Transforming Building Design through Integrated Project Delivery in Architectural and Engineering Education

José L. PERDOMO¹ and Humberto CAVALLIN²

¹ Associate Professor, Department of Civil Engineering and Surveying, University of Puerto Rico- Mayagüez, PR 00680, PH (787) 265-2815, josel.perdomo@upr.edu
² Associate Professor, School of Architecture, University of Puerto Rico-Río Piedras, humberto.cavallin1@upr.edu

ABSTRACT
Changes experimented in the interaction of the different disciplines involved in building science during the XXth Century have increased the divide between what is taught in the classrooms and what is then later expected by the real world of professional practice. However, recent advances in computer technology and demands that come from contemporary professional scenarios have challenged this divide. This new reality has given birth to the development of an integrated interdisciplinary approach, under the umbrella of Integrated Project Delivery (IPD). Through IPD, the traditional consultant based model has been substituted by an integrated one in which the different professions are required to work together from the beginning of the building project.

The purpose of this paper is to describe an initiative aimed to implement an integrated minor degree to provide the substantial knowledge required to address these new professional scenarios. We have called it “Transforming Building Design through Integrated Project Delivery in Architectural and Engineering Education.” Through this initiative, students from both architecture and civil engineering schools will be jointly face scenarios that mimic real professional challenges. This initiative will provide students the opportunity to develop solutions to real building design projects collaboratively, using BIM and a project-based learning.

INTRODUCTION
It is common knowledge nowadays that there is a clear professional divide between the different disciplines involved in the design of buildings; mainly because the academic preparation of architects and engineers usually takes place in different and separate educational environments. These divisions encompass aspects that go beyond the disciplinary knowledge, affecting the values and roles that stakeholders play in the design, development, and execution of building projects. The theorist of education Donald Schön (Schön (1983), Schön (1987)), pointed out that this divide is due to an ‘epistemology of practice’ that can be traced back to the American scholars that imported this philosophical approach from Germany at the end of the XIXth century. Schön (1987) refers to this perspective as “epistemology of technical rationality”. This epistemology assumed that universities were the place in which ‘pure’ knowledge had to be taught, separating this type of knowledge from the professional practice, and therefore establishing a distinction between theory and practice in the professions. Once the theoretical knowledge is acquired, students were expected to seamlessly apply it to the problems that they would face in practice. This
approach also established that this knowledge was discipline specific and had to be taught separately.

Problems in building sciences and design however, do not present themselves in ways that are efficiently addressed from this epistemology of the technical rationality. As Rittel ((Rittel 1972), Rittel and Webber 1972) pointed out, the nature of design/planning problems work in a different way than any other types of problems, calling them “wicked problems”. According to Rittel, this type of problems are not fully described or stated to the problem solvers, they do not have a definitive formulation, nor a stopping rule, and the nature of their solution depends on the formulation given to the problem by the problem solvers. Rationality does not help much when solving wicked problems, and that is one of the major reasons why pure conceptual knowledge learning does not suffice in order to become a successful problem solver in the non-academic world. According to Rittel, when problem solvers develop a solution to a wicked problem, at every single step a judgment has to be made that is not based only on scientific expertise but also on deontic premises. Additionally, Rittel pointed out that in order to solve a wicked problem no single person has all the knowledge that is needed to reach a successful solution; therefore, all the professionals that hold a partial segment of the knowledge needed to solve it need to communicate and collaborate to reach a solution.

The disregard of the actual professional problems’ requirements in academic education, exacerbated by the exaltation of individuals’ creative work with little or no concern for the role other professionals or even peers play in actual design projects results in distorting the view students have of what building design is in everyday practice. “Students are taught in school to think of themselves as individualists and even encouraged to be iconoclasts. One result of that individualism is that it has accustomed us to think of ourselves as competitors, something more characteristic of a trade than a profession” (Koch, et al., 2003). In those rare cases where collaboration between students is stimulated, it is usually constrained to the data collection that precedes the design phase, in which collaboration with other students is usually seen as something that hampers individuals’ best ideas (Koch, et al., 2003).

**PROBLEMS ADDRESSED BY THIS INITIATIVE**

A report produced by American Institute of Architecture Students (AIAS) on design culture points out (Koch, et al., 2003), the design studio in architecture concentrates the largest attention of the students, and although they are meant to articulate these contents with other areas of knowledge, this aspect of “integration” rarely takes place in the studio’s dynamic. Although, and as Cuff (1992) points out, architecture schools are places in which future architects learn not only to solve design challenges, but also what design challenges are about and what are reasonable resolutions to them, the integration with other disciplines and the facing of “real life” problems rarely take place in the academic environment.

Similar to architecture schools, engineering education faces similar problems when addressing real life situations in the academic environment. Engineering education is strongly focused in quantitative aspects; analysis, application of a scientific approach, modeling, and systems because its main goal is to teach students to analyze a problem and design a solution. These problems are usually academic in
nature – a simplification of reality, and are seldom based in real life projects. Therefore, the students are not exposed to problems similar to the ones with the complexity they will encounter in the practice of engineering. The students learn a procedure to solve the problem and obtain the correct answer (Schön, 1987).

There are five different areas in civil engineering, namely, transportation, geotechnical, structural, environmental and water resources, and construction engineering and management. From these five specialties or concentrations, environmental engineering is considered in many civil engineering departments as a separate academic program because it requires greater knowledge in chemistry and biology, among others. The remaining specialties, except for construction engineering and management (CEM) are focused in design, therefore theoretical concepts are taught and students learn to find solutions to problems posed by the instructor.

Unlike many civil engineering courses, the quantitative aspects of CEM courses do not present a great challenge to students. The challenging aspects of CEM courses are for students to understand how the construction industry works, the interactions among the major players (owner, contractor, and designer), and the management tools available to control aspects related to costs, time, and quality. Therefore, students need to learn to think in a different way, not as designers but more as master builders. CEM courses present a number of new concepts to engineering students; the understanding of these new concepts becomes a real challenge for professors to present and students to grasp.

As the New London Group defines, the primary mission of education as “to ensure that all students benefit from learning in ways that allow them to participate fully in public, community, and economic life” (Jenkins, et al, 2006). There are issues that have to be rethought in both architecture and engineering education if we want students to learn the required skills that will allow them to have a smoother transition into the professional realm, and to also become better practitioners by becoming better team players in the building design and construction.

In order to achieve these major goals, we are convinced that there have to be substantial changes in the way in which we deliver professional knowledge both in architecture and the engineering disciplines. We have to foster an education that will allow students to learn about the nature and benefits of interdisciplinary collaboration in the building sciences. Through this initiative we want to address a series of key issues that we consider are core to the changes we understand are required: 1) the need for students to learn in the environment in which they will face the challenge in a way that echoes the manner in which problematic situations are presented in practice; 2) to work on the creation of common knowledge base, in which the different professions will find commonalities that will enable them to value the need for other disciplines, and the role they play in the collaborative generation of building projects; and, 3) to work on the communication and leadership skills that will empower students, allowing professionals to become better team players, and to properly address the dynamics of the design and building processes.

PREVIOUS WORK

There are several experiences that had addressed the issue of learning to practice and/or from the practice. In the architectural design domain, Mitchell (1974)
pioneered courses in which architectural students learned about collaborative design by using digital tools. The Building Stories course at the University of California, Berkeley, in which architects, students, and young professionals produce case study research about professional practice in San Francisco, is another example in which students are confronted with the practice in an academic environment (Martin, et al., 2007). Both of these academic experiences mainly involve students of architecture. One other program worth mentioning is the “Clinic” at the Department of Engineering of the Harvey Mudd College in California, which has already been successfully run for decades. This Clinic is a set of three-unit required courses for junior and senior engineering majors, and it is the centerpiece of the design and professional practice component of the engineering curriculum. In it, students work in project teams of juniors and seniors, experiencing professional design and development projects for clients from industry, government, and the community (Clinic Handbook, 2006).

In the engineering and construction domain, efforts to integrate participants into collaborative process toward project delivery include the Integrated Project Delivery (IPD) framework. The IPD is recognized as a project delivery strategy that integrates the overall project organization with the objective of providing better processes to enable better design and construction of facilities. This integration aims at the creation of facilities that are designed and constructed more efficiently and have better performance through their life cycle. Based on this statement, team creation is an important aspect for the success of IPD. The needs and requirements for the design and construction of the facility need to be filled by individuals with the adequate competencies and expertise.

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>IPD</th>
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<tbody>
<tr>
<td><strong>Teams</strong></td>
<td>Segmented</td>
<td>Integrated, collaborative</td>
</tr>
<tr>
<td></td>
<td>Linear, distinct, segregated</td>
<td>Concurrent, multi-level, integrated</td>
</tr>
<tr>
<td></td>
<td>Individually managed</td>
<td>Risk</td>
</tr>
<tr>
<td></td>
<td>Individual success, minimum effort for maximum return</td>
<td>Collectively managed</td>
</tr>
<tr>
<td>Paper based, 2D, analog</td>
<td>Individually focused</td>
<td>Reward</td>
</tr>
<tr>
<td>Minimize or transfer risk, don’t share</td>
<td>Technology</td>
<td>Value-based, team success</td>
</tr>
<tr>
<td></td>
<td>Agreements</td>
<td>Open sharing, collaboration, full integration</td>
</tr>
<tr>
<td></td>
<td>Education</td>
<td>Team-based, integrated, collaborative</td>
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According to the American Institute of Architects, California Council, “Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction.” The differences between the traditional and the IPD methods are depicted in Table 1.
Projects in which the IPD system is used are most successful when an early collaboration is executed. By doing so, a review of project scope, requirements, targets and performance could be more complete and accurate. Information and availability of information are key aspects for the success of an IPD system for a project. The project team feels that Building Information Modeling (BIM) is an excellent platform for sharing project information; therefore that is why we are proposing the use of BIM models in our project. Moreover, as pointed by the 3xPT Strategy Group, “Much of the project information that supports the analysis, visualization, communication, and decision-making during the IPD process is best represented and shared in building information models (BIMs). BIM enables virtual design and construction (VDC), which is the most effective tool available today to support an integrated organization of project team members.”

Based on the definition of IPD, the authors understand that for the design and construction of building structures it is very important to include students from the most important disciplines related to building components. For this reason, we are including students from civil engineering, construction engineering and architecture. By including students from these areas, we feel that we are bringing expertise to be involved in the design of the most relevant components of a building. As pointed out by 3xPT, “Overall project performance goals might include project capacity, desired energy performance, the expected seismic performance of the structure and the architectural and MEP systems, first cost and lifecycle cost budgets, egress time goals, and target opening date.” Based on the arguments of 3xPT, the authors feel that it is complying with the common requirements of the industry for successful IPD.

A very relevant precedent for our work is the PBL course, coordinated by Prof. Renate Fruchter at Stanford University. This course integrates undergraduate and graduate students worldwide, and it operates by creating teams of architecture/engineering/construction management (AEC) students that work on a building project using Internet based communication technologies to connect and interact in geographically distributed shared environments. Each AEC team has an owner representative whose responsibility is to set the budget, program, and context limitations as well as approve variances to the project. In addition each team has an existing site and a user program for the building. Other academics and practitioners interested in the initiative act as mentors, each of them representing one of the three professional areas of expertise.

The University of Puerto Rico was very successful in implementing a professional development program using the planning, design and construction of the Urban Train in the metropolitan area of San Juan Puerto Rico. This program involved students from three faculties, namely Engineering, Architecture and Planning and from two universities, UPR and MIT. The students worked together using a real project as the basis of their studies and research. In many ways this visionary project is a good proof of our belief that an education that integrates the disciplines and uses real projects as the laboratory is the best way to educate our future professionals in engineering and architecture (González-Quevedo, et. al, 2000).
TRANSFORMING BUILDING DESIGN THROUGH INTEGRATED PROJECT DELIVERY IN ARCHITECTURAL AND ENGINEERING EDUCATION (TBD-IPD)

Our initiative consists of the development and implementation of transformational pedagogical interventions that will challenge and change the previously mentioned disciplinary split. It will also help blur the distinct differences between academic education and professional practice through the TBD-IPD curriculum. In order to achieve this purpose, we established the following goals: a) To develop an integrative and scalable curriculum that will focus on the articulation among disciplinary domains, and that will build upon the nature and values of today’s students; b) To integrate new instrumentation or equipment and software into undergraduate and graduate classrooms, laboratories and field work to improve students’ learning through real practice simulation, and c) To develop a program to educate existing and future faculty about the methods and techniques developed through this initiative.

In order to implement our initiative, we are establishing a collaborative interfaculty cooperation between two University of Puerto Rico campuses: Rio Piedras and Mayagüez. Each of these campuses offers a different educational component that is relevant to the interaction we are expecting to obtain through this initiative. The Rio Piedras Campus offers the only accredited Master of Architecture program in Puerto Rico as well as a four years’ bachelor degree on Environmental Design that stresses on architectural design. The Mayagüez campus has a Civil Engineering Department is one of the strongest in Puerto Rico regarding research and development. The Department of Civil Engineering has the highest percentage of female students in the nation, with one of the few undergraduate programs in surveying in the United States, and offers a graduate degree with specialty in Construction Engineering and Management. It also offers the only PhD in Civil Engineering in Puerto Rico. The integration of these two programs could lead to a more comprehensive education of our students in the domains of building sciences. The program will launch in the fall semester of the academic year 2014-2015.

In order to reach our academic goals in a long term plan, we have envisioned this endeavor as one that will allow us to create a wider scoped shared curriculum between the two campuses that could eventually become a degree on integrative practice that we have called the Integrated Program in Building Science, which could work as a minor for students of the two campuses (refer to Figure 1).

This program consists of a series of integrated, interdisciplinary courses taught concurrently between the two Campuses at the undergraduate level. In the integrated design course, students faced profession-related problems that require them to collaborate with each other. Each student from the different Campuses/Schools provides the expertise related to their discipline. In order to address the proposed goals, we ground our program on three pedagogical emphases:

Interdisciplinary education

Interdisciplinary knowledge is also a requirement of interdisciplinary education. It means on one hand to have together students of more than one
discipline, but also to develop syllabi and curricula that will extend beyond the disciplinary boundaries.

**Interdisciplinary collaboration**

The design and construction of buildings requires communication and collaboration of people coming from different professional backgrounds, and not always sharing similar goals and/or worldviews [Cuff, 1992, Habraken, J., 2004]. These skills are stated in the Criterion 7 of the Student Performance Criteria of the National Architectural Accrediting Board (NAAB), which reads that in architects’ education it is required for students to develop “collaborative skills ability to recognize the varied talent found in interdisciplinary design project teams in professional practice and work in collaboration with other students as members of a design team”. However, and as it has been mentioned before, students of architecture are rarely exposed to collaborative experiences. Because of the nature of the physical location of the two Campuses, we will be using both face-to-face and remote interactions between the students.

**Project based learning**

Project Based Learning (PBL) is an approach that stresses learning through experiences that echo settings similar to the ones in the real world. This type of setting fosters the type of learning that Schön (1987) proposed in opposition to the tradition of the epistemology of technical rationality.

![Figure 1. Model showing the different phases of the proposed Integrated Program in Building Sciences](image)

To achieve these goals, we have either developed or selected courses within the curricula of the two individual programs that present students with problems and conditions set in terms of PBL teaching methodologies. Some of these courses include Integrated Design Lab, Construction Engineering and Management, Sustainable Construction, Information Systems for Building Modeling, among others. We emphasize on a curriculum that stresses on the importance of problem setting, learning in action, reflecting on the process, and communication between the different stakeholders. We expect that during the implementation of the first phase of
this project we will also turn this experience into a test bed for research on the factors that will either support or hinder the development of this academic initiative. By doing this, we are expecting to assess the results of this program, and therefore help us on implementing timely corrections to the academic model.

**MODULE DESIGN AND SAMPLE**

As has been mentioned before, this study builds on three dimensions: the structure of building design problems modeled as PBL, the use of BIMs, and the implementation of techniques of both collocated and non-collocated collaboration. The development of this initiative on integrated project delivery (CIPD) in Architecture, Engineering, and Construction will provide the academic rigor for conducting the collaborative learning process.

This TBD-IPD initiative focuses on the development of an integrated design project in which students from the three campuses will work collaboratively in order to produce a shared solution to the given design task. This course has been conceived with the integrated paradigm in mind, facing both architecture and engineering students with problems and processes that require them to address them from a multidisciplinary approach, from the conception, to the development, to the production of the documents for the project.

As has been pointed out by the American Institute of Architects, “IPD strategically realigns participants roles, underlying motivations, and sequences of activities on a project to utilize each participant’s best talents and abilities at the most beneficial moment. Success is project-centric under an integrated delivery approach and relies on collaboration. The focus is on collectively achieving shared goals rather than meeting individual expectations. Success is measured by the degree to which common goals are achieved” (A.I.A., 2007). Although it seems logical from every possible point of view, this type of interaction has been unattainable at the professional level, and it is even more critically separated at the academic level, as a consequence of the disciplinary divisions that have been historically created between architecture and the engineering.

As was shown in Figure 2, concurrently with the development of the project, the students will be attending weekly virtual meetings on BIMs training, as well as conferences on specific topics associated to the projects. Different to traditional teamwork in building design, the exercises stress on the benefits of early collaboration and open communication, as means to reach integration. In order to augment the communicational channels, we will rely on the use of BIM software, which will also aid on encouraging the behavior of early collaboration by means of using shared three-dimensional models to support the decision making in the teams. The use of BIMs and shared digital models will be also encouraged by the physical separation between the campuses that will require students to remotely communicate via the internet in order to establish the required collaboration.

**Sample module**

Taking the module for week 11 (Figure 2) as an example of what the contents of a particular week could be, we can see in the following table examples of deliveries
that are expected for this stage, as well as the linked to expected contents and meetings to be covered during this week.

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Expected Deliveries</th>
<th>Linked Contents</th>
<th>Meetings</th>
</tr>
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<tbody>
<tr>
<td>Architecture</td>
<td>• Wall sections showing detailed development of the building regarding materiality and constructability&lt;br&gt;• Design of Structural Elements</td>
<td>• BIM class on annotating and detailing using Autodesk Revit</td>
<td>• Regular weekly virtual meeting with team members&lt;br&gt;• Virtual meeting for the BIM class.</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>• Wind and Earthquake considerations&lt;br&gt;• Cost Estimate&lt;br&gt;• Schedule&lt;br&gt;• Environmental Protection Plan&lt;br&gt;• Sustainable Considerations&lt;br&gt;• Permits and Regulatory Issues</td>
<td>• Mentorship: Students have to plan a meeting with at least one mentor of each of the disciplines</td>
<td></td>
</tr>
<tr>
<td>Construction Management</td>
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</table>

**Architecture**

At this point in the project, the architect is expected to have finished the layout of the functional spaces of the building. The definition of the structural grid has to be finished, as well as the pre-dimensioning of the structural members. Main systems of the building regarding electrical and mechanical requirements have to be also incorporated at this point. Finally, the project has to clearly show attention to UBC, and also take in account both ADA and LEED criteria.

**Civil engineering**

At this stage, the civil engineering students should perform a preliminary design of the building. The structural analysis at this stage should include plan views and sections where the structural elements selected are shown. The group needs to describe the type of structure to be used.

**Construction management**

At the preliminary stage of the project, the construction management students are responsible for preparing a preliminary cost estimate of the project, a preliminary schedule, an environmental protection plan, an explanation of the sustainable considerations for their project (to comply with LEED certification).

**FUTURE DEVELOPMENT**

As we had already made the case, the current scenario in which we play is conducive to the development of a thorough review of the professional divisions of the past, thereby allowing us to take a fresh look professional and academic settings,
also fit more appropriately to the nature complex real-world problems, as well as the dynamics of social and technological development our contemporary world demands.

For all these reasons, we expect that our work will contribute to increase interaction among students of the areas of architecture and engineering, by encouraging the joint exploration of knowledge and research in practice integrated design and construction of buildings, as we expect will take place in the future scenarios for the practice professional.

REFERENCES


