

Interdisciplinary Education in an Integrated Project Delivery Studio: Designing and Building Prefabricated Components

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Many undergraduate architecture, engineering and construction management programs are exploring interdisciplinary education strategies. The collaboration of the various disciplines to solve problems has become prevalent in professional practice. So why not collaborate in the classroom? The integrated project delivery methodology and other collaborative strategies can be and have been engaged in the classroom, but it is difficult to infuse the motivations of professionals practicing in the field into students learning in the classroom. Prefabrication, also called panelization, offsite fabrication, or modular construction, allows various building elements – anything from bathrooms to pre-wired light fixtures to exterior walls – to be built in a factory and transported to a construction site. Prefabrication can only occur in a culture of collaboration. Thus, a strategy of designing and building prefabricated components can be engaged in the classroom learning environment as a focal point effecting the collaboration of the various disciplines to solve problems in the classroom.

Key Words: interdisciplinary education, prefabrication, integrated project delivery, integrated learning objectives, collaborative strategies.

Introduction

The construction industry of our past will not be the construction industry of our students' future. While none of us can predict its future with certainty, we can already see where it is headed. Construction is moving indoors. This nascent movement is occurring in all sectors. It is driven by an explosion of innovative new materials; increasingly complex assemblies, systems, methods and technologies; demand for greater construction efficiency; severe shortages of skilled construction labor; the drive toward sustainability; and widespread adoption of lean construction techniques.

Literature Review

Textbooks focused upon integrated project delivery are not in abundance. However, there are some very good recent textbooks that are focused upon the topic of prefabrication. In *Prefab Architecture*, prefabrication is seen as inseparable from collaboration (Smith, 2010, p.44). The nexus between prefabrication and collaboration positions this textbook as a useful classroom resource on integrated project delivery. *Prefabricated System* is highly informative on systems and assemblies (Knaack, Chung-Klatte & Hasselbach, 2012, p.47). This is valuable information for construction management students in particular, who may receive little exposure to the conceptual and schematic design phases. *Refabricating Architecture* suggests new ways of thinking about the role of prefabrication in the designing and building of our built environment (Kiernan & Timberlake, 2004).

Prefabrication

Environment

Prefabrication, also called panelization, offsite fabrication, or modular construction, allows various building elements – anything from bathrooms to pre-wired light fixtures to exterior walls – to be built in a factory and transported to a construction site (Bunch, 2017). Prefabrication is a construction process, not a specific type of building (Bunch, 2017). It is increasingly being employed on every type of building.

Other countries use of prefabrication in construction is very high. In Japan as well as in Sweden, prefabricated housing currently accounts for 90% of all housing (Knaack, Chung-Klatte & Hasselbach, 2012, p.47). In Japan, Toyota Home began full-scale production of factory-built homes in 2004 (Smith, 2010, p.140). These homes are based on what they call a "skeleton and infill" approach that some describe as mass customization (Smith, 2010, p.140). In Sweden, the BoKlok House employs the principle of IKEA's flat-pack, do-it-yourself kit of parts, to appeal to a younger generation of homeowners (Knaack, Chung-Klatte & Hasselbach, 2012, p.47). According to *Automated Builder,* a magazine that monitors the construction industry's use of prefabrication in housing, 56% of all residential construction in the United States is now manufactured, modular, and panelized (Smith, 2010, p.62).

The non-residential sectors of the construction industry in the United States have quietly and without fanfare undergone a process revolution. The owner who builds a one-off project has become a rarity. Today's owners are serial builders, organization with continuous building programs, such as Kaiser Permanente, Marriott International, Sutter Health, Walt Disney Imagineering, Target, the Hines Group, Starbucks, and the Massachusetts Institute of Technology (Thomsen, C. and Sanders, S., 2011). Serial builders employ prefabrication. Prefabrication, in all of its forms, is a scalable production model that delivers bespoke projects with an economy that arises from repetition and refinement on the factory floor and the rotation of people, processes and products into an owner's continuous building program.

More than 85% of construction industry participants have used prefabrication processes on their projects, according to McGraw-Hill Construction (2011). Of respondents to their 2011 survey, 63% reported using prefabrication strategies for more than five years (McGraw-Hill Construction, 2011). At the time of their research, Forbes had forecasted that 98% of all industry participants would be using prefabrication by the current time (McGraw-Hill Construction, 2011). Validating their forecast, Forbes magazine reported this year that the last real estate cycle has pushed prefabricated construction into prominence today (Bunch, 2017). Standing in evidence of this reality, Marriott International has announced plans to modularly construct 13% of its North American developments in 2017 (Bunch, 2017).

Structure

Prefabrication can only occur in a culture of collaboration (Smith, 2010, p.44). At California Polytechnic State University at San Luis Obispo (Cal Poly) we have recognized this reality and have responded to it by embedding both prefabricated systems and collaborative behavior into the IPD Studio. The IPD Studio is a partnership between architecture, engineering, and construction management faculty. This partnership employs Integrated Project Delivery (IPD) as its teaching strategy. IPD is an emerging project delivery methodology that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants. The distinguishing feature of this new methodology is interdisciplinary thinking: a means of solving problems and answering questions that cannot be satisfactorily solved or answered by a single discipline.

Integrated Project Delivery

The built environment is recognizable by its indelible imprints: the large built artifacts of our world. Each built artifact emerges from the collective work of many contributors: owners, equity partners and debt holders; insurers and sureties; engineers, architects and sub-consultants; construction managers, constructors, specialty contractors and subcontractors; permitting, regulatory and entitlement agencies; and the increasingly important fabricators, manufacturers and suppliers. To bring it into being, an ad hoc business organization gets formed for the purpose of bringing the many contributors into coherence. Such ad hoc organizations are known as project delivery methodologies. The taxonomy of project delivery methodologies in current use include traditional design-bid-build, multi-prime contracting, construction management at risk, bridging, and design-build.

The materials, assemblies, systems, methods, and technologies that enable large, built artifacts are becoming increasingly more sophisticated. Moreover, the underlying intellectual property arises from the research and development, trade secrets and know-how of manufacturers. The harvest of this proprietary bounty is profitably licensed to specialty contractors, subcontractors, fabricators and suppliers. This nascent reality is reversing traditional knowledge flows. Knowledge that used to flow downward by prescriptive specification from the

architect/engineer to the general contractor, subcontractor and supplier, now flows upward by performance specification from manufacturer, subcontractor, and general contractor, to the architect/engineer. New project delivery methodologies have emerged to better manage this nascent reality of reversed information flow.

Integrated Project Delivery [IPD] is an emerging project delivery methodology that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all contributors. The distinguishing feature of this new methodology is interdisciplinary thinking: a means of solving problems and answering questions that cannot be satisfactorily solved or answered by a single contributor. This requires contributors to step out of the comfort zone of their own discipline.

In its purest form, IPD is distinguished by an integrated form of agreement. The integrated form of agreement is a tri-party agreement between owner, architect/engineer and contractor, typically featuring a mutual waiver of liability. In practice, few companies are willing to sign on to the expanded liability exposure of a mutual waiver, preferring instead the traditional allocation of liabilities between owner, architect/engineer and contractor. Although a tri-party agreement can be drawn with traditional liability allocations – projects have been successfully delivered in this manner – the industry has been somewhat allergic to doing so. Notwithstanding that the integrated form of agreement has gained little traction, the collaborative methods embedded in the integrated form of agreement have increased in popularity. Collaborative methods have begun to be superimposed onto design-build, bridging, construction management at risk, and even traditional design-bid-build. This results in hybrid forms of these project delivery methodologies. We also find new expressions emerging for these hybrids, such as "Partial-IPD," "IPD Light," and "IPD-ish." The common feature of all such hybrid project delivery methodologies is the collaborative harnessing of the talents and insights of all contributors.

IPD requires well-informed, well-intentioned, and well-educated people who are willing to interpret their common interests. IPD, properly understood, is not so much about methodology as it is a way of life. Successful contributors must acquire collaborative skills; develop proficiency with resilient and sustainable practices; and learn new forms of leadership.

Integrated Project Delivery Studio

Pedagogic Strategy

At Cal Poly, our motto is *Discere Faciendo* or *Learn by Doing*. Cal Poly stands proud of its approach to education: it has the efficacy to shape student into future professionals. Through the process of doing, Cal Poly's College of Architecture and Environmental Design (CAED) aims to evaluate the process of building design and construction by addressing larger issues within the building industry. The CAED is also expanding its experience with sustainability by enveloping issues of design and construction relating to resiliency. Where sustainability has been aspirational; resiliency is emerging as a new focus, especially with an increase in natural disasters associated with climate change. Resiliency demands a systemic approach to design. This invites a host of potentialities: examining the materials we choose for construction; evolving building methodologies in the face of this problem; unprecedented levels of investment; cooperation in examining how we change our practices for moving past disasters; and changing variables and adaption needed to survive events that have systemic consequences.

The IPD Studio at Cal Poly provides a unique, interdisciplinary experience for upper division undergraduate students in architecture, structural engineering and construction management. Interdisciplinary classes require compatible instructors who value collaboration (Smith, J.C., 2009). The IPD Studio instructors thus share the common thread of collaborative know-how, founded upon extensive industry experience. IPD is employed as a pedagogical strategy in their IPD Studio; thereby serving as a professional model for project-based teamwork in the trading of interests and examining systems thinking from project design through completion. The faculty of the IPD Studio partnership all share the common thread of collaborative know-how, founded upon extensive industry experience.

IPD Studio Format

The IPD studio is taught in several modes including short lectures, team coaching, self-guided in-studio workdays,

instructor-team or instructor-student desk critiques, analytical exercises, and case studies. Group work is spent meeting in small and large group settings, depending on the content delivered. Students receive instruction in professional practices including integrated project delivery processes, teaming and leadership skills, practices pursuant to effective team performance, and discipline-specific instruction related to the programmatic solution. Guest lecturers are engaged to provide topical information within their areas of specialization. Students present their work throughout the term, typically to a panel of external clients. Students also participate in a series of enrichment activities that include readings, research, site visits, field trips, and micro-workshops/tutorials, that delve into course topics in greater depth. Some topics are interdisciplinary. Others are discipline specific.

The studio meets in common sessions, three times a week, over a quarter term. Meetings are in a large laboratory space, featuring a common area suitable for lectures and presentations, and separate team work areas. The laboratory is open 24/7 for the duration of the term.

A prototype project was chosen for the 2017 fall quarter. Great Northern Services (GNS) of Weed, California had asked Cal Poly to assist in the design and construction of housing for a subdivision destroyed by the Boles Wildfire in September of 2014. We tasked each of the student teams to discover what the clients valued, to express that as a "value proposition" and then to distill their value proposition into a set of goals and objectives. Each team devised a unique value proposition and associated goals and objectives. Value discovery began on a field trip to the client's offices and the site of the disaster. It continued through periodic client videoconferences and emails. Teams were challenged to justify their design choices throughout, by measuring them against their value proposition. This process had mixed results.

Endeavoring to maximize delivery of value to its client, the IPD studio was structured as a competition between interdisciplinary teams of students to design single-family and duplex housing for a new subdivision. Its curricula emphasize resiliency, passive energy design, prefabrication, constructability and best value design. At completion of the course, GNS will proceed with construction of the design (or designs) of one or more teams. Their choice will be made by determining which design (or designs) yields the greatest value. During the winter quarter, Architecture will evolve documents for the purpose of permitting while collaborating with CM to produce shop drawings for fabrication. The prefabricated components will be fabricated by the CM students in the spring quarter and will then be shipped to site. The first new home is expected to be erected on site by the end of summer 2018 by a local contractor working together with students from the College of the Siskyous (COS), a local community college in Weed, CA.

There is a conflation of interests between the IPD Studio and a prototype project because the curricula that was designed around the prototype can be structured into a repeatable course structure. There are many resiliency-based projects in planning by non-profit agencies throughout the State of California. We are depending on a stream of such projects to provide the working content for future implementations of the IPD Studio.

Team Formation

It is well established that self-selected teams are not as effective as teams that are selected by instructors (Porter et al, 1994) (Michaelson, 2002). Students were organized into teams of four or five students: each team composed of two architecture students; one or two structural engineering students; and one construction management student. Team rosters are permanent for the quarter. The teams were formed in one stage, the faculty making all of the selections outside of class, based upon a self-assessment where the students informed the faculty of their basic qualifications and comfort level in risk-taking. All teams were heterogeneous by discipline.

Research also suggests that teams become higher functioning when they are heterogeneous by discipline but homogenous by interest (Porter et al, 1994). The architecture, structural engineering and construction management students were not at first homogenous by interest. Students in architecture and structural engineering chose the IPD Studio voluntarily. Students in construction management were required to take the course. Heterogeneous/heterogeneous groups are still more highly functioning than groups selected at random (Porter et al, 1994). To make teams homogenous by interest, students who must take the class should be placed on different teams than those who take the class as an elective (Porter et al, 1994). Doing so was not possible. The faculty chose to make all teams naturally homogenous by interest. To accomplish that end, a subset of eight construction

management students were solicited to volunteer for the IPD Studio. Fifteen remaining construction management students took another, non-interdisciplinary, required course. By doing so all teams were made homogeneous by interest; thus, all teams were set up as higher functioning because they were heterogeneous by discipline but homogenous by interest.

Learning Outcomes

In order to prepare their students to enter their specific discipline, discipline-specific learning outcomes are chosen by architecture, engineering and construction management programs. That our educational programs tend to yield students who function best within their own functional silos is an acknowledgement of this reality. Many industry stakeholders and professional associations are calling for functional silos to be dismantled and replaced with more holistic approaches that integrate the courses and curriculum of different disciplines.

The Cal Poly IPD Studio explores the applied ontology for the driving forces behind the relationships formed in the interdisciplinary domain. Its pedagogical strategy is executed within a set of interdisciplinary courses that explores relationships and assesses the integrated learning outcomes therefrom.

The overarching goal of this course is to mimic a professional project scenario while exposing students to collaboration, developing leadership skills, and gaining insight into the work of other disciplines. Students are expected to be familiar with the work of each of their other team members so that their presentations are integrated and unified. This course also has discipline-specific course learning objectives.

At the conclusion of this course, students should be able to: 1) Demonstrate effective teaming; 2) Employ interdisciplinary decision-making; 3) Create and apply value propositions; 4) Deliver an integrated presentation; 5) Define project-specific goals; 6) Outline the appropriate objectives for quantifying goals and ensuring achievement; and 7) Develop communication strategies for interdisciplinary and project-centered work

Learning outcome assessments is embedded into the IPD Studio. By repeating the course, we avail ourselves of repetition and refinement to continually improve its learning outcomes. In addition, new developments and best practices from industry can be rolled into the course content, thereby maintaining the relevance of that content.

Assessment

Timely performance feedback is essential for the development of high student motivation and effective group functioning (Birmingham & McCord, 2002). Informal desk critiques provide invaluable and timely performance feedback to the teams. Desk critiques are provided by an instructor as any discipline-specific question arises or by the instructors as a group whenever a collective response is more appropriate. These desk critiques are most effective when all team members are present. Feedback is also provided in the usual way; through posting of grades.

Class work specific to each student's discipline constitutes 60% of students' grades. Interdisciplinary teamwork constitutes 40% of students' grades. This interdisciplinary teamwork component is the sum of grades for the course learning objectives. These are measured at four points during the quarter.

Highly effective learning groups are facilitated by performance assessment systems that include measures of and rewards for both individual team member contributions to the group and group performance (Birmingham & McCord, 2002). Peer evaluation is an effective teaching tool, appropriate for team projects (Bray & Manry, 2010). At four points during each term, students are surveyed to solicit their evaluation of the performance of the other members of their team. Survey results flow to the instructors who use those results to inform their assessment of grades. Peer evaluations have the potential to cause as much as a full letter grade adjustment to an individual student's grade.

The peer review is accomplished by an online survey administered by the Comprehensive Assessment of Team Member Effectiveness (CATME). For each question posed in the survey, students rate each one of their teammates on a 5-point scale. After all students have completed their surveys, two values are calculated: 1) an effective teaming grade; and 2) an individual adjustment factor.

Individual adjustment factors have an average value of 1.0. High performing students – judged by their teammates – earn an adjustment factor greater than 1.0. Low performing students – judged by their teammates – earn an adjustment factor less than 1.0. Typical adjustment factors are in the range of 0.85 to 1.15.

A student's interdisciplinary teamwork grade is calculated by multiplying the score earned by his or her team for each of the course learning objectives by that student's individual adjustment factor. The first peer review is informational. It does not modify students' interdisciplinary grades. Subsequent peer reviews are operational, modifying students' interdisciplinary grade.

It is important to comprehend collaboration as an organic process. This necessitates that teams examine the strengths and weaknesses of their team's performance and respond in ways that change and evolve the process. It is hard to think about how strengths can change but students should be able to examine the value in the strengths and apply them to the weaknesses - not only in processes but in individual performance. With this, it is imperative that during the process, the students are involved in the feedback loop of the course - as is necessary and in the spirit of the IPD process.

Concurrent with their coursework, students compile an IPD Report in which they chronicle their team's successes and failures. This report is construed as a living document, continually being updated over the course of the term; recording the tools and methodologies employed by the student teams in assessing their collaborative strategies. It is also a guide for further instruction. For gaining insight into the strengths and weaknesses of each team, the instructors can better direct the future course experience.

Collaborative tools can be introduced and tested within the studio. Some of these tools may be new to industry. The IPD Report can serve as a channel for introducing new tools and methodologies. Typically, preparing the report requires students to research tools methodologies that are currently being used by industry. These tools and methodologies serve as guides for testing and modifying newly introduced tools and methodologies. Through these means, students gain insight into the experiences of others who are engaging the IPD process.

Summary

Prefabrication is increasingly being employed on every type of building. Prefabrication can only occur in a culture of collaboration. This nexus between prefabrication and collaboration can empower interdisciplinary learning outcomes in a university studio for design and construction.

The IPD Studio at Cal Poly is an undergraduate interdisciplinary experience notable for the collaboration of students and faculty in architecture, structural engineering, and construction management. IPD is employed as its pedagogical strategy. This serves as a professional model for project-based teamwork in the trading of interests and examining systems thinking from project design through completion. Its current curricula is structured as a competition between interdisciplinary teams of students to design single-family and duplex housing for a new subdivision being built by a non-profit in the wake of a fire that destroyed their community. Resiliency, passive energy design, prefabrication, constructability and best value design are emphasized.

The pedagogical strategy of the IPD Studio explores relationships and assesses the integrated learning outcomes therefrom. Its overarching goal is to mimic a professional project scenario while exposing students to collaboration, developing leadership skills, and gaining insight into the work of other disciplines. The course also has both integrated and discipline-specific course learning objectives.

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