AC 2009-303: PROJECT MANAGERS, ARCHITECTS, AND ENGINEERS--OH MY! AN INTERDISCIPLINARY COLLABORATION

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Project Managers, Architects and Engineers, Oh My: An Interdisciplinary Collaboration

Abstract

The Architectural Engineering (ARCE) Program at the California Polytechnic State University in San Luis Obispo is creating a unique and novel interdisciplinary course where architecture, architectural engineering and construction management students collaborate to design and plan the construction of a building structure. The current plan is to develop a default interdisciplinary experience that can be taken by every student and then allow course substitutions for other options as they are created. This paper reports on one of those other options, specifically a unique real world, global, multi-disciplinary experience in East Africa that has resulted from a master's degree project that incorporated 14 undergraduates into the work. The project is entering its second year, now includes 24 undergraduate students and has the potential to continue well into the future. The students are supporting the Catholic diocese in Same, Tanzania to design a polytechnic school to accommodate up to 500 students. The design experience is allowing students to address the social, political, economic, constructability, and global issues that come from a real world project on a different continent. The students are incorporating local labor capabilities, regional material availability, climate, seismic vulnerabilities, and local customs and traditions into their design. To minimize the costs of construction, operation and maintenance, the student design includes efficient construction methods, energy sustainability and water sustainability.

I. Introduction

The Architectural Engineering (ARCE) Program at the California Polytechnic State University in San Luis Obispo is housed in the College of Architecture and Environmental Design (CAED) which makes it one of the few accredited engineering programs located outside of a college of engineering. With the Architecture (ARCH) and Construction Management (CM) programs located within the same college, there is a wonderful and unique opportunity for students to engage in interdisciplinary collaboration with those same design industry professions that they will encounter on real world projects. To that end, the ARCE students take four design studios from the Architecture Department and multiple courses from the CM department to attain the proficiency required by the ABET ARCE program criteria. Similarly, both the Architecture and CM students take a five course sequence in structures from the ARCE Department. What is currently lacking is an upper division, interdisciplinary, project-based design experience for every student. The college is committed to creating such an experience for the benefit of every student.

ABET criterion 3d [1] requires that "students are able to function on multi-disciplinary teams". A multi-disciplinary team does not truly exist until each individual member of a team possesses some specialized knowledge that the other members do not have. A priority goal for the ARCE program is to create a unique and novel interdisciplinary course where architecture, architectural engineering and construction management students collaborate to design and plan the construction of a building structure. The course objectives are for students to be able to:

1. Function effectively on an interdisciplinary team to create an integrated building design.
2. Select and configure appropriate building systems based on interdisciplinary criteria.
3. Communicate effectively with other members of the building profession.
4. Apply real world constraints to the solution of a building design problem.
5. Integrate standards of professional and ethical responsibility into the design / construction process.
6. Use the current industry-standard tools and technologies in the creation and presentation of a design

Rather than starting from scratch, the CAED department heads are examining current interdisciplinary efforts that have been successful on a smaller level and considering what is required to expand these successes into a large enrollment experience. There are several elective courses that represent successful collaboration between ARCE, ARCH and CM students. There have been multiple senior projects that would qualify such as architects and structural engineers competing together in the AISC competition[2] and architects from Iowa State and ARCE students from Cal Poly collaborating on the design of a building[3]. Two advanced electives in the college comprise excellent interdisciplinary experiences. ARCE x410 Building Cladding, is an elective course team taught by members of the ARCE, CM and ARCH departments where REVIT is the software platform[4]. CM 431, Integrated Project Delivery which is offered every quarter and already has an enrollment of over 50 ARCE, CM, and ARCH students is the most likely candidate for expansion. In addition, ARCE 453 Senior Project includes a variety of interdisciplinary efforts. The project described herein is one example.

The current plan is to develop a default interdisciplinary experience that can be taken by every student and then allow course substitutions for other options as they are created. This paper however reports on a unique real world, global, multi-disciplinary experience in East Africa that has resulted from a master's degree project that incorporated 14 undergraduates into the work. The project is entering its second year, now includes 24 undergraduate students and has the potential to continue well into the future. Not only does this experience meet all of the multi-disciplinary course outcomes listed above, it also provides an invaluable experience for understanding engineering in a global and societal context (ABET outcome 3h) and developing a knowledge of contemporary issues (ABET outcome 3j)[1]. These outcomes are also key elements in both the first and second editions of the Civil Engineering Body of Knowledge[5,6].

II. Project purpose and overview

The ultimate purpose of the master's project is to provide a set of recommendations and suggested guidelines for the design of buildings and other facilities in the arid and semi-arid regions of rural East Africa by using the actual project design of the Same (Sah-may) Polytechnic college as an example. It is intended that this document will serve as a reference and informational resource for groups and organizations in the design and construction of buildings and other facilities required to support development efforts.

The task of designing the Same Polytechnic was charged to an interdisciplinary team of students in the College of Architecture and Environmental Design at California Polytechnic State University, San Luis Obispo. The students represented the degree programs of Architecture,

Architectural Engineering, Construction Management, City and Regional Planning, and Landscape Architecture and were advised by faculty members during the design process. Many of the undergraduate students obtained course credit for the experience through the Senior Project.

This challenge is amplified by the unique conditions for construction in this region of Africa. Locally manufactured building materials are inconsistent in quality and availability and conventional building materials are inflated in price. There is no established system to regulate the quality of work of building contractors nor are building codes enforced. It is common for buildings to be designed by local workmen who usually do not have the background or education to provide a completed project that achieves the necessary requirements. The workforce in rural areas does have substantial training in the execution of building trades but often lacks a solid grip on the principles of construction that ensure structural safety. These conditions often lead to inflated construction costs, additional costs for repairs and sometimes a complete loss of the initial construction capital when the completed facilities are inadequate, unusable or unsafe. The immediate goal is to design a polytechnic that will meet these constraints, provide a usable facility for the local population, and will serve as a model that others can follow.

III. Project mission

The Same Polytechnic is a development project proposed by the Catholic Diocese of Same. The purpose of the Polytechnic is to provide vocational training to between 250 and 500 students who have graduated from Tanzania's public secondary school system. Recent efforts by the Tanzanian government to improve the population's education level have included a mandate which requires all students to graduate from secondary school. Some students will continue on to the university level but a majority will not and will need to enter the work force. The primary and secondary school curricula provide no training or programs for acquiring job skills. This will limit opportunities and reduce the overall standard of living for the individuals not continuing on to a University. It is hoped that the presence of a skilled work force will attract both government and non-government group interest and attention to the area bringing funding for further social and civil development.

In addition to providing vocational training, the Diocese has several secondary goals for the school to achieve. The first is for the school facilities to serve as an example of improved construction methods and practices for the attending students as well as the surrounding community. Due to the underdeveloped status and poor economic conditions in the area, much of the local population is left to build their own homes and places of business with most having little or no experience in construction. Compounded by the fact that the area does not see enforcement of the country's building or safety codes, the district sees a high rate of building failures in a variety of forms. It is the Diocese's hope that the local population will use the faculty of the Same Polytechnic as a resource and view the facilities as a physical example for how to construct their homes and other buildings.

IV. Tanzania

The United Republic of Tanzania is located in East Africa and is bordered by Kenya and Uganda to the north, Rwanda, Burundi and the Democratic Republic of the Congo to the west, Zambia,

Malawi and Mozambique to the south with the Indian Ocean to the east as shown in Figure 1. Tanzania is divided into 26 regions with the project site for the Same Polytechnic located in the northern region of Kilimanjaro (Figure 2a). Within the region, the project site is situated in the district of Same, one of six which subdivide the region and is one of the least developed in the country in terms of civil infrastructure (Figure 2b). The district itself has a population of approximately 212,000[7] and has seen a shift in agriculture away from the traditional cash crop of coffee to the sustenance food crops of maize and rice[8].

V. Project Scope

The initial step in the architectural design process was the development of a list of the types of facilities required to support the functions of the school and provide the necessary accommodations for the student body. Once this list was compiled, a required size needed to be assigned to each category of building. The size was determined from the requirements of the specific task the particular building needed to support and the number of individuals intended to use the building.

The technical college is intended to provide training in computer science, auto mechanics, construction, and hotel management. Each of these areas requires space for classrooms, shops/laboratories, a library, storage, and faculty offices totaling 16,350 square feet. About the same amount of area is needed for the community support requirements including a mosque, a multi-faith hall, a student union, infirmary, and a dining hall. The 2,100 square foot administrative area required a lobby/waiting area, administrative/ reception area, director and assistant director offices, conference room, supply room, file storage room and bathrooms for men and women. Facility support requirements included electrical and mechanical shops, bulk storage, and a laundry. A photograph of the project site is shown in Figure 3.

VI. Design effort

The majority of the work on this project is being conducted by Cal Poly students. Undergraduate architects, landscape architects, architectural engineers, city planners, and construction management students are all contributing to a comprehensive site plan and building specifications. The project lead, a master's student who developed this experience for his master's project, made an extended site visit to East Africa and returned with a series of case studies that highlighted regional material availability, local customs, labor force capabilities, and a series of construction lessons learned from looking at specific projects. After the initial site visit to Same, Tanzania, the design team assembled to communicate the considerations and challenges each of the different fields needed to address in the design. This required constant communication and open dialogue in the team which was sub-divided into groups based on degree programs.

The architectural considerations had the greatest influence on the physical size and appearance in the design of the Same Polytechnic's facilities. These considerations were based on the goals cited by the Diocese of Same and secondary goals of efficient construction methods, energy sustainability and water sustainability. The architectural design of the Polytechnic needed to provide all the necessary types of facilities with enough space to accommodate the faculty and

students for the school to operate properly. At the same time, constant attention needed to be given to the resulting cost of construction of the final design. The Polytechnic's design needed to meet the set goals while being cost efficient for the Diocese to be able to fund the project.

Each team researched information relevant to their field which was then used to develop initial designs that provided the basic form of the buildings. These initial designs were mainly the priority of the Architecture team but were constantly reviewed by the other teams to ensure all the considerations were being addressed. Once the conceptual designs were agreed upon, the final design process began with the different teams working out the details of the design based on information obtained from the site visit, research that addressed the goals of the Same Polytechnic's developers, and independent industry review and validation. The final design produces building plans or drawings that graphically explained exactly what is to be constructed.

Teams were presented with a project overview. What followed was a compressed design process in which teams generated concept plans and design details in one evening. Each team then presented their results to the other teams. Four interdisciplinary teams were created. These teams were composed entirely of students. Each team was required to account for specific project elements within the concept plan. Figure 4 shows photographs of the student working groups and project discussions.

There were a series of design charettes to facilitate an exchange of ideas and communication. The teams were given instructions to select a facilitator, get to know team members, establish rules, create a concept, complete the details, prepare a short presentation, and present their ideas to the group. Each team was presented with tracing paper, tape, glue, markers, and scissors to create a site plan. From the presentations, some general overarching concepts and priorities emerged which included:

- bamboo forestation in the rear
- parking incorporated near roadways
- auto shop located near the gateway
- centralized node/ plaza surrounded by mixed uses
- pocket plazas in residential and classroom areas
- library as the focal point of central nodes
- small recreation areas between residential uses
- large scale recreation areas towards the rear of the site
- community uses at the gateway
- agriculture on exterior sides of the site
- hierarchy of centralized space
- environmental mitigation [swales, building orientation]
- connections between uses
- building alignment that minimizes environmental impacts and maximizes views
- phased planning for expansion
- shading between spaces

After each group presented, there was refinement based on coordination with other project teams to finalize the concept plan for the site. As building footprints and more precise site dimensions were available, the concept plan was finalized. The detailed site plan was made in coordination with other project teams and finalized. With the site plan complete, the individual designs of the structures, water system, landscape, waste system and construction sequence proceeded. Figure 5 shows both the concept sketch that resulted from the design charettes and the detailed final site plan

VII. Design Considerations

The project design involved the consideration of numerous social, political, economic, constructability, sustainability and global issues.

- To prevent unnecessary delay of construction, the Polytechnic's facilities were designed to be built in phases. Each phase included all the necessary buildings such that the Diocese will be able to build the phases it can afford and still open the school to operation. The phased design led to a repeatable and modular design of the Polytechnic's buildings. By this method, several buildings served the same purpose with their combined capacity meeting the size required of that type of building by the current number of students (see Figure 6). For example, instead of designing one dormitory building to house all 500 students, 7 dormitories were designed. Each dormitory unit had the same architectural plans and could house 72 students. If the Diocese could only afford to construct the number of facilities to support 200 students, they were not bound to a larger financial commitment.

- The issue of constructability affects the practical feasibility of the project and is affected not only by the chosen materials but also the skill level of the local work force. Significant consideration was given to the abilities of the workforce as this variable has an impact on the structural and architectural designs. The modular design of the facilities also enabled the use of focused rotating construction teams. With the construction of similar buildings taking place at the same time, teams of laborers could be formed that performed a singular task in the construction of the buildings.

- Construction scheduling became a factor in the design as well. Some of the central buildings (i.e. administration, kitchen & dining, multi-faith) were required in full capacity in the first stage because of their importance and central use. The classroom and dormitory buildings made up a majority of the later phases as these buildings corresponded more directly with the growth of the school's population.

- Access to electricity is readily available but extended use will incur regular expenses that will expand the operating costs of the school making it less financially sustainable for the Diocese to maintain. To reduce the amount of electricity required by the school facilities, the need for artificial lighting and electrically powered environmental control systems is reduced. Solar panels to produce electricity are available but require a large amount of initial capital. This makes them unavailable to the local population and the Diocese would also like the methods used to reduce electrical consumption to be applicable for

the local population. A passive system was selected in the design of the Polytechnic for its use of solar energy. The system's use of solar energy contributed towards the goals of improved environmental and financial sustainability by further reducing electricity consumption. Additionally, the system was ideal for the Polytechnic due to the project's location in East Africa which is positioned on the equator, exposing the region to a large amount of solar energy.

- Humidity was also a concern for internal comfort. Relative humidity in the region ranges from 57% during the dry months to 77% during the rainy season[7]. The higher level of relative humidity mandated that it was necessary to provide ventilation during the warmer and wetter months. Air movement assists the body's cooling mechanism by accelerating the rate of evaporation of perspiration from the skin which is important for comfort in humid environments. The design of the buildings considered ways to achieve air movement naturally through appropriately placed openings. Figure 7 shows the resulting design which features a double roof to keep heat out of the building, a shade structure that keeps direct sunlight away from windows while providing sufficient daylight reflection to eliminate the need for electric lighting, and selected openings to allow adequate ventilation throughout.

- The school included the construction of a mosque which required sensitivity, awareness, and some research into cultural and religious issues for the predominately Christian design team. The age of the students who will be attending the Same Polytechnic meant that the arrangement of living accommodations of male and female students in relation to one another needed direct attention. While it is common for young men and women to attend the same educational institutions after graduating from secondary school, there were sensitive religious and cultural expectations of how the Polytechnic's students would live in proximity to each other. Social intermingling was acceptable during the day but gender separation was mandatory during the evening and night hours. Therefore, the student dormitories were segregated into single-sex units and positioned on the site with sufficient buffer space. To provide a more comfortable living environment for the resident students, the design of the dormitories was modeled on an element common to family group living accommodations of many different cultural groups in the East Africa region. Many family group compounds are arranged in a circular format with the different homes facing towards the center. This was done to provide the family and their livestock safety from predators during the night. This centralized inward facing design was adopted for the individual dormitory modules. Each module was laid out in a rectangular cluster with the entrances to the individual student rooms opening to an inner courtyard as shown in Figure 8. The courtyard also contained a central study and social building for the students to gather in outside of their rooms.

- The primary concern of structural engineering is to provide a structural design for a building that makes it safe for human occupancy. Tanzania uses the British Standards Codes of Practice as its governing building code. However, this building code is not heavily enforced in rural regions of Tanzania. The only expected design review is by the local office of the Ministry of Education to ensure that the classrooms provided enough space for the intended number of students. The US Military code was chosen for several

reasons. First, it is very similar to many building codes in the United States requiring the structural design team to make very few adjustments and shortening design time compared to having to learn a completely new code. Secondly, the US Military code is the governing code for military and US State Department installations and is intended to be used throughout the world. This gave its use in Tanzania more credibility as opposed to using the California building code. Additionally, the US Military code contained site specific information for design structures in East Africa.

- The main criteria for the selection of building materials to be used in the construction of the Polytechnic were availability and cost. Locally available or manufactured materials were advantageous for their cost-benefit and their selection benefited the local economy by supporting local tradesmen. A unique consideration to building in East Africa was accounting for the materials the local workforce was experienced in using. It may have been possible to find inexpensive materials or to have received donations but if it was an option the local workforce was not experienced with then quality control issues would arise. Incorporating the types of materials required by the architectural design of the environmental systems affected the selection of building materials. The primary building system chosen for the construction of the Polytechnic was masonry. This choice was dictated by the lack of availability of other options. Timber framing is not used because of the presence of large colonies of detritus feeding insects (i.e. termites) which can cause wide spread damage to timber framed construction. Reinforced concrete is used on a limited scale and structural steel was too expensive and limited in availability for full scale use. The local workforce was well experienced in the use of masonry and a reasonable level of quality could be expected in construction.

- The final design for most of the structures was a cement stabilized form of adobe brick that would use local materials while alleviating deterioration of the adobe during the rainy season. Because Same is located in a highly seismic area, the adobe bricks were supported by a system of reinforced concrete columns and beams designed to confine the unreinforced masonry walls. The walls were further confined by a steel mesh on the exterior that also served to prevent the spalling of the stucco that protected the adobe bricks from moisture.

- The landscaping of the Polytechnic was intended to be both ornamental and functional as well. The landscaping design employed trees with extended canopies to support the passive environmental systems designed into the architectural form of the buildings. The shade trees were placed to help keep direct solar radiation off of the buildings to prevent heating of the interior spaces. The landscaping was also used to define space within the site. The boundaries surrounding buildings, courtyards and social centers were defined using landscaping. Various recreational fields were included in the site and the fruit orchards were laid out around the recreational fields to separate them from each other and the rest of the compound. There were two main criteria for the selection of plant species that were included in the landscaping of the Polytechnic's grounds. The first requirement was that the plants either had to be indigenous to East Africa or already established. It was preferable to select species native to the region but some pre-established species such as the mango and papaya trees shown in Figure 9 were selected as well. Secondly, the

plants needed to be able to thrive in the semi-arid climate of this part of East Africa. Therefore, the plants needed to be established in the region and able to survive in the semi-arid climate of the District of Same. Additionally, the Diocese also requested that giant bamboo was included in the landscaping for several reasons. Giant bamboo grows rapidly and needs little care. It can serve as a natural barrier and can be harvested for fencing and construction purposes. The local bamboo crop has been over-harvested and reforestation is desirable for the region.

- A very limited infrastructure for the distribution of water exists in the area. Only one pipeline supplies clean drinking water to the town of Same with one community access point. The design of Same Polytechnic includes the digging of a well that will require a pump system capable of providing a constant supply of water to the school.

  Mechanically powered pumps require electricity from either fuel consuming generators or expensive solar panels. Either option would bring additional costs so limiting the amount of water required to be pumped will help to ease operating costs. For this reason, the amount of water pumped from the well will try to be limited to that necessary for human consumption. To provide a water supply for other applications such as irrigation, laundry and other grey and black water uses, a rain water collection system will be designed for the site. The main water storage tanks were placed at the highest point possible on the site. This allows gravity to perform the work necessary to distribute water to access points below and provide an adequate level of water pressure to operate sinks, showers, toilets and hoses. It was necessary to consider the amount of water use expected at the different points of access so that the distribution pipes had a sufficient diameter and rate of flow to meet the demand. Separate water tanks were provided for the water pumped from the well and collected rainwater to prevent cross contamination since the rainwater is not safe for drinking. The well water source was more reliable so the water pumped from it had to be available for all the applications: drinking, cooking, sinks, showers, toilets, and irrigation. When rainwater was available, it would be used for toilet and irrigation applications since those did not require drinking water. The two systems had to be integrated together to provide water to the same locations.

- Heavy earth moving equipment and tractors were available for hire at a daily rate including the time of a trained driver and the cost of fuel. The alternative was to excavate using manual labor. While the hiring of heavy equipment would allow for the work to be completed faster, the cost could outweigh the benefit. Labor is inexpensive but moving large quantities of soil is time consuming when only using hand tools. The buildings were situated in a manner that limited the amount of excavation required without interfering with the passive environmental systems of the buildings.

VIII. What's next

At the time of this writing, the master's student has completed his thesis[9], works for a prominent design firm, and continues to lead the effort on this project. Student teams are finishing the schematic design for Same Polytechnic and consulting with practicing engineers on their designs. One team has involved the Wallace Group, a local San Luis Obispo firm, to advise and evaluate the wastewater design and the rain water collection system. Another group is working with Arup in Los Angeles for review of the passive ventilation and lighting designs. Once the

concepts and ideas are validated by industry partners, complete construction documents will be completed by the end of 2009 and submitted to the Ministry of Education for approval. Figure 10 shows the current design teams at their recent design meeting. Architectural renderings have been provided to the Same Diocese for review and approval. Figure 11 shows several examples. They are also being used as a fund raising tool to solicit donor support. The goal is to start construction in 2010 using local labor with supervision from students currently involved in the project but who will have graduated at the time of construction. Pending the resolution of liability and financial issues, the plan is to involve Cal Poly CM students in the project management as well. The project team is now reporting their project progress on a web site: http://www.samepolytechnic.org/tanzaniahomepage.html as shown in Figure 12.

Similarly, there are requests for Cal Poly students in the CAED to support other projects as well. For example, the Diocese in Same has proposed public works projects that include a bus terminal, a marketplace and the repair of homes. Similarly, the Catholic Church has proposed projects in Nairobi, Kenya that include a convalescent home, a hospice and a morgue.

VII. Conclusions

The Same Polytechnic project demonstrates what can happen when a single champion emerges and is willing to lead others in a common effort. Students thrive in real world projects where they can see the clear impact of their results. This effort provides collaboration among students in different disciplines who might otherwise never interact. Not only are students required to use their technical education, but they must grapple with the cultural, political, economic and social consequences that accompany design projects. In this special case, they also have the additional benefit of assisting those who have no other means of support. It appears that there is an opportunity for this effort to grow and continue for as long as the Cal Poly CAED is willing to support it. While the pursuit of a common large-enrollment multi-disciplinary experience will continue, the curriculum needs to be flexible enough to accommodate opportunities that provide an even richer experience.

Acknowledgments

Any opinions expressed here are those of the authors and not necessarily those of any supporting agencies.

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Figure 1. Location of Tanzania on the continent of Africa

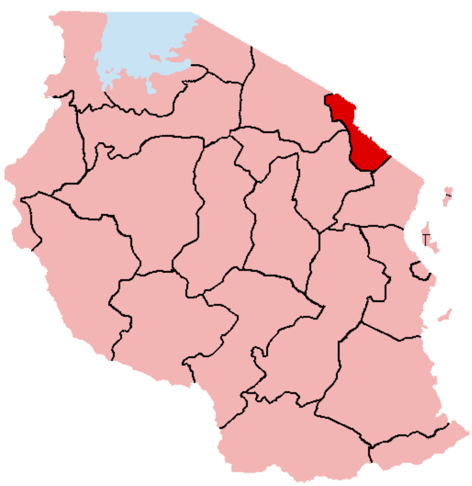
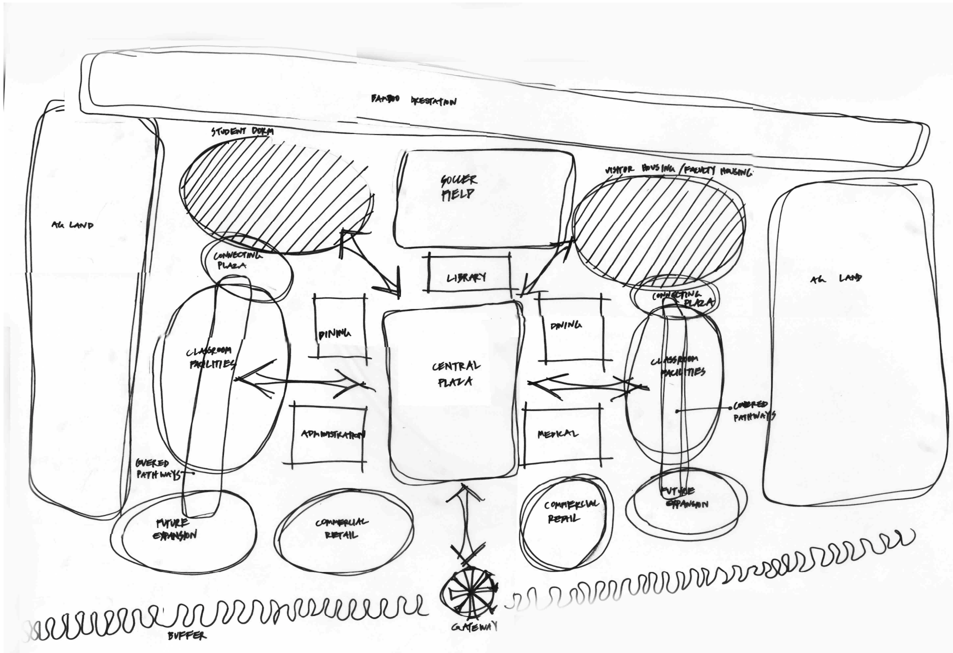


Figure 2a. Map of Tanzania showing regional borders with the Kilimanjaro Region highlighted

Figure 2b. Map of Kilimanjaro Region showing district borders with the District of Same highlighted

Figure 3. A photograph of the site where Same Polytechnic will be constructed

Figure 4. The Cal Poly CAED team of undergraduates collaborate on the concept plans for the Same Polytechnic



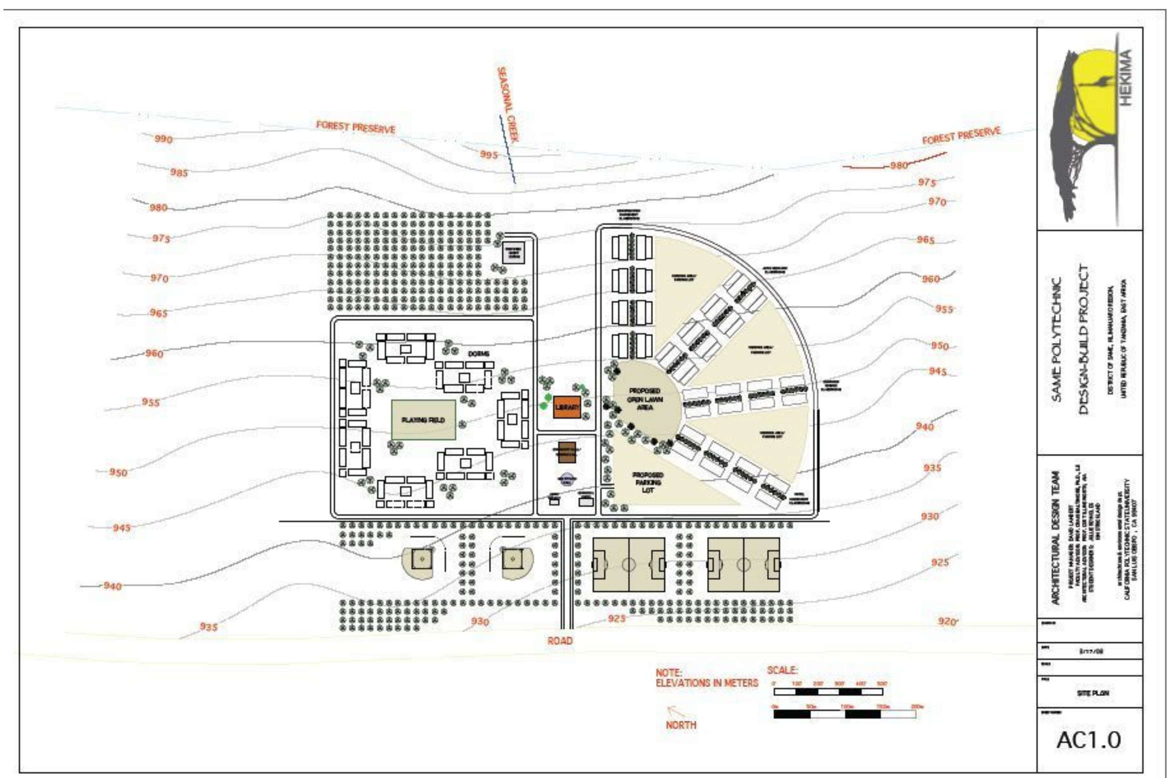


Figure 5. A comparison of the concept plan that resulted from the design charettes to the final site plan that was adopted

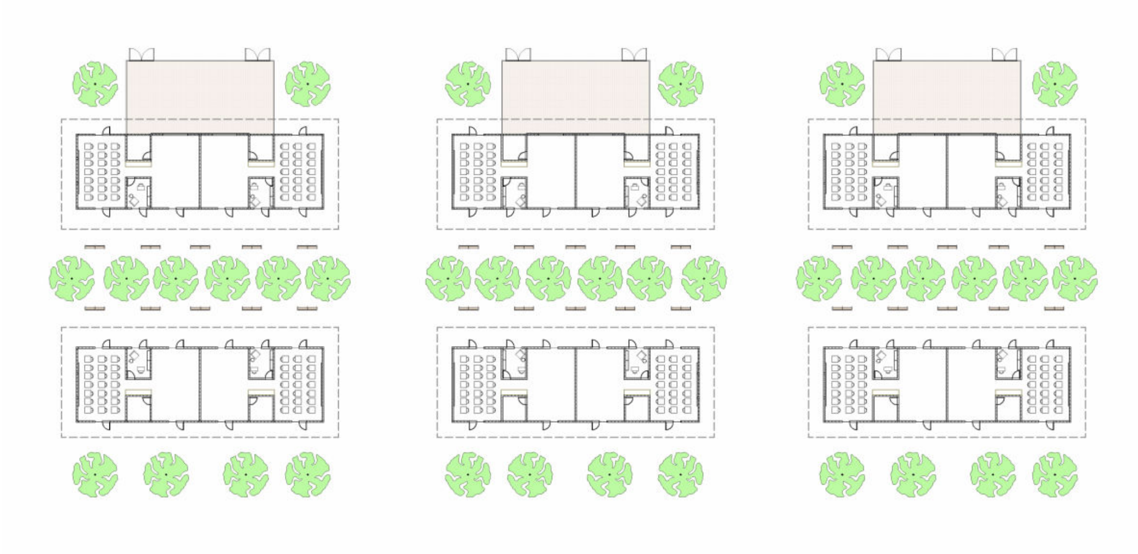


Figure 6: Classroom layout showing modular design and repetition of the same building plan

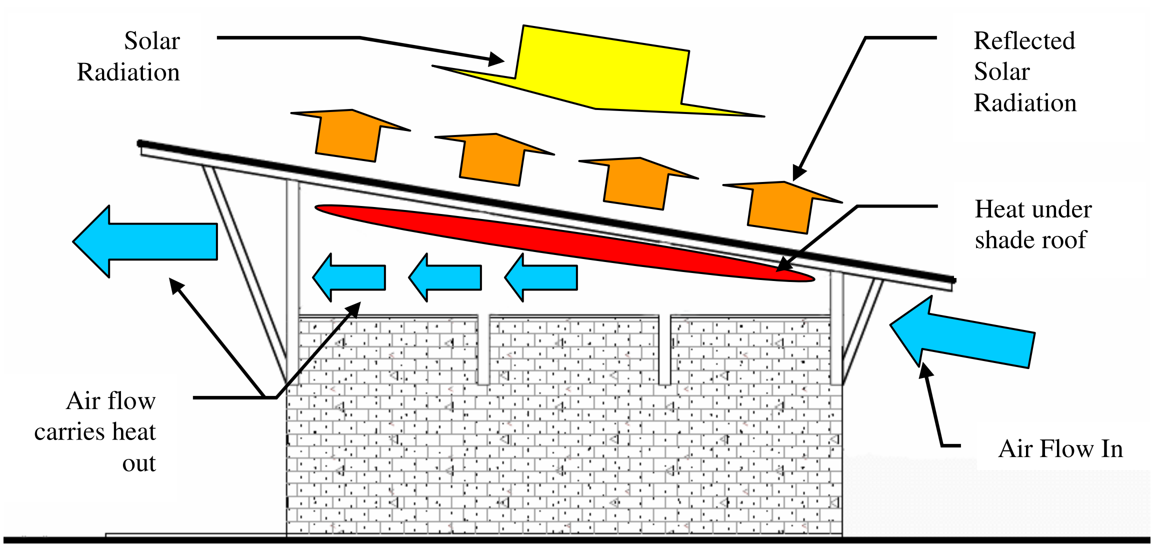


Figure 7. Elevation of typical building with double roof passive environmental control system, designed ventilation, appropriate shading, and maximum use of ambient light

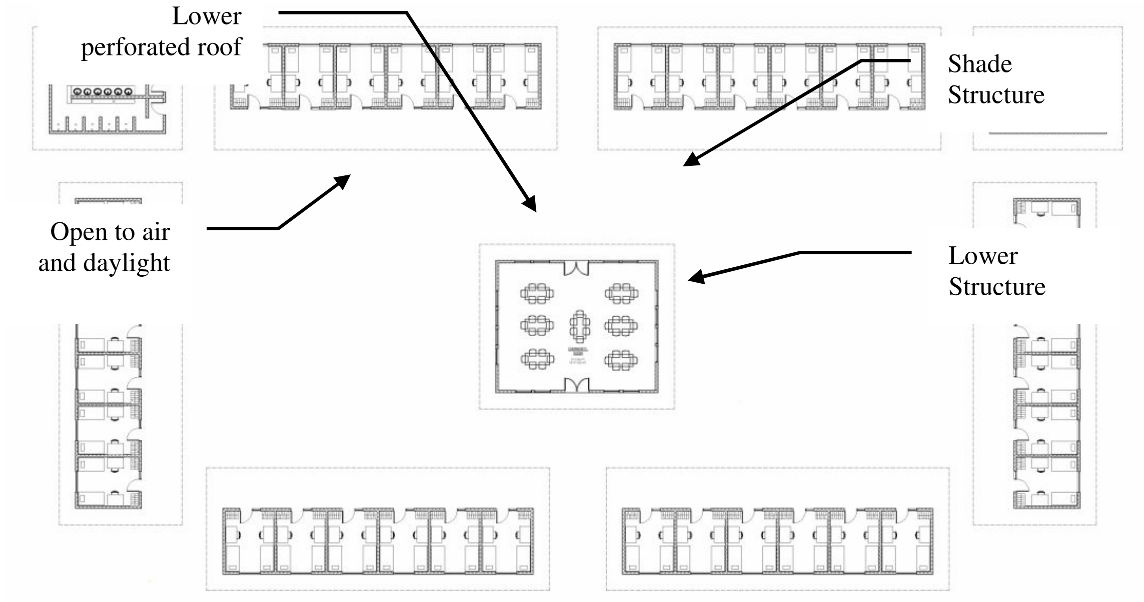


Figure 8. Layout plan of a single dormitory unit

Figure 9a. Mango tree

Figure 9b. Papaya tree

Figure 10. Photographs of the current design team taken at a January 2009 design team meeting

Figure 11. Examples of architectural renderings and models for the Same Polytechnic

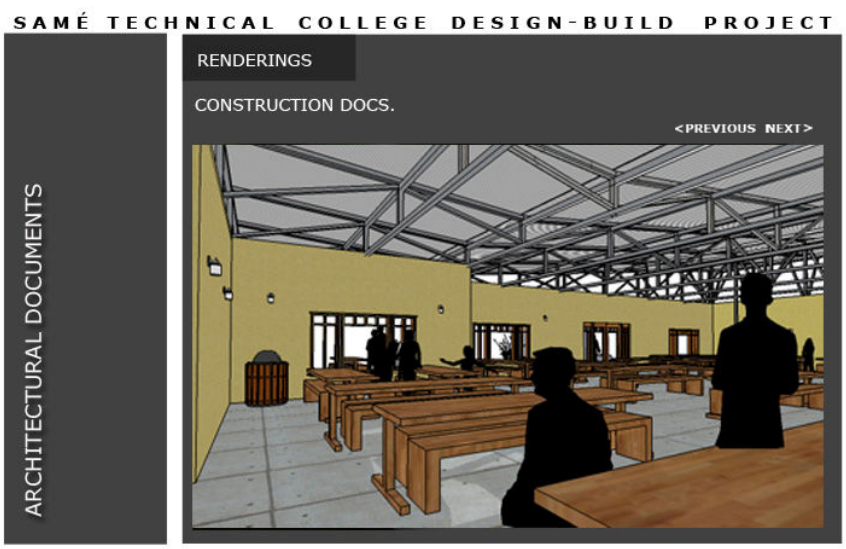


Figure 12: The project team reports their project on a web site:
http://www.samepolytechnic.org/tanzaniahomepage.html