LEVERAGING THE U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON DESIGN CHALLENGE AS A FRAMEWORK FOR STUDENT-LED ADAPTIVE REUSE PROJECTS TO ADDRESS CONTEXT-SPECIFIC SUSTAINABLE DESIGN, HOUSING AFFORDABILITY, AND COMMUNITY RESILIENCE

Tom Collins, PhD, AIA, LEED AP,[1]
Daniel Overbey, AIA, LEED Fellow, NCARB, WELL AP, EcoDistricts AP[2]

ABSTRACT

This paper discusses the context, pedagogical approach, and design outcomes of two net-zero energy residential design projects completed by graduate architecture students as part of a comprehensive design studio course and submitted to the 2018 and 2020 USDOE Race to Zero/Solar Decathlon Design Challenge competition. The competition aims to give students real-word experience designing high-performance buildings by encouraging collaboration, involving community partners, and requiring a high degree of technical design development. Working within the competition parameters, two teams at Ball State University worked with outside partners to identify vacant/abandoned homes as a significant problem for rust-belt Indiana communities, and then focused their design efforts on high-performance retrofits of two blighted homes in Muncie and Indianapolis. Each project will be described in detail and the implications of the 2018 project on the 2020 project will be addressed. This paper will demonstrate that adaptive reuse projects can be used to engage students in context-specific challenges and to meet stringent high-performance design targets and thresholds. *(162)*

KEYWORDS

Adaptive reuse, Zero/Solar Decathlon Design Challenge, high performance retrofits, urban single-family planning, urban and community renewal

INTRODUCTION

Ball State University's Department of Architecture offers a NAAB accredited M.ARCH graduate degree. The curriculum for this graduate program contains a comprehensive design studio that focuses on integrated design and requires students to address issues related to technical design and systems in their projects. Although curricula have changed in the past several years

1. Assistant Professor of Architecture, Ball State University, Muncie, IN. Email: tdcollins@bsu.edu
2. Assistant Professor of Architecture, Ball State University, Muncie, IN. Email: djoverbey@bsu.edu

with corresponding changes to course numbers, the comprehensive design studio experience remains. The university also has a commitment to immersive learning, which aims to provide learning experiences outside the classroom embedded in the community. Courses that include an immersive experience are given opportunities for additional funding, resources, and publicity.

Since 2017, four graduate comprehensive design studios have satisfied departmental curricular goals and leveraged university-level support for immersive learning projects by having students compete in the Solar Decathlon Design Challenge (formerly known as Race to Zero). Of the 11 teams that have competed in the competition as part of the graduate-level comprehensive design studio, two teams competing in the 2018 and 2020 competitions have won prizes for proposals that focus on adaptive reuse of vacant/abandoned housing in rust-belt Indiana cities. This paper will describe these two proposals in detail and comment on lessons learned from these projects.

Race to Zero/Solar Decathlon Design Challenge Competition

In 2014, the US Department of Energy (USDOE) started an annual student design competition called Race to Zero (RTZ). To better align with the US DOE's Solar Decathlon program, RTZ changed names in 2019 to become the Solar Decathlon Design Challenge (SDDC). Now, a design challenge, a build challenge, and a local build challenge are all organized under the Solar Decathlon program umbrella. Despite the name change from RTZ to SDDC, the annual student design competition intent and structure remain much the same. RTZ began as a housing design competition but has expanded in recent years to include several commercial/institutional building typologies. For 2020, the six typologies offered are: Urban Single-family, Suburban Single-family, Attached Housing, Mixed-use Multi-family, Elementary School, and Office Building.

One of the primary goals of RTZ/SDDC is "the effective integration of building science principles and best practice guidelines for the building enclosure and mechanical systems" (NREL, 2018) as a means of preparing students for real-world challenges related to high-performance building design in the design and construction industries. RTZ/SDDC use USDOE's Zero Energy Read Home standard (ZERH, 2018) to establish a set of design criteria for students. The competition asks students to work in teams to design a net-zero energy ready building that meets the USDOE requirements. Teams are encouraged to work across disciplines and to engage community and/or industry partners outside the university. Teams compete in ten "contest" areas, which change slightly from year to year. For 2018, the contest areas were: architectural design; interior design, lighting, plug loads, & appliances; energy analysis; constructability; financial analysis; envelope performance/durability; indoor air quality & ventilation; mechanical, electrical, & plumbing systems design; innovation; and presentation quality. For 2020, the contest areas were: energy performance, engineering, financial feasibility, resilience, architecture, operations, market potential, comfort/environmental quality, innovation, and presentation quality. The inclusion of a "contest" related to resilience and carbon is a recent addition.

The two-stage competition runs from fall through mid-April and, as such, does not align perfectly with academic calendars. Many schools register in the fall, begin preparing, but do not start the design work until Spring Semester after the winter holidays. In this scenario, teams have approximately 11–12 weeks to complete their design proposals. There is an interim Progress Report due in February which determines who the finalist teams will be, the Final Report due in late-March/early-April, and then a series of juried presentations in mid-April organized as a weekend event at the National Renewable Energy Lab in Colorado. Due to Covid19, the 2020 in-person event was cancelled, and a virtual event was held in its place. Prizes are awarded at the event following the team presentations. For 2020, there were First-Place, Second-Place, and Honorable Mention prizes for each building typology. Generally, there are approximately 8 finalist teams per building type (e.g. 48 total teams). Teams come from around the world including India and Australia, but the majority of the teams are from US and Canadian institutions.

Adaptive Reuse

One of the hallmarks of RTZ/SDDC is that it allows student teams to address the shared competition requirements in their own unique ways. Teams have a great deal of freedom in the site/location they choose, the composition of their team, the partners they choose to engage outside the university, and aspects of the design they will highlight. Every year at the competition event, the wide variety of approaches and proposals is testament to the freedom given to the teams by the organizers.

A popular approach appears to be for teams to focus on a building design, development, or community problem that is relevant to a specific location—often a site in or near their universities—and to engage a community partner doing relevant work in that area. One of the most obvious challenges facing the post-industrial Indiana cities near the Ball State campus is the prevalence of vacant/abandoned homes throughout urban neighborhoods that have seen significant disinvestment and population loss in recent decades. This urban blight is an obvious need, and many students have become interested in addressing the complex issue of how to repair, restore, rehabilitate, and reuse this existing building stock.

Adaptive reuse projects are uncommon as design studio projects in schools of architecture. There are many valid reasons why design studios may shy away from such projects. Reusing an existing building requires access, which can be hard to arrange. Reuse projects also require existing conditions drawings as a starting point, which can be difficult and/or time consuming to generate. And, one of the best reasons is that existing buildings may limit or constrain the design decisions made by the students. Said another way, sometimes reuse projects can seem less architecturally compelling. Yet, we also know that existing buildings make-up the bulk of our building stock in the United States. Existing buildings are often prized for the character they contribute to urban neighborhoods and are a focus of historic preservation efforts. We also know that existing buildings perform very poorly compared to new buildings built according to modern codes. In this way, existing buildings become a great opportunity for performance enhancement. Finally, existing buildings are getting a lot of well-deserved attention recently for the amount of embodied energy and carbon that their existing materials contain. Saving existing building material helps reduce our greenhouse gas emissions. In this way, existing buildings become a crucial piece of global carbon mitigation.

Adaptive reuse proposals are gaining popularity in RTZ/SDDC as well. Anecdotal evidence suggests that only several projects of almost 50 finalists addressed the reuse of an existing building in 2018. In 2020, almost every building type had a finalist with an adaptive reuse proposal, which suggests that teams are recognizing the value of looking at existing buildings and that the competition supports those efforts.

In 2018, the Urban Single-family team began working with a community partner that rehabilitates existing housing in Muncie, Indiana. It seemed inevitable that the team would be proposing an adaptive reuse. The competition requirements for RTZ did not specify that projects had to be new construction, so the team took a chance knowing that a net zero energy retrofit of an existing abandoned house would add constraints to their proposal and could be a significant challenge in terms of detailing. Since 2018, we have had one team in each of the comprehensive studios take-on an adaptive reuse project. In this paper, we will focus on the 2018 and 2020 proposals because they were both Urban Single-family proposals for existing abandoned houses with different community partners in two different Indiana cities.

Urban Single-family Type

RTZ/SDDC provides very few requirements for the Urban Single-family housing type. The lot size is limited to 5,000 ft^2 (465 m^2), the building size can be 300–2,500 ft^2 (28–232 m^2), and the projects must meet the ZERH standard (NREL, 2018; NREL, 2020; ZERH, 2018; ZERH, 2019).

Design Studio Format

Over the past four years, Ball State University's graduate comprehensive design studios have engaged the RTZ/SDDC competition using a similar course format. The studio is 6-credit hours and meets 2–3 afternoons per week. Students create core teams of 3–7 students to work on one of the competition building types. Schools are not permitted to submit multiple team proposals for the same building type, which means that within a single studio you may have one Urban Single-family team, one Attached Housing team, etc. These core teams coordinate the project and are responsible for submitting the deliverables. The studio instructor acts as the primary advisor for the competition, and faculty in associated classes act as secondary advisors. Each year, the core teams work with students in other courses who contribute work to the project. For example, a building performance modeling course will run the energy and carbon simulations for the core team and we often have students in Construction Management who assist with the financial aspects of the proposal.

Industry partners from outside the university provide expertise in specific disciplines such as: green design, housing design, photovoltaic systems, HVAC systems, construction, real-estate trends, etc. These partners interface with the studio in different ways. Most often, the partners will come into studio for a design charrette, but we also have the teams correspond via email, web conferencing, etc. Community partners function as project clients. These organizations or individuals are involved throughout the process by providing background information, building tours, and connections to other professionals. In addition, they typically attend the student presentations/reviews.

RTZ/SDDC encourages a student-driven design process. Indeed, some teams at other schools engage the competition as part of extracurricular groups or clubs. However, Ball State always runs the competition through courses, which can be a benefit to teams because they have designated class time to work on the project. However, one downside to this is that students in the class often are unable to self-select to be in a class doing the competition. Therefore, the level of engagement and enthusiasm among students can vary. Every student in the class receives a grade for their progress and proposal. Having a relatively standardized format for running the competition through the comprehensive graduate-level studio has the added benefit of allowing new faculty advisors to join each year without having to create an entirely new course format.

CASE STUDY 1: MUNCIE RE-USE PROTOTYPE: REUSE, REBUILT, RETURN URBAN SINGLE-FAMILY PROJECT

Background

The *Reuse, Rebuild, Return* team project in the Urban Single-family division (henceforth referred to as RRR-USF) was submitted by Ball State University's R. Wayne Estopinal College of Architecture and Planning (CAP) as part of the U.S. Department of Energy's 2018 Race to Zero competition (NREL 2018). (Fig. 1) The RRR-USF team was comprised of a student/faculty team which included five graduate architecture students (M.Arch program), two undergraduate architecture students, four undergraduate construction management students, and one instructional faculty member, and two additional faculty members who offered periodic consultation with regard to construction cost estimating, community engagement, and energy modeling.

The framework of the 2018 RTZ competition offered a productive vehicle to pursue the course objective of the ARCH 501 Comprehensive Design Studio. The graduate-level studio focuses on the synthesis of a wide range of variables from diverse and complex systems into an integrated architectural solution. Students are required to demonstrate their ability to address issues related to environmental systems, site design, codes/regulations, structure, and technical documentation. The scope and type of project pursued in the studio requires applied research methodologies and an integrated evaluation and decision-making process across multiple systems to inform the design process. The studio was held on Ball State's main campus in Muncie, Indiana.

The ten "contest" areas of the 2018 RTZ similarly fostered a rigorous, comprehensive integrative design process. In addition, the competition encouraged student engagement with community and industry partners outside the university. The strategic community partner functions as the client for the building and the industry partners function as technical consultants.

FIGURE 1. Exterior view of the Reuse, Rebuild, Return prototype.

In the interest of aligning the goals of the studio project with those of the local community, the design studio established a direct engagement with several organizations in Muncie.

ecoREHAB of Muncie

ecoREHAB is a nonprofit organization whose mission is to advance its community through the promotion and practice of sustainable design, rehabilitation, and education. The most visible activity of ecoREHAB has been the transformation of abandoned houses in Muncie into durable, efficient, and green homes. Their projects to date have focused on single-family homes in the neighborhoods adjacent to the downtown that have high numbers of dilapidated, neglected, vacant, or abandoned homes. After rehabilitation, these homes are sold to qualifying low to moderate income buyers. Their work demonstrates that dilapidated homes can be repurposed thereby strengthening the neighborhoods they are in and providing affordable housing for the community.

Muncie Mission

Muncie Mission Ministries is a faith-based, not-for-profit agency that has focused on providing hope to the poor, needy and homeless in East Central Indiana for over 80 years. Muncie Mission works to end homelessness by addressing the physical, emotional, and spiritual needs of their guests by providing three meals a day, spiritual nourishment, and a place to sleep. Those recovering also receive counseling services. Muncie Mission also initiated the Liberty Street Recovery Program as a ministry centered on those struggling with addictions that strives to provide training for job readiness. The Mission's facility is located in the South Central neighborhood of Muncie, approximately a mile south of downtown. South Central is the poorest neighborhood in the city and its residents struggle with substandard housing, lack of services (including access to food), high unemployment, etc. In recent years, the Mission has undertaken the rehabilitation of dilapidated and abandoned homes adjacent to their facility as transitional housing for men coming out of their ministry programs. Muncie Mission and ecoREHAB of Muncie partnered to rehabilitate one of these homes and received funding through the local Ball Brothers Foundation to complete the renovation.

8twelve Coalition

The 8twelve Coalition is to improve quality of life as defined by residents of the South Central and Thomas Park Avondale neighborhoods of Muncie. Their work is rooted in connecting organizations with citizens to realize dreams and concerns of residents. One critical aspect of this work is that residents feel they own the successes achieved to ensure that long-term revitalization is impactful. Areas of focus are housing, business development, education, and area beautification. 8Twelve serves the neighborhood that was the focus of the ecoREHAB/Muncie Mission partnership.

Design approach

Studio vs RTZ Timelines

Although the 2018 RTZ timeline encourages team establishment and preliminary submittals over the course of the Fall 2017 semester, the effort of the RRR-USF team was bound by the University's Spring 2018 semester calendar. In general, the submittal milestones and other competition requirements for the RTZ are conducive to a semester calendar (e.g. the submissions occur in February, March, and April and end before the academic year finishes). This schedule alignment made the RTZ a viable vehicle through which to structure an integrative architecture studio. Appendix A includes an example of a team weekly report in which the members document progress toward goals including specifying % of team member time spent on each of the ten SDDC "contest areas," which function as an evaluation mechanism for integrated decision making throughout the design process.

Initially, the 8-students in the ARCH 501 studio were allowed to self-organize two groups of four. Then, each four-student group dedicated their efforts to a unique residential typology offered by the RTZ guidelines. This process of exploration and discovery was conducted throughout January 2018 in concert with ecoREHAB, Muncie Mission, and the 8twelve Coalition, who shared information on the property the students would use for their design, the neighborhood surrounding the property, etc. Industry partners were sought for periodic feedback. These advisors included a local electrical contractor who specializes in on-site solar electricity generation (Jefferson Electric), a housing design expert, and an Indianapolis practitioner and Ball State faculty member with extensive knowledge of high-performance green buildings.

After a series of reviews, the RRR-USF team dedicated their efforts to developing a scheme for further development. A Project Progress Report was submitted in mid-February, a Final Report was submitted in late March, and the team presented their proposal to a jury at the National Renewable Energy Lab in Golden, Colorado in mid-April as part of the Design Weekend organized by USDOE.

Re-Use Prototype

The community partnerships were predicated on the idea that one RTZ team in the ARCH 501 studio would focus on the adaptive reuse and rehabilitation of an existing, abandoned house that ecoREHAB and Muncie Mission had previously secured funding to renovate. (Fig. 2) Therefore, the team knew at the onset that they would focus on an adaptive reuse proposal. As previously mentioned, adaptive reuse was not a requirement of the 2018 RTZ. However, focusing on an adaptive reuse project allowed the Ball State team to distinguish their proposal from other RTZ teams (most teams seemed to focus on new construction) and to address a vital issue in the Muncie with local partners already engaged in community revitalization work (there are over 4,000 vacant or abandoned homes in a city of 70,000 residents).

Project goals

The RRR-USF team focused their efforts on a major renovation and retrofit of an existing, dilapidated worker's cottage on Liberty Street that would subsequently be acquired by ecoREHAB/Muncie Mission through a county tax sale process. To the end, the project team identified three overarching project goals.

Goal 1: Reuse building materials from the existing abandoned house in the retrofit project.

Adaptive reuse is predicated in the idea of reusing a building or part of a building in a new way or for a new purpose rather than constructing a new building. One major benefit of reuse is that material from the existing structure can be retained, reused, or reappropriated provided it is still serviceable. The RRR-USF team decided early-on to devise a material selection hierarchy to guide their design process. Reuse of existing material was determined to be the best option to save on material cost, landfill waste, and to take full advantage of embodied energy/carbon in existing materials. The only requirement for saving existing material was that it be safe,

FIGURE 2. Photographs of the existing Liberty Street house in Muncie.

low-VOC, and healthy for future occupants. If existing material was not sufficient, the second preference was for reuse of local salvaged material brought from off-site (e.g. old panel doors, flooring, etc.). The last preference was for new material when necessary.

Goal 2: Rebuild an abandoned house to be a high-performance pilot house.

The design team carefully considered important questions related to adaptive reuse projects. What makes a house worth saving? How much saving is enough? Can the saving be symbolic? Existing houses are a part of the character and history of a city and, as such, they tell important stories. They can provide physical evidence of community revitalization. They can demonstrate thriftiness/resourcefulness by using what a city already has. They can even reflect/mirror the experience of users. In our case, the house was intended for men coming out of homelessness—transitioning to a new way of life much the way a house rehab begins a new life for an existing structure.

Goal 3: Return a rehabilitated house as a prototype for future retrofits in the neighborhood.

The Liberty Street house is a typical worker's cottage house type found throughout the older neighborhoods in Muncie. This typology was common in the late 19th/early 20th century when Muncie was experiencing population growth due to rapid industrialization. These houses were quickly and simply constructed for workers. They are one-story with a cross gable, a side entry porch, and a shed roofed extension in the back. The attics are typically spacious but unfinished. The community partners were interested in the idea of using the Liberty Street house as a prototype of how to reuse these common worker's cottage houses. The idea was that, if a set of procedures or strategies for a deep energy retrofit could be devised for the Liberty Street house (an example of a worker's cottage that was in particularly poor condition), then it could be used as a model for wide-scale retrofits across the city.

Design highlights

Site: 1810 South Liberty Street

Muncie Mission and ecoREHAB selected the project site because it is across the street from the Mission's facility, it is directly next door to another existing house that the Mission rehabilitated for transitional housing, and because it was a badly dilapidated and abandoned property-an eyesore for the neighborhood. The house sits on a narrow urban lot that is approximately 5,000 square feet. A city alley runs along one side of the lot. The existing house was likely built around 1890 and is approximately 1,000 square feet on one-level. Again, the house is very typical of many older worker's cottage-style homes in the city. The house, while old, had been altered so much over time that very little of the historic character or finish materials remained. This was not a deep energy retrofit of a house with historic character-defining features. Instead, this was a retrofit that involved a careful reconfiguration of the interior layout to suit a new user group. (Fig. 3)

FIGURE 3. Floor plan of the Reuse, Rebuild, Return prototype.

Structure: The challenges of salvaging an old foundation and framing.

The deep energy renovation proposed by the RRR-USF team is predicated on salvaging the framing of the existing 1890s structure. However, the foundation of the building was in very poor condition. An inspection revealed that the crawlspace was very minimal with soil just inches below the floor joists and the foundation itself was 2 wythes of brick that extended only 6–10" below grade with no footing. There was significant settlement throughout the house. The community partners told the team that they would still rehab the house even if a new foundation was necessary.

Envelope: Continuous thermal barrier solution.

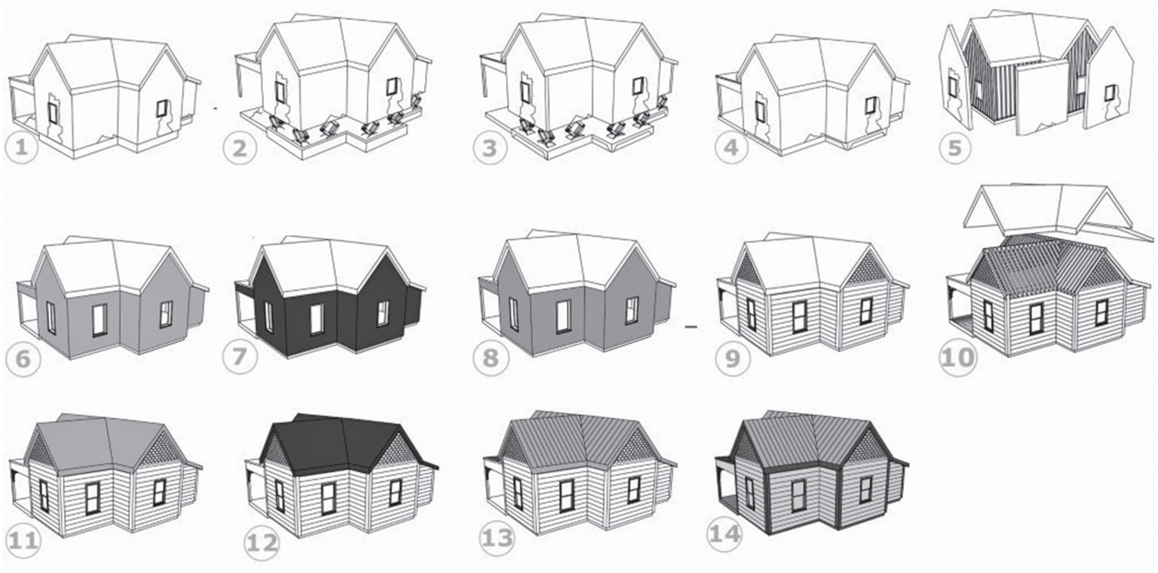
One of the biggest challenges with an adaptive reuse is achieving continuity of envelope control layers with existing envelope assemblies such as walls, roof, and foundation. To achieve the high-performance, net-zero energy ready goals of the RTZ competition, it was important for the envelope of the RRR-USF design to have as much continuity of control layers as possible. Although replacing an entire foundation on an existing house would be challenging and costly, it also allowed the team to achieve control layer continuity at the ground—something that would be impossible in most retrofits. The team chose to replace the crawl space with an insulated slab on grade, which addressed moisture and radon mitigation issues below the house. All that was salvageable of the existing envelope was the wall framing and some board sheathing. This meant that interior wall cavities could be filled with dense-packed cellulose insulation and continuous exterior XPS rigid insulation could be placed beneath the new siding. The WRB attached to the sheathing covered with the continuous insulation allowed for dramatically better control of air, bulk water, vapor, and heat than would have otherwise been possible on an existing house. This coupled with new triple-glazed windows that had a U-0.24 and SHGC of 0.30 created a good thermal wall enclosure. Since the attic was not used, the team opted to use a cold roof design and insulate the ceiling joists with dense packed cellulose to achieve an R-49. Figure 4 below illustrates the scoped envelope improvements. Steps 1–4 involve jacking up the existing house, removing the existing inadequate brick foundation, pouring a new insulated slab on grade, and leveling the house frame on the new foundation. Steps 5–9 involve removing the existing wall assemblies down to the studs, insulating the stud cavities, installing new sheathing installing new water, air, and vapor control layers, covering control layers with a layer of continuous rigid insulation, and installing the new exterior cladding. Steps 10–13 involve insulating the attic ceiling for thermal control, removing the existing roof, installing a new roof for bulk water control. Step 14 shows the completed house.

Mechanical / Electrical / Plumbing

Following the implementation of architectural solutions, the remaining heating and cooling loads were quantified and further assessed using BEopt. The team decided to pursue a 100% electric solution with the RRR-USF prototype. The team also closely adhered to the U.S. Department of Energy's Zero Energy Ready Home National Program Requirements (ZERH, 2018).

A ductless mini-split heat pump system was selected in order to provide both heating and cooling. Sized to account for the peak heating and cooling hours, the system comprised of three zones: one for each bedroom/bathroom and one for the common spaces. The three indoor units are linked by closed loops of refrigerant lines to the outdoor unit to provide heating and cooling to each zone uniquely. This arrangement provides the two residents with individual control of

FIGURE 4. Diagram outlining the scoped envelope improvements for the Reuse, Rebuild, Return prototype.



heating/cooling in their private spaces and helps to account for different cooling/heating needs on the south/bedroom side of the house. Another benefit of the ductless mini-split system is it did not require ductwork runs, which would have been problematic particularly if they had to be run outside the thermal envelope in the attic. It also eliminated the need for a gas line, which saved cost.

A dedicated outdoor air system (DOAS) was specified to circulate fresh air throughout the house, using an energy recovery ventilator (HRV). In addition, the team designed for an alternate hybrid ventilation system using a whole house fan to be used in conjunction with operable windows during shoulder seasons to provide fresh air and some passive cooling. EcoREHAB had never retrofitted a house with a dedicated ventilation system, but this system was required by the ZERH standard due to the face that a mini-split heat pump provides no fresh breathing air. In this way, the team pushed the partner to consider something new in their retrofit process.

Plumbing was carefully designed to not run in any exterior walls and to limit pipe runs in the interior. An extensive cost/benefit analysis was conducted to determine the domestic hot water heating system. Ultimately, the team selected an electric tankless on-demand system based on cost, maintenance, and acoustical properties.

All appliances were presumed to be ENERGY STAR qualified (when applicable) and the project specified 100% LEDs for lighting. Since the building users are men who are transitioning out of homelessness, the team decided to provide sufficient wired interior lighting rather than relying on occupant-supplied plug-in lighting. This also helps to ensure that the lamps used in the building lighting are predominantly LED.

On-Site Renewable Energy

The RRR-USF engaged local professionals Jefferson Electric for the design of the renewable energy system. Based on the predicted annual energy use, the team selected a 6.4kW PV array. The array uses power optimizers to allow panels to function independently. The team calculated a 12.8 year simple payback on the system. The cross-gabled geometry of the existing roof was a significant challenge for the team in terms of PV yield. A sufficient number of panels could not be located on the south-facing roof. The team explored having smaller arrays on different roofs before deciding to design a new carport in the back yard that supported the entire array. The budget for the project did not support the cost of the renewable energy system. The RTZ guidelines only required proposals to be zero energy ready. Therefore, the PV array was designed to be a project add-on that would require additional funding.

Modeled Building Energy Performance

The RTZ guidelines requested that teams submit a HERS score for project. The residential building industry commonly uses the Home Energy Rating System (HERS) Index to indicate energy efficiency and it can be calculated by using any Residential Energy Services Network (RESNET) accredited HERS software. The team RRR-USF struggled with obtaining an accurate HERS score using the RESNET software and opted to use an ERI Index using BEopt software. Similar to the HERS score, the ERI score is defined as a numerical score where 100 is equivalent to the 2006 IECC and 0 is equivalent to a net-zero home. Each integer value on the scale represents a one percent change in the total energy use of the rated design relative to the total energy use of the ERI reference design.

BEopt was used to determine performance improvements, and the team demonstrated that they could reduce the existing ERI of 223 (177.4 MMBtus/yr) to an ERI of 52 (69.2 MMBtus/yr). These envelope enhancements demonstrate good industry best practice even if they are not particularly innovative; however, the performance benefits gained from these assemblies are primarily what allow the design to achieve net-zero energy onsite. The important lesson learned for this team is that not all existing building envelopes can be altered to be high-performing—especially if exterior cladding or interior finishes need to remain in place.

Construction Costs and Financial Feasibility

As previously mentioned, our community partners—ecoREHAB and Muncie Mission—secured funding for the project prior to the student team's involvement in the redesign. The budget for the project was $90,000. Of this amount, the design team was told to reserve $7–8,000 for costs associated with purchasing the property. This left the team with approximately $83,000 for a construction budget. The total construction cost for the RRR-USF project fell within the budget and was estimated to at $82,594, which equated to $92/sf. This cost did not include the cost of the PV system, which was priced separately. The team compared the estimated costs for their adaptive reuse against costs for new construction, and they estimated that reuse saved the project $16,500. Because the house will be owned by Muncie Mission as transitional housing, the typical metrics used to assess financial feasibility were not applicable (e.g. debt to income ratios, average annual family income, mortgage cost, etc.). EcoREHAB's use of some volunteer labor contributed positively to the lower construction costs.

It is also worth mentioning that the South Central neighborhood where this project is situated suffers from extremely low housing quality and low values. The assessed value of the existing Liberty Street house is $8,800. The median price per square foot in the neighborhood his $39 compared with $62 per square foot elsewhere in Muncie. Therefore, a high-performance adaptive reuse at cost of $92 per square foot significantly exceeds the cost of other housing in the immediate area. This highlights a very real and challenging reality with regards to the cost effectiveness of improving the performance and quality of housing in rust-belt Midwestern cities.

Achievements

2018 Solar Decathlon Design Challenge Results

In April 2018, the U.S. Department of Energy Race to Zero recognized Ball State University's *Reuse, Rebuild, Return* team entry, with a Second-Place award under the Urban Single-Family (USF) division. The competition, the jury recognized the team for proposing a reuse project that was thoughtful, well-considered, and actionable. In addition, the jury was pleased to see that the team demonstrated that the met their material reuse goal and the implications this had on carbon emissions and mitigation. The jury did not seem as interested in the idea of the RRR proposal being a viable model for similar reuse projects in Muncie, which was an important component of the team's goals.

Educational Impacts

The studio's use of the RTZ competition and framework to guide the student team proposals met the pedagogical objectives of the graduate level integrated design course. RTZ requires the synthesis of myriad design and construction considerations into a holistic and coherent project proposal, and these go above and beyond the site, structure, code, and systems considerations we typically address in the studio to address issues related to carbon/environmental impact, constructability, cost/financial feasibility, building science, etc. Indeed, the RTZ framework raised the expectations for student studio project success and assisted faculty advisors with access to resources and building science training modules. In addition, the competition aligns relatively well with the semester-based academic calendar and course schedule at our institution.

RTZ also offered a scope and framework that fostered cross-disciplinary work and professional and community engagement. This aspect of the competition aligns well with department, college, and university-level interest in immersive learning or learning focused on projects in the community. In the case of the RRR-USF team, the community partner and engagement piece allowed the group to learn more about Muncie, its existing problems with vacant/abandoned homes, its lack of safe housing for vulnerable populations, and the challenges associated funding projects to address these problems. It also allowed the team to connect with a host of organizations in town that are actively working on issues related to their project. In this way, the project real and relevant to the team.

Finally, the technical rigor required by the RTZ prompted the students to learn new software for building energy simulation, climate data analysis, hygrothermal explorations, life-cycle assessment, and cost estimating as an integral component of their studio project. RTZ also required each student to complete a building science training course consisting of 12 modules, which further developed their technical competencies. The analysis tools and coursework broadened the students' skillsets, elevated their knowledge of high-performance design and construction, and positioned them for greater sustainable design leadership in the profession of architecture.

Sustainability Impacts

The RRR-USF team's achievements with regard to sustainability revolved around a comprehensive approach to reducing the carbon footprint of the local residential building stock by salvaging high-embodied energy materials reducing the carbon impact of newly installed materials and achieving net-positive energy performance. However, indoor environmental quality, water efficiency, and constructability were also high-priority, interrelated sustainability considerations.

One challenge that the RRR-USF team encountered early in their design process was that the existing building they were using for the redesign had been chosen for them and did not possess characteristics that would have allowed the team to maximize the reuse of existing material. The Liberty Street house was chosen by the community partners because of its location, not because of its condition, character, or architectural qualities. An existing conditions survey quickly determined that the house needed extensive work and the wood frame was really the only aspect of the building worth saving/reusing. The team proceeded with these difficult constraints but recognized throughout their process that more careful building selection would have allowed them to more effectively demonstrate the merits of reuse. The simple truth appeared to be that, while saving material is almost always a good thing, the significant effort and cost associated with rehabilitating a house in such poor condition raises an important question: how do we determine whether a building is worth saving? The RRR-USF team learned some valuable lessons in confronting these challenges.

Future Impacts

Interestingly, the story of the RRR-USF team proposal did not end with the course and the competition. The community partners always viewed the student proposal as design work for a real project—perhaps even one that other students would physically work on. Since the proposal was designed to meet the high-performance building requirements of the Zero Energy Ready Home standard (ZERH, 2018), it was exciting to think that the Liberty Street house would be constructed to perform far better than typical ecoREHAB retrofit projects—in a sense the competition would be raising the bar on adaptive reuse projects in a small rust-belt Midwestern city. In summer 2019, a second graduate-level class was organized to work with ecoREHAB on the reconstruction of the house using the design developed by the RTZ team—in particular the exterior wall assemblies. Massive construction delays due to poor weather severely restricted the amount of work students were able to do on the house. However, the students could clearly see the challenges associated with reuse such as jacking an entire house up to set on a new foundation. The Liberty Street house remains unfinished today and it is unclear how much of the student proposal will be implemented in the finished retrofit. Once again, these are good sustainability lessons for students to learn. Students can design a building to be high-performance and net-zero energy ready on paper, but it can be easy for these aspects of the design to be jettisoned during the construction process due to labor, cost, scheduling, and other issues.

CASE STUDY 2: INDIANAPOLIS RE-USE PROTOTYPE: MIDWEST RE-ESTABLISHED URBAN SINGLE-FAMILY PROJECT

Background

The *Midwest Re-Established* team project in the *Urban Single-Family* division (henceforth referred to as MR-USF) was submitted by Ball State University's R. Wayne Estopinal College of Architecture and Planning (CAP) as part of the U.S. Department of Energy's 2020 Solar Decathlon Design Challenge (NREL 2020). The MR-USF team was comprised of a student/faculty team which included seven Master of Architecture (M.Arch) students, one Bachelor of Science (B.S.) in Architecture, one instructional faculty member, a professional adjunct instructor who served as a dedicated design advisor in studio, and three additional faculty members who offered periodic consultation with regard to construction cost estimating, community engagement, and energy modeling.

The framework of the 2020 SDDC offered a productive vehicle to pursue the course objective of the ARCH 602 Integrative Architecture Design Studio. The graduate-level studio work pursues synthesis of a wide range of variables from diverse and complex systems into an integrated architectural solution (Fig. 5). Students are required to demonstrate their ability to comprehend site conditions, structural, environmental, and building systems and assemblies, accessibility and life safety, environmental stewardship, and technical documentation. The scope and type of project pursued in the studio will require applied research methodologies and an integrated evaluation and decision-making process applied across multiple systems to inform the design process. The studio operates out of Ball State University's Indianapolis satellite facility located in the City of Indianapolis' near eastside. Previously located in the City's downtown Wholesale District, the College's "CAP:INDY" program was relocated to its current site in Englewood Village in 2019 with the intention of establishing more direct geographical proximity and potentially deeper community engagement with the disadvantaged communities in the area.

The ten "contests" of the 2020 SDDC similarly foster a rigorous, comprehensive design process. Moreover, the SDDC's *Design Partners Pilot Program* aligned with the Ball State University's vision to deepen community engagement on Indianapolis' near eastside through the CAP:INDY program and other initiatives. As part of the Design Partners Pilot Program, a "client partner" to the collegiate institution is to be established who may be directly engaged and served through the design challenge. This strategic community partners stands as "the customer" for the team and their design project. In the interest of aligning the goals of the studio project with those of the local community, the studio sought to establish direct engagement with both

FIGURE 5. Exterior view of the Midwest Re-Established prototype.

the Englewood Communitive Development Corporation (Englewood CDC or ECDC) and the City of Indianapolis.

City of Indianapolis and Marion County: Unigov

The City of Indianapolis is the state capital and most populous city of Indiana. It is also the seat of Marion County. According to 2019 estimates from the U.S. Census Bureau (USCB 2020), the consolidated population of Indianapolis and Marion County was 876,384. Since the 1970 city-county consolidation, known as "Unigov," local government administration has operated under the direction of an elected 25-member city-county council headed by the mayor. The U.S. Census Bureau's 2014–2018 American Community Survey (ACS) indicated the median household income for Indianapolis was $46,442/year and the per capita income was $27,119/year (USCB 2020).

Thrive Indianapolis: The City's First Sustainability and Resilience Plan

In March 2017, Indianapolis Mayer Joe Hogsett pledged that the City would achieve carbon neutrality by the year 2050. To make good on this commitment and in acknowledgement of the emerging climate-related stressors on local community resilience, the City launched the *Thrive Indianapolis* planning process. The plan brought together various City departments, County agencies, community partners and residents to define a course for Indianapolis' future that is equitable, healthier, and prepared for future climate-related challenges.

The Thrive Indianapolis plan was published and subsequently adopted by the Metropolitan Development commission as an element of the Comprehensive Plan for Indianapolis and Marion County in February 2019. The plan consists of 16 key objectives and 59 action items, all of which are to be executed by 2025. The objectives and action items center around two overarching goals: 1) increase community resilience by prioritizing equity in policy, planning and project implementation; and 2) achieve net zero greenhouse gas (GHG) emissions by 2050. Achieving these goals will require multifaceted public-private engagement ranging from top-down regulatory solutions and grassroots community-driven solutions.

As part of the Thrive Indianapolis planning process, the City conducted GHG inventories for two interim years to better understand the potential impact of various action items. The community-wide GHG inventory followed international protocols and revealed that despite the total population growing approximately 4% from 2010 to 2016, Indianapolis was able to reduce GHG emissions by 11%. This reduction is believed to be primarily the result of converting two coal plants and a coal-powered steam plant to natural gas in addition to other energy efficiency measures. The City's 2016 greenhouse gas emissions are believed to have been approximately 14,630,253 metric tons of carbon dioxide equivalent ($MTCO_2e$) (Thrive 2019).

The MR-USF team intentionally sought to engage the City for critical input regarding the studio's housing prototypes. One of the project goals of the MR-USF project was to develop a design and construction solution that could scale across the City's predominant existing detached housing stock to significantly affect both the embodied and operational carbon contributions to the City's carbon footprint.

Great Places 2020 Initiative

Great Places 2020 is a community development initiative established to envision and plan for strategic development in Marion County neighborhoods that align with priorities related to dynamic centers of culture, commerce and community, and preparing Indianapolis for continued economic growth. It is intended that philanthropic, civic, and private partners will engage with the Great Places 2020 neighborhoods to make significant social and capital investments to enhance quality of life and spur private investment.

The initiative has been administered by Local Initiatives Support Corporation (LISC) Indianapolis, which is the local component of the 501(c)(3) charitable non-profit organization assists resident-led, community-based development organizations improve distressed communities and neighborhoods.

Englewood Village

Englewood Village is a neighborhood district just east of Indianapolis' downtown Wholesale District. Over the ten-year period from 2000 to 2010, the Great Places study area experienced dramatic population loss, with total numbers decreasing by over twenty five percent. However, growth is expected to quicken through 2020, with a 3.7% gain over the 5-year period. At $21,990 per year, median household income in this low-income study area is only 55% of its Marion County equivalent (LISC 2016). By 2020, household incomes are expected to grow at a slower rate than in Marion County. Educational attainment in the study area for residents ages 25 and up is generally lacking compared with Marion County. High rates of residents with no high school diploma underscores the importance of workforce development in high-growth, "blue collar" sectors, as a strategy to bolster long-term economic success.

Englewood Village is one of the first disadvantaged neighborhoods in Indianapolis to be identified by the Great Places 2020 initiative due to the neighborhood's potential, unique assets, and support from active neighborhood groups. Through a participatory process involving community stakeholders, a number of goals have been identified. In particular, the Great Places 2020 activities identified the following "vitality goals":

- Provide a variety of housing types and financing mechanisms
- Increase local control of concentrated vacant property areas
- Retain existing residents with homeowner and rental repair funds and programs

Strategic Community Partner: Englewood Community Development Corporation

Established in 1996, the Englewood Community Development Corporation has a long history of investment in the Englewood neighborhood. ECDC was involved in the Great Places 2020 initiative and has since sought to orient its development projects toward realizing the goals of Great Places 2020 and respond to the Thrive Indianapolis plan.

Englewood CDC provides a range of affordable housing options in the Englewood neighborhood, including rental and homeownership options. Consider the following recent work by ECDC:

> *Oxford Place Senior Apartments* offers thirty (30) one- and two-bedroom apartment units at market, low-income, and recently-homeless residents through a unique financing structure. Moreover, the facility is designed for high-performance, features on-site photovoltaic energy production and stands as the first multifamily structure in Indiana designed net-positive energy.
>
> *Restoration Homes* focus development on strategic blocks within the Englewood neighborhood. The endeavors target vacant and abandoned homes, which undergo deep renovations before being sold—encouraging prospective homeowners to locate and

participate in the life of the neighborhood. Restoration Homes are the historic roots of ECDC's work and has attracted over 30 households to the neighborhood.

ECDC served as the primary "design partner"/client for the MR-USF project. A key strategic community partner in the development of the project, ECDC staff offered consistent, ongoing support to the CAP:INDY studio. As such, the MR-USF team focused efforts on current ECDC property assets and ultimately arrived at an ECDC-owned site directly across from their headquarters.

Design Approach

Studio vs SDDC Timelines

Although the 2020 SDDC timeline encouraged team establishment and preliminary submittals over the course of the Fall 2019 semester, the effort of the MR-USF team was bound by the University's Spring 2020 semester calendar. In general, the submittal milestones and other competition requirements for the SDDC were conducive to a semester calendar. This schedule alignment made the SDDC a viable vehicle through which to structure the integrative architecture studio. Appendix B includes an example of a team weekly report in which the members document progress toward goals including specifying % of team member time spent on each of the ten SDDC "contest areas," which function as an evaluation mechanism for integrated decision making throughout the design process.

Initially, the twenty-one students comprising the ARCH 602 studio were allowed to self-organize into three groups of seven. Next, each seven-student group dedicated their efforts to a unique residential typology offered by the SDDC guidelines. Then, the seven-student groups broke into three sub-groups for a series of research efforts and design charettes. This process of exploration and discovery was conducted throughout January 2020 in concert with ECDC, who shared a variety of assets including information on sites the CDC had possession of. Professional advisors were sought for periodic feedback. These advisors included the Indiana Chapter of ASHRAE, a local electrical contractor who specializes in on-site solar electricity generation (Jefferson Electric), a large local architecture/engineering firm (Cripe), a City of Indianapolis architect, and other professions.

After a series of reviews, the three sub-groups consolidated back into groups of seven and dedicated their efforts toward one single scheme for further development. Consolidation of the sub-groups preceded the SDDC scheduled Project Progress Report in mid-February 2020. Subsequent studio efforts through the end of April 2020 closely adhered to scheduled SDDC milestones and deadlines. (The Design Challenge Weekend was originally supposed to take place April 17–19, 2020 on the NREL main campus in Golden, Colorado. However, due to the COVID-19 crisis, the activities migrated to an online platform.)

Parallels with the Muncie Re-Use Prototype

The MR-USF team considered the advantages and disadvantages of new construction versus major renovation. An unanticipated parallel between both the Muncie and Indianapolis case studies offered here within was the independent exploration and discovery processes which yielded similar determinations that a major renovation would be the preferred approach to accomplishing the sustainability goals of the projects. Both SDDC prototypes identified the relatively large proportion of embodied carbon saved by salvaging existing structures.

Project Goals

Ultimately, the *Midwest Re-Established* team dedicated their efforts toward the major renovation of an existing, dilapidated bungalow owned by ECDC. To the end, the project team identified three overarching project goals:

Goal 1: Rehabilitate Englewood's (and Indianapolis') nascent vacant housing stock.

Many residential parcels in Englewood are ripe for reinvestment. Approximately 36% of the housing units in the neighborhood are now vacant and projected to stay vacant through 2020 (Fig. 6). This is almost triple the current and projected vacancy rate for Marion County as a whole. Additionally, home ownership rates in Englewood Village are much lower than the rates for Marion County. The MR-USF team proposed a scalable, replicable housing redevelopment solution that could serve to aid in the recovery of the City's urban fabric. That "fabric" is twofold—referring to both the unique and varied physical qualities of the structures as well as the long-standing residents of Englewood—many of whom have household incomes well below the City's median income. Thus, in order to prevent gentrification, any proposed housing rehabilitation solution would need to include various points of entry in terms of financial commitment.

Goal 2: Better position the detached single-family housing stock toward pursuing carbon neutrality.

The City of Indianapolis' carbon baselining exercise conducted for the Thrive Indianapolis plan revealed that between 2010 and 2016, buildings account for roughly two-thirds of the community's GHG emissions. In 2016, buildings accounted for 65.9%, which equates to 9,641,337 $MTCO_2e$/year (Thrive 2019). While these figures represent the annual contribution of operational energy consumption, the MR-USF team also identified embodied carbon contributions from construction activity as another source for reduction by salvaging existing structures. Deployed at the scale of the neighborhood—or the City—the high-performance solutions developed by the MR-USF team could yield a significant reduction in GHG emissions.

Goal 3: Aid in the growing affordability challenges with local housing.

Under the guidance of University faculty from Construction Management and recent development cost models from ECDC, the MR-USF project team continuously evaluated their prototype's costs to ensure that the proposed solution(s) would meet the goal of being economically feasible for low-income families and effectively address the growing affordability challenges in the neighborhood and City.

Design highlights

Site: 36 North Rural Street

Among the parcels owned by ECDC, the project team eventually made the decision to develop the lot located at 36 North Rural Street. The vacant, dilapidated 1,666 square-foot two-story 1918 bungalow with a basement sits on a 5,009 square foot property located directly across the street from the Englewood Christian Church, which serves as the headquarters for Englewood CDC. This decision was influenced by its close proximity to ECDC and the opportunity to be exhibited and easily accessed as a prototypical high-performance development.

FIGURE 6. Photographs of various vacant houses in Englewood Village. The property at 36 North Rural Street is pictured in the upper left-hand corner.

Structure: The challenges of salvaging a century-old foundation and framing.

The deep energy renovation proposed by the MR-USF team is predicated on salvaging the existing foundation and framing of an existing residential structure. Many of the existing, vacant units in Englewood are approximately a century old. The structure at 36 North Rural was believed to have been constructed in 1918 (and renovated in 1964) using 2x4 wood framing atop concrete masonry units, which comprised the unit's basement walls. A visual inspection suggested that the existing block foundation walls were salvageable. The team realized that in many instances, foundations may be compromised, and the entire unit will need to be razed unless a creative solution is devised to maintain the structures.

Envelope: Innovative 100% out-board thermal barrier solution.

One of the unique challenges with regard to the envelope was salvaging the existing 2x4 wood framing at 16 inches on-center. Contemporary high-performance residential framing typically utilizes 2x6 wood framing in order to accommodate higher levels of infill insulation. The team's energy analysis through BEopt and WUFI clearly determined the performance advantages of establishing continuous insulation out-board of the existing framing. In order to meet the project's modeled performance requirements, the proposed roof and above-grade exterior wall assemblies needed to achieve an overall R-value of at least R-36 and the infiltration needed to be no more than 1.0 ACH50. An elevated risk of radon prompted the team to price a radon mitigation system and air-sealing to the basement walls. The basement's component of the thermal barrier was determined to be no less than a nominal R-30. The full renovation scope also included high-performance triple glazed window assemblies with maximum values of U-0.18 and SGHC-0.4.

The MR-USF team ultimately arrived at a unique "igloo" solution in which the entire envelope would feature an 100% outboard continuous thermal barrier. To this end, the existing wood framing would need to remain completely exposed to the interior although it could be painted with an interior latex paint. Sheathing would be fastened to the exterior of the framing; upon which, the weather resistant barrier (WRB) was applied. Outboard of the WRB, 8-inches of rockwool insulation (nominal R-36) would be fastened before applying furring strips and wood siding (walls) or underlayment, roofing paper, and shingles (roof). Though unconventional, the MR-USF team identified several advantages to exposing the existing framing regarding accessibility and future adaptation. Although, the aesthetic effect may be undesirable to some homeowners and electrical wiring would need run through conduit. (Fig. 7)

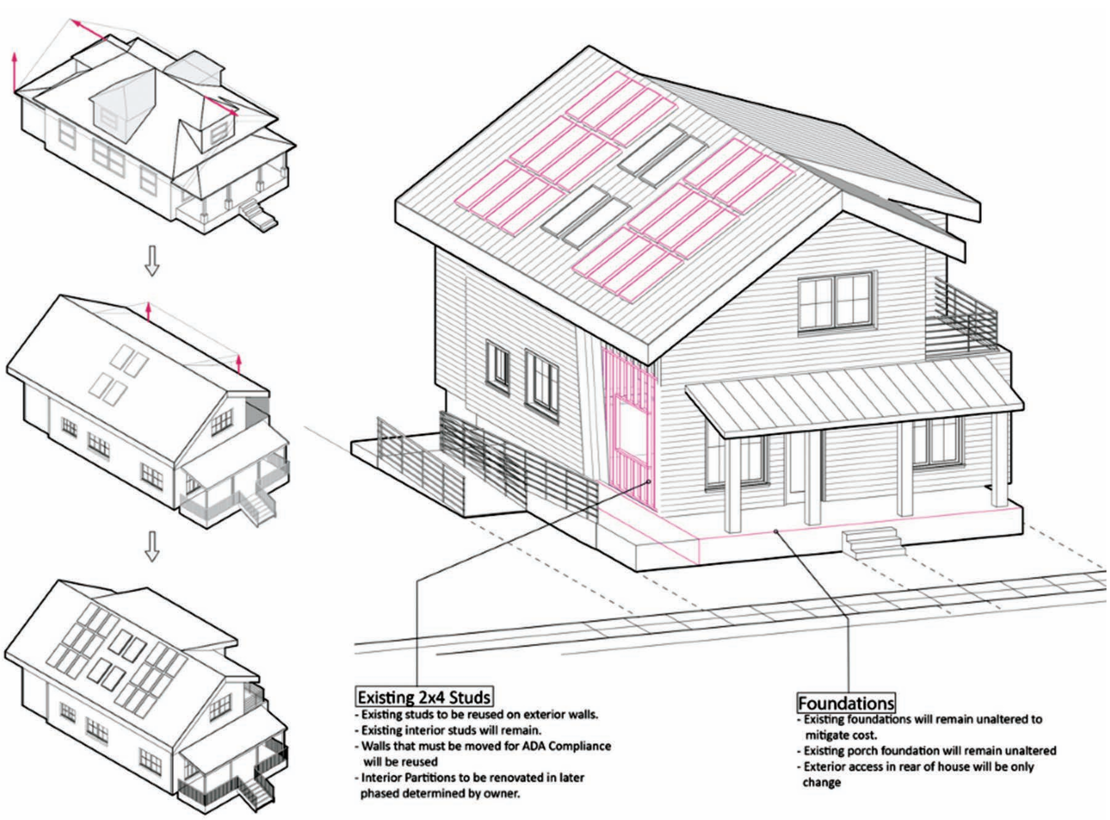
Mechanical / Electrical / Plumbing

Following the implementation of architectural solutions, the remaining heating and cooling loads were quantified and further assessed using BEopt. The team decided to pursue a 100% electric solution with the MR-USF prototype. The team also closely adhered to the U.S. Department of Energy's Zero Energy Ready Home (ZERH 2019) National Program Requirements (Rev. 07, c.2019).

A ductless variable refrigerant flow (VRF) system was selected in order to provide both heating and cooling in one efficient, highly adjustable, integrated system. Sized to account for the peak heating and cooling hours, the system comprised of two zones: one on the first floor and one on the second floor. The two indoor units are linked by closed loops of refrigerant lines to the outdoor unit to provide heating and cooling to each zone uniquely.

FIGURE 7. Interior view of the Midwest Re-Established prototype.

FIGURE 8. Diagram outlining the scoped envelope improvements for the Midwest Re-Established prototype.



A dedicated outdoor air system (DOAS) was specified to circulate fresh air throughout the house, using an energy recovery ventilator (ERV) to avoid salvage sensible and latent energy in the conditioned air stream.

Building energy modeling suggested that the VRF system would perform 40% more efficient than a standard SEER 13 air-source heat pumps (ASHP). Moreover, the ERV was determined to save as much as 73% of energy in the exhaust air stream.

All appliances were presumed to be ENERGY STAR qualified (when applicable) and the project specified 100% LEDs for lighting. The electric water heater was specified to meet the requirements of the DOE Zero Energy Ready Homes program.

On-Site Renewable Energy

For certain aspects of the MR-USG design development and specifications, the project team engaged local professionals. For the anticipated on-site solar energy generation, the team engaged Jefferson Electric, who utilized Helioscope to assess a photovoltaic (PV) array and its balance-of-system components. The team ultimately arrived at a 6-kW system consisting of eighteen 340-watt silicon heterojunction solar cells with a bifacial structure, enabling an 18% performance improvement over typical monocrystalline PV production. The MR-USF solar panel configuration was projected to generate an average of 7,464 kWh/year and, with available financial incentives, a simple payback of approximately 14 years.

Modeled Building Energy Performance

The SDDC guidelines requested that teams submit a HERS score for project. The residential building industry commonly uses the Home Energy Rating System (HERS) Index to indicate energy efficiency and it can be calculated by using any Residential Energy Services Network (RESNET) accredited HERS software.

The MR-USF project team utilized BEopt for building energy modeling, which is not a RESNET accredited software platform. Therefore, the team opted to utilize the Energy Rating Index (ERI) as an alternative to the HERS score. Similar to the HERS score, the ERI score is defined as a numerical score where 100 is equivalent to the 2006 IECC and 0 is equivalent to a net-zero home. Each integer value on the scale represents a one percent change in the total energy use of the rated design relative to the total energy use of the ERI reference design.

An assessment of the existing structure revealed an ERI score of 147.4. Based on the local utility's residential electricity rate at the time of this analysis, the annual energy costs equated to $2,521/yr. After incorporating all of three phases of proposed renovation scope, which exceeded the DOE ZERH standard, the project was anticipated to achieve an ERI score of 43.5. Once the anticipated on-site photovoltaic-based solar energy generation was incorporated, the MR-USF project achieved an ERI score of –1.8, achieving net positive energy.

Construction Costs and Financial Feasibility

One of the most critical aspects of the MR-USF proposal that helps it to better achieve its three project goals (i.e., rehabilitate the City's nascent vacant housing stock; drive the housing stock toward carbon neutrality; and aid in the growing affordability challenges with local housing) is a multi-phase pathway toward net-positive energy.

The MR-USF team worked closely with Englewood CDC to develop a multi-phased cost model that could balance the high-performance goals of the project against the budgetary constraints necessary to keep the development financially feasible for lower-income homeowners.

External financial assistance is critical with most of ECDC's work for underserved communities. In recent detached urban single-family residential work, the organization has utilized Community Development Block Grants and the HOME Investment Partnerships Program (HOME) through the U.S. Department of Housing and Urban Development (HUD). In aggregate, through external funding ECDC has had success in reducing the total development costs for such work by approximately 30%.

The total construction cost for the MR-USF project was estimated to at $124,954, which equated to $56.97/sf. However, the team assumed that the prospective homeowner in Englewood would have a household income in the 65th percentile—which would be a median household income of approximately $38,000 per year. If no more than one-third of the household income went toward the total housing cost—including a 30-year fixed rate mortgage (3.92% interest), utility costs, property tax, insurance, etc.—that would equate to $12,666/yr or $1,055/mo. The MR-USF team projected that after securing external financing for the high-performance renovation of the property on 36 North Rural Street would equate to $865 per month, plus miscellaneous maintenance costs. This puts the net positive upgrades within the realm of financial feasibility.

Achievements

2020 Solar Decathlon Design Challenge Results

In April 2020, the U.S. Department of Energy Solar Decathlon Design Challenge recognized Ball State University's *Midwest: Re-Established* team entry, with an Honorable Mention award under the Urban Single-Family (USF) division. As with the Muncie RRR entry in the 2018 cycle of the competition, the jury recognized the virtues of exploring innovative means by which a growing stock of vacant structures in cities across the U.S. Midwest rustbelt can be rehabilitated in a manner that is financially feasible for economically disadvantaged communities, achieves high-performance, and can mitigate—perhaps eventually eliminate—GHG emissions from embodied resources through construction and operational resources or energy. These achievements better ensure community resilience and also posit their cities for long-term economic viability.

Educational Impacts

With regard to achieving its pedagogical objectives, the studio's pursuits with regard to the SDDC achieve the intended scope of the graduate-level integrated architectural design studio. The requisite synthesis of site conditions, structural, environmental, and building systems and assemblies, accessibility and life safety, environmental stewardship, and technical documentation required to effectively compete in the SDDC was compatible with the studio's course goals. SDDC's alignment with the semester-based academic calendar was also critical to success.

SDDC also offered a scope and framework that fostered cross-disciplinary work, professional and community engagement, and addressed community resilience. Such facets of the competition maintained a scope that pursued the mission of the CAP:INDY program. The regular and localized community engagement created immersive learning opportunities for the students that are commonly lacking with traditional on-campus design studios.

Finally, the technical rigor required by the SDDC prompted the students to learn new software for building energy simulation, climate data analysis, hygrothermal explorations, life-cycle assessment, and cost estimating. The SDDC also required each student to complete a multi-component building science training course, which further developed their technical competencies. The analysis tools and coursework broadened the students' skillsets, elevated their knowledge of high-performance design and construction, and positioned them for greater sustainable design leadership in the profession of architecture.

Sustainability Impacts

The MR-USF team's achievements with regard to sustainability revolved around a comprehensive approach to reducing the carbon footprint of the local residential building stock by salvaging high-embodied energy foundations and structures, reducing the carbon impact of newly installed materials, and achieving net-positive energy performance. However, indoor environmental quality, water efficiency, and community resilience were also high-priority, interrelated sustainability considerations.

The MR-USF team identified thirty-one (31) additional vacant properties across Englewood Village that potentially met the criteria to be similarly developed using the phased high-performance framework applied for the SDDC submission—potentially saving approximately 720 $MTCO_2e$. Scaled to the estimated 14,000 salvageable houses across the City of Indianapolis could result in approximately 252,000 $MTCO_2e$.

The aggregate effect of all energy-conservation measures on the MR-USF project is projected to be 5.3 $MTCO_2e$/yr. Deployed at scale across Indianapolis, the full potential is projected to be upwards of 77,500 $MTCO_2e$/yr—equivalent of annual energy use of over 8,900 homes.

Achieving financial feasibility unlocked the potential for realized sustainability impacts. For all of the project's potential sustainable design outcomes when deployed at scale across Englewood, the City of Indianapolis, and beyond, the MR-USF team realized that the potential would only be realized through solutions that were financially accessible across the widest swath of a community's socioeconomic stratum. While the MR-USF team generally achieved its goal of defining a phased renovation framework that could serve a range of budgets, grants and other financial subsidies were necessary. However, the MR-USF construction costs were controlled within the range of a typical affordable housing project in its locality.

Future Impacts

The Thrive Indianapolis plan revealed several emerging threats to long-term community resilience due to climate change. This elevated the imperative of achieving carbon neutrality by 2050. This will require top-down and grassroots initiatives; public programs and private sector initiatives; and success will hinge largely on the success or failure of the City's ability to adapt its existing building stock for high-performance and low-carbon. The innovative solutions explored by the CAP:INDY studio into localized and cost-effective deep energy retrofits is an effort that should continue—whether through future SDDC team explorations or otherwise. This could be a central focus of the community-based CAP:INDY integrated architectural design studios.

Considering the location of the Ball State University's Indianapolis satellite within the Englewood neighborhood on the City's near eastside, the MR-USF project's engagement with Englewood CDC and other strategic partners in the City's near eastside, and the MR-USF project site in Englewood, CAP has committed to serving the neighborhood through involvement in the Sustainability Task Force for Near Eastside Quality of Life Plan in the interest of establishing a more protracted engagement with Englewood and City. This multiyear service commitment should serve future efforts by cultivating a closer alignment of CAP:INDY community-based design activity with local goals and planning regarding equity, sustainability, economic mobility, and resiliency. One of the near-term projects related to this engagement is the prospect of advancing a built derivative of the MR-USF project for the Solar Decathlon Build Challenge.

CONCULSIONS

Lessons Learned

There were several pedagogical lessons learned through the execution of the RTZ/SDDC project work in 2018 and 2020. First, having a primary community partner that acts as a client to the teams is vital to effective community engagement. However, this primary partner can be further enhanced by secondary community and professional partnerships. The RRR-USF team engaged ecoREHAB as a local community partner but had access through this primary partner to secondary partners like 8Twelve and Muncie Mission. Strategic industry partners brought their expertise at specific points in the design process related to solar PV, green design, and housing design. The MR-USF team engaged Englewood CDC as a local community partner but had access through this primary partner to a host of secondary partners. Strategic industry partners brought their expertise at specific points in the design process related to solar PV, product manufacturers, HVAC, and others.

Second, the fast pace of the competition requires that student teams receive feedback regularly from the studio instructor, but also from additional team members outside the core teams as well as other faculty and partners. The MR-USF team benefited from having an additional adjunct faculty meet with the teams each week to provide strategic feedback to supplement feedback from the instructor. While more than one faculty member is certainly helpful, the RRR-USF team was able to solicit feedback via regular pin-ups and reviews. One caveat, however, is that the teams need specific types of feedback at specific points in their process to move the projects ahead. Soliciting feedback that aims to rethink aspects of the design that were finalized weeks earlier can be counterproductive. We found that providing feedback prompts to reviewers is a helpful way to solve this problem. Having students in the course associated with the team (e.g. the building performance modeling course) allows the core teams to receive targeted feedback on their design based on analysis that students in the other courses are doing.

Third, RTZ/SDDC moves at a fast pace in order to allow the teams to have time to develop technical details for the Final Report. This means that anything that faculty advisors/ instructors can do to facilitate quick reconnaissance at the beginning of the semester (or even before the beginning) helps to propel the teams along rather than allowing them to languish in the early-stage information gathering and site analysis work. The RRR-USF team had a site selected and existing conditions drawings prepared by the community partner and the advisor prior to the start of the semester. The team still had to meet and establish a relationship with the community partner, but the background information was already available for them to use on day-one. The MR-USF team had potential sites selected by the community partner ahead of time. However, the team also had more members, which allowed quick retrieval of background information such as master plans, historical assessments, climate and site data, and more. Some students sought interviews and/or explored unique veins of academic inquiry related to their delegated scope of work.

Fourth, relative alignment between the competition schedule and a one-semester design studio course was critical as it did not require faculty advisors to coordinate student team efforts between different student cohorts. While more time may be an advantage for student teams in terms of producing the required materials, it would not be possible given our curriculum to have the same student teams working on the projects during fall and spring semester and having different groups would complicate the process.

Finally, the ten "contest" areas that the RTZ/SDDC juries use to evaluate proposals ensure that the work of the student teams achieves a high level of systems integration necessary for a comprehensive design studio. The only disadvantage of the "contest" areas may be that they encourage technical development of the projects to such an extent that teams are left with limited time for the typical design studio project activities including good space planning, developing a strong organizational concept, opportunities for design expression, etc. This is a particular problem for adaptive reuse projects where layouts and program distribution are often complicated by the existing building features, structural systems, etc.

Ideas for Future Work

Successful student engagement with local community partners on adaptive reuse design proposals has sparked interest in a built local demonstration project. A counterpart to the Solar Decathlon Design Challenge is the Solar Decathlon Build Challenge (SDBC). Teams competing in the Solar Decathlon Build Challenge will work during a two-year period to design and build a local housing project, culminating in April 2021 with the Solar Decathlon Competition Event at the National Renewable Energy Laboratory in Golden, Colorado. SDBC participants will design and build complete, functional houses within their respective communities to demonstrate creative solutions for real-world issues in the building industry. Much like the Design Challenge, the Build Challenge offers an opportunity to advance Ball State University's vision of deeper community engagement on the near eastside but in order to most effectively serve the neighborhood, the student/faculty teams must uphold an ongoing commitment to stakeholder engagement and strategic community partnerships. Involvement with such efforts as the Near Eastside Quality of Life Plan as local community partner is a first step toward this objective.

ACKNOWLEDGEMENTS

2018 RRR-USF team

This project was the product of a rigorous Master of Architecture studio effort during the Spring 2018 semester. With gratitude, the authors wish to acknowledge the members of the RRR-USF student/faculty team. The students were Miranda Osborn (M.Arch), Meghan Miller (M.Arch), Katie Gordon (M.Arch), Lauren Maloney (M.Arch), Emily Epple (B.S. ARCH), Hunter Crews (M.ARCH), Jimmy Toler (B.S. Construction Management), Alisha Heath (B.S. Construction Management), Michale Delong (B.S. Construction Management), Justin Sanford (B.S. Construction Management). The faculty members were Tom Collins (architecture), Walter Grondzik (architecture, energy modeling), Tarek Mahfouz, (construction management, construction cost estimating), and Daniel Overbey, (architecture). Special thanks is extended to the strategic partners involved with the project: ecoREHAB of Muncie (Craig Graybeal, Executive Director), Muncie Mission, 8Twelve Coalition, Christina Bollo (housing expert), and Jefferson Electric (PV systems design).

2020 MR-USF team

This project was the product of a rigorous Master of Architecture studio effort during the Spring 2020 semester. Despite the challenges presented by the COVID-19 pandemic, the students and faculty persevered. With gratitude, the authors wish to acknowledge the members of the MR-USF student/faculty team. The students were Schyler Cerqueira (B.S. Architecture), Kurt

Green (M.Arch), Jeffrey Miller (M.Arch), Aaron Strayer (M.Arch), Ethan Talbot (M.Arch), Michael Timberlake (M.Arch), Nick Wesley (M.Arch), and Brittany Williams (M.Arch). The faculty members were Walter Grondzik, PE (architecture faculty, energy modeling), Jonathan Hess, AIA (professional adjunct architecture faculty, design advisor), Tarek Mahfouz, Ph.D (construction management faculty, construction cost estimating), Daniel Overbey, AIA (architecture faculty, studio instructor), and Megan Phillippe, AIA (architecture faculty, community engagement). Special thanks is extended to the strategic partners involved with the project: Englewood Community Development Corporation, the City of Indianapolis, Cripe, ASHRAE Indiana Chapter, and Jefferson Electric.

REFERENCES

Indianapolis (2019). *Thrive Indianapolis*, City of Indianapolis, Indianapolis, IN.

LISC (2016). *A Compressive Development Plan for Englewood Village: Great Places 2020*, Local Initiatives Support Corporation—Indianapolis Affiliate, Indianapolis, IN.

NREL (2018). *2018 U.S. Department of Energy Race to Zero Student Design Competition Guide*, National Renewable Energy Laboratory, Golden, CO.

U.S. Department of Energy Solar Decathlon 2020 Design Challenge Competition Guide, National Renewable Energy Laboratory, Golden, CO.

USCB (2020). *Quick Facts: Indianapolis city (balance), Indiana*, U.S. Census Bureau, Washington, DC. <https://www.census.gov/quickfacts/indianapoliscitybalanceindiana> Accessed 14 August, 2020.

ZERH (2018). *DOE Zero Energy Ready Home National Program Requirements (Rev. 06)*, U.S. Department of Energy, Washington, D.C.

ZERH (2019). *DOE Zero Energy Ready Home National Program Requirements (Rev. 07)*, U.S. Department of Energy, Washington, D.C.

ABOUT THE AUTHORS

Tom Collins

Tom Collins, PhD, AIA, LEED AP is an Assistant Professor of Architecture at Ball State University where he teaches upper level design and environmental systems courses. His work focuses on high performance building design, occupant energy use, and indoor environmental quality. Tom is a Registered Architect and has worked on green building projects in Massachusetts and New York. He is a member of the American Institute of Architects (AIA) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). He currently serves as the Treasurer of the Society of Building Science Educators (SBSE). He has advised over nine Race to Zero/Solar Decathlon Design Challenge teams since 2017.

Daniel Overbey

Daniel Overbey, AIA, NCARB, LEED Fellow, LEED AP (BD+C, ID+C, O+M), WELL AP, EcoDistricts AP is an Assistant Professor of Architecture at Ball State University and the Director of Sustainability for Browning Day in Indianapolis. His work focuses on high- performance building design and construction, environmental systems research, green building certification services, energy/ life-cycle assessment modeling, and resilient design. Daniel has offered sustainable design leadership on a number of high-profile green building projects including the first certified zero net energy (ZNE) building in Indiana. Daniel is also a committed volunteer at the local, state, and national levels of the American Institute of Architects (AIA) and U.S. Green Building Council (USGBC).

APPENDIX A

RTZ Weekly Report

Team: [SSF or USF] Date: 3/16/2018 Week 10

1-architectural design, 2-interior design, lighting, plug loads, & appliances, 3-energy analysis, 4-constructability, 5-financial analysis, 6-envelope performance/durability, 7-indoor air quality & ventilation, 8-mechanical, electrical, & plumbing systems design, 9-innovation, & 10-presentation quality

Member Self Report:										
Team Member 1	This week I continued to work on the site and exterior of the house. I brought several of the site ideas and exterior ideas (such as color, trim, planters and the carport) into the Revit model to create presentation renderings/elevations and diagrams for Friday's review and the upcoming final report. This weekend, I worked on addressing some of the comments made during the review in our design as well as worked with REMrate to develop an initial HERS score for our home.									
	1	2	3	4	5	6	7	8	9	10
	50%	%	%	%	%	20%	%	%	%	30%
Team Member 2	Set up final report file, created outline for presentation, created reused/ new graphic, made final floor/ roof decision, researched material sources, explored passive ventilation techniques, created passive ventilation graphic.									
	1	2	3	4	5	6	7	8	9	10
*note: some research overlapped categories. Ex. Flooring covers 1, 7, and 9	30%	%	%	%	%	30%	30%	%	30%	40%
Team Member 3	I spent my week continuing to research and design the systems including the hot water heater and plumbing design, electrical plans and lighting fixtures, and the PV array, among others. I have also consulted with the other team members regarding the systems as they required.									
	1	2	3	4	5	6	7	8	9	10
	%	%	10%	%	%	%	20%	60%	%	10%
Team Member 4	I began to really investigate the details and the connections between the wall, roof, and crawlspace. I learned about the unvented crawlspace codes from our Friday presentation and we managed to still make that work. We had to readjust where our barriers were located but it all works out.									
	1	2	3	4	5	6	7	8	9	10
	50%	%	%	%	%	%	%	30%	%	20%

Team Self Report: (to be completed by the whole team)	
Overall Progress	We have made great strides towards finalizing our design. Our site plan is coming along well. Our energy analysis shows that our design is feasible to achieve ZERH. We acknowledge that our presentation skills are rather rusty and that we should include more contextual information into our presentation such as the existing plan and buildings that neighbor the site. We also need to emphasize our concept more and why it contributes to the innovation aspect of our project.
Evaluation Parameter Progress	As we developed our PowerPoint presentation, we began to define the areas of the competition that were underdeveloped. We then assigned these areas to team members who became responsible for research and selection as we move forward. We have produced a legitimate HERS score with REM/Rate.
Submission Progress	Volume 1 of final report is set up, info is being dumped in as it is created. List of requirements is analyzed as decisions are made
Immediate Needs	Discuss structure solutions with Craig (Wednesday) Prepare list of things to investigate on site visit Wednesday
Next Steps	Finalize plumbing fixtures and mechanical systems, create MEP plans, additional interior architectural design, write stuff for report, and work on carport to create a cohesive site.

Evaluation:				
Excellent (4)	Good (3)	Average (2)	Below Ave (1)	Problematic (1)
95%	85%	75%	65%	55%
Team goals and tasks for the previous week have all been met and exceeded. Work demonstrates significant progress toward project completion. The team has gone far above and beyond expectations. Excellent balance of work among the group.	Team goals and tasks for the previous week have all been met at least one two goals or tasks have been exceeded. Work demonstrates good progress toward project completion. The team has gone above and beyond expectations. Good balance of work among the group.	Team goals and tasks for the previous week have all been met. Work demonstrates average progress toward project completion. The team is meeting basic expectations. Average balance of work among the group.	Team goals and tasks for the previous week have not been met. Work demonstrates below average progress toward project completion that must be address within the next reporting cycle. The team is not meeting basic expectations. There is an imbalance of work among the group.	Few team goals and tasks for the previous week have not been met. Work demonstrates problematic progress toward project completion that must be addressed immediately. The team is meeting few of the basic expectations. There is a significant imbalance of work among the group.
General Comments:				
Self/Team Evaluation Comments:				

APPENDIX B

BALL STATE UNIVERSITY
R. Wayne Estopinal College of Architecture and Planning

ARCH 602
Spring 2020

Weekly Team Report

Ball State University | Spring 2020 | Overbey | 2020 Solar Decathlon Design Challenge

1-energy performance, 2-engineering, 3-financial feasibility, 4-resilience, 5-architecture, 6-operations, 7-market potential, 8-comfort/environmental quality, 9-innovation, & 10-presentation quality

Team: USF Date: 2020-23-02 For Week: 07

Member Self Report:										
Team Member 1	Kurt composed a narrative about the market potential and produced graphics to give context to the city, neighborhood, and site.									
	1	2	3	4	5	6	7	8	9	10
	0	20	0	0	40	15	0	0	15	10
Team Member 2	To save on our budget myself and others brainstormed to find cost cutting solutions for the stairs and the basement. Other cost saving measures was using Tarek's Excel spreadsheet									
	1	2	3	4	5	6	7	8	9	10
	0	%	50	10	10	%	%	%	10	20
Team Member 3	Aaron revised revit model per discussion with advisors and peers. Generated renders, floor plans, and sections for presentation.									
	1	2	3	4	5	6	7	8	9	10
	%	%	%	%	%	%	%	%	%	%
Team Member 4	Worked on innovation for the progress report. worked on ways of possibly lowering the cost of the building by brainstorming ideas with others.									
	1	2	3	4	5	6	7	8	9	10
	%	%	%	%	%	%	%	%	%	%
Team Member 5	Worked on formatting the competition progress report, writing text for the introduction, and helping the team collaborate. Continued thinking of ways to make the project unique and meaningful in the big picture.									
	1	2	3	4	5	6	7	8	9	10
	20	10	10	0	10	0	10	0	10	30
Team Member 6	Extensively researched strategies for resilience and operations goals in the project. Although not yet directly applicable to the project, it does apply to the typology in question. It also ties in with the city's goals for resilience and net zero carbon.									
	1	2	3	4	5	6	7	8	9	10
	%	%	%	%	%	%	%	%	%	%
Team Member 7	Mostly worked on formatting the progress reports as well as continuing to explore energy analysis and strategies for comfort and environmental quality.									
	1	2	3	4	5	6	7	8	9	10
	10%	%	%	%	%	%	%	%	%	80%

Team Self Report: (to be completed by the whole team)

Overall Progress	Completed and submitted the competition Progress Report to NREL, which took substantial effort and collaboration.
Evaluation Parameter Progress	The majority of the effort went toward refining the progress report and only briefly summarizing the 10 contests and our plan for their completion.
Submission Progress	We submitted the Progress Report on time and gave ourselves a chance to be invited to Colorado, even though there are things we could have improved.
Immediate Needs	We are focusing on the template for the final submission and need to figure out how to communicate an overall message of a scalable solution that could be applied to many houses across the city, state, and country.
Next Steps	We will be working to build a template for the final submission, though we don't have all of the ten contents figured out yet. We are also modifying our overall design in response to the cost estimation, and eliminated moves that majorly increase price without sacrificing the identity of the project.

Evaluation: (to be completed by the instructor via Canvas)				
Excellent (4 points)	Good (3 points)	Average (2 points)	Below Average (1 point)	Problematic (0 points)
Team goals and tasks for the previous week have all been met and exceeded. Work demonstrates significant progress toward project completion. The team has gone far above and beyond expectations. Excellent balance of work among the group.	Team goals and tasks for the previous week have all been met at least one two goals or tasks have been exceeded. Work demonstrates good progress toward project completion. The team has gone above and beyond expectations. Good balance of work among the group.	Team goals and tasks for the previous week have all been met. Work demonstrates average progress toward project completion. The team is meeting basic expectations. Average balance of work among the group.	Team goals and tasks for the previous week have not been met. Work demonstrates below average progress toward project completion that must be address within the next reporting cycle. The team is not meeting basic expectations. There is an imbalance of work among the group.	Few team goals and tasks for the previous week have not been met. Work demonstrates problematic progress toward project completion that must be addressed immediately. The team is meeting few of the basic expectations. There is a significant imbalance of work among the group.

--- END OF WEEKLY TEAM REPORT ---