Imagining a Healthy Future: Cross-Disciplinary Design for Sustainable Community Development in Cange, Haiti

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Abstract. A new center for community development and sustainable infrastructure is being planned for the central plateau of Haiti. This Center of Excellence will support the ongoing applied research of the Clemson Engineers for Developing Countries (CEDC), a service-learning program at Clemson University, which has, to date, produced an exemplary municipal water system and a net-positive-energy waste treatment system in the town of Cange. The new Center of Excellence is envisioned as a setting for collaboration, demonstration, and the exchange of ideas between local communities. Tying into the preceding water and waste infrastructures, the new facility itself is being designed as a leading example of resilient, self-sustaining construction that is replicable in its setting. Renewable energy solutions, including a combination of solar and small-scale hydroelectric, will compliment passive thermal and ventilation strategies. Moreover, embodied energy is addressed through careful attention to the materials and methods of construction in this resource-constrained environment. These topics are especially important in the wake of the reconstruction that continues after the devastating 2010 earthquake in Haiti.

The design and planning of the Center of Excellence has been orchestrated through a unique educational partnership between students and faculty in the Clemson University School of Architecture and their counterparts from CEDC. In this setting, architecture teams are supported through specific technical consultation from CEDC project teams and former interns, with topics ranging from anaerobic waste treatment, to expected laboratory energy loads, to concrete masonry specifications and testing. This collaboration ensures that the new facility will incorporate and demonstrate the latest research coming out of CEDC, while simultaneously opening the doors to new areas of inquiry.

This paper details the collaborative structure of this research-based design studio, and how multidisciplinary intellectual resources are leveraged toward integrated building and site solutions. The specific goals and parameters of the Center of Excellence facility in Cange will underpin the discussion.

1. Introduction
From January through May of 2019, the Graduate Comprehensive Studio in the Clemson University School of Architecture formulated detailed design proposals for a new community development facility for Cange, Haiti. The project was conducted through a unique collaborative partnership with an interdisciplinary service-learning program at Clemson, enabling new depths of inquiry and applications for ongoing research. This paper describes the partnership and the resulting projects. It begins with introductions to the Comprehensive Studio setting and to the work of the partnering organization.

1.1. Educational Setting
The Master of Architecture (M.Arch) program at Clemson University is an accredited professional degree program in which students complete either four or six semesters, depending on their standing upon entry. The curriculum for both streams of students culminates in the Graduate Comprehensive Studio, which features a central, terminal project. Students customarily work in pairs for the duration of the project, and the course is co-taught by a team of two to three faculty with diverse and complimentary expertise. The course has been summarized with the following description: “This studio is intended for the comprehensive development, resolution, documentation and presentation of an architectural project.
The project should permit an in-depth exploration of the intuitive, poetic, and humane aspects of architecture when integrated with technical, functional, and theoretical considerations.”

The Comprehensive Studio draws from all of the knowledge and skills accumulated by students in previous coursework, and also must address the following specific performance criteria, as outlined by the National Architectural Accrediting Board (NAAB):

B.3. Codes and Regulations: Ability to design sites, facilities, and systems that are responsive to relevant codes and regulations, and include the principles of life-safety and accessibility standards.

C.2 Integrated Evaluations and Decision-Making Design Process: Ability to demonstrate the skills associated with making integrated decisions across multiple systems and variables in the completion of a design project…

C.3 Integrative Design: Ability to make design decisions within a complex architectural project while demonstrating broad integration and consideration of environmental stewardship, technical documentation, accessibility, site conditions, life safety, environmental systems, structural systems, and building envelope systems and assemblies.

The selected project type and scale varies from year to year, but each is deliberately complex in its programming and in its physical context. The project schedule is carefully orchestrated to provide a balance between early design and technical resolution. This is done such that the integrative aspects of criteria C.2 and C.3 (above) are met in a meaningful and robust way. Each project is organized according to the following phases: Phase 1: Site Analysis and Concept Forming (2-3 weeks); Phase 2: Massing and Building Planning (2-3 weeks); Phase 3: Final Schematic Design (2-weeks); Phases 4-6: Technical Resolution – Structural Systems, Environmental Systems, and Envelope (4 weeks total); Phases 7-8: Technical Examination and Final Documentation (3 weeks).

There are two co-requisite courses of note, designed to dovetail with the comprehensive project. The first is a Professional Practice course, in which students do zoning analyses, building code reviews, and cost estimates for their proposed building designs. The second is a course called Building Processes: Technical Resolution, whose content serves as a support for the development of technical systems in the second half of the studio project.

1.2. Introduction to CEDC
The Clemson Engineers for Developing Countries (CEDC) is a service-learning program that brings together students from across the university to respond to real-world needs using applied knowledge. Since its founding by Jeff Plumblee in 2009, much of CEDC’s work has been focused on the Central Plateau of Haiti with the mission of working “with local communities... to develop sustainable solutions that improve the quality of life through interdisciplinary student-led initiatives that embody our core values” [1]. These stated values include:

Accountability
CEDC recognizes and accepts responsibility for its actions and their outcomes while honouring obligations, expectations, and standards of ethical conduct.

Commitment
CEDC acknowledges its generation’s responsibility as global leaders to holistically apply interdisciplinary solutions towards social, environmental, and economic issues to enhance future lives.
Service
CEDC carries out moral obligations to improve the safety, health, and well-being of the human race, effectively advancing the standard of living in developing countries.

Currently, and under the guidance of its director, David Vaughn, CEDC brings together over 80 undergraduate students from 20 to 30 different majors in any given semester [2]. CEDC’s organizational structure is modelled on that of a business, with a specific hierarchy for efficiently managing projects, for continuity and knowledge transfer, and for sustaining organizational growth. Students are organized into either administrative teams (Current Operations, Marketing, Finance, Internal Communications, Assistant Program Directors, etc.), project-based teams, or education-oriented teams [3]. Additionally, CEDC maintains a group of 2-4 student interns, working on the ground in Cange, a mountain community situated along National Route 3 in the Mirebalais Arrondissement of the Central Plateau. The intern program is in place to provide direct service and connections to the community while helping to steward existing projects and oversee new work [4]. CEDC’s interns operate out of a clinic building on the Cange campus of Zanmi Lasante (ZL), the Haitian sister to the global Partners in Health organization.

The first notable CEDC project was the construction and operation of a sustainable clean water system, which provides potable water to some 10,000 people in the area through eight public fountains positioned throughout Cange. This system replaced an earlier, untreated one built by the Episcopal Diocese of Upper South Carolina (EDUSC) between 1983 and 1985. Currently, the water is dammed, pumped, filtered, and chlorinated, all without electrical power, an important feature given the unreliable power grid [5]. It was designed with the capacity to deliver 379 liters/min (100 gal/min). The first of its kind, this remains the only chlorinated municipal water system in Haiti. Among other measures, the success of the system is seen in the precipitous decline in cholera throughout Cange and its immediate surroundings.

Figure 1. Cange water system, installed and operated by CEDC and community partners.

With support from the United States Agency for International Development (USAID), CEDC has also installed and operated a sustainable biowaste treatment system in Cange. This system includes latrines for both the Bon Sauveur school and the ZL external clinic, plus three gravity-fed anaerobic biodigester bags and an adjacent wetland area, which were completed in 2013. The biogasification leads to a 99.1% reduction in total coliforms, and there is a 70-day retention time before the effluent is flushed.
into the constructed wetland. Methane is a byproduct of the biodigesters, and has been harvested in the past as fuel for cooking, at a rate of 25-50 liters per kilogram of human waste [6]. The methane presents an alternative to charcoal, which is the predominant fuel source for the region and a leading cause of deforestation.

One of the numerous ongoing CEDC projects is the development of field-test procedures and equipment for measuring the compressive strength of concrete masonry units (CMUs). Confined masonry construction with CMU blocks is the predominant method of construction across Haiti, but finding suitable, code-conforming CMUs is notoriously difficult. Another ongoing project is a small hydroelectric plant, which will draw on excess water at the dam that supplies the clean water system. The plant is being designed to provide a minimum of 34 kW of power during peak dry season.

2. Project Background, Parameters and Program
In June of 2017, representatives from the UN World Health Organization (WHO) had the chance to tour the clean water system of Cange, and were impressed. They noted that over the years of UNICEF and WHO assessments across Haiti, this was the only system that met their water purity standards. In light of this, the visitors suggested that CEDC consider establishing a “Center of Excellence” (COE) in Cange for the purposes of training, assessment, and implementation of sustainable basic infrastructure.

In the intervening months and leading up to the 2019 Comprehensive Studio project, CEDC began to outline its vision for the proposed COE: “Our mission is to establish a living-learning Center of Excellence in the Central Plateau of Haiti to be a base through which CEDC can continue its work and be a model that addresses global challenges and sustainable development goals.” And, furthermore: “The goal of this project is to provide education for sustainable water, hygiene, and agricultural practices while also proving the concept of a self-sustaining and fully functional entity in a developing country that is capable of serving local communities.”

Through a series of orchestrated charrette exercises with the CEDC membership, its Haiti interns, its director, David Vaughn, its founder, Jeff Plumblee, and various industry partners, specific aspirations and programmatic needs came into focus. It was decided that the COE should function first and foremost as a community development center, enabling the exchange of knowledge throughout Cange and with neighboring communities. As such, the public programming must include an exterior forecourt (along Route 3), flexible meeting space(s), and a demonstration lab. Additionally, and outside of the public realm, the COE will need two working “wet” labs for water testing and other research, plus a workshop for fabrication and prototyping. The COE will also require administrative space for CEDC interns and future staff, as well as on-site housing for these individuals.

In addition to these programmatic needs, there was an expressed desire for the COE facility itself to be a demonstration of sustainable building practices. This includes strategies for passive conditioning and daylighting; considerations for flexibility and adaptability; and the balancing of common construction techniques with low-carbon alternatives, where possible. CEDC stressed that it is critical to advance construction practices through adhering to the standards of the International Building Code (IBC). Additionally, they stressed that the new facility must perform with resiliency, both in the face of natural disasters as well as routine power grid failures, periods of drought, and other threats.

All of these parameters were outlined in a detailed Request for Proposals (RFP) document, prepared in advance of the Comprehensive Studio course by its instructors and student assistants from both Architecture and the CEDC. The RFP also included detailed mapping and analyses of the proposed COE site, an east-facing hillside at the southern end of the Zanmi Lasante complex, immediately adjacent to the existing external clinic facility and the filtration building that serves the water system. Equipped with this RFP as a foundation, the Studio was prepared to enter directly into design, with the overarching goal of delivering multiple and diverse proposals for the COE facility and its immediate site. From these proposals, the most promising scheme(s) would be selected by CEDC for future
advancement, and the related design documents and models would serve as tools for raising funds for the COE project. If all goes according to plan, CEDC will, at some later stage, engage a professional design team to carry the project forward to realization.

![Figure 2. Proposed Center of Excellence site.](image)

3. Design Process and Collaborative Structure

Over the course of the COE design project, the Comprehensive Studio was conducted with a well-defined schedule (as outlined above in Section 1.1) and a carefully orchestrated collaboration between architecture students, who worked in pairs, and their counterparts from CEDC. The partners from CEDC fell into three categories: (a) director, David Vaughn, (b) students who had formerly interned in Haiti, and (c) the student “COE project team.”

Interdisciplinary collaboration between the parties was particularly critical in the early stages. One afternoon per week was set aside for the former interns to come into the studio and work directly with the architecture teams. While site design and building layouts were taking shape, the interns contributed vital insight into the day-to-day laboratory operations, reflections on ideal living arrangements, and thoughts about balancing security with public engagement. They offered ideas about how the work of CEDC could best be displayed and communicated in the new facility. They also provided a critical window into Haitian culture, having each spent 7-12 months in Cange during their internships. The interns acted both as special consultants and also as “clients.” These sessions were overseen by CEDC director, David Vaughn, as well as the studio faculty. Between these meetings, the architecture teams worked to respond to each week’s feedback while preparing concepts and questions for the next consulting session.

The “COE project team” served a different, but complimentary role. One of 19 different project teams within CEDC, this group acted as a conduit to ongoing research from the other teams, such as those working on biodigesters, CMU quality, or the planned hydroelectric plant. The COE team gathered the studio’s technical questions, ranging from lab equipment needs to expected loads to recent construction precedents, and worked to supply answers from the most knowledgeable parties. David Vaughn filled in any gaps throughout the process, and later served as lead consultant, once the projects moved into the technical resolution stages in the second half of the semester. Additionally, the co-requisite architecture courses added depth by requiring thorough code reviews (Professional Practice course) and detailed environmental systems design and documentation (Technical Resolution course).
4. Design Outcomes
The resulting student design work was well-informed and rigorous and was refined by the challenge of responding to the real-world constraints presented in the RFP and affirmed by the first-hand experiences of the CEDC project consultants. The quality of the projects is evident in the integrative strategies for sustainable site design and building operation. Some of the key design outcomes are described in the following sections, and punctuated by illustrations from two student projects.

4.1. Site Design and Building Massing
During the first stages of the project, students wrestled with how to situate the COE onto the steeply-sloping site and arrange its program to best support public interaction while simultaneously establishing separation for private working and living zones. Each of the projects elected to carve into the hillside to some extent, taking advantage of a proposed service road to access the lower floors and terraces. Beyond these commonalities, the projects fell into at least three different approaches to building organization. Some schemes were decentralized, with a long and linear arrangement, running parallel with the topography and oriented to optimize cross-ventilation. Other schemes favoured central courtyards, and stepped down with the topography, forming a series of connected terraces. These projects maintained thin footprints for each the buildings, but had to work harder to ensure natural airflow across each structure. A final set of schemes were more centralized, and featured vertical stacking of the program. These examples set out to take advantage of their height through stack ventilation, but did not work as naturally with the topography as the other two typologies.

Figure 3. Linear organization by H. Polk and M. Polk versus stacked by C. Blevins and C. McRae

In all cases, design teams had to work with the landscape to find solutions for universal accessibility without relying on elevators, which would be prohibitive to maintain and service in the Central Plateau of Haiti. Project teams also paid careful attention to stormwater management, choosing permeable ground surfaces to control runoff. Selective vegetation strategies were employed for water management and for shading both the buildings and exterior spaces used for gathering, working, and/or demonstration. CEDC student consultants played an important role throughout these early stages in advising on probable patterns of circulation for both front-of-house and back-of-house functions.

4.2. Building Layout, Passive Design, Low and Renewable Energy
As the projects advanced, design teams began to formulate more detailed and synergistic strategies for passive conditioning and daylighting, before eventually applying these to solar energy calculations. The student proposals took care to segregate mechanically-conditioned program spaces from naturally conditioned space. From the RFP, the only areas that needed centralized mechanical conditioning were
the wet-labs, which also required fume hoods and laminar air flow cabinets. Most teams elected to use either all-air CAV or VAV systems for these labs, while turning to packaged terminal units or ductless mini-splits for supplemental local conditioning in office areas. Other program spaces relied exclusively on passive conditioning.

**Figure 4.** Passive conditioning study by Harrison Polk and Madison Polk.

### 4.2.1. Strategies for Passive Conditioning

Going back to the earlier building massing, students had worked to keep the proposed buildings thin and suitable for cross-ventilation, with the predominant breezes coming from the east. This became a challenge for the lower levels of any structures built into the hillside. In these cases, clerestory-level openings were employed and benefited from additional negative pressures on the leeward side of the buildings. This being said, there are two challenges with cross-ventilation that needed to be addressed. First, introducing cool outside air is preferable to simply moving the 29–32°C (85–90°F) air that is customary in this hot setting. Second, additional methods for moving air are necessary for calm days without discernable wind pressures.

Two methods for preconditioning air were explored. The first was the use of shaded, vegetative microclimates, which can be sustained in dry seasons through the recycling of water harvested during wet seasons. The second method was the use of “earth tubes,” which are air ducts insulated by the ground. These two strategies can be used in tandem, as indicated in Figure 4 above. Two concerns at the outset with earth tubes are proper sizing and the mitigation of condensation. Sizing is addressed by understanding the volume of the spaces to be conditioned. Condensation is addressed by providing adequate drainage just beneath the location the earth tubes turn vertical to penetrate the ground floor.

For keeping air moving on days without breezes, ceiling fans were one obvious choice, and offer relatively high efficiency. Looking for an entirely passive, and therefore resilient solution, however, numerous teams implemented solar chimneys, which work by absorbing and storing heat from the sun, and creating temperature differentials in a building. The result is a steady draw of air up and through the chimneys. This strategy, when combined with precooled outside air, can provide an effective conditioning scenario if the air inlets and the chimneys exhausting the air are placed in advantageous locations and adequately spaced from one another. In stacked buildings, like the solution depicted below
in Figure 5, this may involve insulated vertical chases for supply ducts. Additional strategies, such as nocturnal radiators, were explored by one student team for supplying cool air to upper-story bedrooms during the night, when the solar chimneys have cooled down and stopped working as well.

![Figure 5. Environmental systems diagram by Cody Blevins and Cameron McRae.](image)

4.2.2. **Renewable Energy.** Using tables provided by Vincent Blouin, instructor of the co-requisite Technical Resolution course, plus the expected energy demands, including loads for the lab equipment specified by CEDC, student design teams were able to estimate the net energy needs for the COE facility. One integral step in this process was a daylight autonomy study of the proposed buildings. Students utilized computational analysis tools such as Insight and Safaira (plug-ins for Revit) or Diva (a plug-in for Rhino) to estimate interior light levels (see Fig. 6 below) and properly scale the amount of electric lighting needed throughout the buildings.

These energy calculations, and the various assumptions contained therein, enabled each team to specify photovoltaic panels and associated battery storage. The desire from the outset, as communicated by the project RFP, was for the COE facility to operate independently of the local power grid. It was suggested that solar power be used to address general building loads, such as lighting, appliances, computers, fans, etc., while the proposed CEDC hydroelectric plant meet the specific demands for equipment, air conditioning and ventilation in the wet-labs. Per David Vaughn’s instructions, the wet-lab HVAC system was assumed to run twelve hours per day at full load and twelve hours per day at half load, all while filtering outside air through high-efficiency HEPA filters.
In the end, and in order to provide as much flexibility as possible for CEDC’s planning, project teams designed for different scales of the PV and battery system to address both ends of the spectrum (unconditioned spaces only, as well as entire facility) and variations in-between. The desired battery capacity would provide for up to two days of autonomy. Additionally, two factors were considered while planning for the future: possible COE expansion and battery degradation. An increase of 25% was estimated for expanded loads (some groups used 30%). For battery degradation, we noted that two of the possible manufacturers guarantee 60% capacity at ten years. Taken together, this resulted in 210% increase over the immediate needs at commissioning in order to meet needs ten years in the future.

4.3. Construction Materials and Embodied Energy

In addition to the considerations outlined above for energy efficiency and power grid independence, student design teams were challenged to consider the energy embodied in building materials and methods of construction. As a result, some groups were critical of concrete masonry, whose cement content is notoriously carbon-intensive. Assuming reinforced concrete frames for seismic stability, three different solutions emerged for alternative forms of masonry infill. The first was dry-stacked local lime stone in gabion cages. The second was compressed earth blocks. Research revealed that such blocks are typically pressed using lightweight equipment that requires no electricity, and that they can achieve compressive strengths of 13.1 MPa (1900 psi). Moreover, this solution could be serviced by the same field test methods being developed by CEDC for CMU quality control. The resulting earth blocks use
around 60% less cement by weight than traditional CMU and are durable enough to be left untreated, if desired [7]. They also repel mold and better regulate temperature, due to their thermal mass properties.

The third alternative was plastic blocks, a solution that addresses multiple concerns at once. Haiti suffers from a lack of municipal waste collection, resulting in rampant litter and pollution. Discarded plastic bottles are particularly troublesome and contribute to contaminated water sources. One student design team looked into the possibility of upcycling this plastic waste and converting it into masonry. Drawing on examples such as ByBlocks, these plastic units can be easily fabricated on site from shredded waste and can result in 95% fewer carbon emissions versus their CMU counterparts [8]. It was proposed that water harvested on site during Cange’s rainy season be stored for later use in the production of plastic blocks during the dry season. Issues to be resolved include methods for the collection of plastic waste plus considerations for proper finishing. Stucco finishes have been suggested, and some form of encapsulation may be necessary for preventing excessive smoke in the case of fire.

5. Conclusions
The Center of Excellence design project was successful on multiple fronts, owing in large part to the balance of interdisciplinary collaboration and applied research through service-learning, a model that we are interested to repeat and adapt in the future. The resulting design proposals were notably robust, having been bolstered by the knowledge and experience of the CEDC consultants, and sharpened by the constraints of planning for the very specific and resource-constrained setting of Cange, Haiti. CEDC likewise benefited from the process, as it helped the organization further articulate goals and visualize solutions for the COE. The proposals also drew on past and ongoing CEDC research, providing demonstrable applications for projects like the biodigesters and the forthcoming hydroelectric plant.

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Acknowledgments
Thank you to the students of the 2019 Comprehensive Design Studio and to the CEDC consultants for their thoughtful work throughout the project. Thank you to Henry Lee, Riley Garvey, Hannah Stewart, Abigail Piedmont and Andrew Crim for helping prepare the project RFP. Thank you to Rob Silance and Vincent Blouin, instructors of the co-requisite courses. Thank you to the following partnering organizations for their support: EDUSC; Clemson Creative Inquiry; the College of Engineering, Computing and Applied Sciences; Fluor; AMECO; Eastman Chemical; CUSG; Clemson’s Community Research + Design Center; Clemson Architecture + Health program.