What to Make of Material

JOHN FOLAN
MARY HARDIN
University of Arizona

> *"Let us guide our students over the disciplined path from materials through the practical aims of creative work. Let us lead them into the healthy world of primitive buildings, where each axe stroke meant something and each chisel stroke made a real statement. Where can we find greater clarity in structural connections than in wooden buildings of old? Where else can we find such unity of material, construction, and form? What feeling for material and what power of expression speaks in these buildings. And buildings of stone as well: what natural feelings they express. What a clear understanding of material. What certainty in its use. What sense they had of what one could and could not do in stone. Where do we find such wealth of structure? Where do we find more healthy energy and natural beauty? With what obvious clarity a beamed ceiling rests on these old stone walls, and with what sensitivity one cut a doorway through these walls. The brick is another teacher, how sensible is this small handy shape, so useful for every purpose. What logic in its bonding, what liveliness in the play of patterns. What richness in the simplest wall surface. But what discipline this material imposes. Thus each material has its specific characteristics that one must get to know in order to work with it, this is no less true of steel and concrete. We expect nothing from materials in themselves, but only from the right use of them. Even the new materials give us no superiority. Each material is only worth what we make of it."*
>
> Mies van der Rohe, 1938

SPIRITUAL POSITION IN WHICH WE STAND

There is an inherent potential in every material: a potential form, a potential means of translating force, a potential for connection/assemblage. These potentials are not apparent. The eye must be trained to perceive these potentials and the hand must be trained to realize the potentials. Both eye and hand can be directed to a sense of material, or rather a sense of what can be made of material through exposure to and engagement of native technologies. The relevance of native technologies in Architectural practice and education is a question of sensibility and ethics. Typically, discussion of native building technology gravitates toward the significance of geographic region and tradition. The bias is logical. Each native technology has evolved in specific response to varying terrestrial and environmental conditions. Consistency of construction modality spanning generations implies the presence of, and even reverence for tradition.

Tradition can be defined in terms of a cultural context, or it can be defined in terms of a physical context – a construction logic that resonates with a specific region/environment. These are two divergent definitions; one establishes relevance with regard to social condition, while the other emanates from understanding of, and response to, fundamental physical principles. Regardless of the varying environmental conditions that define geographic regions, there are a series of constants which inform the development and evolution of construction technology. It is the understanding and engagement of those constants that ensures the vitality of native technologies as a model in methodology and application.

Each institution has the capability to engage regionally specific native technologies as a means of establishing both material and land ethics. Each region will reveal environmental factors that form the core of methodological constancy. As an example, architectural education and practice in the extreme conditions of the Sonoran Desert, demands that the sun be considered as the primary factor informing all decisions material and technical. Native technologies have allowed human life to flourish in that parched basin for at least one thousand years, and continue to inform and shape the built environment. This desert is stark, serene, and minimal. Life in it is a series of contrasting and subtle sensual experiences. Those who choose to live in the desert also choose to embrace the threats and blessings of burning light, relieving shade, and quenching downpour. The native technologies employed in the Sonoran desert evolved out of an understanding of the environment and landscape, linking functional program with profound experience.

For the same reasons that they evolved, native technologies persist today. Logic and rationale informed by locale continues to sustain the relevance of the technology in manifestations that evolve with time and ingenuity. We recognize the potential of the academic realm to influence the realm of professional practice if students gain an understanding of the tenets or precepts that guide native technologies. A series of courses offered within the technology curriculum stream seeks to develop sensibilities about the native technologies of this region. Each course utilizes empirical study to reinforce informed intuitive notion. Intuition is established through the introduction of regionally specific tectonic typologies. Material/construction manifest in case studies from past and current practice are utilized to illustrate the tenets and principles of the typologies/technologies as they have evolved over time. Those tenets and principles are then drawn out as guidelines for inventive use and potential reconfiguration of material in construction: establishing a tradition of sensibility in what to make of material – a sensibility that is sympathetic with the mission statement of our institution.

A MISSION INFLECTED BY IDENTITY

The fact that the School of Architecture at the University of Arizona publicly proclaims allegiance to native technologies ensures a consistent basis from which to develop a teaching methodology. Paraphrasing our school mission statement, a colleague describes our responsibilities as educators this way:

> "We have interpreted our mandate within a land grant institution as in part the responsibility to develop and inculcate in our students (as well as within the larger citizenry of our locale) a land ethic and a tectonic aesthetic that preserve and celebrate the specificities of our unique part of the world, the Sonoran desert. In so doing, we reject the generic – architecture and practice by default, in solutions imported from other contexts – and instead seek to establish a sensitive, non-prescriptive design methodology that takes its cues from the particular local inflections of such universal factors as light, wind, water, earth, and human society."[1]

TYPOLOGY OF NATIVE TECHNOLOGIES

In the Sonoran Desert region (as well as in most desert areas), three categories of construction/material typologies have endured over time: modular Earth systems, Monolithic Earth systems, and Organic Frame with infill.

Modular earth systems have developed in a loose chronological order from mixtures of clay-rich native soils and water formed and stacked by hand to Portland cement-stabilized compositions of soil, water and solid aggregates produced in mechanized molds yet still hand-stacked. Adobe bricks, lumped mud and animal dung, sod strips, compressed earth blocks, fired clay bricks, structural clay tiles, concrete blocks, insulated concrete blocks, and autoclaved concrete blocks are all examples of native technologies in regions where the soil is relatively free of organic matter, has a high percentage of clay content, and can be quickly cured by the intense heat from the sun. The scale of this technology is proportional to the human body and the earliest units measured about what the human hand could hold and lift into place. The patterns for stacking, in turn, related to the strength of the material units and where the weight load from above could best be borne below. The simple running bond is the most common pattern, ensuring that the load of two bricks above split evenly onto the brick centered just below them. Units developed with the addition of Portland cement reflect greater strength in their greater size, but are still proportional to the original units, with each concrete block equal to a stack of bricks three high, two long, and two thick. Apertures in this system are necessarily small, for the units do not easily span long distances and must be aided by lintels fashioned of stone or other strong materials. Spatial qualities of small and compartmentalized volumes naturally result from modular earthen technologies because the regions that produce it do not usually produce long spanning roof members. Habitable spaces are commonly roofed with corbelled units, vaults or domes. The sensibilities that accompany this technology include a respect for human scale and an articulation of the bond patterns and spanning techniques. In this typology, the units of masonry are made to act monolithically by the addition of a binding slurry, or mortar, which can be a more liquid version of the unit itself or a mixture higher in cement content but lower in aggregates. These slurries gave rise to the next category of native technology, monolithic earth systems, as well as contributing to the infill portion of the third category.

Monolithic earth systems include a similar spectrum of clay-rich to cement-rich mixtures packed or tamped into forms made of another material that give shape to the wall, floor, or roof plane. The technology required for the forms, mixing, and placement of the material becomes more complex through time as modern building performance codes are more precisely defined and modern aesthetic preferences favor clean and crisp surfaces. Puddled adobe, cob, rammed earth, pise, tapial, soil cement, and poured-in-place concrete are examples of earthen structures that are monolithic in nature. These technologies are native to a greater variety of climate zones, having originated in arid regions but spread to areas of cooler temperature and higher moisture because the self-supporting systems could dry slowly without threatening structural failure and the earth could

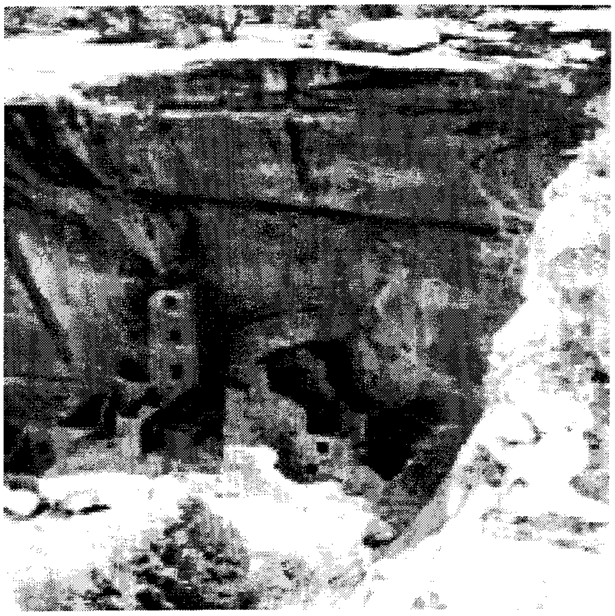


Fig. 1. Modular earth system: dry-stacked stone masonry.

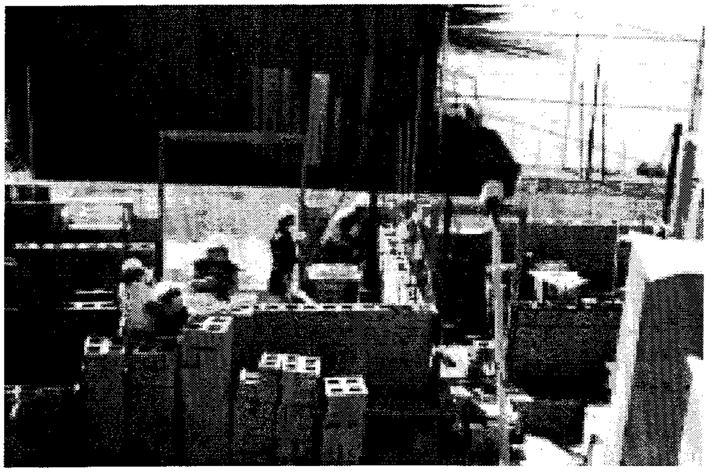


Fig. 2. Modular earth system: foam-insulated concrete block.

be mixed with better insulating materials. The monolithically formed structures also have greater plasticity than modular systems, and often take on more fluid configurations. The sensibilities about human scale and the spatial qualities generated by monolithic systems are otherwise very similar to the modular systems, influenced by the way the systems are made and the capacities of the materials.

Organic frame with infill systems are common to most climactic regions, including the Sonoran Desert. While seemingly few sources of framing timbers occur here naturally, the strength of many native plants is surprising. The interior ribs of saguaro cactus have been used since the beginning of recorded history, as have ocotillo cactus ribs and mesquite tree trunks and branches. Almost all regions have plant material suitable for framing, and other resources for infill materials. Animal skins, fabric, woven reeds and grasses, mixtures of plants and earth, paper, glass, and many other materials have been used to span the spaces in between framing members. In this place, clay and mud were mixed with water and packed between and around cactus ribs to create a wattle and daub enclosure system, with layers of mud and plants placed on top of framing members to form a thatched roof. The advantage of thermal mass is not present in this typology as it is in the previous two, but this system was nevertheless used extensively by nomadic people who chose mobility and expedience over the investment in time and energy necessary for earthen constructions. Some frame and infill systems become monolithic, when the infill material surrounds and subsumes the framing members. This is the case with the "ki" structures built by most of the populations indigenous to the Sonoran Desert; slender cages made of cactus ribs are completely filled and then covered with an adobe mud mixture.[2] This native technology evolved during the twentieth century into a more rectilinear version made of milled lumber and filled with mud in the same manner.[3] The sensibilities that accompany this system have more to do with acknowledging a hierarchy of members than human scale. While there certainly are scalar limits due to the size of available framing members, the more important relationship is between the largest members and the subordinate ones. An articulation of this difference is often seen with a change in linear direction with each material as it decreases in scale and span, layering over the primary members. Patterns of solid/void can be discerned within the system and are sometimes elaborated and accentuated for legibility. Spatial qualities of frame and infill systems are different than those brought on by the use of earthen wall systems. Greater volume is possible, and natural light is more readily admitted through apertures created

Fig. 3. Monolithic earth system: rammed earth circa 1350.

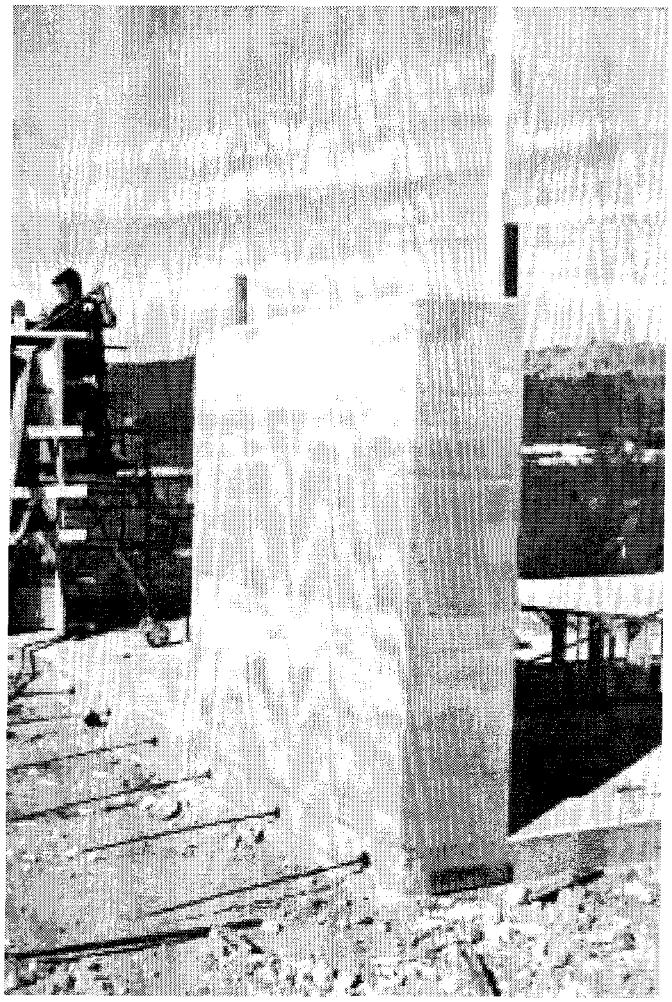


Fig. 4. Monolithic earth systems: rammed earth 2002.

by the framing bay or by the translucency of the infill materials. More regular structural bays are a product of the framing hierarchy and this repetition and regularity becomes part of the system vocabulary.

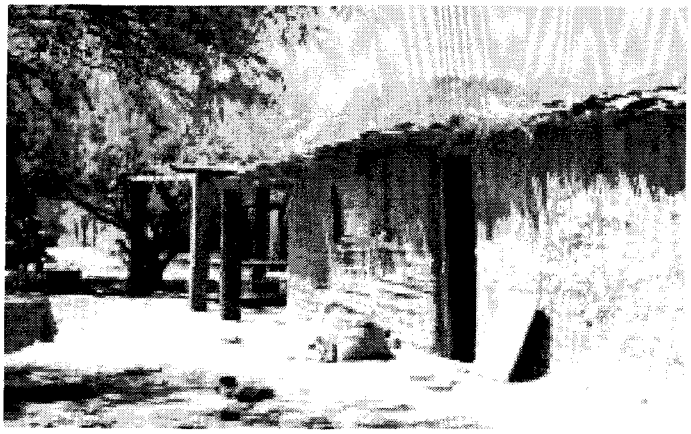


Fig. 5. Organic frame with infill: cactus rib cavity wall.

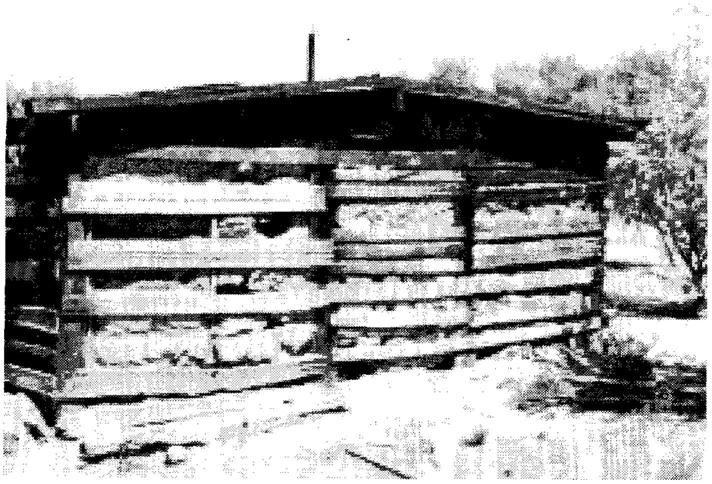


Fig. 6. Organic frame with infill: later era milled lumber cavity wall packed with adobe mud.

NATIVE TECHNOLOGIES IN THE CONTEXT OF CURRICULAR GOALS

The three native construction/material typologies discussed, as well as the methodologies employed in their implementation, establish a foundation for the development of critical thinking skills within our technology curriculum stream. Pedagogically, the technology stream establishes an analogue between material and construction, reinforcing the notion that the art of building can only be understood once the materials themselves are understood. The pedagogy recognizes that understanding of material emanates not only from universal physical characteristics, but also from knowledge of phenomenological characteristics. Structure and form of material are not presumed to be constants as the physical form of a material may imply variable characteristics with regard to the way it may be placed; the way it may resolve intrinsic and extrinsic stress; the way it might be connected to similar or dissimilar materials; the way it will weather; the way it will react to natural light; and ultimately how that material will be perceived – its visceral aspect. Variation in the expression of building assemblages that are the product of native technologies reveal the importance of knowledge in the manipulation of material. As is evident in the development and manifestation of native technologies, material properties and material behavior are not abstract; they are precise and entirely tangible. For that reason, the curriculum stream utilizes native technologies as a model in decision making processes, to reinforce the notion that mode of construction and material implementation are critical in manifesting a physical context that resonates clearly within the cultural context.

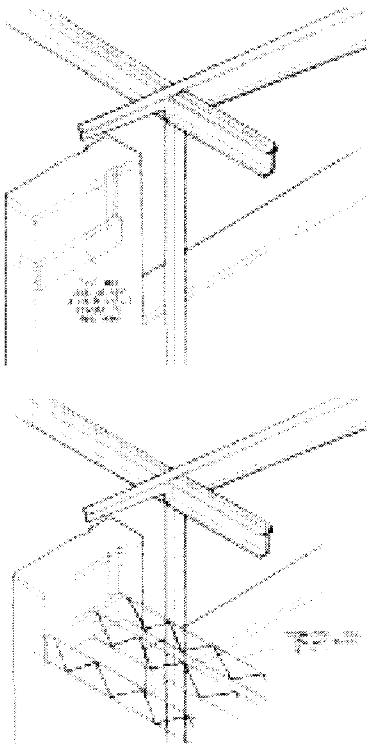
Following are descriptions of components within the technology curriculum stream at the University of Arizona; three sequentially organized half-semester Materials and Methods modules, and one full-semester Design/Build Studio. The descriptions are provided as a means of illustrating how native technologies are instrumental in establishing clear sensibilities with regard to material properties and construction systems; preparing students to perceive the true logic inherent in those materials and technologies. This sensibility is portable. Students who leave the region are capable of making decisions based on comprehension of technologies native to other regions as well as those which are global. Understanding of native technologies informs understanding of all technologies.

MATERIALS AND METHODS MODULE I

The first module in the Materials and Methods sequence is introduced in the second year of the five-year BArch program; just as the students have passed through the portfolio admission gate into the professional phase of the degree plan. As they move from design fundamentals studios in the first year into a year where all five of the curricular streams are represented (studio, technology, visual communication, history/theory, and critical practice), they are immediately exposed to the materials and methods of construction. An emphasis on native technologies begins in this initial module and consequently affects their design thinking from the onset of architectural studios. Module I presents the basic information about major construction materials; their physical properties, aesthetic characteristics, and criteria for use and selection. Lectures are organized into historical accounts of each material, presenting them as native technologies and drawing this thread through time from primitive to industrial uses. The spatial qualities created by the use of each material are illustrated with case study examples of simple buildings that are pure representations of a native technology. A field trip to a contemporary architectural example or fabrication plant reinforces each topic of the first module.

The laboratory project for each offering of Module I requires an analysis of a built example of architecture utilizing native technologies specific to the arid desert region. For several years, the instructor has employed a project under construction in her own professional practice as the vehicle for the laboratory analysis. Each year the project has been built mostly of rammed earth, a native technology of long duration in this area. Site visits to the building under construction, and photographs and drawings made on site give the students the opportunity for three-dimensional understanding of the system and its relationships to other materials assemblies. The methodology of rammed earth construction, illustrated in slide presentations by the instructor is best understood in person, and the analysis project begins after this point. Students are asked to select a critical detail from the project and create a sequence of axonometric drawings describing construction. The detail conditions address the manner in which the building meets the ground, the manner it which it meets the sky, and the way in which the corners are resolved; a manner of analyzing critical junctures within building assemblages that is reinforced throughout the Materials and Methods sequence. The breadth of conditions studied requires an overall understanding of rammed earth technology while ensuring the careful study of intersecting materials and their hierarchical integration within an overarching construction system.

As a follow-up to the main lab exercise, the students are asked to make a significant change to the detail they have come to understand, by altering the design intention at that juncture of materials. For example, if the original detail was designed to bring a glass plane into a recess within the rammed earth wall thus engulfing the glass and obscuring the means of fastening the plane to the wall, the change of intention might be to make the intersection of glass and earth visible, or even accentuate it. Students explore this empirically by modeling the condition, and once they have solved it, they draw it in axonometric as an appendix to the original sequence. With these steps, the laboratory exercise engages students with a native technology, in person and intellectually, bringing them closer to possessing a visceral sensibility for the system and its inherent qualities. The translation from analysis to design also prepares students to apply knowledge and sensibilities gained to their own work, which is the emphasis in following modules.



Figs. 7 and 8. Excerpts of drawing exercises in Module I requiring students to document construction sequence of detail from instructor's professional project, showing connection of ledger and trusses to rammed earth wall.

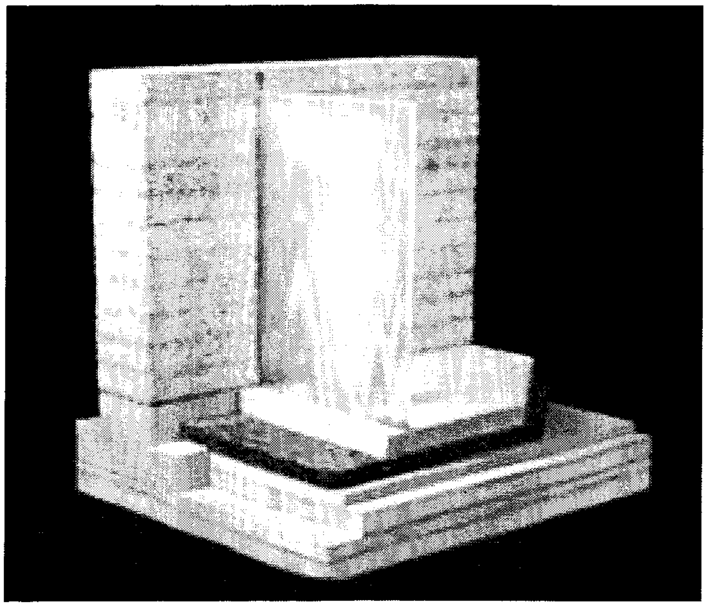


Fig. 9. Example of Module I laboratory exercise – model of detail designed using rammed earth.

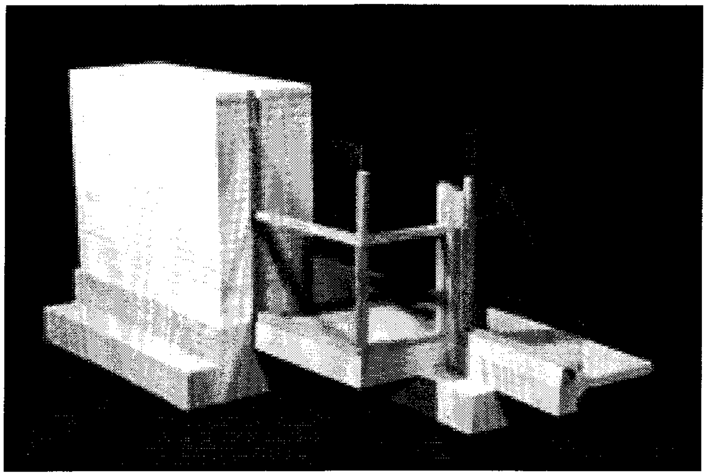


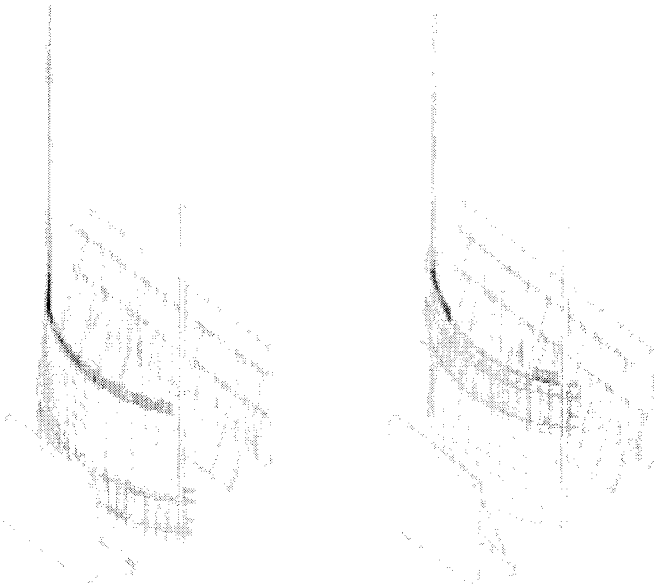
Fig. 10. Example of Module I laboratory exercise – model of detail designed using rammed earth.

MATERIALS AND METHODS MODULE II

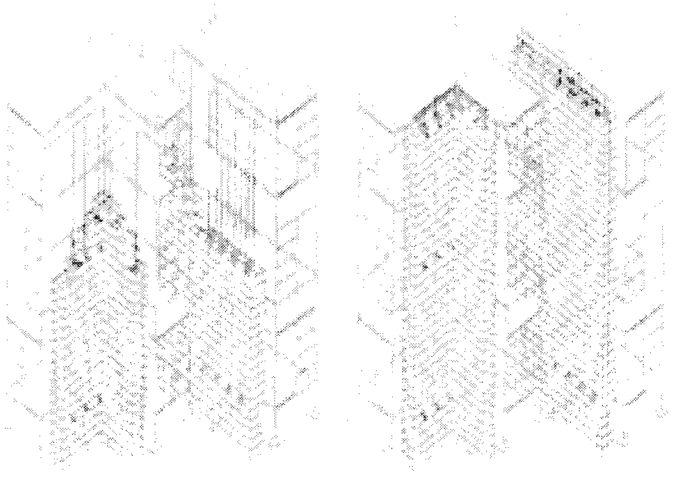
The second module of Materials and Methods is offered in the third year of the BArch program, concurrent with the second year of the professional phase. The course content builds upon the foundation of knowledge gained in the first Materials and Methods Module by introducing issues related to construction sequence, construction tolerance, technical systems integration, and the effect of these concerns on design. Focus is placed on refining the development of intuitive sensibilities while broadening exposure to, and working knowledge of, construction logic gained in the first module. The course material is introduced in a familiar format. Lectures are organized to present the construction process as a series of interfaces with both site and environmental forces, reinforcing the already developed notion that the process of construction is informed by a sequence of design decisions rather than a collection of actions prescribed by generic practices. The module begins with a lecture entitled "Terrain Interface – Placement", is followed by several lectures under the umbrella heading of "Mediating Realm", and concludes with lectures on "Atmospheric Interfaces" and "Terrain Interface – Anchoring". Each of these lectures serves to establish an understanding of the logic and order of construction while bolstering the empirical with theoretical expositions from authors such as Eladio Dieste, and Rafael Moneo; architects who have innovated within the context of native technologies.

Like Module I, Module II employs two modes of analysis in establishing a clear the connection between idea and construction; one mode is observational, and the other empirical. In the first, case studies of significant buildings are used to illustrate the development of criteria for making choices about materials, systems and detailing. The case studies presented in lecture are reinforced by recurring visits to a selected construction site where both modular earth native technologies are being employed. The instructor leads guided tours every second week and students keep written, photographic, and drawn documentation. The act of documentation enables students to gauge progress of the work and compare the results of the construction to the stated design intentions. This establishes a tangible link and informs the lab component within the module.

As the students observe construction, they begin to understand that while ideas and theoretical notions can influence the choice of materials, so can the character and properties of a material initiate design response. This understanding informs the second, empirical mode of analysis. Utilizing a corner of their studio design project (a small cabin on the coast), students engage in establishing an analogue between conceptual intent and material manifestation. The students are required to resolve the construction of an intersection between three horizontal planes and two vertical planes in an environmentally controlled building. The exercise requires them to delineate each stage of construction in the erection of the material assemblage. Each constructive and material element of the walls and the intersecting floor and roof planes are delineated in axonometric on separate sheets of mylar. The layers of mylar each describe a moment within the construction, that when combined, illustrate a full construction sequence: empirically modeling construction through drawing. The scaffoldings and forms necessary for the proposed construction must be drawn in place as well, reinforcing the students' understanding of how buildings are made. Desk critiques in studio reiterate the logic behind each choice of material and its orientation for specific climate and place, while the Materials and Methods module informs that logic through consecutive site visits and the lab project. As a result, the students are imbued with a sense of the inevitability of consequences to every design decision, and are constantly asked to defend their values and design criteria.



Figs. 11 and 12. Examples of single frame sequence drawings made in Module II laboratory exercises. Example of a slip formed concrete casting system.

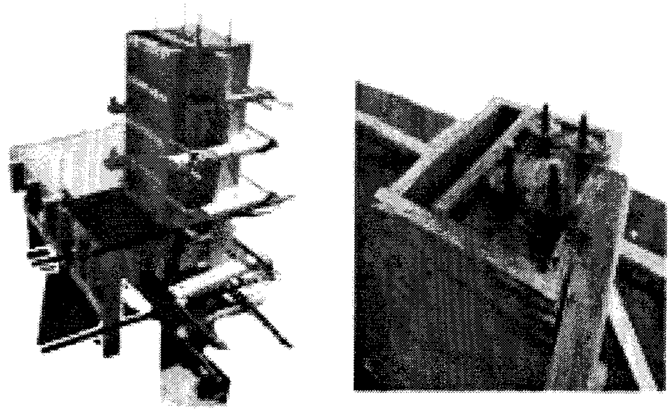


Figs. 13 and 14. Examples of single frame sequence drawings made in Module II laboratory exercises. Example of reinforced concrete masonry system.

MATERIALS AND METHODS MODULE III

The third and final module in the Materials and Methods sequence occurs during the second semester of the third year in the professional phase (fourth year of the five year BArch). By this time, students have had the full sequence of structures and environmental controls modules, and are prepared for a more complex consideration of materials assemblies. This module is an advanced study of building tectonics and the integration of theory, material, material assemblages and construction methodology. The prime objective is to build upon the accumulated knowledge base to clarify the connection between idea and construction. It focuses less on literal utilization of native technologies but encourages innovative application of inherent sensibilities in addressing a broader spectrum of complex issues such as sustainability and life safety. Once again, understanding of material is achieved through empirical research with the laboratory project.

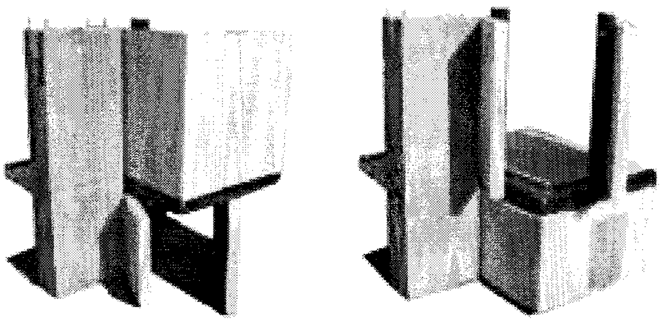
This exercise requires the students to design and construct a full-scale building detail. Students select or devise a connection between three planes in a building, defining the seam between an interior and exterior condition. The detail must manifest an idea, and reflect its position within the context of a larger construction. At this point, the project becomes personal research. Connections, means of connections, transitions from structure to enclosure, enclosure system to enclosure system, and exterior to interior reveal questions with regard to intention in material implementation. Building upon the sensibilities established in the second Materials and Methods Module, the lab exercise provides a tangible means of establishing the relationship between material properties and method of fabrication. As the analogue becomes more apparent, the means of making becomes a prime consideration.



Figs. 15 and 16. Detail shots of a Module III laboratory exercise under construction.

Design/Build Studio

The Design/Build studio is an advanced studio option offered in the fourth or fifth year of the BArch program where students work directly with Native Technologies in the construction of a small residence for a low-income family in Tucson. The design of the residence is accomplished in an earlier semester; some of the students continue on to participate in the studio that will construct it while others do not. The instructional objectives of the studio are to create a hands-on empirical experience in order that students learn the logical order of the construction process and the technical considerations involved at each step,



Figs. 17 and 18. Images of the same Module III laboratory exercise once construction is completed.

in order to refine design thinking for future projects. In the case of a recent rammed earth dwelling, students observed the formation of an innovative "raft slab", formed, mixed and tamped rammed earth walls, installed electrical boxes and conduit, framed roof trusses and purlins, sheathed the roof with a radiant barrier and corrugated metal, framed interior partition walls, hung drywall, plus other construction activities. During the construction process, students designed details for the project including chamfers and reveals for rammed earth to concrete connections, window sills and seats, wood frame connections, and layering of materials and material expressions.

Managerial tasks were necessary components of the design/build studio, as this project had a very real and concerned client. Some tasks were research oriented (comparing alternative products, mocking up samples, deciding on the best alternative for use in the building); some were design oriented (designing and testing connections, joints, details that have not yet been incorporated into the project documents); and others were personnel related (organizing subgroups of peers to accomplish specific tasks at critical times). All brought the students to a deeper understanding of the building system and developed a stronger sensibility in them for how the technology might be used to realize a specific design intention.

This kind of experience is invaluable in helping students to develop a true sensibility about the nature of a material, the tolerances of the system that employs it, and the costs and benefits of native technology in comparison with others. A hands-on relationship with rammed earth construction, for example, lifts the appreciation of rammed earth from a visual one to a real sense of its heft, its effect on air temperature as heat moves through it, its mass and solidity, the story of fabrication revealed in the lines left by tamping consecutive courses, and the attention to craft and detail necessary to achieve square corners and crisp edges. They immediately begin to revise the forming system in their sketchbooks and develop proposals for improving the technology, which are embraced by the next class the next time around.

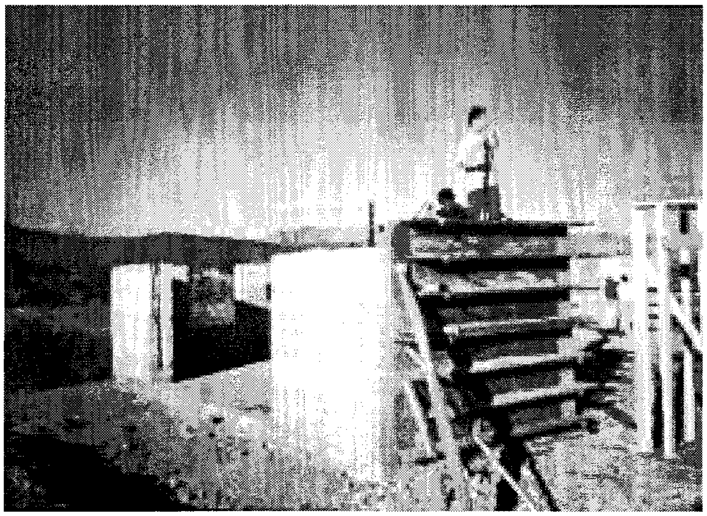


Fig. 19. Stage of Design/Build Studio project: construction of a rammed earth residence. Finished rammed earth wall and formwork.

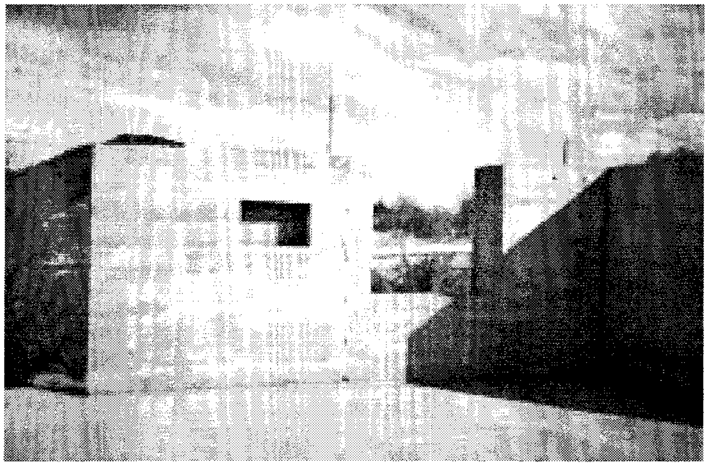


Fig. 20. Stage of Design/Build Studio project: construction of a rammed earth residence.

CONCLUSION

The connection from empirical experience to professional practice is established when students visit and observe the construction of such projects in the first module of their materials studies, and is cemented when they come full circuit to constructing a building of their own design. In this way, gradually and incrementally, the lessons of native technologies and their appropriateness to the circumstances of this region are brought to students as fundamental precepts for design rather than as visual pastiche to be applied at the end of the design process. It is our intention to reinforce the objective nature of material implementation, ensuring both physical and cultural authenticity. Culture and tradition can be honored

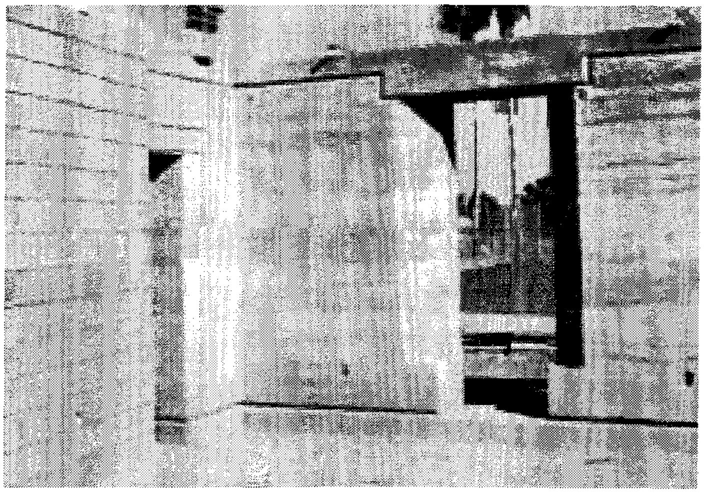


Fig. 21. Illustrates the transition from a native technology (rammed earth) to contemporary methods of achieving lateral support (concrete bond beam).

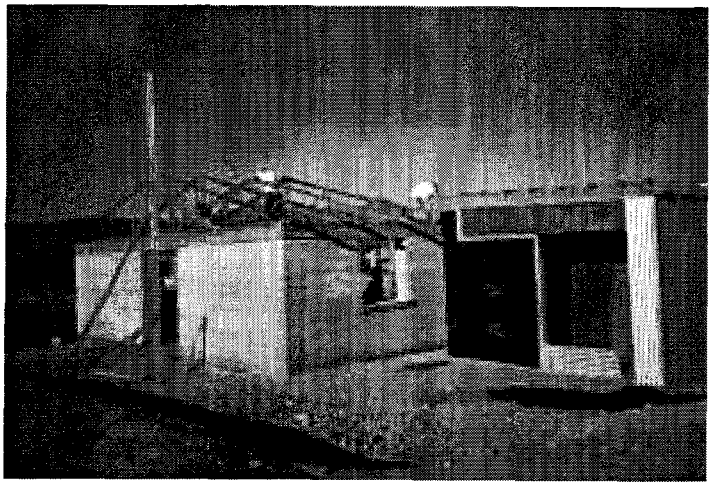


Fig. 22. Illustrates the transition from a native technology (rammed earth) to contemporary methods of achieving lateral support (concrete bond beam) and long-lasting structural roof materials (galvanized steel).

through construction logic that resonates with a specific region/environment: thus suggesting what to make of material.

---

[1] Hollengreen, Laura. "Mind and Body at Work in the World", *Proceedings of the ACSA Southeast Conference*, 2003.

[2] Easton, Robert and Peter Nabakov. *Native American Architecture*. Oxford University Press. 1989.

[3] Van Willigen, John. Contemporary Pima House Construction Practices. The Kiva; Journal of the Arizona Archaeological and Historical Society, Inc. Vol. 36, Number 1, Fall 1970.