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Using Integrated Student Teams to Advance Education in Sustainable Design and Construction

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Abstract
This article describes a case study involving a Midwestern public university that incorporated an integrated, cross-disciplinary project delivery activity to create an effective framework for sustainable design and construction education. The article first provides an overview of sustainable construction and its advantages, describes how sustainable design and construction requires a modernized project delivery system to work effectively, and discusses the primary impacts of sustainable design and construction on the construction industry. The article then describes how one large Midwestern university has attempted to use integrated, multidisciplinary student teams to advance the concept of sustainable design and construction in the classroom environment. Curricula that include interdisciplinary courses on integrated delivery and leadership in construction, engineering and architecture could better prepare students for their future careers in the building industry and develop better managers and colleagues.

Keywords
Civil Construction and Environmental Engineering, Chemical and Biological Engineering, education, integrated project delivery, interdisciplinarity, sustainability

Disciplines
Architecture | Art Education | Construction Engineering | Construction Engineering and Management | Engineering Education | Higher Education and Teaching | Sustainability

Comments
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Using Integrated Student Teams to Advance Education in Sustainable Design and Construction

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This article describes a case study involving a Midwestern public university that incorporated an integrated, cross-disciplinary project delivery activity to create an effective framework for sustainable design and construction education. The article first provides an overview of sustainable construction and its advantages, describes how sustainable design and construction requires a modernized project delivery system to work effectively, and discusses the primary impacts of sustainable design and construction on the construction industry. The article then describes how one large Midwestern university has attempted to use integrated, multidisciplinary student teams to advance the concept of sustainable design and construction in the classroom environment. Curricula that include interdisciplinary courses on integrated delivery and leadership in construction, engineering and architecture could better prepare students for their future careers in the building industry and develop better managers and colleagues.

Key Words: Education, Integrated Project Delivery, Interdisciplinarity, Sustainability

Introduction

The concept of sustainability has become a cornerstone for many institutions around the world. “Sustainability” was defined by a 1987 United Nations (UN) Commission as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Bruntland Commission, 1987). At the 1992 UN Earth Summit in Rio de Janeiro, the delegates adopted Agenda 21, a comprehensive global framework related to sustainable development. Based on this international agreement, the U.S. President’s Council on Sustainable Development was created in 1993.

The primary objective of sustainable design, an aspect of sustainable development, is to eliminate environmental impacts through deliberate decision making and sensitive designs (McLennan, 2004). Sustainable design and construction are important because of the impact building has on the surrounding environment and the environment in other countries. Recognizing the need to mitigate environmental impacts, such as protecting the atmosphere, forests, and biodiversity, is thus important.

It is clear that interest in sustainable design and construction is growing and will change the process of building and maintaining infrastructure (Bourdeau et al., 1998). As sustainable design and construction continue to grow and become a part of the building industry, it is important for university curricula to communicate this information to students. Curricula, which have been slow to change, should evolve to educate students in current industry practices and to include interdisciplinary coursework that focuses on integrated delivery methods, communication, leadership, and sustainable design and construction.

To illustrate ways to change curricula, this article examines a case study involving one Midwestern public university that incorporated an integrated, cross-disciplinary project delivery activity to create an effective framework for sustainability education.

Research Methodology

The objective of the research was to develop new educational systems and structures to facilitate student learning in sustainable design and construction. The researchers employed an Action Research Model in achieving this objective. There are a number of variations of the definition and approach for an Action Research Model (O'Brien, 2001). The research described in this manuscript used Susman's (1983) model as shown in Figure 1 below.

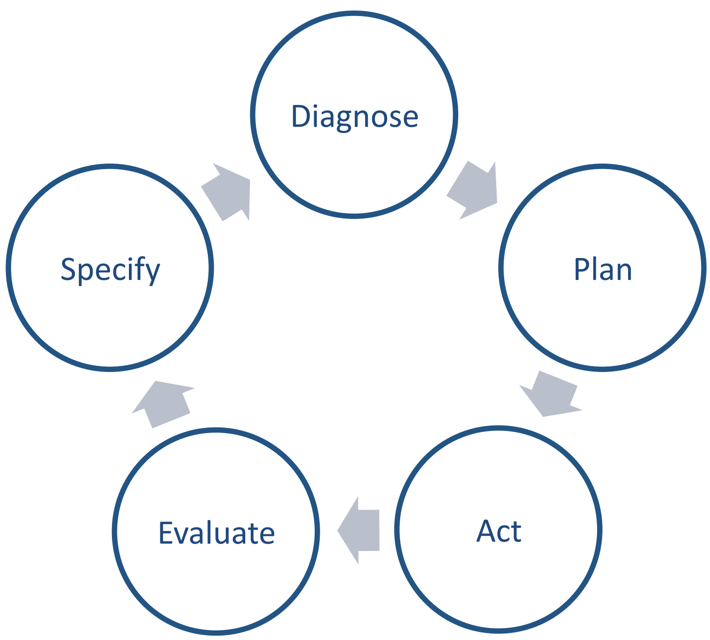

Figure 1 Action Learning Model (adapted from Susman, 1983)

Each of the stages in the action research cycle will be discussed in more detail in the following sections.

Diagnosis Stage: Features of Sustainable Construction

There is emerging evidence from research that sustainable design and construction is maximized when project teams are integrated. One study funded by the Charles Pankow Foundation contained findings regarding the importance of integrated project delivery methods in providing optimal performance and the importance of early constructor involvement in meeting sustainability objectives. One specific finding is that "if owners want [LEED®] gold or platinum certification, they should decide to go green early, specify the level, and use design-build delivery systems to get the necessary integration as soon as possible." (Molenaar et al. 2009) However, most curricula and higher education structures are extremely discipline specific. Therefore, one of the major problems with teaching sustainable design and construction is the lack of disciplinary integration of existing degree programs, coursework and curricula at most colleges and universities. The need for integration extends beyond construction, engineering and architecture because sustainable design and construction includes not only environmental considerations but also integration of environment with cost, schedule, operations, maintenance, and worker/employee relations. Beyond the project-based parameters of cost, schedule, maintenance, and end-user concerns, sustainable design incorporates principles of economics and social justice into ecological sustainability. In order to understand this concept, consider not only how sustainable design and construction can affect society in a positive way but also how this concept varies from one society to the next. Charles Kibert (2007) proposes that, over time, sustainability can actually change societies for the better. Kibert's reasoning for this claim is outlined in figure 2, which depicts a sustainable construction road map as first outlined by Bourdeau et al. in 1998.

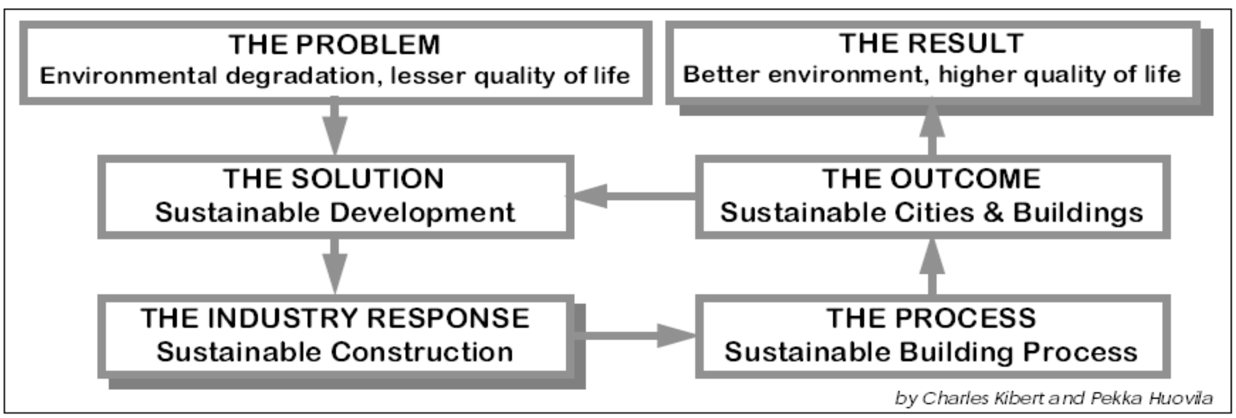

Figure 2*:* Sustainable construction road map (adapted from Bourdeau et al., 1998).

Clearly, a sustainable construction road map implies a change in the function of project management. Figure 3, from Vanegas, DuBose, and Pearce (1996) illustrates how the traditional project management factors will be broadened to incorporate environmental demands into sustainable design and construction. The figure attempts to illustrate globalization's effect on the initial and modified project management factors. When presented in the global context, the economic and cultural factors need to be considered together with environmental issues and competitive factors in order to achieve the most sustainable construction method.

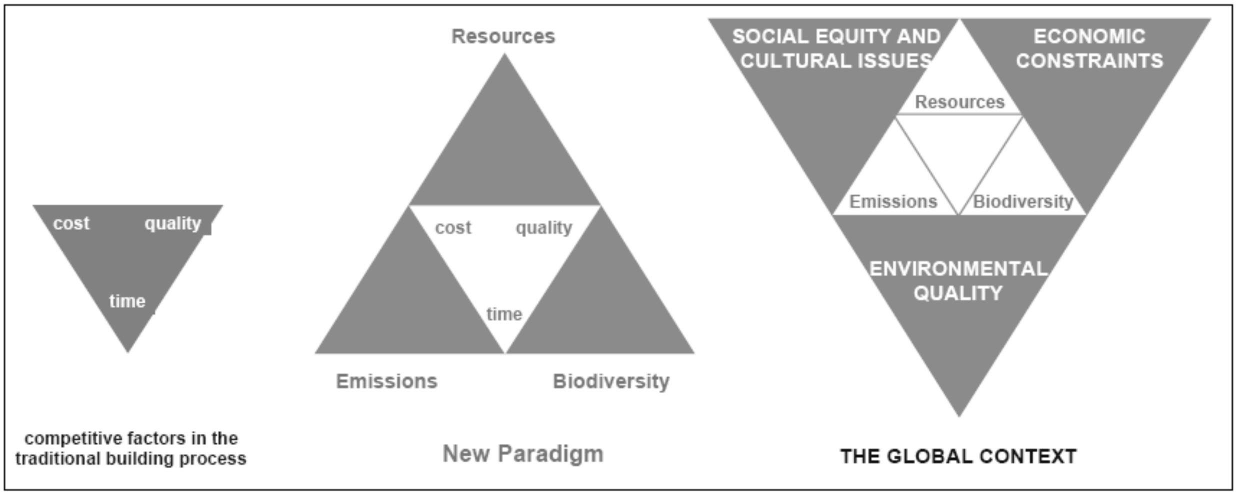

Figure 3: New project management paradigm (adapted from Vanegas et al. 1996).

Change is one of the most significant sources of cost and schedule growth on a construction project and is a significant problem for sustainable design and construction projects because of the added complexities and increased communication and shared documentation needed for integrated design and construction. Many of these changes can be controlled, yet few firms extend the extra effort to do so. With the rise of the integrated delivery method, this control is somewhat inherent in the overall design and construction process compared to the traditional design-bid-build method.

Integrated delivery focuses on combining the design, permit, procurement, and construction schedules in order to simplify the traditional design-bid-build process. This integrated delivery does not necessarily shorten the time it takes to complete the individual tasks of creating construction documents, acquiring building permits, or actually constructing the building. Instead, the project team strives to bring together design and construction professionals in a collaborative environment to complete these tasks at the same and therefore shorten overall project time. An integrated delivery project typically makes one team responsible for both project design and construction. In many cases, if this team is led by a contractor, the process is known as contractor-led design-build. If the team leader is a design firm, the process is known as design-led design-build. In either case, the organization employed by the owner rarely handles both aspects of design and construction in-house. In fact, the organization often subcontracts with either on-site personnel or architects and engineers to help complete the project.

Controlling Changes

In order to understand how integrated delivery positively affects construction projects, consider a common problem on many projects—controlling change. These changes can either be owner-generated or field-generated.

Owner-generated changes occur both during design and construction. The owner, usually after visiting the site or reviewing plans, decides to add to or retract from the project. These changes are often made in an effort to add some item that was overlooked from the design or to reduce the scope of the project in order to control the total cost. Owner-generated changes are common for almost all projects and are inevitable.

Field-generated changes occur in the field during construction. These changes are most commonly associated with conflicts between design features and/or errors in the original design or construction methods. Field-generated changes are the most easily controlled and can usually be avoided or minimized with good communication among all parties involved (Ibbs, 2004).

Knowing what types of changes need to be controlled is only the first step in the process. The parties involved in a project also need to be able to identify the initial cause of the change. Was it a lack of communication or miscommunication, a design error, a defect in a material or process, a construction error, a cost overrun, or just something that was forgotten?

Improving Communication

Communication about a construction project is essential. Communication must occur between all project partners, including designers, owners, builders, vendors, project administrators, government agencies, and other project stakeholders. Furthermore, communication between partners must occur across the entire project life cycle. However, this method of cross-disciplinary, integrated communication is something that few project teams have mastered well. Research has demonstrated found that communication increased satisfaction and safety of all parties involved with a project (Done, 2004).

Improving communication techniques will benefit everyone and should become a primary focus of all project teams. Furthermore, increased communication will result in a fewer number of changes to a project and better cost control throughout. However, education has been slow to adopt curricular changes that reflect the industry movement toward integrated project delivery. University structures and academic programs continue to have high disciplinary boundaries, with little faculty cross-training and few multidisciplinary courses or programs. Bringing the integrated delivery process into the classroom setting would assure that new construction, engineering, and design professionals entering the workforce are prepared for the future of the construction industry. Incorporating integrated delivery into higher education is particularly important if sustainable design and construction practices are to be emphasized in the next generation of design and construction professionals. The following case study from a large Midwestern public university (henceforth referred to as "the University") shows how integrated project delivery education can be incorporated across disciplines to create an effective framework for sustainability education.

Planning Stage: Creating a Structure for Teaching Sustainable Design and Construction

The Department of Energy's Solar Decathlon (http://www.solardecathlon.org) is a sponsored research, education and outreach program combined with a student run competition to build the most beautiful, efficient and innovative 800 square foot prototype house, which is solely powered by the sun. Twenty international university teams were selected and received a $100,000 grant as a start-up funding. The teams had to design the house, fundraise for the house, construct it, transport it to Washington, D.C., operate the house under the conditions of 10 contest parameters and communicate their individual concepts to the general public during public tours in a 10 day period in October 2009. The 10 contest parameters were Architecture, Engineering, Market Viability, Communication, Lighting Design, Net Metering, Thermal Comfort Zone, Hot Water, Home Entertainment, Appliances. Figure 4 shows the University Solar Decathlon team's educational plan to integrate these ambitious goals into the coursework of engineering, design, architecture, business and communication students.

	Spring 2008	Summer 2008	Fall 2008	Spring 2009	Summer 2009	Fall 2009
PROJECT TIMELINE	design	design	construction documentation	construction	construction	competition reconstruction
Club Activities	fundraising publicity design	fundraising publicity design	fundraising publicity construction planning	fundraising publicity construction management	fundraising publicity construction management	fundraising publicity competition management
COURSEWORK *Interdisciplinary Core Courses*						
Design/Build Workshop	schematic design	design development	construction documentation	construction	construction	competition reconstruction
Project Leadership Seminar			planning/ coordination communications	planning/ coordination communications	planning/ coordination communications	competition communications
Special Electives and Independent Studies	•	•	•	•	•	•

Figure 4: Project schedule during the proposal stage (University Solar Decathlon team)

It is interesting to note, that the organization team initially sought to integrate the design and construction of the house into one holistic unifying design/build course and workshop. Due to the limitations of existing curricula regarding course credits and student time, this section was split up into the design workshop run within the College of Design and the construction mock up class run and organized within the College of Engineering. This multilayered organization enabled design development and detailing to continue while the construction crew had already started with the workshop and continued during the main construction. The dual course structure also incorporated development of a feedback loop between the two groups with a few architecture students enrolling in both classes and the construction mock up class leader visiting the design workshop almost daily.

Very important during the further development of the curricular integration was the integration of specific electives and independent studies, which took on parts of the house design and communication tasks. Figure 5 shows the complete integration of all courses that contributed work to the success of the team deliveries and completion of the Solar Decathlon house. Each course had an assigned liaison participating in the design workshop to integrate the outcome and knowledge into the development of the house as a holistic entity. The team and corresponding curricular structure was organized into the following areas:

- Architecture
- Biocomposites
- Communication
- Construction
- Engineering of systems
- Solar Decathlon Team Management (Solar D Leadership)

The specification of design and engineering tasks during the development phase of the project could only be accomplished due to the overarching quality of the design workshop, the leadership course and the experimental construction class, which are the focus of this paper.

	Spring 2008	Summer 2008	Fall 2008	Spring 2009	Summer 2009	Fall 2009
Project Deliverables	Design Development	Design Evaluation	Construction Documentaton	Design / Construction	Construction	Transportation / Competition / Report
Architecture / Engineering / Interior Design Studio	ARCHITECTURE / DESIGN / ENGINEERING: Develoment of a house concept, interior, engineering and landscape schematic design	ARCHITECTURE / ENGINEERING Topical Studies: Energy Evaluation of house alternatives	ARCHITECTURE / DESIGN Studies WORKSHOP : Construction Documentation / Specification	ARCHITECTURE / DESIGN WORKSHOP: Construction Documentation and Specification, Site Supervision	ARCHITECTURE SERVICE LEARNING: Building of Exterior Deck + Landscaping	ARCHITECTURE / CONSTRUCTION / ENGINEERING: Organization of Contests and Public tours, organization of transportation, Assembly and disassembly in Washington,
Design / Engineering specifics			Independent Studies: Qualitative and quantitative Lighting Analysis			
			Independent Studies: Advanced Energy Analysis			
Materials Engineering			Independent Studies: Potential for Integration of Biocomposite Materials			
			Materials Engineering: Thermal conductance of biocomposites	Materials Engineering: Flame retardant for biocomposites		
			Materials Engineering: Effectiveness of ceramics as			
Mechanical Engineering	Mechanical Engineering HVAC Desgin		Mechanical Engineering HVAC Construction Documentation and Specification	Mechanical Engineering HVAC Construction Documentation and Specification		
Electrical Engineering	Electrical Engineering: PV Array analysis	Electrical Engineering: PV Array design	Electrical Engineering: PV Array Construction Documentation	Electrical Engineering: PV Array Construction Development		
			File to Fabrication of assemblies and biocomp material assembly	File to Fabrication of assemblies and biocomposite material assembly		
Landscape			Landscape Design, Plant specification			
Interior Design				Integrated Studio Arts: Furniture Design		
				Integrated Studio Arts: Mixed Media Design		
				Integrated Studio Arts: Ceramics: tiles and dinner ware		
Communication	Business / Graphic Design: Web site Analysis / Design	English: Writing of web site text	Journalism: Public Relations Writing: Development of Target	Architecture: Advance Digital Media: Design of Animations for the	Development of Communication Materials	
				Journalism: Strategic Planning for Advertising and Public Relations: Communication Concepts		
Construction Engineering			**Construction Mock up**	**House Construction / Safety Plan**	**Paid student construction team and volunteers**	
Overarching Organization			Leadership Course as topical studies: open to all majors	Leadership Course as topical studies: open to all majors		

Figure 5: Final project schedule and courses at the end of the project (ISU Solar Decathlon team)

The logic behind the Solar Decathlon team structure and related curricular innovations represented a deliberate attempt to address the student learning and project development from an integrated perspective. These curricular innovations are in line with the best practice recommendations from industry. With the rise of sustainable construction across the world, the most direct effect on the U.S. construction industry (other than cost, social, and geographical factors) is the effect on constructability. Constructability reviews are typically undertaken on a facility design to improve construction ease and anticipate the effect on cost and schedule. A constructability review entails getting experienced construction personnel involved with the project from the earliest stages to ensure that their experience can properly influence the project owners, planners, and designers. Constructability reviews involving integrated teams from a broad perspective will be required for successful sustainable construction projects. It is for this reason that the future construction industry needs to focus more on integrated team development, not only in industry practice, but also within the curricula of our educational institutions.

To further iterate this point, in 2003 the Technical Research Congress published a study examining the relationship between constructability and sustainable design at the Pentagon in Washington, DC (Pulaski et al., 2003). The results of the study found that the two cannot be fully accomplished if viewed separately. As part of the research, Pulaski and his fellow researchers established a joint list of best practices for building a sustainable project. The best practices for sustainable design and construction are as follows:

- Form an integrated sustainable design and constructability team.
- Establish a facilitative organizational structure and supportive contracting strategies.
- Use the U.S. Green Building Council's LEED rating system when possible.
- Treat the built facility as an integrated whole, a key tenet to both sustainable design and constructability.
- Establish early integration of green design and constructability reviews (Pulaski, 2003).

Action Stage: University Solar D Case Study

As noted in the previous section, there was a comprehensive plan for developing new structures and classes to facilitate student learning in sustainable design and construction around the Solar D project. A description of the entire action plan exceeds the scope of this manuscript. Some aspects of the action plan have been reported elsewhere (Cardinal-Pett,Horwitz, Passe, 2010; Passe, 2010). The section of the action plan reported in this article focuses on the special integrated construction engineering courses developed as part of the Solar Decathlon project.

The University Solar Decathlon project was divided into three phases: the planning phase, the design phase, and the construction phase. In a truly integrated project, these three phases have a significant amount of overlap and have no defined start or end dates, apart from the overall project start and completion. However, for the purposes of communicating information in this article, the phases have been identified based on the bulk of the work undertaken in each phase.

The Planning Phase

The planning phase began in fall 2007 when the University began the process of applying to participate in the 2009 Solar Decathlon. The integrated process began at this early stage, although many students and faculty leaders may not have realized it. The integrated delivery entailed the combined effort of multiple disciplines to complete a given task. At this early stage, what would become the integrated team consisted of the Department of Architecture and other units in the College of Design and several programs in the College of Engineering, the College of Liberal Arts and Sciences and the College of Business. Even before the first necessary change was encountered, this group of participants was exposed to integrated delivery's necessity for communication. The colleges worked together to develop a proposal for the U.S. DOE in order to be considered for the Solar Decathlon competition. Undertaking this task was undoubtedly difficult. The colleges had not attempted a project of this type before, and they had limited experience working on other interdisciplinary projects. However, key individuals from each of the colleges were able to recognize the need for a higher level of communication and developed a working strategy that led the team as a whole to complete the task. The proposal was submitted on time in fall 2007 and resulted in the University's acceptance in the 2009 competition.

The Design Phase

The design phase was the first phase to truly encounter the subject of change on a large scale. For an integrated project, change during the design phase is actually more common than for a comparable design-bid-build project. This change was the result of the increased communication between all parties involved. In theory, all parties are more closely linked and can achieve a higher level of detail with the design versus traditional methods. Parties that may not have a large role at this stage can still have input in the design. This area is where integrated delivery gains several advantages over design-bid-build. Ideally, because all parties have had their input, unforeseen conflicts are kept to a minimum. Integrated delivery has the inherent ability to rapidly tweak the design as each party reviews and anticipates future needs during the design phase. The end result should be a well-planned, thought-out design that the owners, builders, and designers have worked together to achieve. This process should drastically reduce the previously discussed owner- and field-generated changes during construction.

The design phase of the University's Solar Decathlon project was challenging because it was structured around coursework, so the phases of the work were somewhat artificially constrained by the academic calendar. Student rosters changed in the spring, summer, and fall academic terms, causing a loss of continuity and some changes in both formal and informal leadership within the Solar Decathlon student teams. Each of these semesters is discussed separately to reflect that artificial chronology.

The design phase began in January 2008 with the start of the spring semester. In this semester, the bulk of the design work was assigned to a Design Studies option studio class, which had students from architecture, interior design, landscaping, and mechanical engineering enrolled. Ironically, communication—the concept that helped the planning phase excel—was the biggest obstacle that this new team of students struggled to overcome. The students lacked experience in the design studio, and the construction students involved during that phase lacked construction expertise. In addition to the lack of professional experience, the student teams lacked experience in working together in large, project-scale groups and were unfamiliar with the extraordinary information sharing needs required for a large-scale, technically complex project. Though most professors would perhaps like to believe that their students are capable of communicating with students from disciplines other than their own, the reality of the situation was that most students had never encountered an opportunity to force themselves to learn the art of working with professionals with thought processes different from their own. Architects were quickly troubled by the thought of designing with an engineer who cared more about how something worked rather than how it looked. Likewise, engineers struggled to understand why the architects would choose to create overly complex and inefficient designs in favor of a good look.

These student perceptions obviously reflect an oversimplified view of the reality of both engineering and architectural decision making. Adding to the issue was the students' lack of understanding different decision processes. Specifically, engineering curricula frequently favors individual work; quantitative, competitive evaluation (e.g., low bid, most efficient); and an emphasis on a single "right answer." Architecture and design curricula feature more team-based approaches to coursework, with more qualitative, peer-led assessments and recognition that more than one "right answer" is possible. These curricular conflicts created a series of problems within the design team. Lack of communication led to many members of the team not being able to truly understand the technical requirements of the design, which in turn led to many designs being developed that could not be built under competition rules. This issue was exacerbated by the difficulty in defining the problem at the earliest stages of the project. In essence, the student teams were trying to define *and* solve the problem at the same time, which led to numerous false starts on design solutions.

Furthermore, a lack of defined leadership was apparent during the bulk of the semester, which led to multiple instances of conflicts of personality, non-professionalism, and individuals not performing their fair share of the work.

The design team student leaders finally understood the nature of the communication problems toward the end of the semester, at which point it was too late to make any real progress on design completion. Mistakes made during this time included poorly defined expectations of the people involved, poorly organized and inefficient group meetings, a lax organizational structure that allowed non-performers to go unnoticed or unpunished, a failure to promote the idea of a workable solution versus an ideal solution, and, finally, not getting the construction team's full support at the proper time.

The summer semester began where the spring semester left off, with a design that was incomplete and that did not comply with competition rules. The more pressing issue was the deliverable that was due in early June. When the spring semester ended, most students left campus for the summer, which created a frantic rush by the design team members who remained on campus to work on the project throughout the summer. Fortunately, through the efforts of the original team and the few remaining members from the spring semester team, the June deliverables were completed. The effort to meet this deadline drove the realization that dramatic changes needed to be made. Through the help of some construction management tools offered by the construction team, a new leadership structure was developed for implementation in the fall semester. One of the tools was called a RACI (Responsible, Accountable, Consulted, and Informed) diagram, which specifically identified all known tasks and clearly specified who was accountable for completing each task. It further identified which team members needed to take part in each task. Once this new team structure was implemented, it created a sound method for enforcing team members' individual roles and, as such, created an avenue for higher levels of communication for the students who would return in the fall. In addition, once the hurdle of defining roles through the use of the RACI diagram was overcome, new team members easily found their positions for the remainder of the project without the need to recreate the RACI diagram with every personnel change. The use of management tools was supported by more frequent, better-run meetings and the implementation of a leadership seminar (taught by the Architecture Department) for student leaders working on the project.

The fall semester began with a whole new roster of students within the design studio. However, with the new leadership structure, the new students were able to better understand the concepts and goals for the project from the start. The leadership structure is shown in Figure 6 and was used as the basis for the RACI assignments.

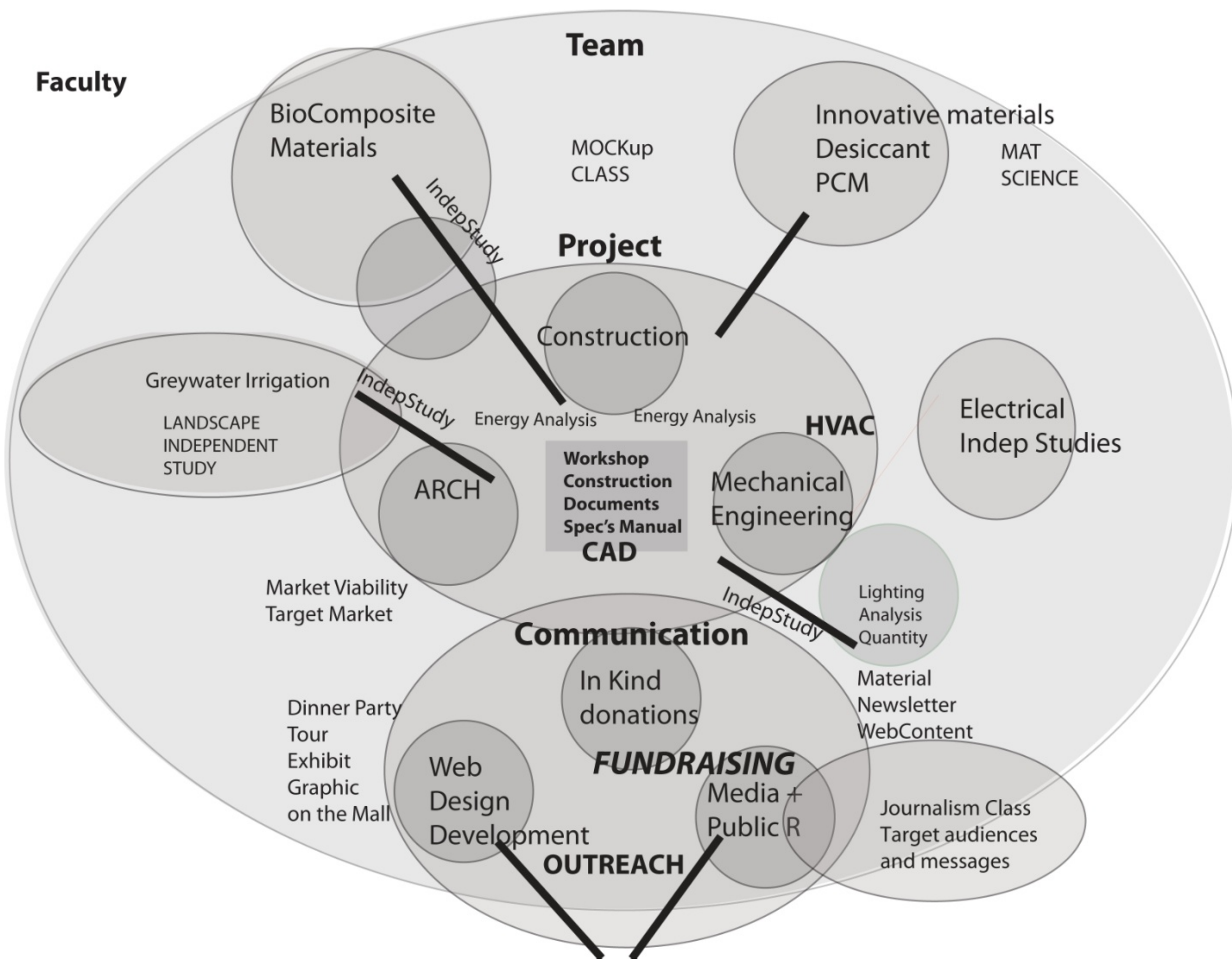

Figure 6: Solar Decathlon project structure.

To kick the semester off with the new strategy, the project leadership team asked the studio to look at what had previously been designed and comment on it. After a week of review, the studio took advantage of integrated delivery's major benefit and chose to perform a rapid redesign. At this point, there were multiple other disciplines working to design and construct areas of the project, but the integrated delivery method allowed these areas to continue or modify their work to coincide with the newly developed design. In the end, the new design far exceeded the quality of the first.

During the fall semester, the construction team began to take on a larger role in the project, which amplified the benefits of the integrated delivery method. The construction team decided that they would host their own course in order to study the constructability of the design and to perform some problem solving with regard to construction techniques and detailing. The communication between the design studio and the construction class reached new levels that the project had not been able to accomplish before this time. Architecture students from the design studio workshop enrolled in the construction mock-up class, which helped this process immensely. Also, the project leaders met weekly in the leadership class to discuss the process and any conflicts, which also helped. Working together, the students in these three courses (design studio, construction mock-up, and leadership seminar) were able to solve design problems by constructing mock-ups of the various features, thus allowing the construction team to comment on the constructability and the design studio to examine the visual appeal. In the end, the increased communication among all parties involved was a complete success. The involvement of the construction team in the project before the design was finished allowed for a stronger design that offered an excellent compromise between visual appeal and constructability. As the design phase of the project neared its end and the next set of deliverables came due, preparation for them was rolling smoothly.

Integrated Design Phase Experimental Class Part I

The Solar Decathlon project was an ambitious, highly integrated student-led project. Other classes (besides the three mentioned in the previous section) included communication, business, and research classes, among others. This section focuses on an experimental cross-disciplinary class on integrated construction.

Class Structure

In the fall 2008 semester, a construction engineering course (Con E 490) consisted of researching, constructing, and testing concepts and designs for the University Solar Decathlon house. Students from engineering and architecture participated in order to further promote the concept of integration at all levels. These students were expected to take partially designed concepts and complete these designs through research and testing. The class schedule allowed for a number of research and development days, construction days, and several days for testing the effectiveness of the designs. Students were expected to have prior knowledge of residential construction techniques and be self-motivated to complete the required tasks on time and to the highest quality. Once new designs were constructed, students took part in testing their effectiveness according to strict scientific procedures. After the testing, the designs were evaluated to determine if modifications would be necessary.

Objectives

The objective of the experimental course was to expose students to the basic concepts involved in designing energy-efficient homes and to provide students with practice in developing detailed designs for the University's Solar Decathlon house. When the class was finished, the students were to have met the following requirements:

- Recognize the scope of planning and design effort that is required.
- Communicate with other participants about construction facilities using appropriate terminology.
- Independently design uncomplicated systems using appropriate design codes and resources provided from the class.
- Act as the technical point of contact for the constructor when a facility is designed by others.
- Demonstrate skills that show an understanding and ability to develop energy-efficient construction techniques for projects in the future.
- Identify areas of weakness in residential structures and derive methods of reinforcement while validating these methods through performance and analysis of self-designed testing procedures.
- Formulate and justify tests for proving the effectiveness of designs of residential structures in regards to energy savings.

Assignments

For the first assignment, all students in the class were required to submit a document that summarized, in detail, the goals of their project. They were given a list of areas that still needed development, and each student took one of these areas and created a solution for the problem. Once these solutions were submitted, they were reviewed by the rest of the class and were either accepted into the design, modified and accepted, or placed under continued development. The reason that this assignment was used was to give the students a sense that they had a part in the overall design of the project from the beginning.

For the second assignment, the students developed a safety plan for the University's construction team. They were given this task because it was considered beneficial for them to be aware of all of the work that goes into a safety plan for an organization and so that the students would be most familiar with the safety guidelines for the project when they took over roles as teaching assistants the following semester. By having these select students exposed to both the construction side of the project and the concept of integrated delivery, they could promote these concepts to a much larger group of students the next semester.

For all subsequent assignments, the students were given tasks that helped them develop their final report. These tasks included, but were not limited to, weekly updates, daily journals, outlines, and concept ideas.

Final Report

The final report contained the selected designs and construction techniques established throughout the semester. The final report also discussed the results and recommendations from tests that the students designed to evaluate the effectiveness of the final concepts for construction.

Lessons Learned

A well-defined schedule at the beginning of the project is a good way to get everyone on the same page regarding expectations. Giving team members a chance to make themselves a part of the project initially is a good way to get higher quality work later. Frequent progress updates are useful because these updates hold each student accountable, and the process allows for guidance if necessary. A motivated leader will naturally motivate the team to do its best work. A small percentage of the team will take up a large percentage of the leader's time, and the leader needs to budget for that expectation. Frequent positive reinforcement will also create an enjoyable working environment for the team.

Integrated Design Phase Experimental Class Part II

Class Structure

The spring Con E 490 course consisted of researching and constructing the project based on drawings for the University's Solar Decathlon house while simultaneously studying four specific potential obstacles to a successful construction project: communication, conflict resolution, personality types, and leadership styles. Students in this class were expected to participate in an interdisciplinary work environment and function as a team to complete their research and the construction of the Solar Decathlon House. To help achieve this goal, students were given multiple assignments throughout the semester that were intended to help them better understand the four particular issues identified that affect modern construction projects. Each of these reports, homework assignments, and presentations were requested to emphasize the obstacles of significance in a multidisciplinary work environment.

The construction phase of the University's Solar Decathlon House officially began in mid-January 2009. The design and construction teams both predicted that the number of changes that would occur after this date would be kept to a minimum because of the communication and involvement among all disciplines during the planning and design phases. They were correct, with the only changes being limited to detailing features and redesigns for visual appeal and/or functionality.

Objectives

The objectives of the spring semester course were as follows:

- Expose students to the basic concepts involved in designing energy-efficient homes.
- Provide students with practice in developing working relationships within multidisciplinary teams.
- Help students recognize individual differences in personality and communication styles, especially differences that may be prevalent in disciplines other than their own.
- Understand the art and science of leading multidisciplinary teams.
- Create opportunities for students to develop leadership skills.

Assignments

The assignments for this class revolved around a common theme of effective integrated interdisciplinary project teams. The course was developed using Tuckman's (1965) four-stage team formation framework, consisting of forming, storming, norming, and performing stages. The first assignment consisted of the individual sections of the class working together to write a short document that outlined the reasons why they wanted to select a particular research topic for the rest of the semester. These topics consisted of communication, conflict resolution, leadership styles, and personality types. This first assignment served two purposes: to obtain a request for the topic that the particular section would like to research and to speed up the initial team building process. In the end, this first assignment aided in quickly guiding the sections through the forming stage of the traditional team development model.

The second assignment was designed to help the sections finish moving through the forming stage by introducing them to all aspects of the project. They were asked to read and reflect on everything that was done thus far on the project. With their reflection, they were asked to give any suggestions or new ideas that might help the project and to identify issues they believed might arise throughout the semester.

The subsequent assignments were all designed to aid the sections with the research for their final papers and presentations. By completing assignments that dealt with conflict resolution, communication, leadership, and personality types, the students should have been able to understand the scope of their research.

The final assignment for the class was class participation. Participation was determined to be a very effective method for pulling the students out of the forming stage and pushing them through the storming stage. Through high levels of motivated participation (grading), issues and conflicts were quickly resolved so that the students could begin work on their final papers earlier.

Final Project

The final report and presentation emphasized the preselected obstacle's significance in a multidisciplinary environment. The group's content was expected to be specific and verifiable. A minimum of three books, journals, and/or articles were required to be cited in the final report. The groups were expected to research their topics as a team and share the information with each other so that all of them would be able to answer questions about their topic during the final presentation.

This final project was intended to be the activity that took advantage of all of the team development that had occurred throughout the fifteen weeks of class. The students were expected to have completed their storming and norming stages during class and to complete their final paper efficiently within the performing stage. The four sections each gave a presentation and submitted a report on one of the four topics (conflict resolution, communication, leadership, and personality types).

These presentations and reports turned out to be quite impressive, given that the groups were allowed the liberty to address their topic however they chose. The reason for this unusually high level of quality was perhaps due to the team's ability to understand one another and work together effectively after a semester's worth of work and development.

Evaluation Stage: Lessons Learned

A well-planned schedule does not always work as planned, but early team development leads to better performance. Proper planning and coordination by management can allow for separate teams to complete shared tasks without the need for physical integration (e.g. co-location). Separate teams need to meet and socialize periodically in order to maintain connection with the project. Additionally, a stressed-out leader will create a stressed-out team, thereby lowering productivity. A lenient leader will create an overly relaxed team, also lowering productivity. Large quantities of rework will greatly affect team morale and productivity, making patience a definite virtue for team leaders.

Once the spring 2009 semester ended, the construction team continued to build the house over the summer. The student workers who built the house over the summer were recruited from the students who had built the house in the experimental integrated delivery courses during the school year. By using these students, the University had the most qualified and experienced students not only building the house, but also assembling it on the Mall in Washington, DC, during the Solar Decathlon competition in October 2009.

The impact of the Solar Decathlon project at the University continues after completion of the contests. The house will be used as a case study for analysis of lessons learned, as a teaching lab and to continuously examine and evaluate the design and concepts with respect to its performance evaluation. In fall 2009 an architecture student already took on the challenge of post-project evaluation of the Solar D house. The student enrolled for a Special Topics class within the Construction Engineering curriculum to start the evaluation process with regards to the project management and best practices, and used the Solar D project as case study. During this class, the student interviewed five participants (students and faculty) of the Solar Decathlon team and conducted a benchmark ranking with regards to a specifically developed questionnaire. Benchmark for positive aspects from various questions had been taken as above 3 points on a five point Likert scale response. This benchmark has been chosen with the assumption that above 3 would be able to receive a better ranking in the competition next time around. The choice of practices was based on the relevant best industry practices as understood by the interviewing student from prior coursework. The various best practices chosen were –

1. Post project review of lessons learned
2. Alignment
3. Change management
4. Project health assessment
5. Constructability
6. Zero injury technique
7. Materials management

Some preliminary evaluative results can be taken from this survey and analysis, although post-project assessment is a continuing process. Therefore, it is important to note that the responses from the initial five surveys and interviews may not necessarily be representative. However, the initial assessment does provide some guidance for the lessons learned phase of the Action Research Model.

With regards to the post-project lessons learned, the interviewer concluded, that a formal meeting of the entire Solar D team where specific lessons learned were discussed would have been extremely useful for the team members. A partial discussion of 'lessons learned' in a variety of follow up meetings is not sufficient. Most room for improvement in such a multidisciplinary project was detected in the Alignment section as there were certain aspects which are observed clearly as lack of skills and experience to handle critical situations. Leadership and planning processes developed during the short time frame were not able to communicate the necessary clarity among the various team participants. This result stresses the importance to develop a specific interdisciplinary set of skills for these kinds of team efforts. The interviewer concluded that the construction process nevertheless was successful. The reasons for this include 1) constructability was taken into consideration right from the planning and design stages of the project, 2) design elements were standardized and 3) design facilitated accessibility of materials and also facilitated construction in adverse weather conditions. This result can be taken as a signifier that the experimental construction class contributed widely to the success of the overall concept. Overall the competition result is also a proof, that the interdisciplinary approach to the project contributed to the success as the team scored well in the communication related interdisciplinary contests. The team finished 12th overall out of 20, 3rd in Market Viability, 4th in Communications, 5th in Engineering and 6th in Net Metering. These scores show that in many aspects the group had followed best practice in a considerably effective manner. (Ghandi, 2009).

Specification Stage: Future Challenges and Need for Change

In the specification stage of the Action Research Model, general findings are used to specify what needs to change in order for future actions to be more effective.

Education Changes

In order to develop curricula that allow for integrated, multidisciplinary teams, individual degree programs are going to have to provide flexibility for learning outside traditional specialty areas. The most obvious and perhaps easiest method for accomplishing this required flexibility is to designate a certain number of elective credits be taken from within a pre-approved list of multi-disciplinary courses. This method would follow traditional degree program approaches to general education and technical electives. In order to be effective, however, the multidisciplinary electives would need to be carefully managed to ensure a balance among different majors. For instance, if class size is limited to 40, perhaps no more than 10 students from any one major can enroll. In addition, leaders within each colleges or department are going to have to agree to offer at least one multi-disciplinary elective course. Such university-wide participation may require provostial level coordination or inducements to ensure sufficient, high quality courses are being offered. However, the situation proposed is not markedly different than the current approach to general education in many universities.

Another issue that must be address is to develop a method to incentivize faculty to develop and refine multidisciplinary courses. Current tenure and promotion policies at many colleges and universities do not have mechanisms in place for rewarding and recognizing broad-based, multi-disciplinary contributions. In fact, many tenure eligible faculty are encouraged to develop very highly specialized, narrowly focused fields of research with corresponding graduate-level courses. The external review system used by many colleges and universities as part of the tenure review process also does not lend itself well recognition and evaluation of multi-disciplinary work. However, this issue may not be as intractable as many scholars believe. Tenure and promotion policies can be adapted to include “multidisciplinarity” as an area of expertise. The rise of integrated delivery in the design and construction industry along with a growing recognition among university leaders of the need for broadly multi-disciplinary research and education will likely lead to greater acceptability of scholarship in this area.

Perhaps the most challenging change will be to de-link professional licensure requirements from undergraduate education programs. Currently, much of the content in undergraduate engineering, architecture, and design classes is driven by knowledge and preparation requirements for professional licensure. For many programs after courses needed for licensing board requirements are added to the general education requirements of the college or university, there is little room left for any elective classes. There is movement towards requiring some post-graduate coursework prior to sitting for professional exams (i.e. NCEES “Bachelors Plus 30” proposal), and many architecture programs have already adopted a professional school model (e.g similar to law or dentistry). If some licensure requirements could be moved to graduate coursework, it would free up credit hours in the undergraduate curriculum of many programs to add multi-disciplinary electives.

Industry Changes

The design and construction industry has made great strides in the last two decades towards integrated project teams, and this trend must continue if sustainable design and construction is to become commonplace. Although alternative project delivery systems have become routine, many of the project agreements fail to provide incentives for designers and builders to work together effectively. Even more innovative project contracts can be developed with team performance metrics (in addition to traditional project performance metrics) that reward designers, engineers, builders, vendors, etc. for working together effectively for the good of the project. Sustainability goals beyond LEED standards can also be incorporated into these innovative contracts.

A significant barrier to adopting sustainable practices in design and construction are the arcane procurement laws of many public agencies. Open bid, low cost award procurement based solely on price cannot possibly be structured to reward the innovation, risk-taking, and team-based value-added professional services required to bring about fundamental change in the built environment.

Another issue that needs to be addressed to spur innovation in sustainability is current building codes. This is a particularly problematic issue, as public health and safety is the paramount concern to most permitting agencies. These agencies are quite understandably averse to granting exceptions to standard practices and designs that are well understand and predictable, even though they are inefficient and unsustainable. This issue can be overcome with small-scale experimental projects (like Solar Decathlon) and long-term observation and refinement of new designs. Codes can be changed incrementally as technologies and design innovations become proven.

Summary

Sustainable construction has grown to be a major driving force in new development all around the world. As larger economies continue to develop and integrate sustainable concepts into aspects of their societies other than construction, it will continue to be a major part of all future construction. Even though the definitions of sustainable construction vary from one country to the next, the necessary communication and integration processes for construction firms hoping to work in these countries is very similar, which is something that all project managers need to be aware of when pursuing future business.

Future building designs will be expected to be more energy-efficient and reduce carbon emissions. Knowing that, sustainable construction materials may vary in terms of qualities and/or quantities and will therefore be subject to more change orders, unless the design team has been sharing the broad experience of the integrated delivery approach and is easily able to adapt designs and/or predict problems. This article has attempted to illustrate the great need in today's world for teams of professionals that not only understand what and why they are designing or constructing, but also how to work together as a unified team of multidisciplinary professionals. Such a team needs to have the ability to push itself forward and excel beyond the norm while holding its members accountable for accomplishing the team's goals. In integrated delivery, the focus on teamwork and understanding personalities will favor managers who reflect the social responsibility expected for sustainable projects.

Through the information gathered from the University's Solar Decathlon case study, the positive effects of educating students about the integrated delivery process have been made apparent. The University team began the project knowing how to function only according to the traditional methods of design and construction. The concept of integrated delivery was something that the team may not have encountered, except in a few lecture class periods. Despite being a young team with limited real-world experience in the building industry, the students were able to learn to communicate in order to develop innovative designs according to strict sets of specifications and competition rules. They have also been able to build their teamwork skills in a way that most students never encounter until after they reach industry. The experimental, cross-disciplinary courses in integrated delivery, design, and leadership have been rewarding learning experiences for the University team and have revealed the need for an adjustment to the current curriculum to include greater emphasis on the subject of integrated delivery.

Throughout the fall and spring semesters, the students learned about team leadership, scheduling and coordinating large groups and tasks, procuring materials and equipment, conducting constructability analyses, making emergency field modifications, dealing with personality and leadership issues, and developing peer relationships. These students were fortunate to have engaged in all of these activities as part of their undergraduate experience, and they will be more efficient and productive members of the building industry as a result. This experience will stand these students in good stead as they prepare to confront a service market demanding that buildings not only be sound and cost-effective, but also sustainable.

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