AC 2011-1559: CONNECTING CONCEPTS IN SUSTAINABLE DESIGN AND DIGITAL FABRICATION: A PROJECT-BASED LEARNING CASE STUDY

Dr. Stan Guidera, Bowling Green State University

Stan Guidera is an architect and chair of the Department of Architecture and Environmental Design at Bowling Green State University. His primary teaching and research area is in 3D applications for computer aided design for architecture and Building Information Modeling.

Jon Stevens is an instructor in the Department of Architecture and Environmental Design at Bowling Green State University. His primary teaching and research areas are design studios, design-build, and intrductory computer aided design for architecture and construction.

Jon M. Stevens, Bowling Green State University

Jon M. Stevens is an Instructor of Architecture at Bowling Green State University. Jon primarily teaches first and Third year Design Studios, Design Build Seminars and Introductory Computer Aided Design courses. His interests / Research include Urbanism, Representation and Design Build projects.

Connecting Concepts in Sustainable Design and Digital Fabrication: A Project-Based Learning Case Study

Abstract

This paper documents a project-based learning experience involving undergraduate architecture students working with a Fortune 500 construction materials manufacturer. The project required the students to design and construct components that were incorporated into a trade show display booth at a major international exposition on sustainable construction. The students were required to meet project criteria related to material preferences established by the company along with the sustainability criteria related to the exposition itself. The paper discusses the concepts underlying project-based learning and documents the evolution of this particular project from its initial conception through delivery. Recommendations for faculty considering similar learning experiences are provided.

Introduction

Project-based learning has increasingly been recognized as a mechanism for synthesizing real-world experience with academic course content. In recent years, it has been widely acknowledged that classes designed by utilizing PBL Project - Based Learning are effective in enhancing the problem-solving ability of university students. [1] First coming to prominence in the 1990's, effectively structured project-based learning exercises provide a framework in which students are required to draw on their prior coursework to develop solutions for "real world" problems. In a project based learning environment the learners are "actively engaged in working at tasks and activities which are authentic to the environment in which they would be used" with a focus on "learners as constructors of their own knowledge in a context which is similar to the context in which they would apply that knowledge."[2] Such integration of theory and practice is an important component in the development of expertise. [3] According to Bromme and Tillema, [4] "becoming a professional is not a process of substituting experience for theory but a process in which theory and experience are fused." The connection between development of professional expertise and experience was also emphasized by Tynjala, Valimaa, and Sarja:

> "Getting students to cross boundaries between education and work through different forms of work-based learning would seem to provide a promising starting point for developing the prerequisites for professional expertise. However, this requires that true integration of theoretical, practical and self-regulative knowledge takes place."[3]

From this position it can be inferred that a key difference between traditional cooperative education models, full semester formal employment experience, and project based learning lies in the self regulative characteristic of the experience. Self-regulative knowledge has received attention from both educational and working-life researchers. Theorists of adult education have typically discussed it in terms of reflective thinking and theorists of student learning in terms of metacognitive skills. [5]

According to Larmer and Mergendoller, project-based learning must fulfill two criteria:

> "First, students must perceive the work as personally meaningful, as a task that matters and that they want to do well. Second, a meaningful project fulfills an educational purpose. Well-designed and well-implemented project-based learning is meaningful in both ways."[6]

Therefore, effective project based learning is conceptualized in the context of educational outcomes that serve to develop skills that enhance the professional, as well as personal goals of the students involved. As a result, project-based learning activities provide a unique opportunity to make a substantive contribution to intellectual and professional growth.

A project based learning case study

In fall of 2009, Owens Corning Corporation, a Fortune 500 construction materials manufacturer approached the Department of Architecture at Bowling Green State University to determine if students would be interested in participating in a design project involving an installation for an upcoming trade show exhibition. In their proposal they asked if students could develop design concepts leading to a fully fabricated installation that would be used by the corporation at Greenbuild, a high-profile international conference and trade show dedicated to green design strategies and materials. The company, which would act as a client, had already established several project parameters. These included the integration of new high performance insulation products into the display, and that the materials would be utilized in ways that enhanced visitor interaction with these products. Additionally, the exposition itself had its own parameters for exhibitors. These included compliance with "green design" parameters with specific criteria related to the project's carbon footprint, restrictions on the use of volatile organic compounds (VOC's), and recycling requirements related to the use of materials.

Initial review of the proposal suggested that the project could be utilized as an assignment in a semester-long material and methods course typically taken by third and fourth year architecture students. After more detailed review, it was determined the timeline for project development and delivery presented two problems to the integration into a pre-existing course. First, the timeline did not align with the class schedule. The project had been presented by the company just prior to the start of classes which made revising the established course activities problematic. Secondly, early in the project analysis it was determined that meeting the design, fabrication, shipping, and installation timeline could only be accomplished by applying a digital design process that would enable a seamless transition to digital fabrication of the final project components. However, the materials and methods class did not include development of digital design and fabrication skills as a learning outcome or objective. While most students taking the course were proficient with some form of CAD, the specific applications they were experienced with varied and in some cases not conducive to producing geometry conducive to fabrication.

Faculty then considered organizing the project as an out-of-class activity. A key disadvantage of this strategy is that it would place additional time-demands on students who were already involved in an academically challenging program. However, it was determined that the potential educational benefit to the students arising from their participation in the activity was substantial. Subsequent discussions lead to the conclusion that an independent project-based learning activity would yield the greatest benefit for both the students and the company. This approach would provide a timeline independent of course activities and provide greater autonomy for the students in responding to the project parameters. Additionally, the strategy for using digital technologies from design through production would require students to expand their skill set in the use of computer applications. It was also determined that in order to access the necessary fabrication equipment, the students would need to seek out partnerships with private industry in order to have access to CNC routing equipment not available at the university. This would provide an additional opportunities for student learning and engagement that would not have occurred in a conventional classroom activity.

In this context, the project was clearly aligned with the criteria established by Larmer and Mergendoller [5]. Additionally, as the goal of the project was to produce a physical installation that would be utilized by a client in a high profile context it was aligned with the position of Thomas, Mergendoller, and Michelson [7] who proposed that such projects "culminate into one or more realistic products or presentations".

Establishing the Project Team

The project team was composed of students who were invited by the faculty. All students selected were in their fourth year of the program. They were invited based upon their team-working abilities, and on their prior academic performance. Specific skill sets were also taken into consideration. Since digital fabrication would at least to some extent play an important role in project delivery, faculty selected Rhino 3D as project software. In addition to robust modeling capabilities, geometry developed in Rhino 3D is conducive to multiple fabrication processes. Therefore, students with strong design skills and also experience with Rhino were actively recruited.

Project Parameters

The project parameters for this project were multiple. In order to meet the November 11, 2009 opening date for the conference, a shipping deadline of November 1st was established. This allowed about two and a half months for research, design, fabrication, and shipping. This time frame given to the student design team was to include all phases of the design and fabrication.

The initial scope of the project was for the design of the company's entire trade show booth and display area. This included furniture, a refreshment station, numerous furniture pieces, wall panel systems, and a central focal point installation that would be suspended from the ceiling of the trade show venue. The design of the booth was to accommodate seating for up to fifteen to twenty patrons and display space for company literature. Additionally, the design team was required to comply with the technical parameters established by the trade show organizers. A 400 square foot area (20' x 20') was the size of the floor space allocated for the company's exhibit. In addition to the client company's requirement that the booth display highlight only their own products and that these products were to be used in displays that facilitated interaction of the visitors, the project parameters included the following environmental specifications:

- Recyclable content of all materials used must meet or exceed 95%

- No Volatile Organic Compounds (VOC's) permitted in materials, including in coatings, finishes, and packaging
- Low material weight for products used (to minimize environmental impact and carbon-footprint of exhibit component transportation and shipping
- Efficient field assembly and dismantling for recycling

Design Process

In order to fully comprehend the entirety of the project, students were required to conduct initial research on previous tradeshows, furniture materials, the booth location on the trade show floor, and traffic volumes and patterns within the convention center. They were also asked to identify locations of the company's competitors relative to their installation's location (Figure 1). This background research allowed the students to optimize the layout of the furniture and booth in order to maximize the exposure to the visitors and conference attendees.

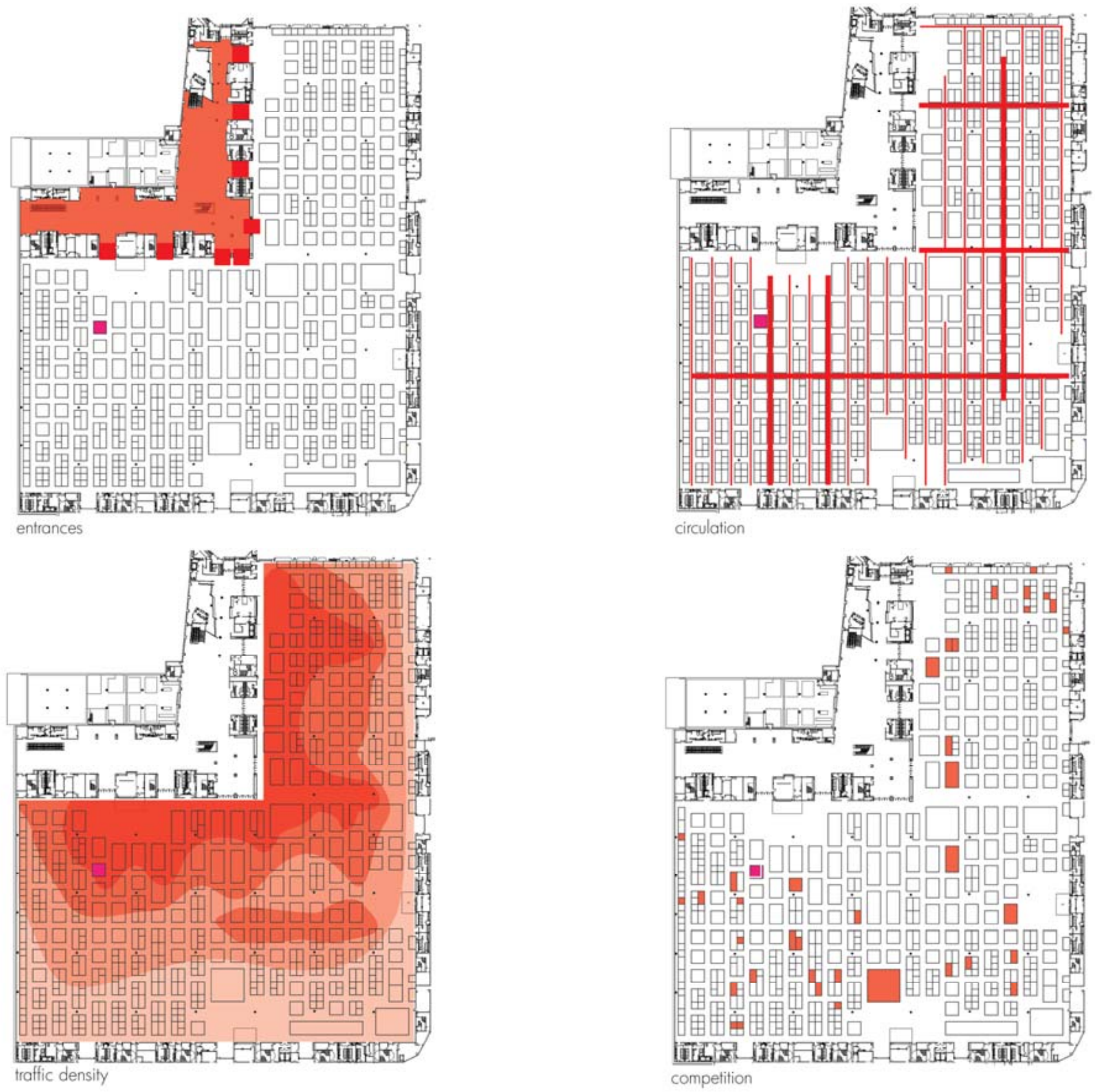

Figure 1. Analysis diagrams of the conference facility layout.

Once the research was complete the student design team separated the project into multiple phases, (schematic design, design development, and construction documents) each with a submission and meeting to discuss the imagery and design strategies with respect to that phase. Students worked on multiple designs schemes. The design decisions came through a series of student workshops and charrettes (Figure 2). The Faculty and students met to discuss and design each night for over a two-week span. The communication with the student team from the client company was minimal at this point. The design team received an initial briefing regarding general directions and were told to be "creative" in solving the problem.

Figure 2. Design team at work on proposal.

The materials available for the design team were limited to products manufactured by the client company. However, there were several products the company was particularly interested in featuring in the trade show display. These materials included the high density "Foamular" rigid insulation, and a new spray on insulation, that comes in thin rolls around 1/8" thick and 6" wide. Any other materials utilized were to be of recycled material and of minimal volatile organic compounds (V.O.C's). Additionally, both the furniture and the fabrication and assembly processes needed to maximize "green" design strategies. This requirement extended to details as well. As an example, when considering methods to connect materials, the design team was required to research the VOC content of adhesives and the extent to which VOC's would be emitted when bonding various materials. While this proved challenging and involved numerous trials with many different adhesives and glues, it also provided a learning experience for the students that was unique in terms of their conventional classroom experiences.

As the design developed, two-inch thick Foamular 250 insulation board was selected to be used as one of the primary materials in the installation components. In addition to providing a strong material that could be easily cut, it was also lighter in weight relative to conventional rigid insulation board products and completely recyclable, which would be beneficial in meeting the shipping and sustainability parameters (Figure 3). This material would be augmented with other recyclable materials such as wood.

Figure 3. Owens Corning Foamular 250

At the end of the schematic design phase, the students and faculty assembled a presentation and met with officials from the client company. The meeting comprised of 6 high-ranking officials from the company and the entire student and faculty teams. Students presented the design proposal, which included the central focal piece, suspended from the ceiling above, numerous furniture pieces, four wall panel display pieces and a front counter podium. (Figure 4 and 5). The student team received critical feed back as to how to improve the design and booth experience.

Figure 4. Trade show proposal with furniture, panels, and furniture pieces.

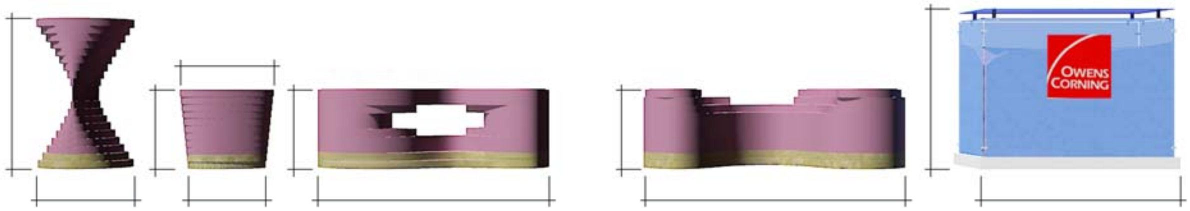

Figure 5. Proposal for tables and other furniture elements.

However, as the project developed, engineering concerns caused the client company to reconsider the scope of the project. This decision was not attributed to the design team's proposal but rather to specific engineering and safety concerns raised by the client company. The company's engineers were concerned that the central focal point, which was to be suspended from the ceiling in the exhibition hall, may prove to be too complicated to install and the limited time frame did not allow sufficient time for an adequate suspension system to be developed and tested. As a result, the engineers decided to utilize an installation used at previous exhibitions rather than redesigning the structural system for the new design proposal. Therefore, the project scope was reduced from the total design of the exhibit to that of just furniture and wall panels. Based on the student's design proposal, two wall panel assemblies (Figure 7) were approved to be included in the installation. These would be used as a tackable surface for product literature and representatives information to be picked up by trade show attendees. The approved seating was to accommodate various configurations: four-person seating, three-person seating, two-person seating, and multiple single-person seating. (Figure 6).

Figure 6. Proposal for wall panels.

Figure 7. Proposal for two and three person seating installations.

It is important to note the design process was not finalized until the technology, materials and fabrication techniques were decided upon. The main challenge facing the students was the fabrication. Initial design studies involved geomorphic shapes that were unrealistic without the use of a CNC (Computerized Numerical Control) Router. Faculty and students were interested in digital fabrication and pushing the limits of what a normal construction material like rigid insulation could do in an alternative production application.

More importantly, the use of digital fabrication technologies provided an additional opportunity for the project to help the students link theory and practice. Both architects and contractors are increasingly using computers to generate designs and then CAD/ CAM (Computer Aided Design/Computer Aided Manufacturing) and digital fabrication to build models for design review and as a means to produce full-scale building components. [8] The trend toward an increasing role for CAM in architecture and construction is also being driven by the need to compress project delivery schedules by overlapping design and construction. [9] For the student design team, CAM was determined to be essential in order for them to meet the project deadline. The use of CAM also was aligned with recent research on thick-layered object manufacturing and fabrication based on a higher order approximation of the shape and application of a flexible curved cutting tool. This method enables the manufacturing and the re-assembly of the parts without affecting the requested functionality [10] and was particularly relevant given the prominent use of Foamular 2” panels.

However, the students were also aware of several recently publicized projects that had utilized CAM extensively in design and construction. Published projects such as elements of the Virgin Atlantic Clubhouse at JFK Airport [11] and the Camera Obscura installation in New York City [12], both by SHoP Architects and both of which were digitally designed and fabricated with CAM technologies, were relevant in that the smaller scale of the projects was similar to that of this Greenbuild project. Therefore, for the students exploring the use of CAD/CAM provided additional opportunities to associate key trends in the discipline with classroom theory and the real-world aspects of the project.

Early in the project the students sought out local manufacturers in the region to secure the donation of time and usage of a CNC Router. Once the access to router was secured, the team’s strategy quickly shifted to one in which they explored ways they could optimize the design of the components to take advantage of the specific characteristics of the fabrication technology they would be using. It is important to note that without the use of such technologies and fabrication techniques, the student's design strategies would have had to be more restrained. The use of the CNC Router allowed the students to explore the geomorphic curved shapes. These types of cuts using the high-density Foamular 2" rigid insulation would have been very difficult to achieve with an acceptable level of precision and quality.

The design team continued to develop and refine their design proposal in order to insure the design of the furniture and wall panels complied with the client companies' parameters. A final presentation was emailed to the company representatives. This comprised of a booth floor plan, renderings of the furniture pieces and wall panel, an itemized budget and material list, and imagery for the company website and brochures. The design proposals received high remarks from the client company's representatives. Once the students received the final approval the client to proceed with construction, they were both excited and apprehensive as most had not been through the process of fabrication before. However, the client was energetic and excited to see what the students could accomplish.

After receiving the approvals from the client, the students tasks shifted to production of the CAD files needed for fabrication of the individual pieces. Rhino 3D, which was used in the preliminary design phases, was utilized in the production phase due to its inherent capabilities to generate robust and computationally accurate geometry, extensive support for a variety of file formats for import and export, and extensive features that support the extraction of 2D geometry from 3D models. Students supplied the cut-sheets and digital files to the fabricator and the cutting process took place over the next several days (Figures 8). Workers from the manufacturer provided additional services on their own time to assure the pieces and parts came out in the manner in which they were conceived.

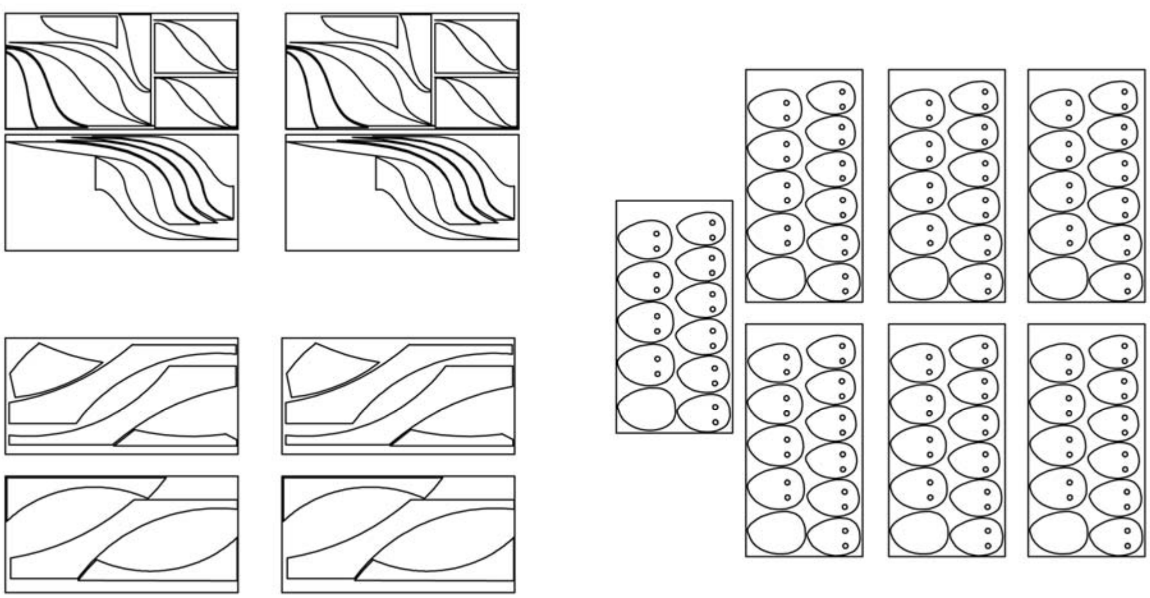

Figure 8. Example of 2-D CAD file cut-sheets for fabrication.

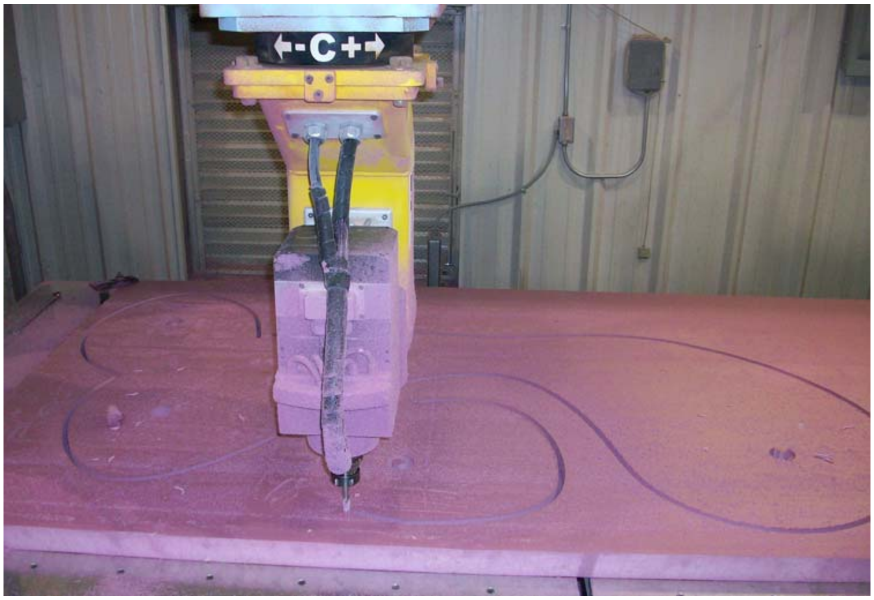

Figure 9. Foamular 250 in process of being cut by the CNC Router.

Fabrication and Delivery

Upon the completion of the cutting of parts, the furniture and wall panels were assembled over the course of three evenings. Since the parts were delivered to the studio with fabrication defects such as flaking edges and a large amount of material dust from the routing, the first night was allocated to minor cleaning and touching-up of the manufactured parts. Before assembly could start the pieces must be cleaned and maintained to ensure an effective bond between the materials (Figure 10).


Figure 10. Refining the component pieces.

Upon completion of the cleaning, the students left the first night with a rough fitting of all the pieces. The design and use of the CNC router allowed for a high level of precision that resulted in pieces fitting together as planned. However, some design modifications were implemented.

These included inserting wooden dowel rods into pre cut holes in the pieces for stability, which would also contribute to an accurate and efficient assembly on-site.

The assembly of the furniture and wall panels came on night two. As the faculty members worked with the client company on shipping logistics, the students focused on the final steps of fabrication and assembly of the furniture and wall panel components (Figure 11). The scheduling of the shipment of the completed project components required that the materials were to be placed in the crates and sealed up the night prior to the pick up. One faculty member and an alumnus from the college fabricated the crates two nights prior to the scheduled pickup date.

Figure 11. Assembling the components.

On the third night, the students began to finalize finishes and details on the furniture and wall panels. The components were then wrapped in construction paper and placed into the shipping crates with additional steps taken to securing the pieces to the crate to prevent any damage during the transportation process (Figure 12).

Figure 12. Left: Crating the finished product. Right: Student team with Professor Jon Stevens (on left)

The two crates were successfully picked up as scheduled and delivered to the Greenbuild Conference and Exhibition trade-show floor on time. One member of the student team was able to attend the conference as a representative of the student design team (Figure 13) However, it should be noted that during the unloading of the assemblies, a forklift punctured one of the crates and damaged a wall panel. Unfortunately, the damage was beyond repair and, as a result, only one of the two walls panel assemblies that had been designed and fabricated was actually installed at the exhibition.

Figure 13. OCF exhibit at the Greenbuild Conference and Exhibition in Phoenix, AZ.

Project Outcomes

This project allowed students to experience the entire design process in a limited basis. Students dealt with program and objectives, schedule and real materials. They had to identify and solve issues directly related to fabrication and assembly of the furniture pieces. Students were required to Develop and apply fabrication and CNC router skills. Students were required to apply knowledge related to Sustainability in the following areas: Material Selection, Maximum utilization of Recycled Materials, Overall carbon Footprint, Optimization of material (minimized waste), and Recyclability Factors. Finally, students had to deal with product distribution parameters, which included weight, assembly processes, product configuration, and packaging.

Students gained first-hand experience working with a Fortune 500 corporate client, interfacing with multiple management levels, regularly meeting and formally presenting their ideas in a corporate environment. Additionally, students had to “sell” the project design to a real client and team and meet that client’s expectations and time frame all while working under the constraints of the budget and project parameters established by the client. Their experiences with the client’s engineers also contributed to the learning experience.

To some extent the final outcomes of the project diverged from initial project expectations. However, the design team was encouraged by the final results of the furniture and wall panels:

- The final components were professional in appearance, finish, and function.
- The project came in slightly under budget.

- The components were designed and fabricated within the parameters set forth by the client company.
- The components were delivered on schedule.
- The installation functioned as intended on the trade-show floor.

Additionally, the students responded very well to the rigorous timetable and schedule despite the demands of their other coursework and the fluctuations in project parameters. The response from the client indicated the company was very pleased with the outcome and final furniture pieces and company representatives stated that the exhibit, in particular the furniture and seating, received considerable attention from trade show attendees. As an indicator of the project's success, after the trade show ended the installation components were shipped back to the company's national headquarters in Toledo, Ohio for display. An additional indicator of the effectiveness of the project was that each of the participating students included the project in their academic or professional portfolios.

Recommendations

Project-based learning experience has increasingly been recognized as a mechanism for synthesizing real-world experience with prior academic experiences. For faculty considering similar types of project-based learning, the following recommendations should be considered:

1. Be very specific with the project parameters. This particular project was established and limited to a small physical area. However, the project parameters remained in flux until the very end. The project began with a larger scope of work but in the end was reduced to a smaller scale project. While to some extent this contributed to the experience of a real-world design project, students found it difficult to adjust their schedules to accommodate the changing project parameters and also meet the demands of their other courses.

2. Faculty should pay close attention to the processes related to selection of team members. The students that participate can be a critical factor in the success of the project. Assembling talent that best fit the needs of the design team and project parameters proved very important in this specific project. Self-selection of members and/or project teams by the students themselves may result in additional limitations or students that are not able to effectively contribute to the project due to lack of skills.

3. Allow enough time to be able to run the project as either a class or studio. In the manner this project was run, it was necessary for students and faculty to be cognizant of other classes. A project like this one is very involved and could easily envelop students and their other studies. Students in this particular case were very dedicated to their other studies, and did not let this project interfere with their academics. However, faculty must be cautious in structuring the project deliverables and related commitments in order to attempt to minimize the potential for conflicting academic demands.

4. Secure incentives for the students. The client company was reluctant to supply funding or opportunity for members of the design team to attend the conference. It wasn't until late in the development process that they were receptive to the idea of funding student's hotel

and entry fees to the trade show. In the future it is recommended that students be compensated in some fashion for their hard work and devotion to the project. Fortunately, the faculty members leading this project were able to secure funding to enable one student to attend the trade show and conference. However, securing financial commitments in advance to provide additional incentives for the students is highly recommended.

Bibliography

1. Saeko, M. (2006). An evaluation method of project based learning on software development experiment. ACM SIGCSE Bulletin. 38, (1). 163-167.
2. John R. Savery, J. & Thomas M. Duffy, T. (2001). Problem Based Learning: An instructional model and its constructivist framework. CRLT Technical Report No. 16-01.
3. Tynjala, P., Valimaa, J., & Sarja, A. (2010). Pedagogical perspectives on the relationships between higher education and working life. Educational Leadership. 68, (1). 34-37.
4. Bromme, R., and Tilleman, H. (1995). Fusing experience and theory: The structure of professional knowledge. Learning and Instruction. Vol. 5, 261-267.
5. Larmer, J. and Mergendoller, J. (2010). Seven essentials for project-based learning. Educational Leadership. 68, (1). 34-37.
6. Larmer, J. and Mergendoller, J. (2010). Seven essentials for project-based learning. Educational Leadership. 68, (1). 34-37.
7. Thomas, J., Mergendoller, J., & Michaelson, A. (1999). Project-based learning: A handbook for middle and high school teachers. Novato, CA: The Buck Institute for Education.
8. Lawrence, S. (2007). Synthesis of design production with integrated digital fabrication. Automation in Construction, 16, (3) 298-310
9. Chaszar, A. (2006). An exploration of current CAD/CAM techniques. *In* Blurring the lines: Computer-aided design and manufacturing in contemporary architecture. A. Chaszar, Ed. Wiley & Sons, Ltd.: West Sussex, UK.
10. Sharples, C. & Sharples, W. (2006). Virgin Atlantic Clubhouse. JFK Airport, New York. *In* Blurring the lines: Computer-aided design and manufacturing in contemporary architecture. A. Chaszar, Ed. Wiley & Sons, Ltd.: West Sussex, UK.
11. Sharples, C. & Sharples, W. (2006). Camera Obscura, Greenport, New York. *In* Blurring the lines: Computer-aided design and manufacturing in contemporary architecture. A. Chaszar, Ed. Wiley & Sons, Ltd.: West Sussex, UK.