Material Matters: When Material Studies Drive the Pedagogy

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The challenges of framing pedagogical goals for Design-Build studios are well known; the struggles to determine the size and scope of the projects, find funding, and fit the work into an academic calendar often define the learning objectives rather than reflect them. Developing projects that must conform to building codes adds a layer of pedagogical risk for the studio professor (who is typically responsible for project delivery on time and within budget regardless of teaching goals), but can also provoke innovation and new research questions in the effort to trade prescriptive solutions to the codes for the performative ones.

Folding materials studies into the pedagogy for design-build studios allows for learning objectives such as deepening the knowledge of materials properties and fabrication techniques, adding to the body of knowledge about architectural fabrication, addressing contemporary design and social issues, and underscoring the value of applied research to critical practice.

THE STUDIO CONTEXT

This studio, situated in the U.S. desert southwest, began with the pedagogical objectives of bringing students through a trajectory of designing a small, affordable dwelling in order to learn how to bring design intentions into built reality, translate ideas to drawings that serve as construction instructions, understand the sequence of construction trades, and master some aspects of hands-on and digital fabrication. An objective of investigating materials properties and performance vis-à-vis design intentions was added to encourage innovation rather than passive acquiescence to prescriptive building codes and common practices.

One tenet of affordable housing design is that the use of locally sourced materials reduces initial construction costs, and that often, vernacular building traditions are rooted in efforts to control indoor comfort without the use of expensive mechanical systems (thus reducing long term operational costs). Students in this studio were encouraged to examine earthen building methods indigenous to the area, for information about potential wall materials and thermal mass strategies for environmental control. Combing historical accounts of building with available materials unearthed some examples of the use of pumice stone as a wall material – in its raw form as stackable masonry or as a lightweight, air-entraining aggregate in concrete products. The students became enthusiastic about the thermal and aesthetic properties of "scoria", (a mixture of ground pumice stone, cement, and water) as a low-cost candidate for the perimeter walls of their project because it could potentially simultaneously address the issues of affordability, availability, and thermal performance.

DESIGN PROCESS AND LEARNING OBJECTIVES

Students and faculty explored the fit of scoria into the local amendments to the national building codes, created full scale mock-ups and test cylinders, designed and produced contract documents for a small residence, constructed it, and monitored the thermal transfer through the scoria walls for one year post-occupancy. This account of the studio investigations focuses on the inclusion of materials studies in the project design phase, and the realization of the objective of empowering students to look beyond existing practices for the accomplishment of their design goals.

Precedent studies revealed that scoria has some history in the desert southwest; it was used in the early part of the 20th century [i] and again during the recent decade [ii], [iii] in dwellings outside of towns with volcanic hills and abundant pumice. A "recipe" for scoria was not codified, nor were any performance requirements articulated since it was not recognized in national or local building codes. In order to consider its use in a permitted building within city limits, the studio had to determine how to couch it within the building codes and then experiment to learn how to build with it.

A local concrete block company provided information on sources for crushed pumice; several regional mines excavate and crush larger pumice stones for use in landscaping (as ground cover) or as aggregate for lightweight concrete and masonry units. Large amounts of "fines", small particles that are byproducts of the crushing process, are leftover and considered debris by the mining businesses. For little more than the transportation costs, many tons of red and black pumice fines are available for other uses. Identification of these sources, and determination of the costs to acquire the raw materials for making scoria was the first step students took in their materials studies.

Figure 1. Scoria test cylinders and full-scale mock-ups. Photos by author.

The studio professor, who had experience with both unreinforced earthen wall construction and concrete-based, reinforced masonry, weighed the pros and cons of both methods of building a small dwelling. Multiple test cylinders of pumice/cement/water mixtures were prepared by students and tested under compression in the University's Civil Engineering Soils lab, in order to establish a reliable mix for combining the elements in the field and obtaining consistent performance results. The studio then experimented with construction methods likely to be used on site – building plywood forms and pouring full-scale wall segments, including concrete bond beams. Through this process, it was determined that the best way to guarantee structural adequacy in the walls for first-time builders (who are often inconsistent in their processes and craftsmanship) was to use a bond beam that tied the walls together and distributed the roof loads. This allowed the structure to fall into the Earthen Materials building code section, rather than in the category of Low Strength Concrete. Earthen Materials are held to lower compressive strength requirements, because the concrete bond beam assures that point loads such as roof beams don't affect a small section of wall material that may not be sufficiently strong to carry the weight, and also adds lateral stability So, while the results of the many test cylinders under compression always revealed a strength higher than is required for earthen walls (300 psi), the results were not always high enough to meet the code for low strength concrete (1000 psi). Through this process, the students learned that design decisions regarding materials choices can be dependent upon many factors, including the structural performance when it must be proven rather than already known. Taking responsibility for this level of decision making – and proving empirically rather than only citing bibliographically gives students agency as designers to promote their design intentions knowledgably and actively. An obeisance to the prescriptive building codes is a difficult barrier to break down in the education of architects, because proving the performative alternatives can seem daunting until the steps become familiar.

Students also investigated ways of casting voids into the walls, and creating textures on the exterior wall surfaces. This involved creating positive shapes in the CNC router or vacuum form compartment to be fastened inside the wall forms before scoria placement. Full scale mockups of the forms and insertions were critical to understanding the behavior of the scoria as it was placed, cured, and revealed. Drawings gave important information about dimensions and processes, but the actual physical construction was necessary to learn at what scale relief molds broke down the consistency of the scoria mix and caused pieces to scale off the wall. Students found, through trial and error, that larger shapes created better results with patterns and relief textures. Mocking up these endeavors used only a small amount of material but averted potentially ruinous experiments on the actual building itself. A common activity in high end projects, the full-scale mockups proved important for this more modest project as well; especially when time and budget constraints made the untried methods seem risky. The careful use of mockups to make design decisions is also a pedagogical tactic to train students into a cycle of action and reflection-on-action that defines a thoughtful practitioner.

While these lab and field tests progressed, students designed a 1200 square feet dwelling with long scoria walls facing east and west. The design hypothesis was: walls with those exposures receive full sun for only part of the day, thus the mass of 18" thick scoria walls would allow them to serve as thermal flywheels, cycling heat back outside as the exterior temperatures cooled off at night. A full examination of this hypothesis, and the results measured by thermal sensors placed within the scoria wall assembly, is a topic for subsequent writing. The pedagogical note here is that the design process was not sequential (empirical materials testing followed by schematic design). The overall design of the dwelling had to happen simultaneously with the materials studies, due to the time constraints of an academic semester. The learning objective of this interwoven design thinking and full scale investigation was to realize that big picture design activities can coexist with the fine-grained research done to determine the materials

Figure 2. Plywood forms for scoria walls. Photo by Queston Kwolek.

and methods of construction. The fine-grained knowledge cycles back into the macro level design and there has to be a comfort level with releasing design ideas that are not valid once detailed information becomes available. Teaching this type of flexibility in design thinking is difficult in paper based studios because willful design intentions have a long shelf life. The design-build studio creates an environment of problem solving that is sharply focused on physical deliverables rather than on design ego. The teamwork necessary in a design-build studio is also a powerful motivator for individual students to let go of early ideas that prove infeasible in the face of empirical information.

Students then developed construction documents to include diagrams of construction methods for some aspects of the structure – both for the benefit of the plan review officials and the for the students who would tackle the build. These diagrams proved to be invaluable later, and copies of them turned up in the students' construction journals as a way to commit to memory the techniques that were most effective. The journals are intended to be a chronological, daily account of the processes and problem solving of each individual student. The documentation allows for careful notation about dimensions, layering of materials, order of installation and instances of difficulty and failure to be recorded and later resolved. The pedagogical goal of requiring daily entries and hand drawings is to break down the blur of activity across a semester into discrete moments of consideration and significant milestones of the progress. Without a daily reckoning, the minutiae of the decision making and results are often lost in the vastness of the bigger picture. The smaller moments and details of the process prove valuable in subsequent design experiences, when the fine-grained knowledge once again informs the macro level design.

CONSTRUCTION PROCESSES AND LEARNING OBJECTIVES

After the acquisition of building permits, construction commenced on the actual dwelling, and the learning objectives for the studio shifted farther from the design process goals of designing-testing-revising to organizational goals of implementing the design intentions in a final full scale building. This learning was about breaking down a large number of tasks into increments that could be assigned a time frame, specific tools and equipment, and a team of builders. Objectives were to help students understand the sequence of the construction work, the dependencies of some tasks upon successful completion of others, the necessity of scheduling work to correspond with weather conditions, required building inspections, and interactions with other trades. A large format project calendar was created and updated each day on site, to illustrate progress toward completion goals and to warn of upcoming needs for certain purchases, equipment rental, or offsite shop work that had to be done in order to keep the flow of the overall project moving.

An example of a critical path item in this project was the planning for sequencing the scoria wall pours in consideration of the limited amount of time available to the project. The bond beam that would connect all sections of the scoria walls had to have continuous reinforcing steel in order to meet the code requirements, yet pouring the walls in a linear sequence was not feasible because parallel sets of scoria walls were necessary in order to begin framing some volumes before all of the scoria was completed. The students had to first grasp the process (of setting up wall forms, pouring the scoria layers and then adding form blocking to accommodate horizontal bond beam rebar for the bond beam segments, pouring the bond beam segment, removing the wall forms and setting them up in a new location) before they could understand how the sequence could be manipulated to create some areas of bearing walls where framing could begin. Bond beam rebar had to protrude from each segment of scoria wall and bond beam, so that the code required overlap could be made when the next wall segment was formed. This was a three-dimensional puzzle that was sketched and re-sketched many times in order to optimize the timing of building the scoria walls versus adding in the framed wall and roof components. The complexity of this forming process was not easily grasped by the students, although several were able to understand it and begin to anticipate the steps.

The need for flexibility in design and willingness to regroup continued into the building phase of the project.

The design goal of creating a hidden concrete bond beam (with only scoria visible once the roof structure was completed) added a component of vexing complexity to the project. Having to pour the scoria walls to a certain height, then add blocking and rebar into the forms before continuing with a

Figure 3. Completed scoria residence. Photo by Velen Chan.

concrete pour meant great precision was needed with dimensions within the wooden wall forms. The biggest challenge for the students was keeping dimensions absolutely consistent from wall segment to wall segment as the forms were moved around the site. They had little or no experience with builder's levels and reading elevations from benchmarks. The first two wall segments suffered from this learning curve and the bond beam levels did not line up precisely. Later, this became a source of great angst for the students because it was visible and they responded by designing new ceiling details in situ to address a craftsmanship problem. The significant lesson at this point was that it is difficult in the field to carry out the level of precision necessary to bring off details that show material intersecting perfectly and cleanly, without trim to cover joints and mishaps. Students began to realize and accept that "zero edge" details are in reality very difficult to achieve. However, their ability to react to the unhappy results of the first few bond beam pours by designing a new detail is an example of one of the most important learning objectives in a design-build studio – realizing that open-mindedness and nimbleness are more valuable traits than fealty to an early idea in a context where risks are taken.

The lessons learned during the design and construction of the scoria dwelling were the immediate adaptations that had to be made to linear design processes and the acceptance of risk and possible failure when making bold innovations. An important metric for this pedagogy would be to ascertain whether students carried the learned behavior forward to subsequent projects or into their professional practice. While this author does not have a method for determining this metric, it has been noted that many of the design-build students over the past ten years have gone on to design-build practices, either with established firms or by starting their own.

PEDAGOGY CONNECTED TO LARGER CONTEXT

Beyond the studio pedagogy, the contributions of the material studies have had larger impacts to architectural practice in the region. Thermal sensors were placed throughout the scoria wall assemblies to measure thermal transfer through the material, and this data was collected for a full year after the residence was occupied. This data was first useful to provide evidence of the building's environmental control performance when the code required blower door test was failed four times. This is a relatively new code requirement in the metro area, and is based on air-tightness of the building envelope. To pass the test, only a small amount of air infiltration is allowed, and that signals that the insulated assembly can function effectively to control interior temperature. But, thermal mass assemblies work in a completely different way.

Figure 4. Wall and window forms, bond beam. Photo by Queston Kwolek.

Figure 5. View through kitchen to living area. Photo by Velen Chan.

(functioning as a thermal flywheel to take advantage of the diurnal temperature swing) and air tightness is not as important. Also, pumice stone and pumice-crete (scoria) are full of air pockets and the wall assembly does breathe a bit. So, despite repeated caulking of all joints, the air infiltration happened right through the walls anyway. In order to obtain a certificate of occupancy for the house, the head building official of the metro area required submission of one month of the thermal data as evidence that the house was performing well in controlling indoor comfort. This data (plus data from eleven more months) was then entered into the public record, and has become a precedent for passing Mechanical inspection in new construction that relies on thermal mass rather than insulation for environmental control. In this way, the materials studies and documentation gained greater significance than the achievement of a single project; they paved the way for future construction with locally available material.

The successful use of a regionally available material, and establishment of precedent for obtaining building permits with performative data is also a contribution to the field that is greater than the studio learning objectives alone. An academic setting such as a design-build studio is ideal for this kind of research and development, which most architectural firms can't afford to build into project budgets, especially when the results are so far from predictable. The documentation of this project paves the way for more work with scoria in the desert southwest, with a public record on file in the Building Services department of the city government. Because the materials were affordable in the context of available building materials, and the labor and methods proved to be affordable as well, the studies are particularly valuable to the development of alternatives for achieving low cost housing in the region. While the specificity of these studies may not be useful in other climate and/or geological regions, the principle of researching vernacular traditions in search of economical and environmentally sound building solutions is more broadly applicable.

PEDAGOGICAL CONCLUSIONS

Based on this studio experience, the instructor saw some pedagogical goals realized, while others proved to be too complex for the students' capacities. The goal of empowering students to add to the available body of knowledge about architectural fabrication (rather than choose only amongst well known alternatives) was clearly within their wheelhouse, with guidance about interpretation of building codes and use of testing methods. The goals of increasing students' flexibility in moving between macro and micro decisions while designing, and allowing new information to alter previous design ideas, were also realized (although were stressful). The students did demonstrate nimbleness during their design process, as they rather begrudgingly came to accept new information as a stimulus rather than a constraint. Besides having to continuously adapt their schematic designs to accommodate new information about the materials properties and construction methodology, they had to adjust the project schedule and scope to control costs and the feasibility of completion within the academic timeframe. The realization that cost data and construction time schedules are an important part of early design phases is a lesson that could have far reaching impact in budding architectural careers.

Students were not able to understand or manage all of the logistics of the construction methods and schedule on their own, however. Even as the processes became more familiar, they did not have the experience to look ahead and envision the entire trajectory of the project. This, however, is the province of the instructor and can hopefully be appreciated in hindsight by the students who have the ability to view the bigger picture. Students did tend to retain an understanding of the construction details to which they were exposed or discovered, and subsequent studio design proposals showed evidence of this. Some, if not most, understood their contribution to deepening knowledge about materials and fabrication, and the value of adding to critical practice through dissemination of the knowledge, rather than focusing narrowly on a single project.

ENDNOTES:

1. McHardy, Scott. Pumice-Crete Building Systems of NM, http://www.pumicecrete.com/index.html
2. Weiner, Paul. Tucson Lava House, DesignBuild Collaborative, Arizona, 2014.
3. Hayes, Cade and Jesús Robles, Casa Caldera, DUST, Arizona, 2016.