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THE TUSKEGEE UNIVERSITY SOLAR DECATHLON HOUSE ENTRY: A CRITICAL ASSESSMENT

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Introduction

This paper describes Tuskegee University's entry in the First Solar Decathlon Contest, sponsored by The Department of Energy. First, the project goals, design, construction, logistics of moving the house to the Capital's Mall, setup, and testing are described; then an analysis of the project success and failures is presented.

In 2000, The Department of Energy (DOE), British Petroleum Solar (BP Solar), and The American Institute of Architects (AIA), challenged all the American Schools of Architecture, Construction Science, and Engineering to design and build a house that used only the power of the sun for all its energy sources. Additional requirements were that the house include all the normal livability and comfort required in a typical residence. The initial selection process narrowed the proposals to 11 of the entrants, which were to build and display their entry on the Capital Mall. This number increased to the final 14 contestants by spring 2002. Each applicant received a $5,000 startup grant with all additionally required funds raised by the individual schools. The amounts raised ranged from a low of $200,000 to a high of over $1.5 million.

Tuskegee University spent $200,000 and was the only Historically Black University (HBCU) represented.

Tuskegee's project soon turned into a multidisciplinary project with students from Architecture, Construction Science, and the Mechanical and Electrical Engineering departments participating. This paper will dissect the relationship of these disciplines during the design and construction of this project. The pros and cons, the successes and the failures, and the final solutions of the project will be discussed with a focus on how to improve the process for Tuskegee's possible entry in the second Solar Decathlon.

The pictures included show the work of the students during the various phases of the project.

The Program

Each Team was to design a house, build, transport the house to Washington, D.C., and set it up for display and testing on the Capital Mall. The house had to meet the following general specifications and requirements. It should be noted, that these are the final requirements as they were finalized under what seemed to be constant change and refinement during the process:

- 650 square foot of living space with no more than a total of 800 square foot under-roof area
- Living, Dining, Sleeping, Kitchen, Bathroom, and Office Areas to be Heated and Cooled
- designated area for the Utility, and Battery Storage room
- designated area for the Solar Car to be parked and charged as needed
- total height of the House not to exceed 16 feet
- the solar system had to supply enough electricity to provide for cooking, washing clothes and dishes, lighting, heating and cooling, and daily charging of a battery operated car upon a daily basis
- the solar system had to supply enough hot water for cooking, washing clothes and dishes by direct solar gain and/or electricity
- be able to pass demonstration tests in all competition categories: Design, Electrical, Mechanical, Cooking, and Hot Water\
- the student teams had only three days to assemble their houses at the beginning of the two-week competition, and at the end, three days to dis-assemble, pack and remove their houses from the Washington D.C. Mall lawn

- each school had to raise the entire funds for the project from design through all equipment, lodging and other expenses while in D.C.; including transportation to and from the individual schools to D.C. and back

This was quite a daunting list for any organization, let alone for teams of undergraduate students, to undertake and successfully complete.

The Design

Designing a house with such a small area footprint and so many constraints is not an easy task for a professional. The Tuskegee project was designed by and largely built by architecture and construction science undergraduate students. The typical student has very little working knowledge of materials, the best and most effective ways to use those materials, or, of the building process. The typical architecture, construction, and engineering programs focus on theory not application—the hands on application of this competition opened a "new world of opportunities" in learning.

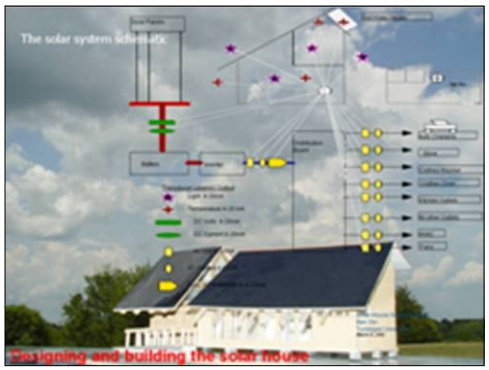
The design constraints began with a very small house that had to provide all typical amenities for living as a standard house, plus the additional stipulation that all power must be completely supplied by the sun. The specific size and height constraints imposed by the competition forced additional tough requirements that had to be resolved before any construction could begin. Beyond these constraints, the designers had to also create a house that could be dismantled, packaged, and remain strong enough to survive the 800-mile trip to Washington D.C. Once there it would be unpackaged and be re-constructed on the Mall grounds in three days. Then it was to begin a period of being tested, judged, and opened for display to the public. It was required that the house would again be dismantled, repacked for the trip back to Tuskegee, and once there again be re-assembled. After all this, every element and system still had to work.

As a teaching tool, the project's potential is to convey an ability to deal with the requirements of the entire project and facilitate the appropriate decision making skills. To maximize learning, the Tuskegee faculty advisors stipulated that the students be responsible for design, materials, and construction decisions. A consensus developed that the fairest way to obtain the most suitable design and the most capable team was to hold a competition to design the building.

A team of four architecture and engineering faculty chose three designs from eighteen design entries as the semi-finalists for the solar house. Finally, after much student/faculty interaction, consideration, and debate, a 'winning' design was selected for the Tuskegee University entry.

The major objectives of the Tuskegee student design teams were to:

- show that traditional conventional construction could be used as the base for the highly technical solar structure
- the design would show the traditions of the South by employing traditional Southern design elements such as a dog trot or a breezeway
- construction materials used were to be readily available in local chain hardware/box home stores, such as dimensional lumber and interior finishes
- the mechanical system, plumbing, and as much as possible of the electric system were all to be standard readily available units



Students felt by following these general goals they would be delivering a house that could still be build using the traditional building trades and fulfill the high technical demands this solar project required. They succeeded.

The Construction

In order to construct and move the house the 800 miles to Washington D.C., mobility of the house became a primary design focus. Since transportable size limitations are strictly enforced on the interstate highway system, the team decided to build the house on two bases equipped with wheels. The house was built on these bases in a fashion that would allow them to be separated upon completion. This imposed additional complications on the electrical, plumbing, and mechanical systems of the house—they had to be designed in a way so as to be able to be easily separated and re-attached when the house was split and re-assembled.

Plumbing and mechanical design issues were easily solved by designing the house with all the necessary components in one side or the other. This easy solution did not work for electrical power, as electricity was needed throughout the whole house. The team creatively solved this by keeping the disconnections of the electrical system to a minimum through designing the electrical system so that one section would be on a single separate circuit with the majority of the components required by the solar electrical system to be in the other. The single circuit could then be easily disconnected and reconnected as needed for the moves.

Delays

Due to various reasons including changes in the design, structural engineering issues, and mechanical and electrical changes, construction of this project was delayed until August 5th giving only five working weeks to start and finish both the construction and testing phases of the project house.

The Architecture and Construction Science students by focusing their efforts—incredible effort—did deliver the project. However, the students had to change the goals of the completion in the process. At this point, the team collectively decided to use this project as a learning tool rather than think of it only as a competition. They wanted to learn as much as possible about the total aspect of the project and not worry about winning or losing. The issue of successfully getting this project completed, moved to Washington D.C. and then being able to demonstrate a working totally solar house, designed and built by Tuskegee University students to the public became the primary goal. On September 10, 2002, the team made it; the completed working solar house was in the nation's capital; ready for viewing to the world by a proud Tuskegee team with all solar aspects successfully operating.

The Competition

This project being the first design build project for the Tuskegee team, as expected, had numerous problems. The team tried to solve the problems as they arose. The stress on team with rapidly evaporating time and the quickly approaching deadline was somewhat lessened by the knowledge that all competing teams shared the same lack of adequate experience. This made it a little easier for each team to recognize and for the most part successfully deal with their specific problems. For example, the solar hot water tank of one of the competitors burst due to failure to install a safety valve. This resulted in a quick self-check by the other teams, thereby saving some of them from similar fates.

The majority of the teams had code problems of one type or another with their handicapped access ramp. Almost every handicapped ramp needed to be redone or completely re-built at the last moment due to small changes in slope at the specific location of each house site. When a completion such as this prohibits any modification of the site for the structure, and all of it components have been pre-made, a ¼" error should be ignored, however, the sponsors did not agree, necessitating many last minute changes and points lost because of this or other similar

small infractions. This being the inaugural solar decathlon, the rules and regulations seemed to change daily as new situations arose. Unfortunately, this led to even more confusion and problems. It appeared that there was little consideration given to the consequences of rulings on the teams' time and or resources. There was a general feeling among the teams that in a new completion of this magnitude being built by student teams without experience there should have had been some appropriate flex and leeway.

In spite of the presence of many obstacles—not the least of which was the shortage of construction time—Tuskegee's small nine-member team managed to assemble the house on the assigned lot and opened it for the competition on schedule.

The competition consisted of ten categories from Design and Livability to Energy Usage. Each category was scored separately with total points ranking the entries. Tuskegee University Solar House placed eleven out of fourteen placing ahead of much bigger universities such as the University of North Carolina and Texas A&M.

It was difficult, demanding, and arduous for all teams. Considering the small size of the school, the number of students on the team, the limited resources, and the late beginning construction date, Tuskegee faired surprisingly well. It was the consensus of the Tuskegee team that all teams that completed their houses in Washington, D.C. were winners.

Positive Issues

As the construction team advisor, it was truly satisfying to see the students work together learning to design, build and strategize their work in order to reach their project's goal of showing a totally solar house designed and built by Tuskegee students on the National Mall.

Having a small team and a very limited time of construction, the students and team advisor did as much of the work as possible by themselves. Work included, but was not limited to, structural framing, electrical, plumbing, insulation, and finishes. Due to this intense work, the team members had the opportunity to learn the principles of each of the construction phases with hands-on experience. Even though the design of the house had been fine-tuned, there was not ample time left for construction. The shortage of construction time forced the student team to schedule their work as precisely as possible; including the decision making process regarding what had to be built on the Tuskegee University site and what could be left to be completed in Washington, D.C.

Unfortunately, the construction was in the hot muggy dog days of the summer. During these five weeks of intense construction work, the general expectation of most was that the project could not be completed. However, contrary to negative expectations the student team working with their advisor, was able to complete the house construction, ready the house for moving (un-assembled and packaged), got the project transported to Washington, D.C. (no small task) and re-assembled it on the mall in time. The driving force was not winning, but the satisfaction of being able to put their theoretical knowledge of construction into actual work for this project. The students were determined to finish their project on time. Meeting the due date became more critical to them than winning any part of the competition, and that required true teamwork, which is a reality of construction. Winning in this competition was simply being able to deliver the finished project. It appeared that this was the general feeling among all the contestants. It was pleasant and quite motivating to witness this team as they learned to work together, delegate responsibilities to each other, and demand results from themselves and each other. It was a comprehensive classroom in action.

Through this project, students were exposed to many types of material and usage. No classroom can duplicate this. They had to find solutions to problems that could only be solved if they were willing to do intense research. The research to solve a roadblock created learning when applied and success in using what they had researched appeared to motivate the students to do more research.

During mid-August working on this project became incredibly hard for the students. The actual competition, the showing and testing of the houses, was scheduled to start in mid-September — Tuskegee's classes start in mid-August. The team members had to attend their classes while trying to complete the construction of a house in near record time. "It is not a matter of placing in this competition, it is a matter of meeting the due date and learning these materials," one of the student team members commented; another one continued, "Getting to D.C. with our finished house indicates our winning."

To move the house, parts of the house had to be disassembled and then reassembled again after the house was at its location in D.C. To make the schedule work, the team decided to re-design the entire roof/ceiling finish system to enable them to build this portion of the house after their arrival in D.C. This proved to be the correct decision, the team gained an extra day by not having

to build a more complicated system then disassembling it, packing it and then re-assembling it again in Washington, D.C.

In conclusion, for the Tuskegee team, the triumph of teamwork and learning while working with limited resources summarizes the true positive points of this project. Issues that students are typically never exposed to in a classroom had to be identified, researched, and solved very quickly for the project to progress, invaluable experience that will help them in their career. Construction is engineering at work, and the only way this work happens is by true teamwork and with a mutual respect for each other's work. This type of team work is mentioned and discussed in innumerable chapters in text books, and is taught in theoretical lectures in class, but needs to be experienced to be fully understood. The Solar House Decathlon became a perfect laboratory setting to learn, appreciate, and understand the advantages and need for true teamwork, without it Tuskegee's solar house would just still be an unfulfilled goal.

Negative Issues

The Tuskegee solar house entry had many problems and issues to confront as did all the decathlon entries. The major problems and issues were in the following categories:

- Resources
- Budget
- Project Limitations
- Identifications of Teams
- Outcome of the Project

Resources

Department of Energy (DOE) rewarded $5,000.00 seed money to 14 finalists in the Solar Decathlon House Project. Raising the massive funding to complete this project was a challenge left to the competing schools to solve. Such research and demonstration projects, especially the initial ones of any competition, are very difficult to fund by any school administrator or funding agency. It was almost impossible to convince Tuskegee's upper administration of the importance of such a research project to Tuskegee University. We hope that on any future project, the

sponsoring agencies will provide better assistance in helping the schools to find the resource needed.

For Tuskegee, finding the required funds was the most crucial issue. We had to be sure we could finance this project before we could start it. Most of the initial time allocated to the project was spent in securing the needed resources rather than in design and refining the entry. We were lucky that the Tennessee Valley Authorities (TVA) was eventually convinced this was a worthwhile project and agreed to be the major funding agency. They contributed $195,000.00 plus additional in-kind assistance to the project.

Another major hurtle for Tuskegee was the small size of the architecture and construction programs making it difficult to spread the labor demands over a large number of students. Schools with larger programs were able to have three or four teams of ten to fifteen students each, who were able to take shifts working on this project making it easer for the students to meet their other commitments. Tuskegee's team of nine students were stretched very thin with trying to complete the major construction project while attending and passing their required courses—for several students, competing in the Solar Decathlon delayed their graduation date.

Budget

The challenge for any building project in engineering, architecture, and construction is always how much money the owner is willing to spend for that particular project. To clarify this issue, typically before the project starts, the project investors identify the total amount of the money they are willing to spend. This determines the

budget for that project. Spending above this sum leaves the client unhappy, while keeping the spending below the budget creates not only a satisfied client, but a successful conclusion to the project.

The Solar Decathlon House had no defined budget limitations. If there are no limitations as to how much money any one team may spend on such a project, the resulting competition tends to become unequal. For example, the Tuskegee University team spent $200,000.00 on this project, while the University of Porto Rico spent $1,500,000.00 on its project. This posses a major problem for the judging, for the way the various projects are presented, and to how the public interprets the results. It would be helpful if the sponsors set a budget or established budget categories for the judging if they wanted to keep the budget open.

Project Limitations

Although the project's program criteria were specified at the start, major requirements seemed to change almost daily throughout the process. Since this was the first Solar Decathlon and neither the competitors nor the sponsors had all the answers, the limitations needed modification. However, the sponsors continued to change the criteria past what was a reasonable time for the contestants to be able to successfully respond. Program modifications continued even as the projects were being setup in the final three days on the Capital Mall.

The Tuskegee team, like other teams, tried to comply with the required rules; however, they found themselves facing some rules and requirements not part of the original program. For example; to creatively—a competition requirement—reduce the risk of injuries caused by battery acid, and to eliminate special encasement for the battery bank, our team decided to use gel batteries for the house's battery bank rather than the cheaper liquid acid batteries. This change was approved in one of the many conference calls we had with the sponsors' engineers who were working with the teams through DOE. However, upon our arrival in D.C. the same engineers required us to build a sealed casement for our battery bank even though the gel batteries had been approved to eliminate the problem.

Another example concerns the requirement that the houses be handicap accessible. Since digging into the Mall was not allowed, ramps were required. The Mall, however, is not level making the distance from the ground to the finish floor variable. Even ramps that exceeded the maximum slope by less than 1" had to be rebuilt. Another interesting last minute unexpected rule was that gasoline generators needed to run the tools to build the house could not use gasoline on the Mall, a major headache for most teams. Inspectors who were inexperienced in the needs and realities of construction themselves caused many problems for the contestants.

Team Members

Some teams used students for design and work, some teams used professionals for advice and some teams had all types of paid experts on their team doing the work; electricians, mechanical engineers, and even plumbers. Guidance is needed as to how much if any professional assistance is allowable. If professionals are allowed, different categories should be established so the judges and the public know if a project was mainly a student project or a professional project with student help.

Summary

The initial feeling was that even though the students learned a great deal more working hands-on on the project than they could have in a classroom, due to the unduly stressful confusion of the project they probably would not elect to do it again. The effort dedicated to the project was just too great for the benefits. For some, the incentive to come back for another competition was virtually nil. Students, on every team, worked hard. They invested time, effort, and tremendous amounts of energy into their projects. Some students ended up needing an extra term to graduate simply because they spent their time on this project instead of their course studies. Part of the problem was that the timing of the actual Washington, D.C. component occurred during the school term. It would be much better if it was scheduled during normal break times such as the summer. For Tuskegee, entirely too much work had to be completed during that final stage. Realistically, for a small team to be able to attempt the construction labor required, they need to have at least the fall, spring and an entire summer as building and testing time--this is after ALL design and design changes have been approved and completed. All programs need to coordinate

and work together as equals and as a team providing learning opportunities for all elements throughout the entire project process. This would provide not only an opportunity for learning about ones own career of choice, but of other related professions thereby furthering the knowledge of the value of interrelated skills.

Should our school enter in such a competition again? That decision will depend upon reasonable guidelines, time constraints, and the will of the students. The faculty of the Architecture and Construction Science Programs at Tuskegee University will support the students in such project endeavors if the students want to participate again.

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