Sustainability and Resilience as Design Constraints

In October 2012, Superstorm Sandy, the largest Atlantic hurricane on record, pummelled the East Coast of the United States. In New Jersey alone, Sandy caused US$30 billion in damages, killed 38 people and left 2.7 million homes and businesses without power, 350,000 of those needing repair or reconstruction.1 The Federal Emergency Management Association (FEMA) responded with regulations that mandated construction above the floodplain. This was a sensible technical solution, but disastrous from an architectural and social standpoint in that it would lift many buildings well above street level, disrupting longstanding existing neighbourhoods with entrenched and vibrant living patterns.

A small group of architecture and engineering students led by faculty from Stevens Institute of Technology in Hoboken, New Jersey countered with the SU+RE House, a new paradigm for coastal housing and the winning entry in the US Department of Energy’s 2015 Solar Decathlon competition. Hoboken sits on the Hudson River across from Manhattan and in 2012 Sandy had flooded the city. Just months later Ecohabit, Stevens’ entry in the 2013 Solar Decathlon, was being built by students in a parking lot adjacent to the Hudson as a storm threatened to flood the river again. As an emergency measure, the building had to be craned out of the danger zone. When Stevens decided to enter the 2015 Decathlon and utilize the same parking lot for construction of the SU+RE House, it seemed clear that the design challenge had to be an intelligent, replicable response to Sandy.

The result was the development of a building system that allows for construction in the floodplain, thereby reclaiming a densely populated site condition currently being lost worldwide to more frequent and severe flooding. Through conscious envelope design, the house also requires only a fraction of the energy to run compared to its conventional counterparts, its roof-mounted photovoltaic system producing considerably more power than the building requires. During a storm-induced grid failure, the system ‘islands’ itself to continue producing power, becoming an oasis of energy to supply standby electricity to the neighbourhood.

The project is now a permanent exhibit at the Liberty Science Center in Jersey City, N.J. The prototype is well-documented through a project website and an edition of AD, “Sustainable and Resilient Design Systems”, edited and contributed to by project faculty.
Low-tech Adaptation Combined with Plug and Play Innovation

The SU+RE HOUSE project design constraints defined the envelope as a hybrid combination of existing low-energy building and marine industry materials and methods. It was noticed that a boat hull is a structural insulated panel (SIP), a well-established assembly for creating low-energy building envelopes. Building SIP skins are most often wood-based sheet goods, while in boats they are glass-fibre laminates. When used in buildings, the foam cores of SIPs are excellent insulators, while in boats they are part of an efficient buoyant waterproof shell. In both instances, the foam sandwiched between and bonded to continuous skins uses similar structural principles to create very strong panels. Therefore, to deliver flood-proofing, why not simply build a boat configured to perform as a very low-energy house? This design thread provided many potential advantages including untorn insulation, integral rather than applied flood-proofing, standard methods for performing anti-sealing against air and water leakage, and simple adjustment of insulation thickness for different climate zones. The biggest problem encountered was finding structural and fire code equivalence between glass-fibre composite panels and wood-panel-based SIPs designed for buildings. Used ubiquitously in craft designed for water, air and space travel, the technology was clearly there for the composites, but the regulatory infrastructure was not. A case in point and a cautionary tale for design processes that prioritize innovation.

The eventual solution went to the other end of the project material pallet spectrum. A conventional stick-frame envelope was modified to deliver required thermal resistance, air tightness, and resistance to buoyancy forces with flood-proofing applied as a layer in the floor and wall assemblies. Joint-sealing detailing was borrowed directly from proven marine practice. Performance enhancements were therefore accomplished through rearranging ubiquitous materials in existing construction details. The sage design advice of not fixing what isn’t broken was followed and proven durable, and easily repairable vernacular beach exterior and interior materials in existing construction details. The biggest problem encountered was finding structural and fire code equivalence between glass-fibre composite panels and wood-panel-based SIPs designed for buildings. Used ubiquitously in craft designed for water, air and space travel, the technology was clearly there for the composites, but the regulatory infrastructure was not. A case in point and a cautionary tale for design processes that prioritize innovation.

A large expanse of southern glazing created a transition between indoor and outdoor rooms. As part of a Modernist tweak on classic passive solar design, the glass needed a large overhang to maximise winter and minimise summer solar gains. Movable bi-fold shutters were designed that, when open provide the overhang. In the event of a storm, the shutters can be quickly closed and locked, compressing their gaskets against a structural frame. Marine hardware, gas springs, and a 6:1 mechanical advantage pulley system allow two people with limited strength to close the large foam core glass-fibre composite panels. Fibre-laminate schedules were customised in each panel to maximise the weight and strength. The lower panel heavy and stronger to withstand the lateral and uplift forces of flood waters; the top panel lighter to allow for easier movement of the assembly. The assembly works in harmony with standard methods for perfect joint-sealing against air and water leakage, and simple adjustment of insulation thickness for different climate zones. The biggest problem encountered was finding structural and fire code equivalence between glass-fibre composite panels and wood-panel-based SIPs designed for buildings. Used ubiquitously in craft designed for water, air and space travel, the technology was clearly there for the composites, but the regulatory infrastructure was not. A case in point and a cautionary tale for design processes that prioritize innovation.

The final building envelope is essentially a reorganisation and simplification of a well-established low-energy system...
1. Climate and Comfort

Through most commercial buildings in the southeast are designed though cooling loads predominate, few that fit the opportunities for. For example, one office high NC has almost twice as many heating degrees as cooling degrees days and the burn of time the air temperature is within the psychrometric comfort zone.

4. Combining Form and Site

This basic formal concept is combined with the preferred sitting to generate a solar insolation analysis to inform the building envelope design. The NC facade of the building is well shaded by pedestrian buildings and receives little direct sun throughout the year. The NE facade is better shaded by the building form due to the trajectory of the solar path. The SW facade is very exposed and receives much of SIR, much of which is during the hotter months in the afternoon so has the potential to penetrate deep into the building. The SE building face receives almost as much SIR but more during colder months when the effect is diminished.

7. Daylighting Design

By adjusting glazing amounts and employing simple stationary shading devices based on site conditions, much of the heat gain to theoretically be supplied through passive means.

2. Preliminary Site Analysis

Based on the initial analysis, it makes sense to look for a spot on the site that maximizes the opportunity for exposure while offering shade when possible. By adjusting the location of the available site, the option is close to the bill. The building form maximizes winter solar exposure while offering summer shade. By adjusting the location of the available site, the option is close to the bill. The building form maximizes winter solar exposure while offering summer shade.

5. Envelope Design

Energy analysis of similar buildings which indicate that energy performance concerns with a high solar insolation design. A performative study is undertaken testing a variety of simple forms with the zero square footage of useable space. The forms are kept simple so that the performance of changes in length and width could be clearly studied. Based on the analysis the decision is made to start the design process with a simple form that maximizes floor area to exterior surface area.

8. Materials Specifications

Now that all the base elements of the facade are considered and the performance of the facade is balanced with programmatic concerns. A storefront system is planned for the entry level assembly space.

9. Assembly Performance Maximization

Case Study: basic climate and comfort analysis of site presents an interesting design challenge. Can we design a commercial building that would have most of its loads provided through passive means?
Humans have been mixing concrete for thousands of years and are adept at controlling structural and finish characteristics through mix design. Concrete has also consistently been used as a thermal material in buildings, both to store heat energy and to resist its movement, but it seems that designing mixes to maximize these performance parameters has not been generally considered. In this study, the potential efficacy of defining the specific heat capacity and thermal conductivity of concrete through adjusting paste to aggregate ratios was investigated. Results indicate a potential range of about 30% for specific heat and over 200% for thermal conductivity through such a mix design approach. Geopolymer cement concretes (GCC) show more promise than portland cement concretes for thermal optimization. A zoned thermal wall assembly was designed to prototype application of study results in a low-energy building envelope. This research was published in the *Journal of Architectural Engineering*.

### Simple physical differences make the feasible mix range for GCC’s broader giving them more thermal flexibility.

**Application of this thermal optimization methodology to a high performance envelope.**

<table>
<thead>
<tr>
<th>Zone Type</th>
<th>P/A Ratio</th>
<th>c (W/mK)</th>
<th>k (W/mK)</th>
<th>Application</th>
</tr>
</thead>
</table>
| GCC       | 1         | 730      | 0.53     | high microclimate temperature stabilization; strength | 3
| GCC (foamed) | high low  | high     | low      | based on low k value of 100% GCC paste | 6
| GCC       | 0.15      | 675      | 1.49     | maximize efficiency of hydronic and PCM systems | 6
| GCC       | 0.65      | 707      | 0.92     | balance thermal storage with need for efficient heat transfer to hydronic and PCM; high compressive strength | 6
BIM Construction Detailing
Ongoing experimentation in drawing through modeling components first, assembling them into systems such as the model at left, and then mising documentation directly from the model such as the sections at right. This work is part of long term project to develop a library of high performance envelope configurations that can be used in design and performance modeling taking advantage of Revit’s capability to define physical characteristics of materials.

LOW-CARBON ASSEMBLIES  design research
In the winter, the PV array is moved over the main roof allowing the low southern sun to reach deep inside the house where the geopolymer concrete floor, walls, and cloud store the heat. The solar thermal collectors heat water for domestic use and additional solar energy is transferred to the concrete through the capillary tubes. Any excess heat is stored in the capillary tank.

The building interior and southern exterior living space are shaded from the summer sun by the solar electric (PV) array. The solar array in both summer and winter is being reconfigured from the southern sun to the winter sun's (PV) array. This allows the solar array to be more efficient in both summer and winter.

Graphing passive and active systems. Pre-cast concrete wall system in which each wythe is tuned to perform a specific thermal/structural performance function. Hydronics embedded in interior concrete wythe are plumbed to heat exchangers that act as collectors or rejectors of energy depending on the season. A series of test panels were built and tested using geopolymer cement concrete and the full system was prototyped for the UrbanEden project (see below).
Small flexible interior space (kitchen counter transforms into table to seat eight) made large through connection to outdoors. Living room entertainment center opens to create guest sleeping area outfitted with Murphy bed... and living room moves outside. Outdoor rooms double square footage of living space with living walls and movable PV array shading device.

Building envelope integrated with passive and active systems and designed to Passivhaus standard.

Carbon Reduction Through Fixing Concrete.
Project designed, built, and operated for the US DOE Solar Decathlon 2013. First application of the “passichanical wall system” described above. A geopolymer cement concrete (GCC) mix was developed specifically for this project and prototyped. GCC’s have similar physical characteristics to portland cement concretes with only 25% of the carbon footprint. Since concrete represents about 7% of our collective carbon footprint, this technology could be world changing. UrbanEden was the first building in the world to utilize GCC’s as part of an insulated building envelope.

Architecturally the project concept was to create a a better urban living context through crafting a space that blurs the line between inside and out. A series of connected indoor and outdoor rooms combine into a single healthy environment: the interior completely adaptable to maximize comfort year round and seamlessly connected to a private plant-filled exterior living space, sunny in winter and shady in summer. This outdoors is distinguished from the “great outdoors” in that it is contained within a spatial definition that allows for contemporary life to continue outside, either physically or, if the weather doesn’t permit, then visually.

UrbanEden consists of four indoor modules, each with an outdoor component. Thick insulated concrete walls on the east, west, and north façade facing the street cradle the interior living space, creating a visual and aural separation from the urban context. On the building’s south side is the exterior living space, enclosed by a lush vertical garden that creates a private connection to a hybrid urban/natural environment.

Transition between these interior and exterior living spaces is provided by a high performance floor to ceiling glass wall that allows for exacting interior environmental control while maintaining a constant and seamless connection to the outside. Public and private spaces are defined formally as essentially tectonic assemblies of concrete, glass, and steel, providing an openness that feels expansive in a small square footage. These spaces are separated by a service module, a stereotomic volume of wood from which the bath and mechanical room are carved.

GCC precast wall panels were poured at a local plant showing that this technology is feasible now. The house coming together at UNCC (above) and as constructed on site for the competition in California (below).
Juxtaposition of state-of-the-art building science and high performance industry products with site-made materials and low-tech methods. Compressed earth blocks, earthen plasters, hemp shiv, lime renders, living roof, polyurethane SIPs, closed-cell foam, triple plane glazing, air tight construction, passive coil thermal pre-conditioning for energy recovery ventilation supply. First hempcrete insulated building in the US.

Low-energy hygroscopic envelope. Intended as a carbon neutral prototype, the Nauhaus was designed to have a low embodied energy in construction through the use of site-made, local, and recycled materials and tiny operational energy loads through adherence to the Passivhaus standard. The architectural design incorporated extensive outdoor rooms to keep expensive interior square footage down and enable more time spent outdoors, both enjoyable and energy efficient because inhabitants do not need to heat or cool the indoors when they are living outdoors.
“Building Green” Cottage. Project purpose was to publish the results of research into application of traditional building systems in a contemporary residential context. A demonstration cottage was designed in which different material systems were applied based on their efficacy in the given microclimatic created by building siting.

The design and construction process was documented in detail so that a series of how-to image sequences worked together with written and illustrated offerings on building science, architectural design, and other contextual information. Different materials and methodologies were compared and contrasted from performance, practicality, and aesthetic standpoints.
CONDO PROJECT PROTOTYPE

Programming, 2D/3D modeling, rendering

Charlotte Condo Project. Academic exercise in advanced BIM design. Model built using custom parametrics families including adaptive component, curtain panel pattern based, and other family types.
In the 21st century, architects and engineers are being challenged to produce work that is concurrently sustainable and resilient. Buildings need to mitigate their impact on climate change by minimising their carbon footprint, while also countering the challenging new weather conditions. Globally, severe storms, extreme droughts and rising sea levels are becoming an increasingly reoccurring feature. To respond, a design process is required that seeks to integrate resiliency by building in the capacity to absorb the impacts of these disruptive events and adapt over time to further changes, while simultaneously being part of the solution to the problem itself.

This issue of AD is guest-edited by the interdisciplinary team at Stevens Institute of Technology who developed the winning entry for the 2015 US Department of Energy Solar Decathlon competition, the SU+RE House. While particular focus is paid to this student designed and built prototype home, the publication also provides a broader discussion of the value of design-build as a model for tackling the issue of integrating sustainability and resilience, and what changes are required across education, policy, practice and industry for widespread implementation.

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SU+RE: Sustainable + Resilient Design Systems