USE OF PRECAST CONCRETE IN THE DESIGN OF HIGH-PERFORMANCE SUSTAINABLE HOUSING

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ABSTACT

This paper will examine, through both professional and academic case studies by the author, the use of precast concrete systems in the design and construction of high-performance sustainable housing. Case studies include PREttyFAB, a 2010 PCI Design Award winner for Best Single-Family Home that was professionally executed; and the eNJoy! House, Team New Jersey's entry to the US Department of Energy's 2011 Solar Decathlon competition executed by the author and a team of architecture and engineering students. Both projects were conceptually conceived to integrate passive design strategies, new solar technologies, and contemporary architectural ideas while challenging traditional building techniques and materials. In addition to showcasing the progressive use of precast concrete systems as they are integrated with such sustainable design ideas, the paper will address the adoption of new technologies in architectural design and production, including innovative ideas in the production of shop drawings and the fabrication of precast panels themselves using Building Information Modeling (BIM) software systems and CNC fabrication hardware. The paper advocates both the use of insulated precast sandwich solutions in the construction of much needed sustainable housing as well as a more streamlined and efficient means of working between architects and precast concrete fabricators.

Keywords: Precast Concrete, Building Information Modeling, Sustainability, Shop Drawings, Digital Fabrication

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INTRODUCTION

The idea of using precast concrete in housing is not new. Thomas Edison, who would go on to invent bigger and better things, imagined neighborhoods of concrete houses in New Jersey in 1906. However, the idea of a passively optimized sustainable house made of concrete has found new interests in contemporary architectural and engineering circles of late. Utilizing precast concrete for its high-mass and potential insulation value, and coupling it with sustainable technologies can lead to low maintenance and energy-conserving living solutions. Increasingly, concrete is also a recycled material. More interestingly, because of the plastic qualities of concrete – theoretically panels of any shape can be cast – the material lends itself to novel solutions in which the architect or designer can specifically form the panels to respond to environmental factors such as prevalent winds, solar exposure, and day-lighting.

This paper will investigate, by way of three case studies undertaken both professionally and academically by the author, the utilization of precast concrete and new digital design techniques in the design of environmentally sustainable housing. The paper is also somewhat matter-of-fact in that design goals and solutions are written about chronologically so as to give the reader a fairly detailed understanding of the nuances of each specific project's design and construction goals, sequence and processes. As such, a picture is painted that foregrounds the novelty of each project, from virtual design through construction; and illustrates the progression of research and development of the systems and their specific application which evolved over time. I am less interested here in engaging the theory that surrounds each project, but rather attempt to position each through a loosely related process of design that engages new technologies and an interest in sustainability. Each project contains a different type of precast panel, which presented different pros and cons in the creation of the buildings, with the largest – Jackson Green, in design during the time of writing – utilizing a hybridized system.

USE OF BUILDING INFORMATION MODELING

The building information modeling methodology being used increasingly by architects offers significant new ways in which the designer can analyze a site and design a building. "The potential of building information modeling (BIM) is that a single, intelligent, virtual model can be used to satisfy all aspects of the design process including visualization, checking for spatial conflict, automated parts and assembly production (CAM), construction sequencing, and materials research and testing. The model is shared, and contributed to, by all parties involved in the construction of the building, from architects to engineering consultants, contractors and subcontractors."[1] Further, data from these models can be exported to sub-contractors and fabricators as the basis for shop drawings and even computer numerically controlled (CNC) fabrication. BIM, however, should not simply be thought of as a production tool – something used to document a building after it has been designed. Rather, taking advantage of the software's analytic capacities to assist in preliminary building planning and organization allows the designer to make better decisions about how a building will perform on a specific site. Specific design activities, integrated with the modeling process, will be explained for each project illustrated here. Our work in this area has increasingly focused on the design of sustainable housing generally in cities for redevelopment agencies where cost is paramount, so the testing of each precast system against other means of construction, specifically stick-built and modular, is required. Generally, clients interested in this sort of design are willing to consider the life cycle cost of their house, as opposed to upfront costs only. This has proven to be substantial in cost savings, especially when the minimal upkeep requirements of precast concrete is considered.

PROJECTS

PROJECT 1: PREttyFAB


Figure 1: PREttyFAB, Jersey City, NJ

PREttyFAB was originally conceived as a prototype for urban infill housing in R1 or R2 residential districts. The original house was designed and built in 2008 in Jersey City, New Jersey for a total fee of $250,000 USD or a per square foot cost of just over $150/sf. The private client acquired a small piece of vacant land – ultimately classified as a non-conforming undersized lot – and wished to build a 1,600 square foot house that produced its own energy and had minimal to no maintenance costs. He was originally interested in concrete for this purpose, but as the design commenced became increasingly interested in how concrete, and specifically highly insulated precast panels could be integrated into a total passive and active sustainable solution that also contained a small photovoltaic array, a green roof for additional insulation, low- emissivity glazing, and radiant heating. The client also requested that no cooling system of any kind be used – he wanted the house to be cooled passively.

Our team at GRO Architects quickly understood that the project, if designed per the client's goals, would not be a one-off architect-designed house, but could be repurposed through a series of simple constraints for practically any urban infill housing lot, making PREttyFAB a prototype. Those constraints were:

1. Site Orientation
2. Roof Angle and Direction
3. Set Backs and Lot Coverage
4. Entry Location

Combined, we saw these as a series of metrics can that could be used to optimize the house's exterior form based on site conditions. Site Orientation is primarily important for day lighting, solar collection, and prevalent wind direction. Roof Angle and Direction allows for the optimal amount of roof surface to be south or west facing, again for solar collection. For these first two constraints, we used environmental modeling software to ascertain how various orientations of the house's roof and walls would allow for minimum shadow casting and maximum solar collection for the planned photovoltaic panels. Set backs generally set a maximum building envelope per zoning or development ordinance – it quickly became apparent that PREttyFAB would need several variances to be built on its undersized lot. Entry Location is a local condition based on a corner or mid-block lot. We designed a split stair in PREttyFAB and created a reverse living condition so the sleeping areas were in the basement, which was just about 50% below ground. This allows the insulative values of both the earth and the concrete keeps the sleeping areas cool even in mid-summer heat.

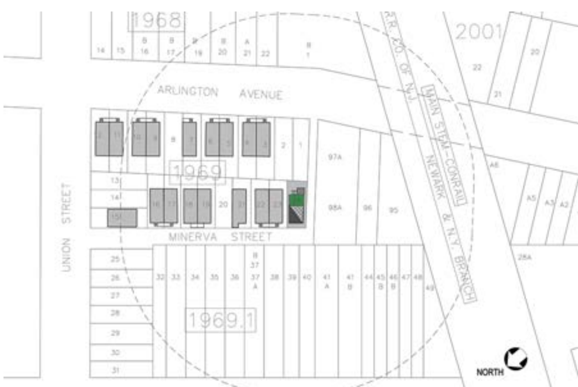


Figure 2: Site Plan, PREttyFAB, Jersey City, NJ. The site is oriented approximately 30° north of west on the last lot of the street. The lot therefore enjoys direct sunlight for the majority of the day.

The house's site, though optimal for day lighting and solar gain purposes presented problems from a bulk standpoint, and required GRO to seek a number of variances due to the site of the lot, which measures 22.45' x 55.95'. The lot is well under the minimum requirement of the R-1 Zone, which is 2500 ft^2. When tallied based on the Jersey City Development Ordinance, it was found that the project would need seven variances from the Jersey City Zoning Board of Adjustment. Variances included minimum lot size, minimum lot width, minimum lot depth, minimum rear yard setback, minimum accessory front setback, fence height front yard, and fence height side yard. While some of these were considered to be preexisting non-conforming uses, others such as rear yard set back needed to be understood as special exceptions.

SECTION NO.	ORDINANCE	REQ'D
345.40-E.1	MINIMUM LOT SIZE	2,500 SF
345.40-E.2	MINIMUM LOT WIDTH	25 FT
345.40-E.3	MINIMUM LOT DEPTH	100 FT
345.40-E.4a	FRONT YARD SETBACK (MIN)	PREDOMINANT
345.40-E.4b	FRONT YARD SETBACK (MAX)	10 FT
345.40-E.5	MIN SIDE YARD SETBACKS	(2) 5.0 FT
345.40-E.6	MIN REAR YARD SETBACK	30 FT
345.40-E.7	MAX BUILDING HEIGHT	2.5 STO/35 FT
345.40-E.8	MAX BUILDING COVERAGE	60%
345.40-E.9	MAX LOT COVERAGE	85%
345.40-E.10	MAX. ACCESSORY BLDG HT	N/A
345.40-E.11	MIN ACCESSORY SETBACKS FRONT	7.5 FT
345.40-E.1a1	FENCE HEIGHT FRONT YARD	4 FT
345.40-E.1a2	FENCE HEIGHT SIDE YARD	6 FT
345.40-E.1a3	FENCE HEIGHT REAR YARD	8 FT

Figure 3: Zoning Design Standards Chart, PREttyFAB showing 7 variances required to build the project as proposed.

In our initial discussions with the client, there were several sustainable attributes he wanted us to look at, the first of which was the concrete design. Additional equipment or program included photovoltaic panels for energy production, low-emissivity glazing, and a green roof. It is this final requirement that allowed us to get beyond the most restrictive of the variances – that of the 30 foot rear year setback.

GREEN ROOF

The client's requirement of a green roof, partially for its insulative qualities, and also to support a gardening hobby, presented an interesting opportunity for us to formally integrate the variance issues posed by the house and lot. The required thirty-foot rear yard setback, customary for typical urban lots, would make building on the lot untenable. With a six-foot front yard set back to match the front facades of other houses on the block, the 30' set back would give a building depth of less than 20 feet, and a total footprint of about 350 square feet.

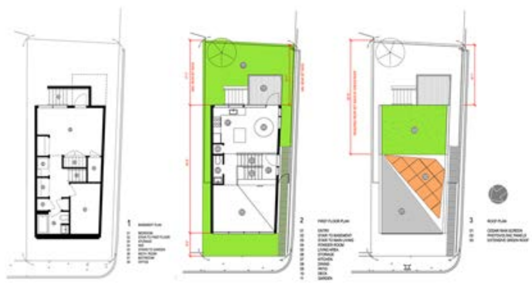
The house was planned with a high roof near the front lot line so as to maintain continuity with the majority of existing houses on the block. It was imagined that the photovoltaic panels would be mounted to a high, south-facing roof in this part of the structure. The back of house on the raised first floor would be the kitchen and dining area with a small walkout deck. Our design team realized that the point at which the high roof ended, and the kitchen roof began could fall at the 30 foot rear year setback. We proposed that a poured-in-place flat roof be poured over the kitchen, effectively capping the house with a lower height beyond the setback line, and allowing us to plant a green roof per the client's wishes.

Figure 4: Preliminary rendering of PREttyFAB showing the photovoltaic array and green roof at the rear of the house – within the 30-foot rear yard setback.

While a green roof does not simply alleviate the need for proper drainage on a site, it will mitigate the flow rate of water on the site by collecting the water and allowing run-off to occur at a slower rate. This allows the surrounding soils to hold additional water; a strategy that we formulated would allow us to forgo the rear yard setback requirement. It would be that we proposed a 16.5-foot clear rear yard setback, with the remaining 13.5 feet being taken up by the rear of the house – the portion under the green roof. While the commentary was at times sarcastic by zoning board officers unfamiliar with sustainable design, “How do you get a lawn mower up there?” (the green roof would be comprised of low impact, extensive, succulents) the board eventually voted unanimously to allow our client to build the house as designed. We had successfully secured seven variances to build the house, something we attribute to the emphasis on our design process and the tools we were able to use to present our case to the zoning board.

From a space planning perspective, PREttyFAB is a split-level building, with the sleeping areas in the basement. The green roof allowed for the kitchen to be planned at the rear of the house with access to a small deck and views to the Statue of Liberty in New York Harbor. The split-level design assisted in two of the client’s goals – he wanted to use radiant heating, which works well with a slab solution, and wanted the house to be naturally cooled through passive ventilation and operable windows. There would be no air conditioning in the house. By putting the sleeping areas in the lower level, not only were we able to take advantage of the excellent insulating capacity of the precast panels, but also take advantage of the split-level solution itself as the house was set into the ground five feet. I visited the house last July on a hot summer day and the sleeping areas maintained a temperature of 76° during mid-afternoon. The lower level contained two bedrooms and a full bathroom, as well as a walkout to the rear year from the larger bedroom at the back of the house. As a poured-in-place slab is recommended to lock the precast panels together, it was decided to polish the floor slab and expose it at this level of the house.

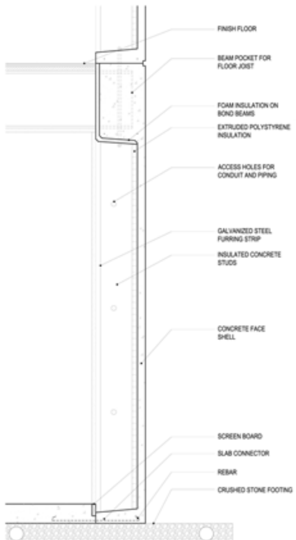
The second, main living floor contains a living area, and kitchen, with a small mezzanine above. Originally, a small bathroom was also planned but was omitted prior to construction. So as to make the house seem larger and ensure that the passive cooling strategy of operable windows and a ceiling fan in the kitchen provided adequate conditioning of the air, we consciously avoided using partitions to subdivide the space so as to allow the uninterrupted flow of air from the front to rear of the house based on prevalent wind direction. Instead, spaces were modulated using ceiling height. One accesses the second floor from the entry stair under the mezzanine, where the ceiling height is lowest, and flat. The living space off the stair is a double height space with a dramatic sloping roofline that is calibrated to solar collection. To the other side of the stair is the kitchen, below the green roof with a flat ceiling height of 10 feet.



Figures 5: PREttyFAB, architectural plans.

INSULATED PRECAST CONCRETE PANELS

PREttyFAB uses for its superstructure an insulated precast panel system widely used as a foundation solution in the United States. The system utilizes an exterior 2” cap of concrete with cast concrete studs at 16” on center. The studs are generally wrapped in Styrofoam or insulation and then capped with a metal stud so that interior sheathing can be directly fastened. Generally insulation board is used to provide up to 6 inches of insulation against the concrete exterior of the panel. By wrapping the concrete studs in Styrofoam a thermal bridge is prevented.



Figures 6: Partial wall section showing insulated precast concrete panel; PREttyFAB.

The panel type was originally conceived to replace poured footings and concrete masonry unit foundation walls in the basements of single-family houses. The creators of the product, now used internationally, have very consciously marketed the panels to be energy efficient, while going as far as suggesting the panels are a lifestyle choice:

“Today's smart home buyers care about creating comfortable lifestyles — while adding dramatic new living space and lowering their energy costs. That's why <*the insulated precast wall system is*> in demand worldwide as the superior foundation for every new custom home.” (end note 3)

Originally, in PREttyFAB, we looked for a cast-in-place solution that would simplify construction of the building’s exterior while answering our client’s request that the house be, in his words, “hassle-free” – that there be no substantial maintenance to exterior materials. Ultimately the cost of insulating the poured-in-place solution became prohibitive, and we began to look at a panelized system. The height and orientation of the building required that 16 unique panels be created, stacked 3 panels high, to achieve the form.

The project, by most standards was considered very small, and with its 18 unique precast panels the majority of precast concrete companies we contacted were not interested in working on the house. After about four months, Northeast Precast, from Millville, New Jersey, agreed to work with us on the project. It was our hope to transmit 3D data directly from our model to Northeast Precast for the creation of shop drawings – we had used BIM on several other projects at this point and were confident the data would be precise and specific enough to build from. The company saw it as an opportunity to do something new, which benefitting from the study necessary to build from our design data, which existed within a leading Building Information Modeling (BIM) format. We worked closely with them to ensure this investment in research and development would pay off.

Northeast Precast provided us with panel requirements in terms of size and thickness, and then requested that we transmit 3D design data once our BIM had been modified to accommodate a panel layout that could be achieved at the plant. After a period of about 4 weeks, shop drawings of the 18 unique panels were cleared for production.

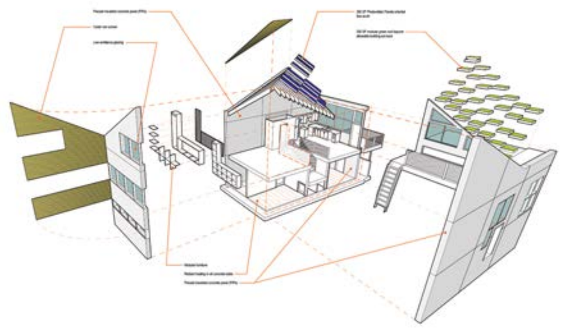


Figure 7: Exploded drawings showing final components including insulated precast concrete panels, Photovoltaic Array, and Modular Green Roof; PREttyFAB.

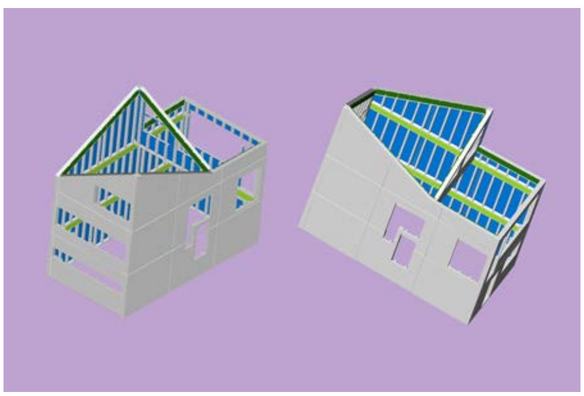


Figure 8: Three-dimensional views of PREttyFAB's panel system as extracted from GRO Architect's BIM and transmitted to Northeast Precast in a popular 3D format for the production of shop drawings. Note the precast wall system and insulation are simulated in the BIM, including ledger boards for the framing of floors.

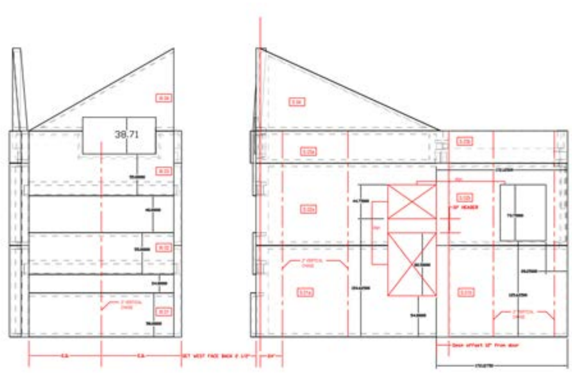


Figure 9: Two-dimensional drawings of the exterior panel system by Northeast Precast for check by the architects. Drawing dated 25 September 2008.

Figure 10: A portion of time elapsed photography of the 3-day erection of PREttyFAB's shell.

Figure 11: Finished interior view, PREttyFAB looking from the double height living area past the entry stairs and mezzanine to the kitchen on the second floor.

PROJECT 2: eNJoy! House

Figure 12: eNJoy! House; New Jersey Institute of Technology and Rutgers University – 2011 US Department of Energy Solar Decathlon competition

Immediately following the construction of PREttyFAB, in 2009, the eNJoy! House was conceived as the submission to a request for proposals announced by the US Department of Energy for the fifth biennial Solar Decathlon competition. The competition "challenges collegiate teams to design, build, and operate solar-powered houses that are cost-effective, energy-efficient, and attractive. The winner of the competition is the team that best blends affordability, consumer appeal, and design excellence with optimal energy production and maximum efficiency."[2]

Based on the success of PREttyFAB, I was asked to put together a team of architecture students from NJIT, where I am an Associate Professor, to work with engineers, planners, and landscape architects from Rutgers University on designing, documenting, and along with the professional contracting firm, Skanska, actually build the house. The eNJoy! House integrated passive design strategies, active solar and sustainable technologies, and contemporary architectural ideas. The use of precast seemed appropriate – not only had the material never been used in the competition prior, making the house novel; but it also seemed like the research that went into PREttyFAB could be capitalized on and further developed through an international competition that would bring almost 300,000 visitors to the house when it was built on the National Mall in fall 2011. In the fall of 2009, Team NJ was one of 20 schools to be chosen to participate.

The list of constraints was highly specific, the each house constructed for the contest would be judged both objectively and subjectively in ten categories:

1. Architecture
2. Engineering
3. Market Appeal
4. Communications
5. Affordability
6. Comfort Zone
7. Hot Water
8. Appliances
9. Home Entertainment

10. Energy Balance

The notion of affordability was added for the 2011 contest, and teams were encouraged to create houses with a construction budget of $250,000. As the maximum size of the house was 1,000 square feet, the budget was healthy at $250/sf.

SITING AND DESIGN

While the house would be built, and ultimately taken down, over a three week period in September and October 2011, together with my students we imagined the house would be ideally suited for use at the New Jersey shore, where the low density would allow us to take full advantage of solar exposure and the concrete would serve as a durable material that could stand up to high winds and rain. The team's goals were simple, we wanted to take full advantage of a coastal site harnessing the abundance of sunlight available, while utilizing contemporary green technologies and minimizing the house's reliance on the power grid.

For the purposes of the competition, we were given a 60'-0" x 78"-0" site in West Potomac Park, just off of the National Mall to site the house. The maximum height allowable was 18'-0". We imagined the house with a rotated plan that held the rear corner of the site with two ramps, making the house completely ADA accessible. The ramps would enter the house in two main areas – the living area and the sleeping area.

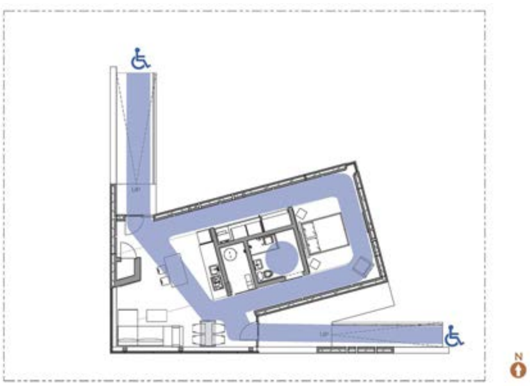


Figure 13: Accessible Plan of eNJoy! with ramps shown.

The site the team was given faced north, meaning that the photovoltaic panels, which were required in the competition, would be mounted at the back of the house if a traditional roof were selected. Ultimately, the given site would prevent the photovoltaic array from being prominently figured at the front of the house – as customary in previous Solar Decathlons – so a new solution was conceived.

Instead of using a flat roof, or a traditional hip or gable, we decided to utilize an inverted hip roof that could contain the framing for the photovoltaic array while also collecting rainwater. Rainwater could be used for many aspects of the house's functionality, but for the purposes of the competition only irrigation was permitted. The roof would also be a dynamic feature of the house's design – the inverted hip would cantilever over the clerestory windows of the north façade approximately 8 feet, providing a south-facing surface for the mounting of the photovoltaic system. The roof would become the most ambitious aspect of the design, with 6 unique sandwich panels coming together at a central component, called “the boat” as it was a monolithically poured part in which four different surfaces join at the central segment of the inverted hip, tying into a monolithically poured “core”.

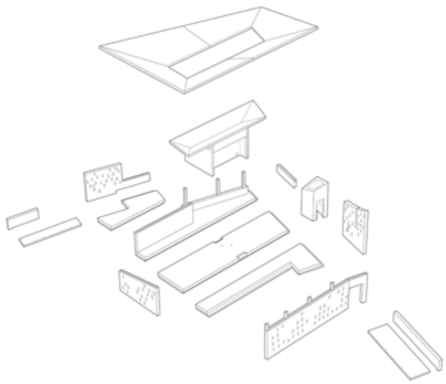


Figure 14: All 26 unique precast house components, note the six (6) inverted hip roof panels that tie into the central inverted hip component in which four opposing angles come together along an internal seam.

Overall, and similar to PREttyFAB, the house was designed for optimized passive performance prior to the additional of any sustainable technology, including solar panels. Specifically, the house was designed using software that simulates environmental conditions that allowed the design team to specifically examine the following:

- Daylighting
- Solar Radiation and Angle
- Shadow Casting
- Passive Cooling

Each of these is interrelated and involves the projection of both shadow and the penetration of sunlight into a space. The goals of such an exercise are simple: find a roof angle and overhang on each building side that allows for a maximum amount of solar collection on an opaque building surface - such as a roof - while allowing the penetration of sunlight during the winter months for warmth and keeping it out during the summer months thereby decreasing heat gain.

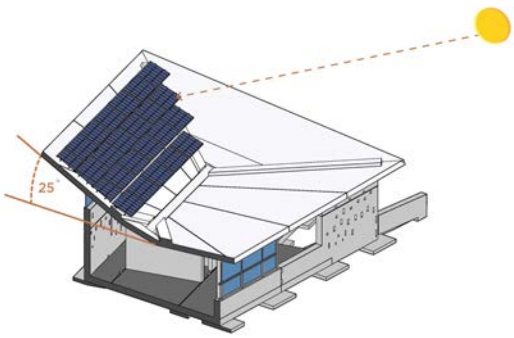


Figure 15: Passive Optimization - Optimal solar angle: The inverted-hip roof's two north panels are canted at 25 degrees for maximum solar exposure throughout the day on the panels facing due south.

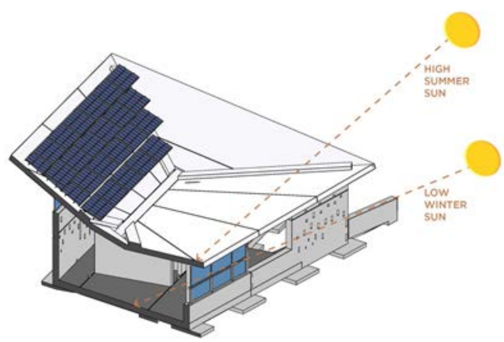


Figure 16: Passive Optimization - Calibrated overhangs: the roof overhang is calculated to allow for solar gain on the southern façade during the winter months and shading during the southern months working passively to prevent excess cooling and heating respectively.

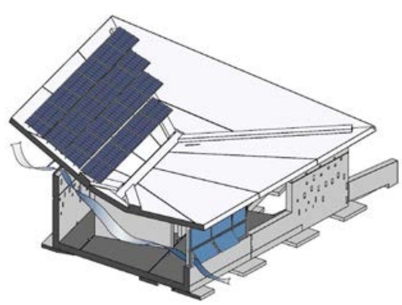


Figure 17: Passive Optimization – Cross Ventilation: the depressed roof angles made possible by the inverted-hip roof and operable windows (low on the south façade and high on the north façade) allow excess heat to flow out of the house.

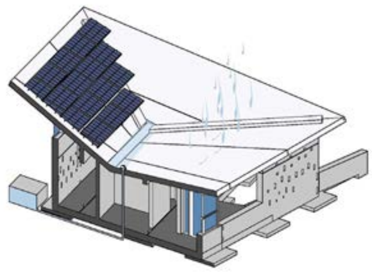


Figure 18: Passive Optimization – Rainwater collection: the roof's inverted-hip roof shape directs rainwater into the center core of the house for future use including irrigation and gray water flushing.

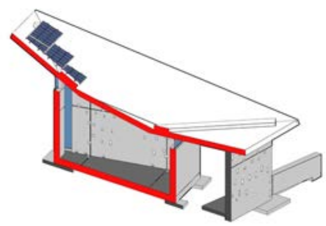


Figure 19: Passive Optimization – Thermal mass: the thermal envelope is comprised entirely of thick layers of precast concrete sandwiched around layers of expanded polystyrene insulation.

BUILDING INFORMATION MODELING

One of the more forward-looking aspects of the competition was in the design deliverable package itself. Unlike traditional two-dimensional design deliverables, the Department of Energy (in keeping with federal standards developed by the General Services Administration) required that a fully developed Building Information Model (BIM) in an industry accepted format be submitted to supplement the transmission of 2D paper sheets which were also to be submitted electronically. This was novel in that the submission was a fully formed virtual building that was coordinated by the students. In replicating a professional environment and requirements, students worked within their specific disciplines – architecture, structural engineering, and mechanical, electrical and plumbing – to develop the model.

The educational impact of such a requirement should not be understated. Not only did the NJIT architecture students work together as a team to develop the BIM and a linked project manual and cost estimate, but the amount of communication with their engineering counterparts and the level of collaboration is rarely achieved in the academy.

INSULATED SANDWICH PANELS

In pushing the use of precast panels as a way to produce novelty for the competition, our team selected a new type of concrete sandwich panel developed by Northeast Precast, and augmented its performance. The sandwich panel consists of three discreet parts, an Inner Wythe, insulation, and Outer Wythe. The insulation, generally Expanded Polystyrene (EPS) or Extruded Polystyrene (XPS), was replaced with a graphite impregnated EPS product. The type of EPS used is dark gray in color, as opposed to the lighter colors generally seen in regular EPS products. The darker color is a result of the integration of graphite within the cell structure of the EPS, so that radiant heat is reflected and absorbed – essentially kept within the insulation material longer – for better insulation capacity. It has been suggested that the addition of graphite increases insulation performance by up to 20%.

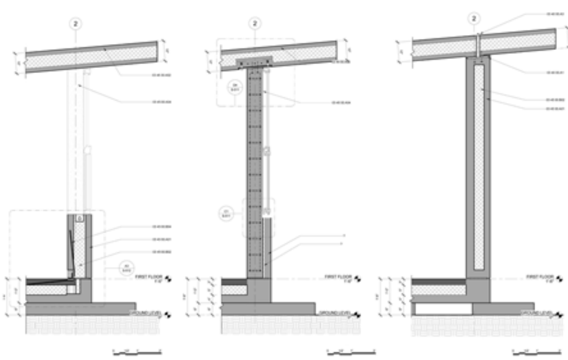


Figure 20: Wall Sections of the eNJoy! House showing floor, wall and roof panels.

In addition to better insulation performance, the sandwich panels supported another important design goal of our team, to minimize the amount of metal within the precast panels so as to reduce the amount of thermal heat transferred by rebar from the Interior Wythe to the Exterior Wythe. This was accomplished in the majority of wall panels by using a fiberglass shear connector. This type of shear connector is constructed entirely of fiberglass, so there is no thermal transmission or heat loss through the panel. The connectors work very well in vertical loading – so all of the walls of the eNJoy! House utilized this technology. The roof panels, with larger spans, a significant cantilever, and uplift to consider, however, required significant amounts of rebar and plates to achieve design goals.

PANELIZATION

One final hurdle in the assembly of the house came by way of a Department of Energy mandate that each team's house must first be fully assembled in the team's home state, with building permits and final inspections by the home jurisdiction's construction office. This presented a challenge in that we now had to build and disassemble the house twice, meaning all the precast connections had to be designed to be unfastened. In PREttyFAB, which was built once on a permanent site, connections were accomplished by embedding steel plates into the precast panels and then field welding them once craned into place. For eNJoy!, such a common practice was not possible, so the mechanical fastening of panels by bolting them to exposed rods was explored. While the team originally decided on a manufactured bolting solution, it was ultimately decided that ¾" bolts would be attached, with steel plates, to rebar during the panel casting process and field fastened with washers and nuts. The team had a similar design problem with the electrical conduit that was run through the walls and floor. Industrial conduit connectors, like those used on factory floors, were selected for this purpose.

SHOP DRAWINGS AND PANEL PRODUCTION

As stated above, one of the most interesting parts of the Solar Decathlon is its goal to raise total design awareness of sustainable strategies, which often includes engaging students in the actual construction of the Decathlon houses. While this has traditionally figured prominently with stick-framed systems that were either constructed off site and shipped – as in a modular solution – or built on site, students generally get a taste of conventional construction techniques surrounding the single-family home building industry in the United States. When proposing a precast solution, which by nature of the material requires skilled labor in terms of crane operation and panel assembly and fastening, we had to rethink ways in which the students could be engaged in the process.

After speaking with the owners of Northeast Precast, it was determined that we would engage a team of twelve (12) architecture students and three (3) engineers in the process of producing shop drawings for each of the 26 unique panels that would form the shell of eNJoy!. These students would ultimately then have the opportunity to work at the precast plan in the panel production process, which included the forming of panels on beds, the laying of insulation, and the insertion of reinforcing bar or shear connectors.

Like PREttyFAB, the building information model figured prominently in the production of shop drawings for each panel. Working with Arup, the engineering firm that performed structural calculations specifically for the roof, the students were tasked with exporting two-dimensional views of each discreet panel (top, right, and front) from the BIM and formatting for review by the structural engineers and precast concrete team. Drawings included all panel dimensions and angles for changes of direction other than 90 degrees as well as diagrams for reinforcing bar layout, the latter specifically for all 6 roof panels and the center module they were fastened to.

Included in this process was the understanding, though the BIM, how pipes and conduit would track through the wall and floor slabs based on the plumbing and electrical design. The team cast a series of PVC pipes in the wall and floor panels for this purpose. This is another example of the high level of coordination that is required of design students for this competition – such work is rarely explored in conventional architectural course work.

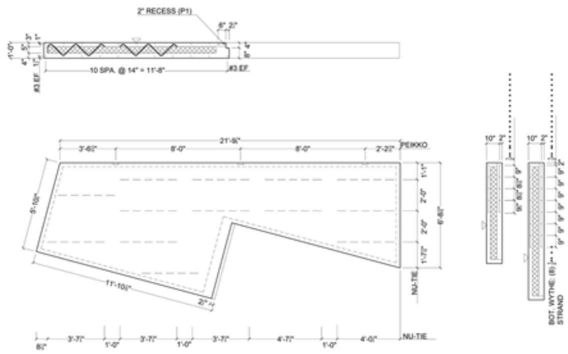


Figure 21: A sample shop drawing produced for the eNJoy! House by architecture students from the New Jersey Institute of Technology. The team worked closely with Northeast Precast in the creation of these documents, and participated in panel forming as well.

Once shop drawings for all floor, wall, and roof panels were complete, the group of students spent about six weeks in Millville, New Jersey working with the team from Northeast Precast. While the majority of panels were flat pours of varying thickness, it was decided that there would be two monolithic pours. The first was the center core, which would be the “brains” of the house – containing all the mechanical and control equipment as well as all the plumbing walls (kitchen, bathroom, and laundry). Next, the center roof module, which was named “the boat” as it had the four inverted roof angles coming together to meet at a single edge. Given the amount of structural stresses on the boat, the amount of reinforcing bar that went into it was significant. Also critical for the correct manufacturing of this complex part was ensuring that the jig the part was cast against was accurate in terms of roof angles and segment lengths.

To accomplish this, our team again relied on the BIM, extracting three-dimensional information for the boat and importing into a three-dimensional design software used by the shipbuilding industry, which offers a robust suite of curve and surface modeling tools and an ability to export 3D data to computer-numerically-controlled hardware such as a 3-axis milling machine or laser cutter through a plug-in, or add-on that increases software functionality, that has been created for that tool. In the case of the boat, we imagined a plywood jig that would have a grid spacing of about a foot to support the large weight of the boat. The plywood was then profile cut on NJIT’s industrial 3-axis milling machine so as to form a precise jig. Once the plywood was cut, it was driven down to Northeast precast and assembled, fastened and clamped with strict tolerances to ensure that the four angles of the boat would be properly cast.

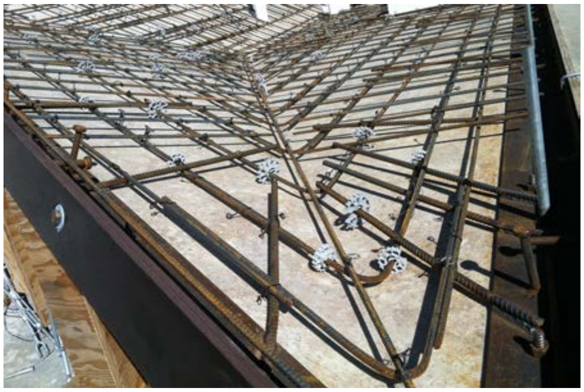


Figure 22: “the boat” being formed within the plywood jig specially fabricated for its manufacture. Note the amount of steel reinforcing to withstand the roof cantilevers.

Figure 23: Roof panels being formed with students of the New Jersey Institute of Technology, July 2011.

During the first week of July 2011, a 160-ton crane and the first trucks carrying precast panels arrive on the New Jersey Institute of Technology campus in Newark, New Jersey. Over the course of the next two months, eNJoy! took shape and eventually was completed prior to disassembly and loading for shipping to Washington DC for a competition start of September 13. During its time in Newark, the house weathered both a rare east coast earthquake and Hurricane Irene.

The house was re-erected in Washington during a five-day period and was visited by over 200,000 people. In addition to being the first house in the competition that utilized precast concrete for the majority of its structure and exterior, the house earned the dubious award of being the heaviest house in the history of the Solar Decathlon, weighing over 480,000 lbs. It served as a novel solution for the contest, and brought a great deal of visibility to the precast industry, and its engagement with energy efficient and sustainable housing.

Figure 24: The monolithic center core, the “brains” of the house, which contains all of the mechanical, electrical, and plumbing systems also supports the inverted-hip roof being craned into place during the Washington, DC build, September 2011.

Figure 25: Large insulated sandwich roof panels being craned into place during the Washington DC build, September 2011. Note the exposed layer of graphite impregnated expanded polystyrene of the set panel on the left.

Figure 26: View looking east at night of the completed eNJoy! House in West Potomac Park, Washington, DC, September 2011. Note the use of clerestory windows gives the impression that the heavy, cantilevered precast roof is floating above the house.

Figure 27: Interior view looking south of the completed eNJoy! House in West Potomac Park, Washington, DC, September 2011. The interior utilized a dark-tinted precast floor panel, naturally finished wall panels, and a roof painted with gloss white epoxy.

CONCLUSIONS AND FURTHER RESEARCH

At the time of writing, GRO Architects has been commissioned to design two additional housing projects, one a two-family house in Brooklyn, NY and Jackson Green, a new 22-unit housing development in Jersey City, NJ being developed by the Jersey City Redevelopment Agency. Both projects, though under preliminary design at the time of writing, will be illustrative of the further utilization of precast concrete in sustainable housing design, while presenting two different conditions that we have not had the opportunity to address prior. The first, in Brooklyn is a two-family house to be built above an existing single story three-car garage. The garage is made of reinforced concrete masonry units set upon a poured foundation, so has been deemed suitable to transfer the additional loading of two additional stories above. The fastening of new precast panels to the existing masonry units below is under current consideration. The project will be another model of sustainable urban infill housing, like PREttyFAB.

Also different is the project faces east, and is separated from the building to its south by another single story garage. After studying the shadows cast by this adjacent building, it was determined that a small photovoltaic array could be proposed. More interesting and different from both of the projects described above is the ability to coordinate the eastern façade to maximize day lighting while still providing adequate shade from the summer sun. The solution is to use a vertical fin system, unfortunately not made of concrete, to allow for direct sun penetration earlier and later in the day. The façade will still employ operable windows.

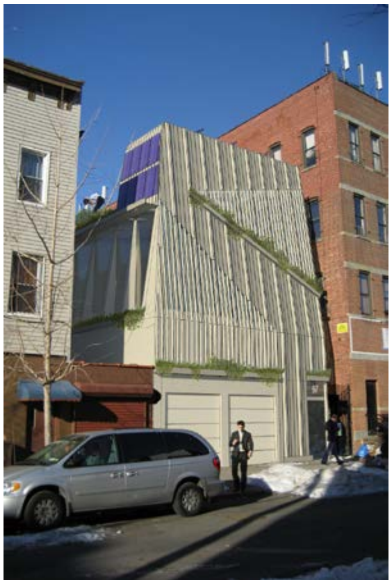


Figure 28: Preliminary rendering for proposed precast building at 97 Sutton Street, Brooklyn, New York. The building has two residential units built above a single-story garage. Note the vertical fins to mitigate eastern sun for adequate day lighting.

Jackson Green is the largest project to date for which we have had the opportunity to consider a precast system. The approximately 45,000 square feet translates into 22 units that are split along a street in the Martin Luther King Jr. hub section of Jersey City, New Jersey. For this scheme we are proposing a hybridized system of both insulated sandwich panels and wall panels that utilize a concrete exterior fastened 14 gauge steel members, these steel studs will also form interior partitions so as to support hollow-core concrete floor slabs during the project's erection. This will allow us to rethink the erection process itself, so floors can be craned and interior partitions can potentially be built during the placement of exterior wall panels

Figure 29: Preliminary bird's eye view of Jackson Green.

The projects represented here are not meant to be exhaustive. Rather, they represent ways in which architects and designers can begin to engage precast concrete utilizing it's high mass, excellent insulative capacities, and relatively minimal maintenance requirements as a key component in the creation of buildings that tread more lightly on the planet; while utilizing tools that streamline and make more integrated the design process itself. As designers and architects are increasingly asked to consider sustainable technologies and life-cycle assessments in the design of new buildings passive strategies that conserve energy will be as important as the more costly active ones that produce energy. In this light, a very old and proven material – concrete – can find new and important applications as we move into what promises to be an exciting time for design and construction.

REFERENCES

[1] Garber, Richard, "Optimization Stories: The Impact of Building Information Modeling on Contemporary Design Practice" *AD Architectural Design*, V. 79, No. 2, April 2009, pp. 8

[2] See http://www.solardecathlon.gov/

[3] See http://www.superiorwalls.com/