer and water at their site, and many people had to buy and install a temporary power pole. In response to this problem, FEMA placed thousands of travel trailers and larger mobile homes in commercial parks, on industrial and private property, and in group sites constructed by the agency (often outside the boundary of the community whose occupants would inhabit the units).

Part of the reason for delays may be organizational, but a factor more difficult to overcome is the problem of providing the necessary utilities for the temporary housing. Even if the trailers had been made available more rapidly, there were no guarantees that the basic infrastructure would be there to support them. Water and sewage, garbage collection, roads, transportation, security and fire fighting can be difficult to reactivate in a disaster region while clean-up is being conducted. Katrina’s prefabricated unit deployment did not provide effective alternatives to the infrastructure. Not only did housing units have to be brought in, but so did materials, equipment, and relief workers for the installation of sewage treatment systems and other temporary amenities.

The relief workers need to be housed in more trailers or tent cities since the number of available hotel rooms—a common source of temporary housing—is often significantly reduced by hurricanes. However, these temporary shelters are not readily available. Consequently, the lack of infrastructure, which generates a lack of housing, also delays the assistance of a readily available and eager volunteer population. Confusion, inability to find accommodations, and inability to communicate with those who need help prevented student and church group volunteer clean-up crews from arriving in the New Orleans area for months after Katrina struck. Using the local population for relief labor is ideal, but in the case of Katrina many people left the city and could not return because they had no place to stay.

**Fabrication Alternatives**

Under the Robert T. Stafford Disaster Relief and Emergency Assistance Act, the President is given primary authority over natural disaster emergency response. FEMA directs the Stafford Act and through the Individuals and Households Program supplies temporary housing (such as trailers) to disaster-stricken regions. The Act also permits FEMA to distribute funds to victims for rental houses, repair or replacement of damaged private homes, or to construct permanent housing where other sources of housing are not available. The Act stops short of authorizing funds for pre-disaster house design efforts, but FEMA instituted an Alternative Housing Pilot Program (AHPP) as a “onetime exception to the limitations on its authority under the Stafford Act to provide non-temporary housing solutions.”

Because of the shortcomings in temporary housing delivery after Katrina and to advance its mission of preparedness, FEMA invited several Gulf Coast states to submit proposals to the AHPP. After reviewing the submissions, the agency awarded grants to four states to develop...
alternative temporary housing designs. Mississippi, Louisiana, Texas, and Alabama received a total of $388 million to support their projects. Within the AHPP, FEMA established criteria by which the proposed projects would be evaluated, and the primary objective in the program was to improve upon the current temporary housing approaches. Other stipulations asked that the proposals offer solutions that could be quickly inhabited, maintain reasonable life-cycle costs, and adapt to varied sites. Submissions to the AHPP included various approaches to providing single- and multi-family disaster housing including modular and prefabricated panel systems, and homes that could be deconstructed and relocated. FEMA encouraged innovative design solutions and emphasized the need for energy efficient schemes.

Design, production, delivery, and inhabitation is a worldwide issue that has been supported by organizations such as Architecture for Humanity, Relief International, and the Office of the United Nations High Commissioner for Refugees (UNCHR). Projects sponsored by these organizations serve a range of purposes and are situated in various countries and climates, but typically the projects meet similar basic technical requirements: compactness, portability, easy assembly methods, durability, and limited natural resource requirements.

The UNCHR has made extensive use of tent structures that can be deployed rapidly. Their Lightweight Emergency Tent provides basic shelter and works best in warm climates such as Chad (Sudanese refugees) and West Sumatra (Indian Ocean Tsunami in 2004). Though early models were sheathed in canvas, more recent tents use synthetic materials that will not rot. Architecture for Humanity provided funding (along with Weyerhaeuser) for the Ferrara Design’s Global Village Shelter. The unit was deployed in Grenada following hurricanes in 2005. The units are cleverly designed to pack flat for shipment and unfold for assembly once on site. According to the designers, the laminated cardboard hut is sturdy, but “designed with a definite limited shelf life” 10 With all emergency relief housing, designers have to address issues of privacy and security, and these goals are often at odds with portability. The UNCHR and Architecture for Humanity has improved upon their initial designs by adding privacy screens to the Lightweight Emergency Tents and locking mechanisms to the Global Village Shelters. 11

Proposal for high-density multi-family water-borne dwelling

In response to these issues, our project investigates the potential of using textile-based composite panels to fabricate environmentally responsible relief housing units. This proposal was part of a submission for the second phase of the What if NYC...Post-Disaster Housing Design Competition. Because of the competition requirements, it focused on coastal region disasters for the U.S. East Coast, but the same design principles can be applied to inland coastal disasters accessible by shipping barges, as well as the many areas from New York to Indonesia where these violent oceanic storms pose a constant challenge. The aim is to develop component-based housing that limits the energy and natural resources required to fabricate, deliver, assemble, and inhabit post-disaster dwelling units, while providing the disaster victims with a sense of identity and community and a positive understanding of living with green infrastructure.

Component Fabrication

The Prefabricated design is directed by transportation, deployment, and energy considerations. The component system consists primarily of two panel types. Type A is manufactured by using the combined processes of loom-based weaving and mold casting. Panel Type B provides a framework for door and window components.

The system is based on innovative three-dimensional weaving techniques that intertwine polymer strands and semi-rigid insulating materials to produce fabrics suitable for use in high-strength, moldable composite panels. The three-dimensional weave of materials integrates insulation into a thick blanket-like textile that will conform to reconfigurable molds. When a resin matrix is added, the composite material is molded into rigid, self-structuring, lightweight, waterproof and super-insulated wall/floor/roof panels with apertures that allow natural ventilation. Simple vacuum forming or spray-on techniques can be used to apply the resin.

The panels’ structural capabilities are derived from creasing, faceting, and pleating the fabric prior to setting the mold. The perimeter is folded to a depth of 2”-0” and the center facets to a 6” depth. Its ribbed structure and depth allows each panel to stand on its own. The ribbing creates cavities constructed to accept both foam insulation and water as insulation. The water
would be pumped into the panels on-site, so it would not add any weight to the panels during transportation, but would aid in stabilizing the units once on site.

Focusing on the long-term effects of the housing energy requirements, the thermal insulation properties and weight of panels directly affect energy consumption values. Insulation providing low heat transfer values ensures fewer pollutants are released to the environment because less energy is consumed in heating and cooling the housing unit. Thermal insulation properties are addressed both within the panel fabric and with additional insulation inserted into the panel cavities. The system could achieve an R-value well over 19, greatly reducing the energy required to heat and cool the units.

Once structural stability is achieved in the insulated panels, passive ventilation and control of rainwater are the main drivers in the panel’s form. The 15’ x 15’ panels are designed with 3’ x 9’ apertures placed in such a way that rotating the square panel will produce four distinct window configurations. Apertures can be formed as positives in the panel’s mold before resin casting, or they can be cut out of the rigid panel after the resin has cured.

The panel design is further developed by energy use considerations in relation to the deployment of the unit. The expenditure of energy used to transport and assemble the housing is largely dependent on the weight of the component parts. The glass-fiber fabric weighs between 30 and 70 ounces per square yard, and the resin matrix constitutes an additional 50-75% to the overall weight. Our typical panel dimension of 15’x15’x2’ (comprised of four sections) uses 38 square yards of glass-fiber fabric would weigh approximately 270lbs. (67.5lbs per 3’x15’x2’ section). To put this in perspective, a 4’ x 8’ gypsum wall board sheet (sometimes used to line the trailers) weighs between 38lb and 64lb depending on whether it is ¼” or ½” thick. Implementing lightweight composite panels results in significantly less energy (fossil fuels and human exertion) consumed in the delivery and construction process. Less fossil fuel is used in shipping the light prefabricated units. One person can lift the lightweight panels with ease, making the effort in assembling the housing units minimal.

**Housing Unit Assembly**

The housing unit is composed of prefabricated panels and box components that can create multiple unit sizes and configurations (Figure 2). All of the components are self-structured and gain further stability through aggregation. The aggregation can enable structural expansion. The resulting configurations form larger-scaled surfaces that require fasteners compatible with the panel layout, composite reinforcement type, and material cross-section. In each of the sample panels, mechanical compression fasteners such as rivets or bolts draw the edges of panels together. A layer of neoprene is compressed between the panels to form a watertight seal.

Two types of panels are used to construct walls, floors, and roofs of the housing units. Panel type “A” is pre-fabricated faceted cellular form with internal diagonal bracing ribs. Each panel’s aperture allows in abundant daylight in addition to promoting cross ventilation in the thin plan of the unit, thus maintaining a comfortable interior temperature. Operable windows or skylights are set on the panels to intake air in directions parallel and perpendicular to predominant winds. When the panels are placed on the floor or ceiling they act as receptacles for the Blue box component which fits into two apertures located directly above each other. When linked, these panels form a rigid, stackable square tube-truss unit. Panel Type “B,” the Access Panel, is a frame in-fill that caps the ends of the tube structure adding to the lateral stability and coupling to a ramp or stair component. A housing unit can be assembled of two, three, or four tube truss cubes, two Blue Boxes, and two Access Panels to achieve various unit sizes.

The Blue Boxes (one bath and one kitchen box), plug into the aligned floor and ceiling panels of one section of the tube-truss. They give the box truss additional structural rigidity. In addition, they are the elements that plug into the barge platform acting like a pier and making the con-
A number of prefabricated panels and components stand ready in storage (more can be produced as needed). High-density temporary multi-family housing is assembled away from disaster-stricken regions beginning immediately after an area is assessed as a disaster area. It is assembled at non-stricken ports, then transported by barge and sited along the shorelines (Figure 3). Components can be delivered to undamaged port facilities. Once barges arrive at port, storage batteries, generators, HVAC units, and water and wastewater holding tanks are installed. These utilities form a series of bundles that will be linked to the Blue Box distribution and collection component. Meanwhile, on land crews of local contractors begin the assembly work. Volunteers from other cities can supplement the work crews since they can easily find transportation and accommodations at unaffected port cities.

The Box truss cubes are propped up and assembled by teams of four. Port gantry cranes insert Blue Boxes and Access Boxes into the cubes before lifting the assembled unit onto the barge. A structural frame that has been added to the barges receives the units. Upper floors stack by aligning and securing the Blue Boxes of one unit to the one below it. Finally, the exterior floor components are installed on barge’s grid frame by the cranes. The assembly crews move them onto the barges to attach access components while others attend to the utility hookups.

The barges, now fully assembled sites, are tugged to the disaster site. Taking into account that one tugboat will often push a group of 10 to 40 commercially loaded barges at a time, and each barge can accommodate 20+ units, use of
energy on transportation can be minimized. When contrasted with the convoys of 500 trucks and pickups moving 500 units per day into Louisiana at certain points of the recovery effort, fuel use could be greatly diminished.

The fully assembled barge communities are ready to be transported within days of the disaster. There the barges are simply docked to existing port facilities or to click together floating docks. The authorities can immediately start to move people out of shelters and into residences or hotel barges depending on the nature of the disaster. Once people are settled, volunteers can fill designated barge floor components and lower roofs with soil for garden plots and green roofs, place the mini wind turbines and hydro-turbines in advantageous positions, and link the system to the regenerative landscape barges that manage the waste water and organic material.

No on-land site preparation is necessary. This process for deploying post-disaster housing allows residents that need relief housing to be housed quickly and away from the clearing crews allowing for thorough and unobstructed debris removal. This accelerates permanent housing reconstruction and repair. It also allows evacuees to return to the city because they can be housed safely and have working utilities immediately.

**Aggregation of Housing Units**

Barges provide a floating platform for the assembled housing. The platform of the barge accommodates multiple unit and garden configurations. The layout of units on individual barges is responsive to human needs by creating a space that promotes community-building by development of identity within individual barge communities. The introduction of tranquil green spaces within the courtyards may also help alleviate some of the stress associated with the chaotic post-disaster landscape. Landscape barges will be attached to the housing barges to provide green spaces that aid in the collection and management of organic matter, the filtration of water for reuse, and recreational activities. If needed due to the shoreline conditions or the scale of the disaster, the barges can connect to piers that expand a confined site out to the water. These provide pedestrian pathways that connect the floating housing aggregations. The landscape barges create lateral connections between the linear piers.

Fig. 4. Section through unit, Blue Box, and barge

The unit and barge combination is responsive to ecological needs limiting the energy and natural resources required to inhabit post-disaster dwelling units by keeping them off the grid (Figure 4). The hollow depth of the barges provides space for utilities to connect to the individual units. The Blue Box is primarily responsible for this task. It performs water and waste management duties and supplies electricity and conditioned air. Its photovoltaic panels generate energy for heating water. They are part of the capping unit for the rainwater collection cistern system. In its composting bins, aerobic water treatment units begin the process of treating water to be recirculated after moving through the landscape barges organic filtering processes. Working with the Blue Box, the convex roof panels channel rainwater into a containment tank. The filters in each Blue Box provide potable water for the unit. Each Blue Box will be equipped with a Rain PC or equivalent water filtration system. “The system is capable of providing a constant flow of about 40 liters of rainwater per hour, enough for a family of five for drinking, cooking and bathing purposes.”

A strand of barges could utilize the connecting pier in the same way that a city utilizes a sewer system (Figure 5). The waste flows
underneath the pier and into a holding tank on the "landscape" barge, a water filtration plant that utilizes a sub-surface flow constructed wetland to purify the waste-water. Averaging 150 people per barge, the optimal ratio is 10 "unit" barges per "constructed wetland" barge. The wetland barges should already be active before the disaster to act efficiently. It takes about two years for a constructed wetland to grow and begin filtering effectively. If the barges were constructed and put in ports around the United States, they could develop as filters for yachts and cruise ships coming back from long voyages with full septic tanks. Once these barges are needed at a post disaster site, the existing wetland is driven to the area where it is needed. Provided that the barges do not come from too far away, the climate should remain stable enough near the ocean that the ecosystems will still function effectively. Wind turbines and hydro turbines are arranged on the barge; combined with solar panels and water filtration system, this renders the barge-site self contained and independent of the land infrastructure. The challenge is to net a zero ecological footprint.

**Potentials of the model**

The potential upside of new models is the possibility that component-based and prefabricated temporary housing could play an important role in revitalizing communities and the natural environment. Temporary housing can go beyond ecological sensitivity to become a key component of ecological revitalization. There is an urgent need to develop built environments (architecture, landscapes, and communities) that revitalize rather than deplete natural resources and wildlife habitats, and there has been substantial research and design in the area of sustainable housing over the past decade. Researchers have explored innovative "green" building materials. Component-based and prefabricated construction techniques—popular in the 1960s—have been coupled with digital technology to revive modular housing fabrication and delivery. Innovative design strategies have produced carbon-neutral, "zero ecological footprint" communities that operate "off the grid."

This speculative design proposes rapid deployment of mass-produced and prefabricated systems to build temporary, environmentally responsible housing along the shoreline of disaster-stricken regions. The design explores ways in which disaster-relief housing communities can provide a radically new means of synthesizing architecture with the environment in a symbiotic relationship that not only lowers, but also eliminates, dependence on distant energy sources such as coal and nuclear plants. These temporary communities could provide a model for the way we plan and construct our more permanent communities.

**Note**

2 Half of the 15,000 trailers that FEMA put in Florida in 2007 after four hurricanes struck that state remain occupied a year later by about 20,000 people. http://www.consumersunion.org/scribbler/other_issues/002685.html


6 Such a system was built to process 47,500 gallons daily to serve just 19 trailers in Plaquemine Parish, Louisiana.


8 Nate Cornman, a student volunteer group organizer was finally able to get his crew to Louisiana four months after the disaster to work with Habitat for Humanity cleaning up homes.


11 Ibid., pp. 60-63, 74-77, 122-125.

12 "The system is capable of providing a constant flow of about 40 liters of rainwater per hour, enough for a family of five for drinking, cooking and bathing purposes. Cost per 1000 liters is as low as $2 to $3. It needs no power and operates at low gravity pressure. Rain-PC is developed by scaling down the multi-staged water treatment method (MST), which involves screening, flocculation sedimentation and filtration and incorporating existing technologies like upward flow fine filtration, absorption and ion exchange. Xenotex-A and activated carbon cartridges along with ultra membrane filtration or micro-membrane filtration modules incorporated in the RainPC has the capacity to deal with E. coli and the potential of meeting the World Health Organizations water regulation standards." (The above information is per the manufacturers’ claims and not based on any study.)


13 Half of the 15,000 trailers that FEMA put in Florida in 2007 after four hurricanes struck that state remain occupied a year later by about 20,000 people http://www.consumersunion.org/scribbler/other_issues/002685.html


13 Ibid., p. 1.


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