Structural Integration Solution for the Texas A&M 2007 Solar Decathlon "GroHome"

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ABSTRACT

The entry by the College of Architecture at Texas A&M University to the 2007 Solar Decathlon competition sponsored by the U.S. Department of Energy was termed the "groHome". It was based on a design system of modular units with a limited set of components that could be customized and would allow for post-occupancy expansion of the structure. The assembly of components relied on the idea of a "snap-on" joint integral with the structural steel tube column termed the "groJoint." The joint also included utility openings through the column to allow integration within the structural framework for the electrical and mechanical services for the solar-powered home. The "groJoints" were intended to accommodate beam modules as well as "groWalls" that could possibly have electrical or mechanical services, such as a bathroom or kitchen component.

This paper presents the evolution of the structural system integration solution for the student-lead, designed, and constructed project; including manufacturing, welding, re-design, construction, and the extent of engineering supervision.

BACKGROUND

The Solar Decathlon competition sponsored by the U.S. Department of Energy showcases student designed and constructed solar powered homes utilizing building-integrated photovoltaics while promoting the public's awareness of solar and energy efficient design and technologies. The process from proposal selection of the 20 teams to the final assembly of the homes on the National Mall occurs over a two year period (NREL, 2005). The teams were chosen based on proposals identifying the phases for design development, construction, and commissioning that would lead to the successfully completion of the design. The proposals addressed the technical innovation and design, the multidisciplinary teaming between design and engineering disciplines. and the curriculum integration of the project with student coursework.

For the 3rd Solar Decathlon competition in 2007, the regulations for the structures that would be situated on lot sizes of 82 ft by 67 ft (25.0 m by 20.4 m) on the National Mall in Washington, D.C. required the houses to stay within a solar envelope and to not exceed 800 ft^2 (74.3 m^2) with the building footprint. Energy storage devices and the solar array and water containment were required to be located within the building footprint with the exception of the battery bank or hydrogen storage vessels (NREL, 2007).

The competition consisted of 10 contests with points being awarded for architecture, engineering, market viability, communications, comfort zone, appliances, hot water, lighting, energy balance, and getting around (on the contest grounds). For the Architecture contest, the qualities related to engineering of the structure included the appropriateness and suitability of the materials chosen, the solution for the challenge of a movable and easily constructed structure, the effective integration of structure and enclosure, and the strategy used to accommodate the energy technologies. For the Engineering contest, the qualities related to the engineering of the structure included a demonstration of integration of the building architecture and system.

The contest regulations included a building code in addition to adopting the 2006 International Residential Code and the 2005 National Electric Code. The National Park Service required the structural drawings and calculations to be stamped by a licensed engineer for review. Protection of the Mall grounds was required, but allowed for staking and shallow anchors along with low impact footings.

The proposal was developed by a design faculty advisor (co-author) with input from student work in design studios during the fall of 2005, had the support of the College of Architecture, and was submitted in late 2005. In the spring and summer semesters of 2006, the design was further developed through architectural and landscape design studios, and regular team meetings were begun in the fall of 2006 when the structural and mechanical systems faculty were added to the team and a specific course on the project was offered.

DESIGN DEVELOPMENT

In addition to the basic requirements of the competition, the design concept focused on providing sustainability with affordability and flexible use, use as post-disaster shelter and for developing communities, and the occupancy needs of expanding families (TAMU, 2007). The proposed design system of a "groHome" submitted mid 2006 (per contest requirements) comprised modular assemblies with flexibility of organization using a limited set of components (Figure 1). The functional components, termed "groWalls", included kitchen, dining, heating, ventilation and cooling (HVAC), bathroom, control, electronics or "edutainment", and photovoltaics & batteries. These units were intended to attach to the main structural frame and extend outside it.

The structural system chosen by the students in the design development consisted of square steel tubing for the vertical posts and bantam sections (T-sections used in mobile home construction) for the primary beams, using the bottom flanges to support insulated structural panels or a deck framing grid (Figure 2). When the bantam sections were welded together the channel formed by the stems could contain the mechanical and electrical services. The foundation system was a tire assembly with adjustable height. The key to the flexibility of the design and the interchange of components was the "groJoint" consisting of a segment of 4 in. (100 mm) square structural steel tube with openings in every side to allow for customized attachments including ones at corners (cover plate or light), beams (stirrup), and non-rectangular alignments (hinge) as shown in Figure 3.

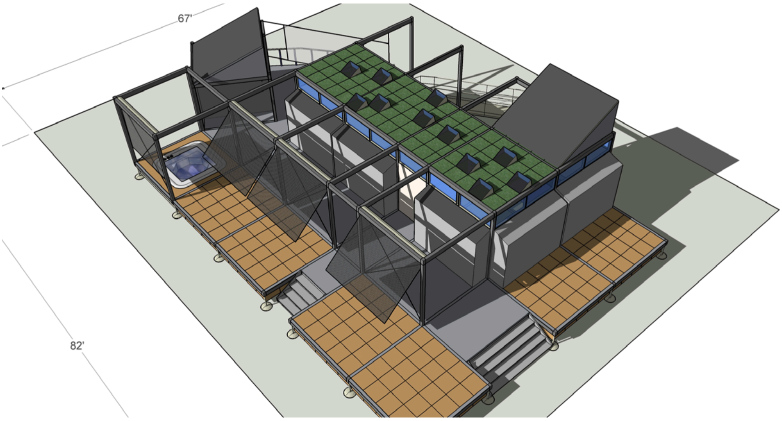


Figure 1. "groHome" Design (2006)

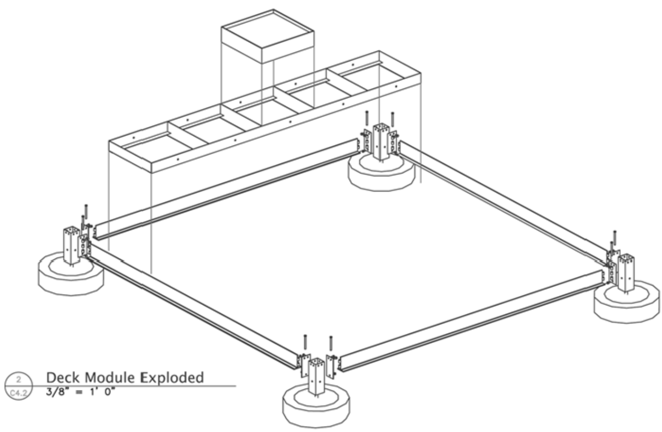


Figure 2. Deck Component Design (2006)

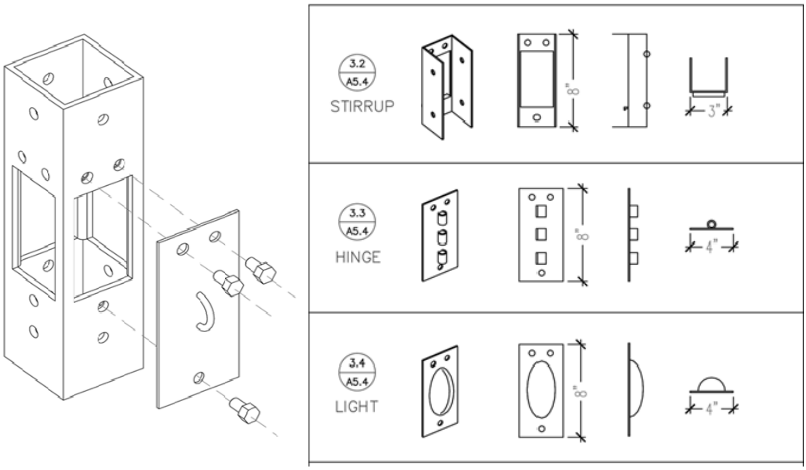
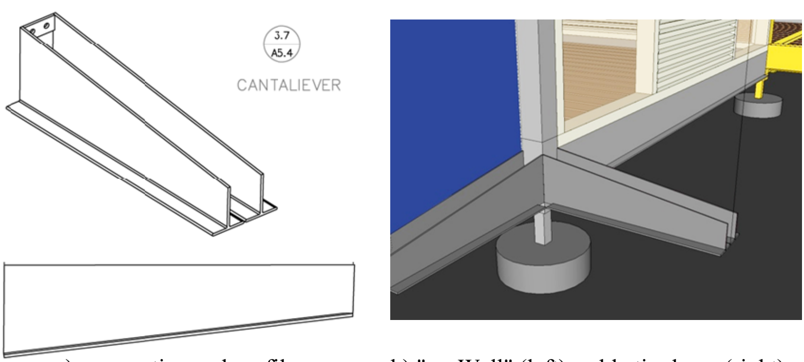


Figure 3. "groJoint" Design (2006)

PRODUCT DEVELOPMENT

In September of 2006, the structural engineering faculty was consulted on the adequacy of the design with respect to the footing loads, tie-downs, and "groJoint" configuration with respect to the intended adaptability as shelter to withstand hurricane loading and option of adding a second story. Of particular concern was the stiffness of the "groJoint" with a 3/16 in. (4.5 mm) thick tube, the 1/8 in. (3.2 mm) plate covers attached and the bolt configuration, the various plate cover stiffnesses, as well as the construction. Also of concern was the design to cantilever the "groWalls out of the "groJoint" (Figure 4).



a) perspective and profile b) "groWall" (left), cable tie-down (right)

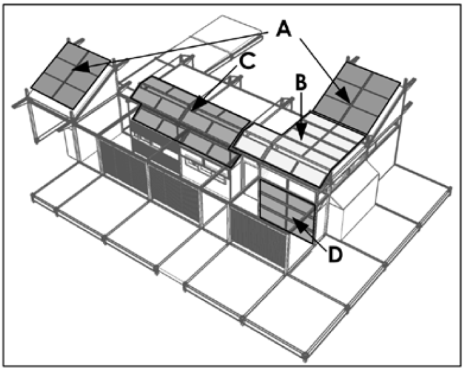
Figure 4. "groWall" and Cantilever Design (2006)

The contest required the following minimum design loads: wind of 60 mph (26.8 m/s) (3-second gust), exposure category C; 200 lb (890 N) load applied to the top of railings; 50 psf (2.39 kPa) interior floor, deck, and ramp live load; 20 psf (0.958 kPa) roof live load; and an allowable soil pressure of 1500 psf (71.8 kPa). The solar panel assemblies were required to resist uplift.

The preliminary evaluation showed the "groJoint" configuration susceptible to yield and collapse under a relatively small transverse loading with no connecting plates attached. To allow for the openings, the "groJoint" was construction using a top section of square tube welded to 5 in. (127 mm) lengths of 7/16 in. (11.1 mm) radius quarter round steel at each corner which was then welded to a bottom section of square tube. As the design was developed, the quarter round was replaced by 3/4 in. (19 mm) diameter steel rod sections with 1/2 in. (12.7 mm) angles, 1/8 in. (3.2 mm) thick, welded at each corner over the full height of the "groJoint". The dowel was tack-welded to the angle steel at the tube junction.

The connection plate arrangement for the cantilever and beam sections was the stirrup (Figure 3). The thickness of the plate steel of the top and bottom straps (with two holes and one hole, respectively) was determined to be inadequate to resist the bending from the cantilever load. The analysis indicated the columns were too slender under a 170 mph (274 km/hr) hurricane wind.

The configuration of the solar panels and quantities continued to be modified, and when a green roof of 67 psf (3.2 kPa) was added, re-evaluation of the structure was required (Figure 5).

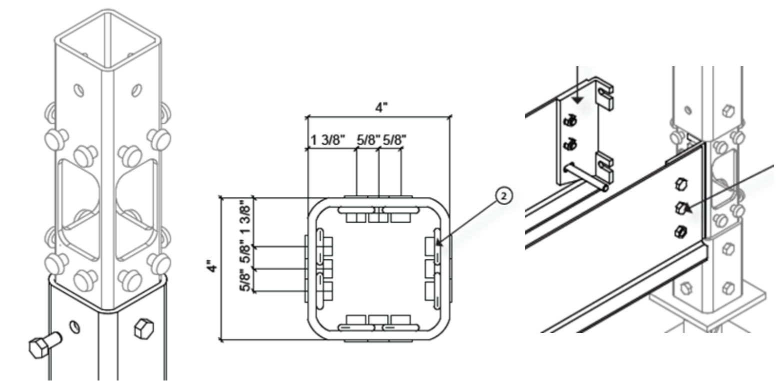


photovoltaic panel schedule

Figure 5. "groHome" Design (early 2007)

The "groWall" design had been modified such that it was no longer supported on cantilever beams. It now specified a standard timber joist floor system and the whole assembly was to be mounted to the columns and beams of the steel frame.

The size of the opening in the "groJoint" and the inner dimensions of the column tube could not be reduced due to the passing of services contained in the beam channels. But rather than have the bolts for the connectors pass through the column, which was difficult to assemble and added to congestion of the passage, the solution of welding headed shear studs to the column was investigated (Figure 6). The transverse shear capacity of the welded shear studs when penetrating the column was adequate, but the punching capacity was of concern. A mechanical test was performed and determined it to exceed the capacity of the column in local yielding (Figure 7). The connecting plate arrangement (stirrup) for the bantam beams to the "groJoint" had been modified as two separate angles with notches to allow the assembly to slide onto the studs (Figure 6c).



a) joint with column b) section with bolts c) joint with beam

Figure 6. "groJoint" Design (early 2007)

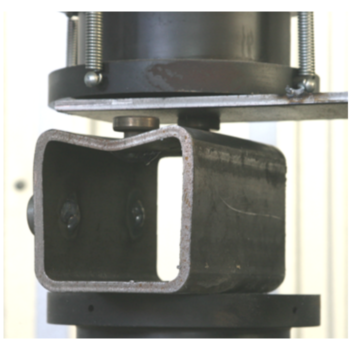
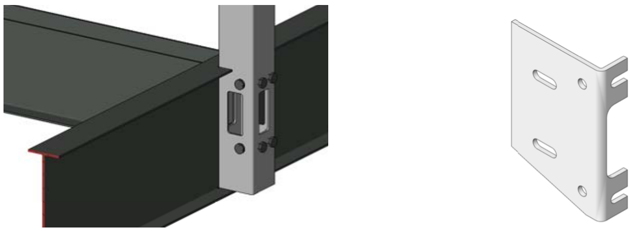


Figure 7. "groJoint" mechanical test of stud welds

Within a few months of the production of the construction documents show in Figure 6, the services of a licensed professional engineer was arranged, and the beam and beam-to-column connection for the "groJoint" was redesigned using wide flange beams adjacent to the "groWalls" rather than the double bantam configuration (Figure 8a). This arrangement would limit the lateral twisting that was a concern with the double bantam beam design that were unrestrained in the compression flange as identified in the preliminary evaluation. All beams of the main core of the house were no longer connected with the new connecting plate assembly, but were specified to be welded. The configuration of the connecting plate assembly or "groPlate" was also revised (Figure 8b). The loads used for analysis were the minimum specified by the contest regulations.



a) exterior beam to column assembly b) "groPlate"

Figure 8. "groJoint" and Beam Redesign (2007)

CONSTRUCTION

The construction effort was fully underway in May of 2007. Over the summer the "groWalls" and core were constructed and proper assembly was assured (Figure 9). The four bays of the core of the house were constructed as one unit, while the separate garage and rear porch/study area were scheduled to be constructed and attached on site.

Figure 9. "groWall" and Core Assembly (photo by College of Architecture)

A towing frame and trailer axles were welded to the underside of the base beams of the core for transport by semi-tractor to the site on the National Mall for the event in October (Figure 10). All electrical conduit and plumbing was located inside the base beams of the core, with the main supply located at the front perimeter of the core.

Figure 10. Constructed "groHome" (photo by College of Architecture)

CONCLUSION

As a learning experience of design conception to application, the project was invaluable to students in the departments of architecture, construction science and engineering at Texas A&M University. The structural integration, as envisioned by the early decision to use bantam beams to incorporate mechanical and electrical through the core of the structure, was not easily realized. Significant effort was spent constructing prototypes, evaluating, and re-evaluating the "groJoint" connection. Cutting openings for every "groJoint", even at those locations where the passage was not necessary, consumed construction resources and time.

Interaction on a regular basis of the structural engineering consultants and professionals with the student team during the design phase rather than at the post-design, pre-construction phase when certification was most important could have shortened the development phase, aiding in design decisions, and reducing design responses. This necessity was not as obvious as the level of interaction of the energy systems faculty with the students due to the purpose and energy performance of the house in the Solar Decathlon contests.

The evolution of the structural integration solution and the "groJoint" of the "groHome", driven by the vision of providing sustainability with affordability and flexible use, was significantly influenced by the constructability, performance, and reliability of the structural system of the 2007 Texas A&M Solar Decathlon house.

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