- Innovate - Evaluate - Learn - : The Importance of Iterative Research

Within the profession in general, there has never been a consistent pattern of innovation, evaluation and learning applied to the design of housing (Plunz 1990).

LISA D. IULO
Pennsylvania State University

SHAHRZAD FADAEI
Pennsylvania State University

KYLE MACHT
Pennsylvania State University

MINA RAHIMIAN
Pennsylvania State University

DAVID RILEY
Pennsylvania State University

R. ALLEN KIMEL
Pennsylvania State University

Affordable, sustainable, well-designed housing is a rising concern. While we have amassed significant knowledge into methods for realizing comfortable, healthy, sustainable housing, through Design-Build programs in post-professional education throughout North America, more information is needed on the long-term performance of projects. It is through the acquisition and evaluation of housing performance data that we can close the loop and move beyond "one-off" construction towards meaningful change in addressing responsible affordable housing. The necessity for a reiterative loop in housing research that considers project evaluation is widely acknowledged. Goals of the iterative process are to synthesize information from previous projects to yield new knowledge, disseminate findings to improve home performance, and implement new information into future Design-Build projects. But the methods for evaluation and, more importantly, dissemination of knowledge are only beginning to emerge, if at all. Dialog around these topics is necessary to improve the delivery and efficacy of affordable housing and Design-Build as research, pedagogy and practice.

This paper will present emerging protocols for project innovation, evaluation, and iterative learning being developed by a multidisciplinary team of faculty, graduate and undergraduate students involved in the Energy Efficient Housing Research group at Pennsylvania State University. The research group is dedicated to the investigation of the entire "life-cycle" of housing – design & construction methods through performance evaluation and optimization – in order to inform more responsible housing solutions for more resource conscious living. In our research, responsible housing means well-designed energy-efficient housing that is affordable over the entire life cycle of the home. Affordability addresses both the initial costs of providing housing and the long-term energy-related expenses carried forth by the resident. One of the foci of the research group is the establishment of tools and methodologies for evaluation that contribute to reflective learning and improving the design of subsequent projects. The work that will be presented has grown out of involvement on multiple Solar Decathlon and affordable housing projects undertaken in collaboration with a local housing authority. The paper is a reflection on previous projects in the interest of identifying opportunities as we embark on another ambitious Design-Build project.

INTRODUCTION

Pennsylvania State University has a successful repertoire of sustainable housing projects including and evolving from the Solar Decathlon homes, American Indian Housing Initiative, Union County Energy Efficient Housing Program projects, and the GridSTAR Smart Grid Experience Center. Each project demonstrates the importance of a holistic approach and the necessity for establishing local connections and reinforcing community development in realizing a replicable model for sustainable housing. These pilot projects have provided significant insight as a framework for achieving more affordable and sustainable homes and are contributing to the pursuit of a model to inform broader efforts. For this goal to be achieved we need to demonstrated performance of projects over time. Towards that end, the Energy Efficient Housing Research group an outreach arm of the Hamer Center for Community Design Assistance is engaging in an iterative process of “innovation, evaluation, and learning”. [1] Almost twenty five years after Richard Plunz’s critique in the preface to *A History of Housing in New York City,* Author Ron Dulaney still identifies a “gap between the potential value of architects and their actual effectiveness at realizing widespread relevancy, innovation and change in improving the quality and attainability of affordable, owner occupied housing and how this gap may contribute to the undervaluing and marginalization of architects’ efforts to address affordable housing needs in the United States”.[2] Dulaney reveals three strategies for “greater effectiveness” in addressing income-affordable single-family housing: 1) cross-disciplinary collaboration; 2) understanding and targeting affordability “to direct efforts toward local and regional needs” and; 3) “to approach the design of low and moderate cost housing with a research rigor parallel to the scientific method…”. [3] All three strategies are essential to our work, however establishing the means to ensure that results can be quantifiable and repeatable has been a challenge. Moreover, although there are impressive precedents for Design-Build-evaluate projects - notably U.VA’s ecoMOD and the work of Onion Flats in Philadelphia - there remains a dearth of shared data and methodologies.[4]

EEHR

The Energy Efficient Housing Research (EEHR) group at Pennsylvania State University is a multidisciplinary team of faculty, graduate and undergraduate students dedicated to the investigation of energy efficient, affordable and sustainable housing - from design and construction methods through performance optimization – in order to inform better housing solutions and more resource conscious living. A LCA (life cycle assessment) approach that considers planning, design, construction, operations, monitoring, assessment and reflection is used to inform and re-inform affordable, sustainable, energy-efficient housing applying an integrative design process. The projects undertaken by EEHR address applied strategies and solutions for realizing tangible, replicable models for affordable, sustainable housing that are locally appropriate and address transforming markets and demographics. Over the past few years, EEHR has attracted interest from and relationships with local affordable housing providers.

SCCLT GREENBUILD

Most recently the State College Community Land Trust (SCCLT) approached EEHR for guidance. Since the mid-1990s this non-profit housing assistance organization has been helping income-qualified individuals and families purchase homes in State College, PA (where Pennsylvania State University is located). SCCLT helps to reduce the cost of buying a home by holding the land permanently in trust, which allows the prospective homeowner to apply for a mortgage based only on the cost of the house, effectively reducing the cost of purchasing a first home by as much as 30 percent (www.scclandtrust.org). Historically, SCCLT has purchased, renovated and resold existing homes in the Borough, and Initially they approached EEHR to learn about energy efficiency retrofit measures. Shortly after our initial meeting, SCCLT had the opportunity to purchase a highly visible site to embark on their first new build. The site is approved for the construction of a duplex, which is consistent with the surrounding community fabric. Having seen a highly energy-efficient and affordable duplex project that EEHR consulted on for the Union County Housing Authority (discussed below), the land trust was interested in whether this project could be adapted to their site. Instead it was determined that a university/community partnership to design the project would be mutually beneficial. The SCCLT project is an opportunity for cross-disciplinary student and multiple faculty engagement that has the potential to leverage existing connections and inform involvement in ongoing educational and research initiatives. There is a large low- and moderate-income population in the Centre County region, and Pennsylvania's modular housing industry may also prove advantageous. Partnership with Pennsylvania State University will provide the SCCLT with added value through design expertise, increased visibility, and potential project donations and sponsorship. It is hoped that the project will provide a "model" for affordable, sustainable housing that will benefit the local community and future projects. As noted above, the question of what constitutes a "model" remains unclear. More importantly, the outcomes of this partnership with SCCLT cannot afford to be experimental, therefore, prior to launching into a MoU with SCCLT for the design of the new duplex, EEHR is reflecting on past projects to inform success on this new initiative.

BACKGROUND PROJECTS

MORNINGSTAR PA:

Concept: The MorningStar Pennsylvania (PA) home was designed and constructed by a collaborative interdisciplinary Pennsylvania State University team for the US Department of Energy's 2007 Solar Decathlon competition. Today the house stands on Pennsylvania State University's University Park campus as part of the Hybrid and Renewable Energy Systems (HyRES) Lab, "utilized to study energy related technologies and strategies on the residential scale."[5] The approximately 800 s.f. net-zero-energy MorningStar PA, constructed primarily by students, represents a "hybrid prefabricated/site-built system for green residential construction."[6] There are three primary components of the home: a modular technical core; an open living space; and a 'breezeway' that serves as a buffer and circulation area between the core and living space. Transportability played a major role in the design and construction of MorningStar Pennsylvania.

Strategies: A goal of the MorningStar concept was to utilize economies of scale, with the prefabricated technical core representing a standard module that can be mass-produced and shipped to any location. This core organizes the home's service program and contains the building MEP systems. The living space – including areas for studying, relaxing, dining and sleeping – is designed to be site-specific, utilizing local materials and, combined with the breezeway, represents ideals of passive solar design. The main mechanical heating and cooling system is a ground source heat pump with a ducted distribution system. Hot water, utilized for radiant heating and domestic hot water, is fed via several sources including evacuated-tube solar

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thermal, scavenged waste heat, the ground source heat pump, and backup electric boiler. MorningStar PA has two strategies for electric energy collection, conversion and storage – a primary AC system with dual solar arrays and a DC system powered by east and west façade arrays of solar slate cladding. Additionally the HyRES Lab demonstrates residential wind generation, advanced lighting, air-source heat pumps, energy recovery, and advanced energy storage including an integrated electric vehicle.

Monitoring & evaluation: Since completed MorningStar PA has served as an education resource and research facility. The systems and data collection infrastructure are constantly in use to monitor and learn about performance in relationship to weather patterns and reconfiguration of controls. Over the past several years, several monitoring systems and data collection services have been explored in order to better understand and demonstrate sustainable energy utilization and behavior

MORNINGSTAR MT:

Concept: MorningStar Montana (MT) was designed based on the MorningStar concept by the 2007 Pennsylvania State University Solar Decathlon Team and built through an integrated education and research program called the American Indian Housing Initiative (AIHI). It is a 1,215 square foot two-bedroom home built for the Northern Cheyenne Indian Reservation in southeastern Montana. MorningStar takes its name from the Cheyenne people and, like Venus 'leading the sun to a new day', was conceived to be a marketable prototype for the first solar home in a community. MorningStar MT demonstrates the adaptability of the MorningStar design concept and how an affordable and regionally appropriate version would take shape.

Strategies: MorningStar MT's highly insulated technical core was built by the 2007 Pennsylvania State University Solar Decathlon Team in a warehouse on Pennsylvania State University's campus.[7] The module was trailered to the site in Montana and set on a pre-constructed crawl space. Volunteer labor (mostly students participating in AIHI) built the site-specific living spaces of the home on a slab comprised of an exposed concrete floor with extruded polystyrene insulation beneath it. The walls were built utilizing a hybrid concept of structural insulated panels and strawbales. SIPs were used around the windows to create "window bucks" which allowed for

Figure 1. MorningStar PA, installed on the National Mall in Washington DC, during the 2007 Solar Decathelon 2007

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the ease of window installation and provided structure. Stucco covered strawbales were set between the window bucks. A SIP roof spans trusses that rest on top of the window bucks. Polycarbonate panels stretch across the north side of the breezeway allowing for ample daylight without significant heat loss. The systems within the MorningStar MT were selected and integrated to be simple, affordable, and high-performance. A high efficiency propane boiler with radiant floor distribution system provides heating and no cooling system is required due to the floor's thermal mass and daily temperature swings. Solar thermal evacuated tube collectors heat the domestic hot water and a grid-tied photovoltaic array generates enough power for the home's electrical needs.

Monitoring & evaluation: Since its completion, MorningStar MT has housed visiting faculty of Chief Dull Knife Community College. While there is currently no technical monitoring system in the house, the occupants have provided deeper understanding of the comfort and low-energy characteristics of the home and confirmation that the fuel costs have been extremely low in comparison to other homes in the region. A testament to the resiliency of the design, MorningStar MT was the only home in the area to maintain power during Montana's destructive fire in 2012.

NATURAL FUSION SOLAR HOME:

Concept: Natural Fusion was Pennsylvania State University's entry for the 2009 Solar Decathlon competition. The 772 SF solar home features an open, adaptable public space and a single bedroom. An operable south façade of tri-fold doors allows the inhabitants to expand the living space to a large exterior deck. Smaller private gardens to the east, off the bedroom, and at the north side of the home create visual and physical connections where inhabitants can relax and become immersed in their surroundings. Exposed wood trusses, reclaimed oak and slate flooring, custom furniture, a spacious cooking and preparation area with energy efficient appliances, and a comfortable color palette characterize the warm interior space. Abundant natural daylight through the south façade and clerestory windows reduces the need for additional lighting and the space feels deceivingly large. The core of the home is the "Nexus," where the innovative and sustainable technologies integrate the essential systems of the home (including the bathroom and mechanical space). The Nexus is aesthetically blended with a central "Life Wall" of herbs and a variety of plants that

Figure 2. MorningStar MT construction sequence

emphasize the home's concept. Continuing on the north façade of the home, the Life Wall dissolves into a heat-treated poplar rain screen exterior cladding.

Strategies: The Natural Fusion home was built as one module inside a modular housing plant to increase control over quality and speed of construction. Aside from an exposed timber-frame post and beam structure, fairly typical modular framing techniques were used, and the home was highly insulated for improved energy performance.[8] The basic building envelope was completed in the modular plant and then transported to Pennsylvania State University's campus where the student team finished the home. Solar elements of Natural Fusion include a unique refillable water bladder for added thermal mass to absorb solar radiation during the winter and three solar-electric systems: the north roof showcases a green roof integrated photovoltaic array (GRIPV); the south roof utilizes Solyndra panels placed above

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Figure 3. Natural Fusion Home as completed for the 2009 Solar Decathlon competition

a white roof; and functional solar fins on a south-facing awning track the sun and provides shade. Two vertical flat plate solar thermal collectors with a passive solar thermal pump system are integrated into the south facade. Two mini-split heat pumps provide the primary heating and cooling and an energy recovery ventilation system provides fresh air.

Monitoring & evaluation: After the competition Natural Fusion was purchased by Bayer Material Science to serve as a research facility and meeting place on their Pittsburgh campus. The home was remodeled slightly to accommodate a conference room and conform to different codes. Noveda, a commercial energy monitoring service was utilized to monitor electricity use and production, the mechanical systems, major appliances, plug loads and lighting loads in the home. Since Natural Fusion is no longer being used as a home, the monitoring of some of the systems no longer proved useful for research.

GRIDSTAR SMART GRID EXPERIENCE CENTER:

Concept: The GridSTAR center (Grid Smart Training and Application Resource Center) includes a grid interactive smart house built within a highly monitored microgrid that is part of the larger unregulated grid located in the Navy Yard in Philadelphia. The exterior of the GridSTAR Home is typical of many American subdivisions. Siding, roofing, porch and deck component materials and colors were selected to have wide “curb appeal” due to the highly prominent location. Functionally the home is a research and training facility coordinated by the Department of Architectural Engineering at Pennsylvania State University and industry partners as a part of the DOE-funded GridSTAR Center. One of the ultimate purposes of the home is to demonstrate a functional environment that is both efficient and economically viable as a grid-interactive home.

Strategies: GridSTAR was constructed from seven modules assembled in a home manufacturing facility to reduce costs and improve quality. Best practices for super-insulated, energy efficient homes, many of which are showcased on the DOE Building America website, were highly considered in all aspects of construction. Signage throughout the facility and on the GridSTAR website provides comprehensive explanations and details highlighting the residential measures employed.[9] As a grid interactive smart house, the experience center is equipped with cutting-edge high-efficiency residential technology including photovoltaic panels for electricity generation, photothermal absorption system for hot water heating coupled with energy storage and multiple home energy management systems and a secure communications network to enable participation in demand response programs.

Monitoring & evaluation: The GridSTAR Home offers scholars and educators a setting for the plug and play testing of the smart grid components and system configuration. The building is finely instrumented with various sensors monitoring surface temperature, relative humidity, heat flux and moisture content. Run 100% electrically, a key objective of the GridSTAR is to show how a house could be resilient to grid outages and also respond to the wholesale electric price signals as a part of a larger development of smart-grid interactive houses. Therefore, management and control of the electric grid requires that energy use and power quality is collected and analyzed in real time to inform decisions about battery use, temperature setpoints, and occupant behavior.

Currently three research oriented monitoring systems are equipped in the house:
1) A Sunverge Integration System that captures the solar energy and stores it for peek need thereby optimizing peak load reduction, improving grid reliability and maximizing return on renewable energy investments. It also shows the energy trading between the solar system, the grid, the battery and the house as a network.

2) Two multifunction Eaton Xpert Power Meters that provide power quality analysis displaying real-time power consumption information and energy trading between the house and the grid.
3) A Forecast EnergiStream system for real-time energy measuring with a user interface that displays energy consumed by residential equipment and system loads.

UCHA ENERGY EFFICIENT HOUSING PROGRAM DUPLEX

Concept: The final case study is the first project of the Union County Housing Authority’s Energy Efficient Housing Program. Located in Lewisburg, Pennsylvania, the duplex home was intended as model for building energy-efficient affordable homes on vacant sites in small towns. This approach addressed the need for quality housing to serve an aging population as well as to revitalize existing communities. Each home is approximately 1000 square feet and designed for universally accessible single floor living. A semi-finished room on the second floor adds flexibility to the program.

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Figure 4. GridStar Construction and educational workplace

Strategies: To control costs and ensure a replicable model, a priority of the project was to use readily available off-the-shelf residential building methods and technology. The design team implemented an intensive integrative design process to enable appropriate planning and adaptability of the prototype. The project followed a conventional design-bid-build process, and a bid from a modular housing provider came in 30 percent less than conventional construction bids. Therefore, A 'whole-house' modular approach was employed and 90 percent of the EEHP duplex was completed in a local manufacturing plant. Comprised of four building modules, oversight during construction resulted in more careful construction and sealing of gaps, significantly eliminated air infiltration and resulting in a "tighter" building. Some commissioning and third-party inspections for Energy Star and 'green' home certification also took place in the factory prior to delivery. The homes' materials were highly durable, renewable, recycled and recyclable, and whenever possible, locally manufactured. A highly energy-efficient building envelope minimized the need for space heating and elaborate conditioning systems. A single compact mini-split heating and cooling unit was used to condition the entire home. A programmable heat recovery ventilation (HRV) system and a hybrid hot water heat pump were selected for long-term energy savings and improved indoor air quality. All lighting, appliances and fixtures were Energy Star rated or otherwise highly energy or water efficient. These measures resulted in homes that are 56 percent more energy efficient than a code home, and each home is "solar ready." [10]

Monitoring & evaluation: Energy monitoring technology was installed to provide live feedback to the occupants with data remotely accessed for continuous optimization of the homes. This feedback will also inform further developments of the model. Outside of the mission of the housing authority, Pennsylvania State University was invited to monitor and evaluate the performance of the homes post-construction, in the interest of providing information to other builders and housing providers. The

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Duplex provides a unique opportunity for better understanding occupant impact on home energy performance since the two attached and identical homes are each resided in by a single female occupant of similar age. The Energy Detective (TED) electricity monitors measure overall home energy use, displaying real-time data on a wireless display monitor located in the kitchen of each home and through an online dashboard. Overall usage can be compared with monthly utility bills. EEHR is exploring the feasibility of installing load-specific monitoring and protocols for feedback to residents that may influence energy usage.

LESSONS LEARNED

Below we identify three areas where these prior projects can serve to inform the upcoming SCCLT project:

Design & Construction Process: The design of the SCCLT project must respond to the unique mission of the land trust while informing what sustainable and affordable means to our specific community. Good design is the foundation for energy efficiency, affordability and sustainability, therefore design will factor highly into the success the SCCLT GreenBuild project.[11] Quality of construction will also be fundamental to project's performance and ultimate success. To assure a durable and long-lasting project (and limit liability), the SCCLT projects will be professionally constructed with the oversight of a construction manager (CM). It is anticipated that the CM will be engaged early and participate in the design process. Regarding construction, although arguable, our experience with the UCHA duplex and GridSTAR shows that modular construction holds potential for achieving integrative, high-performance homes. Where, then, is the opportunity for student and volunteer engagement? The 'hybrid' prefab/site-built concept seen in the MorningStar homes provides a precedent whereby the more complicated construction and integration of systems can be overseen in a controlled manufacturing environment while still affording a design that will take advantage of the particular slope, climate and

Figure 5. Union County Housing Authority Duplex

mountain views of the SCCLT site. Building off of Natural Fusion, potential exists for the primary structure and building envelope to be prefabricated and for students to design and build the "value-added" elements necessary to make a house a home. Moreover, both the university and its larger community can be engaged through the use of local skills and materials. For example in MorningStar MT children and artisans on the reservation contributed to the finishing details of the home.[12] New markets for resilient home energy systems and grid interaction need also be explored as applicable to the home energy economy sought by the SCCLT. Through community and industry partnerships, the modest budget of the SCCLT might be stretched for even higher performance and greater value.

Strategies: The projects above taught us to acknowledge the proverbial "tried and true." Some building methods, technologies and equipment and certain innovations are repeatable and have been proven to improve energy performance or decrease energy use in residential construction. Best practices (including essential passive solar and sound building science principles) can be applied to building form, program, material selection and, to some extent, construction assemblies that are regionally appropriate, support local business and provide opportunities for "value-added" Design-Build. Some equipment, such as mini-split heat pumps for heating and cooling, energy recovery ventilators, and innovative water heating technologies were tried in the different precedent projects and were noted to be successful regardless of the size and program of the projects. Pennsylvania State University is fortunate to have the GridSTAR center, where students, staff and the general public can come to understand systems and the latest in super high-performance residential construction, learn about best practices and practice installing solar systems and related technology, and generally experiment for the betterment of future projects. The center in itself is seen as a model for other academic institutions pursuing Design-Build.

Evaluate and Assess: We see affordability and energy-efficiency as related. To be affordable, project costs and performance will need to be quantified according to a life-cycle approach and long-term housing-related expenses need to be heavily factored into overall affordability. Lowering these "carrying costs," by reducing utility expenses through energy-efficiency, energy management, and other high-performance design measures, may ultimately make the difference as to whether someone is able to afford their home long-term. Therefore, effective measures for monitoring home performance and provide useful feedback to the residents is necessary. Multiple monitoring and data collection systems were explored in the case study projects. However, an obvious choice for implementation in the SCCLT home is yet to emerge. In some cases the products used were unreliable in their functioning or the information collected. Others are too complex or expensive to be used or maintained by the eventual residents. If devices provided by different companies are used, monitoring of multiple online dashboards is currently necessary and cumbersome. Separate, but related protocols are needed to address project monitoring, assessment and resident feedback.

CONCLUSIONS

Because each project is contextually and culturally different it is not possible for any other project to be an actual model for the SCCLT duplex - one design doe not fit all. However, the demonstration projects above represent several opportunities for Design-Build that allows flexibility for site-specific design, supervised construction of the more complicated (but necessary) elements of construction, and opportunity for student and volunteer engagement in the design and construction of the homes.

ENDNOTES

1. In the preface to A History of Housing in New York City, Plunz discusses a "polarization" between architecture and civil engineering in the mid- to late-nineteenth century "through the respective guises of 'aesthetics' and 'utility'" that created the challenge in architecture that "there has never been a consistent pattern of innovation, evaluation, and learning applied to the design of housing". Plunz, R. (1990). *A History of Housing in New York City*, Columbia University Press; Reprint edition: pg. xxxiv-xxxv.

2. Dulaney, R. (2013). "The low-income single-family house and the effectiveness of architects in affecting affordability," *ARCC Journal*, Vol. 9; Issue 1: pg. 24.

3. IBID: pg. 29.

4. Dulaney notes "architects have traditionally neglected to disclose data and methodologies related to their designs and subsequent constructions" and emphasizes the importance of this step in demonstrating that "their efforts are effective" (op. cit., pg 31). Michael Weinstock makes a similar argument in "Can Architectural Design Be Research." He concludes that "longer term research goals have to be conducted through a series of realized experiments," (Weinstock 2008, pg. 114). In "Research in Design Planning Doing Monitoring Learning," Stephen Kieren contrasts architecture with product design, also arguing for an iterative process of reflection and improvement that embraces "measuring performance and learning as the precursors to further planning and doing" (Kieren 2007, pg. 27). See Weinstock, M. (2008). "Can Architectural Design Be Research?" Architectural Design Vol. 78 Issue 3: 112-115 and Kieran, S. (2007). "Research in Design: Planning Doing Monitoring Learning." Journal of Architectural Education Vol. 61 Issue 1: 27-31. These articles partially inspired the study of past Pennsylvania State University projects discussed herein.

   For information on the work referenced, see: *Sustainable, Affordable, Prefab*: The ecoMOD Project by John D. Quale and McDonald, T. (Onion Flats LLC), "Pump-Up the Volume – Passive House, Mass Production and Multi-Family – Can HOUSING save the planet?," in *Proceedings of the 2nd Residential Building Design and Construction Conference*, February 19-20, 2014: 2-17. Available at http://www.phrc.psu.edu/portals/phrc/assets/docs/Publications/2014RBDCCProceedingsFINAL.pdf (accessed 25 September 2014).

5. See: http://sustainability.psu.edu/learn/students/programs/hybrid-and-renewable-energy-systems-hyres-lab (accessed 27 September 2014).

6. Iulo, L.D. (2009). "Hybrid Prefabrication: prototypes for green residential construction." Proceedings of the 2008 Northeast Fall Conference of the Association of Collegiate Schools of Architecture - Without a Hitch: New Directions in Prefabricated Architecture, Peggi Clouston, Ray Kinoshita Mann and Stephen Schreiber (eds.). University of Massachusetts, Amherst: 260.

7. MorningStar MT's technical core module was constructed using panelized 2x6 walls with damp spray cellulose insulation set on a floor structured with engineered wood joists. The flat roof was insulated with dense packed cellulose insulation. The living space envelope was constructed around the prefabricated core site using Strawbale and SIP construction.

"Ultimately, however, architects must demonstrate that their efforts are effective. This requires not only a summary of achievements, but also the data and methodologies [emphasis added] that contributed to them, and 'failures' as well as successes encountered during the work… Architects have traditionally neglected to disclose data and methodologies related to their designs and subsequent constructions."[13]

EEHR hopes to provide a platform for reflection, reiteration, and replication. Important to the Pennsylvania State University/SCCLT initiative is consideration of residents and local connections/community development as an integral extension of any effort. While education and outreach are central ambitions, meaningful and transformative research is important but outcomes cannot be experimental or a burden on future residents. Therefore an iterative, life-cycle approach for linking values and informing responsible decisions in the planning, design, construction and operation of sustainable, affordable housing is necessary. Energy consumption behavior, quality of life issues and policy transformation are important to this initiative. Theoretical frameworks will be undertaken to better understand these relationships, but proven methodologies are sought after. We hope the ACSA dbX can be an ideal venue to inform about project successes and failures - a place where those engaged in Design-Build can innovate, evaluate and learn…together.

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8. Natural Fusion's floor was framed first, using floor trusses instead of conventional floor joists. The open web of the trusses made it easier to run piping, wiring and ductwork below the floor of the home from the centralized mechanical space. The walls and roof were framed using 2x4 wood studs spaced 24 inches on center, reducing the amount of framing lumber required and maximizing space for insulation. The walls, roof, and floor were insulated with a closed cell polyurethane spray foam. The walls had an additional inch of foil faced board insulation to reduce thermal bridging and to act as the drainage plan being the heat treated poplar rain screen. A phase-change material was installed on the interior surfaces of walls and ceilings, directly behind the drywall. These sheets of thin bubble-wrap-like membranes containing cellular pockets filled with soy-based chemicals that changed phase to help regulate the home's interior temperature. An alternative to thermal mass, this highly engineered material liquefied by absorbing heat when the interior temperature of the home increased and solidified by releasing stored heat when the space cooled down.

9. See: https://smartenergyacademy.psu.edu/gridstar/ (accessed 27 September 2014).

10. Some portions of this text originally appeared in: Iulo, L.D. (2013). "Modular Building – three scales/three strategies," in High Performance Homes, Their Design and Construction: New Materials, Renewable Energies and Integrated Practice, Franca Trubiano (ed.). Routledge: 283-295.

11. The parallel between beauty ("good design") and high-performance is increasingly recognized. Kieren, op. cit.: 30, states "We learn from the research and move forward toward even more beautiful and high performance solutions." Beauty is also one of the 'petals' of imperatives outlined in the Living Building Challenge assessment system (http://living-future.org/lbc/certification).

12. See: Iulo, L.D. & Riley, D. (2009). "The MorningStar: A Hybrid Concept for Community Building and Renewable Energy," Proceedings of the 38th National Solar Conference. The American Solar Energy Society, Inc.

13. Dulaney, op. cit: 31.