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# Experiential and project-based learning in BIM for sustainable living with tiny solar houses

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**Abstract**

The tiny house movement represents a unique building initiative that aims to reduce the environmental and financial impacts of modern living. This paper introduces the integration of a tiny house competition project into an undergraduate construction management curriculum, and investigates the role of building information modeling (BIM) in facilitating sustainable living design and construction as well as student learning using an experiential and project-based pedagogy. As BIM is prevailing across the global design and construction industry, higher education has been striving on developing effective pedagogy to cultivate students' competency in BIM. Most recently, the emphasis of BIM education has been transforming from software training to problem-solving in the context of project execution and management. Therefore, experiential and project-based learning seems to be a promising option for BIM education. This paper highlights the synergistic BIM usage in the tiny solar house project with broad student participation and comprehensive inclusion of both lower and upper division undergraduate construction management courses. The tiny solar house project provides the desired pedagogical construct that fosters active student learning engagement in attaining BIM knowledge and developing problem-solving skills with BIM at multiple phases that span from the inception of design, to construction and eventually the occupancy and operation.


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*Keywords:* Building information modeling; Experiential and project-based learning; Tiny solar house; Student learning outcome

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## 1. Introduction

According to the United States Census Bureau, the average size of new single-family houses completed in 2014 was 2,657 square feet [1]. A tiny house, which is a home of 400 square feet or less [2], may significantly reduce the ecological footprint and alleviate financial burdens of housing [3]. Exploring the social, economic and environmental dimensions of tiny houses has stimulated interests among professional and educational communities as well as regional municipalities. In fall 2014, the Sacramento Municipal Utility District (SMUD) launched a competition to challenge collegiate teams to design and build net-zero, tiny solar houses with allowable sizes between 100 and 400 square feet and a maximum budget of $25,000. The competition is modeled after the U.S. Department of Energy's Solar Decathlon. Spearheaded by SMUD's Energy & Technology Center and Community Solar program, the event is anticipated to be held in the fall of 2016, which leaves the participating institutions two years of preparation. Each competition team consists of 10 to 24 students with an educator or other school administrator as their mentor. This paper documents the strategy and process adopted at Fresno State, and investigates the synergistic role that building information modeling (BIM) has been playing in facilitating sustainable living with tiny solar houses meanwhile fostering the development of essential skill sets of students through experiential and project-based learning.

## 2. Background

### *2.1. Tiny house and sustainable living*

Since 1950, average residential living trends in the United States have been towards bigger homes with fewer occupants with living spaces per person increased 250% and home size increased 164% [1, 4]. Larger houses consume more resources – both in construction and during operation, and the biggest environmental benefits of a smaller home come from reduced electricity and fuel use, but also from avoiding additional material production [5, 6]. The idea of tiny homes is nothing new, having been utilized in the form of bungalows and other smaller architectural styles, as advocated in "The Natural House" by Frank Lloyd Wright in the 1950s [7]. Modern tiny house movement began largely in the late 1980s and began booming during the early part of the 21st century, especially following the housing market crash in 2007 and 2008 when many homeowners lost their homes to foreclosure as a result of inability to pay enormous mortgages. Such loss inspired a number of people to reconsider their housing situation and explore the ideas of minimalism and the general rising trend in environmental awareness that serve as the basis for the tiny house movement [8, 9]. There are a number of benefits to living a minimized lifestyle and downsizing one's home to meet the standards to the tiny house movement. One of the largest benefits of inhabiting a tiny house is the decrease in carbon footprint [8, 10]. State of the art in tiny house design has set even more ambitious goals to pursue net zero energy status by integrating solar power generation [11], which is truly pushing the boundaries of sustainable living.

### *2.2. Tiny house, BIM, and undergraduate construction management education*

Fresno State has a legacy of service learning-oriented tiny house experience, as exemplified in the "Eco-Village" project of tiny homes for homeless people, with participation from undergraduate construction management (CM) students led by the renowned architect Arthur Dyson [12]. The multidimensionality of tiny houses that encompasses a range of socio-economic and design/construction issues has engendered strong interests in college education across the architecture, engineering and construction disciplines. The fact that students have the opportunity to program, finance, design, build and occupy a tiny house provides unprecedented opportunities for experiential and project-based learning experience. Moreover, interfacing with local industry and communities in the process of a tiny house project exposes students to the societal and business contexts of their disciplinary study, and lays a solid foundation to their future professional practices. Apparently, CM graduates today must have strong communication and teamwork skills; they must have the ability to work efficiently within co-located teams; and finally, they must know how to apply fundamental engineering, management, and computer skills in practice [13]. With careful pedagogical design, a tiny house project may offer the desired affordance to foster the accomplishment of essential student learning outcomes in both technical and nontechnical areas.

Faculty in the CM department at Fresno State envision the SMUD tiny house competition as a possible facilitator to the undergoing curriculum redesign that aimed to improve student learning engagement and core learning outcomes including BIM, sustainability, communication, critical thinking, interdisciplinary teamwork, leadership and entrepreneurship. As one of the most important industry trends, BIM in college curricula has gradually grown into a common practice [14-16]. BIM is also found synergistic with green building, and can help achieve sustainability and improved building performance with a systematic and whole lifecycle-based approach [17, 18]. In college BIM education, priorities were originally given to technological aspects while recently shifted to emphasize more on the implementation process and the value propositions of BIM [19]. There are ongoing efforts in strategically planning for BIM education and pedagogic approaches with clearly identified student learning outcomes that match desired workforce competencies in the design and construction industry [16, 20].

### *2.3. Experiential and project-based learning*

Traditional lecture-based pedagogy models that treat students as passive recipients with linear and fragmented teaching presentations have been criticized for depriving students of the opportunities for learning the holistic nature of the discipline [21]. In a tiny house project, pedagogy design should reflect both individualized and team-based learning needs. Experiential, project-based learning thus seems to be a promising option. Experiential learning (EL) has long been a part of engineering education in the form of special projects, instruction in design and cooperative programs but most recently with greater variety and degree of innovation [22]. EL focuses on the learning process of the individual and concerns the development of student’s abilities, such as memory, creativity, and sensitivity to achieve knowledge. A cyclic and multidimensional model, which includes *Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC) and Active Experimentation (AE)*, was proposed and developed by [23] to delineate the EL pedagogy development process.

Project-based learning (PBL) is also a proven interdisciplinary pedagogical approach that is student-centered and focuses on real-world issues [21, 24]. PBL encourages learning in both individual and collaborative settings where students will build knowledge [25], develop critical thinking, creativity [26], and a number of essential soft skills including leadership and communication [27]. PBL is widely used in engineering and construction management education [28]. The combination of experiential and project-based learning will build the ideal scaffold to student learning in BIM for sustainable living with the tiny solar house project. A series of studio and field activities can be designed to sustain focus on student-directed exploration, self-reflection, and engaging in group efforts that lead to clearly defined learning objectives and project outcomes of significance.

## 3. Methodology and Research Objectives

Using the SMUD tiny solar house competition as a facilitator, this research investigates the strategies to incorporate BIM and sustainability education across an undergraduate CM program, and evaluates the impacts of experiential and project-based learning on core student learning outcomes. A comprehensive curriculum and pedagogy redesign, accompanied with field trips, student workshops as well as a reflection survey were conducted to facilitate the learning experience and garner student learning data so lessons could be learned to guide next-step actions and future improvement efforts.

### *3.1. Curriculum and pedagogy redesign*

Given the time frame of the competition, which lasts for two years from fall 2014 to fall 2016, a cyclic and rolling strategy was taken to break down the design and construction phases of the project and allocated critical design and construction tasks concurrently into several mandatory CM lower- and upper-division courses (Table 1). As an entry level course, CM4: Construction Graphics replaced the traditional CAD-based graphics class and laid the foundation to essential knowledge and modeling skills for incorporating BIM in ensuing CM courses in the curriculum. Both

CM20 and CM180AS address the design efforts of the project while the former course emphasizes the design concepts and documentation, the latter one focuses on the pre-construction aspects, performance modeling and evaluation as well as project execution planning. CM180B is for the actual construction operation and management. According to the CM curriculum roadmap, students will most likely take these courses sequentially to ensure smooth progression in attaining knowledge and developing problem-solving skills with BIM. Instructors of these courses are well qualified for college BIM education, two of whom are credentialed with the AGC Certificate of Management in BIM.

Students are expected to build the first prototype by the end of fall semester in 2015, and continue on performance-testing and improving the tiny solar house per judging criteria (which breaks into four major categories including *architecture*, *energy*, *house life* and *communications*) till the final competition exhibit in fall 2016. The goal is to maximize learning experience to students at different academic levels. Student leaders in CM and other engineering, business, marketing and mass communication majors were identified earlier at sophomore, junior and senior levels to form a truly collaborative and multidisciplinary project team.

Table 1. Curriculum integration of BIM in the tiny solar house project.

| | Course Info | BIM Learning Activities | Expected Learning Outcomes |
|---|---|---|---|
| Lower Division | CM4: Construction Graphics | Print reading, exposure to BIM concepts; fundamental drafting and modeling with major BIM software applications | Able to: read and interpret construction plans; create building information models per plans |
| | CM20: Contracts & Specifications | Tiny House feasibility analysis; architectural and structural design; construction documentation and specification | Able to: conceptualize, author and evaluate design models; create conceptual cost estimates; create construction documentation & specifications |
| Upper Division | CM180AS: Capstone 1 | Tiny House design review and detailing; building system evaluation, performance modeling; cost analysis; project scheduling | Able to: create and check construction models; conduct performance modeling and 4D simulation; create cost models |
| | CM180B: Capstone 2 | Tiny House construction; project controls and management | Able to: utilize BIM to procure, install and manage the Tiny House project; track budget and schedule |

### 3.2. Project planning and learning process design

The overall project process and expected key events are illustrated in Fig. 1. At each phase, participating students will be dedicated to critical tasks to produce deliverables that will accrue to become the final competition submittals. Cross-course and -disciplinary collaboration to make project stay on critical path will be the key to success.

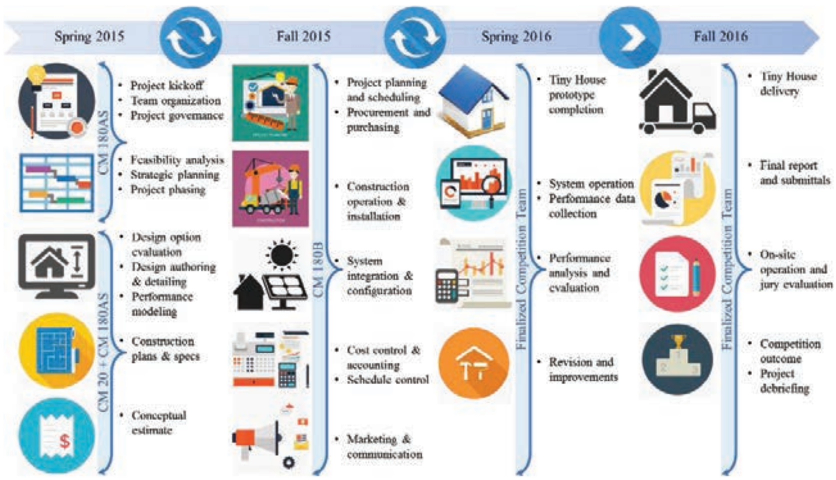

Fig. 1. Project roadmap and experiential, project-based learning process.

## 4. Results and findings

### *4.1. The experiential and project-based learning process*

In spring 2015, the tiny solar house project kicked off with concurrent participation of students from CM20 and CM180AS. While CM180AS took the lead in team building, feasibility analysis and strategic planning, both courses performed design authoring and evaluation, and performance analysis. A grand task for CM20 students was to produce the construction plans and specifications that could be passed along to CM180B students for construction in the fall. The experiential, project-based learning started with a site visit to a local tiny house builder. Students were introduced to the history and philosophy of tiny house, its design criteria and construction process, and system/material selection and performance guidelines. This direct and comprehensive exposure to tiny houses grabbed students' attention immediately and quickly turned into the basis for their own design (Fig. 2).

Fig. 2. Site visit to the California Tiny House.

During the feasibility analysis and strategic planning, such understanding was reinforced, which led into the design authoring and evaluation process. Students were required to propose at least three design options, and compare the pros and cons of each design against the competition judging criteria at a very generic level. Interviews with local contractors and visits to material and equipment vendors were strongly recommended to students so they could make decisions based upon real world scenarios. BIM provided students with insights and flexibility to visualize such variances among these design options and helped determine the optimal design (Fig. 3).

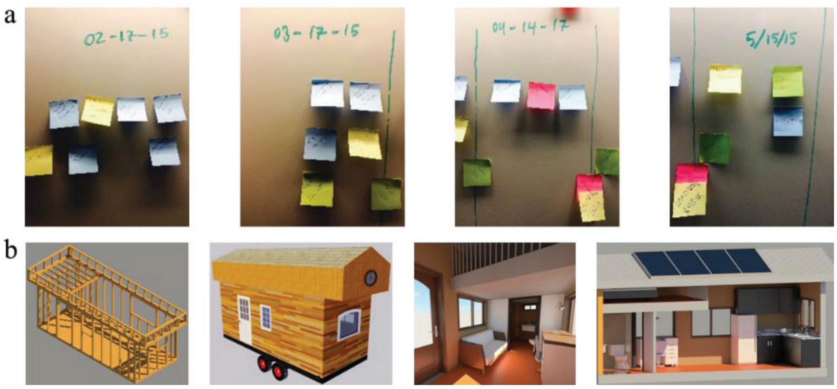


Fig. 3. Students conduct (a) feasibility analysis, programming and (b) design of the tiny solar house.

From design to construction, which signals the transition from conceptualization to experimentation, is a critical step in experiential, project-based learning process. Again, BIM provided students with valuable affordance to plan and control the project outcomes with powerful 3D representation, 4D simulation and 5D cost estimating capacities. Such affordance could sustain through the construction process when students referred to BIM through mobile devices for field installation, performance verification, cost and schedule tracking, to name a few (Fig. 4).

Fig. 4. Students build the tiny solar house with installation details from BIM via tablets.

*4.2. Student reflection on learning outcomes*

To gauge the BIM for sustainable living with the tiny solar house learning experience, a survey was administered to students from CM20, CM180AS and CM180B at the end of fall semester, 2015. A total of 39 students were reached with 21 responses (response rates at 53.8%). It was worthwhile mentioning that 90% of the students were minorities and for 57% of them English was not the first language. The surveyed focused on BIM usages in facilitating the tiny solar house design and construction process, as well as impacts of the experiential and project-based pedagogy on core SLOs. According to Fig. 5, top BIM usages in the design phase include design authoring (schematic 85%, detail 80% and conceptual 60%), feasibility analysis (60%), visualization and presentation (60%). Top BIM usages in construction phase include plan & specs view for scope of work (70%), measurements and framing details (65%), and construction site layout plan (50%).

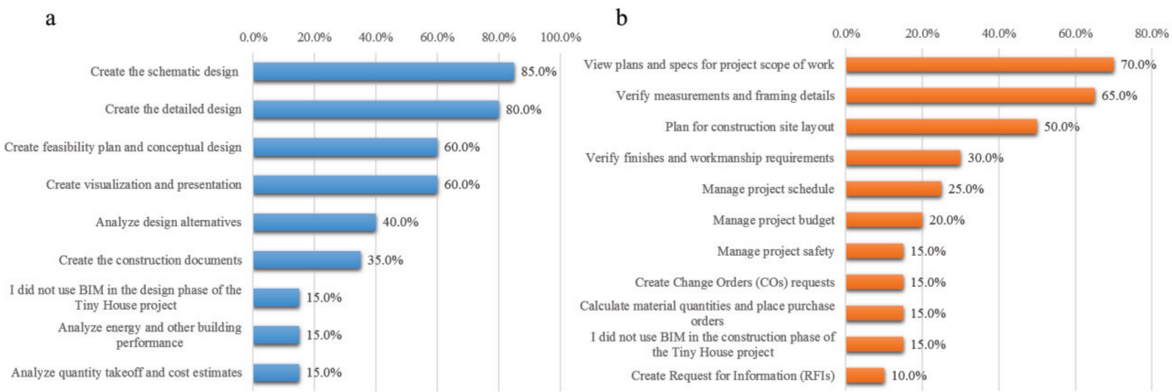


Fig. 5. Reported BIM usage in (a) design phase; (b) construction phase of the tiny solar house project.

In regard to SLOs, Fig. 6 summarizes students' perceptions towards the impacts of the experiential project-based learning on achieving core SLOs through participation in the tiny solar house project using a 5-point Likert scale, where 1 stands for "strongly disagree", 2 for "disagree", 3 for "neither agree nor disagree", 4 for "agree" and 5 for "strongly agree". The results indicate that students tended to agree on enhanced SLOs in BIM in various learning domains defined by Bloom's taxonomy. For instance, "BIM fundamentals" represent learning outcomes at the *remembering* and *understanding* level (Fig. 6a), "BIM for design communication" and "BIM for problem-solving" on the other hand represent learning outcomes at the *applying*, *analyzing*, *evaluating and creating* level (Fig. 6b-c). It is also intriguing that students identified *leadership*, *entrepreneurship* and *learning engagement* in as most accomplished learning outcomes through the tiny solar house project, while *teamwork and collaboration* seemed to vary significantly (Fig. 6d).

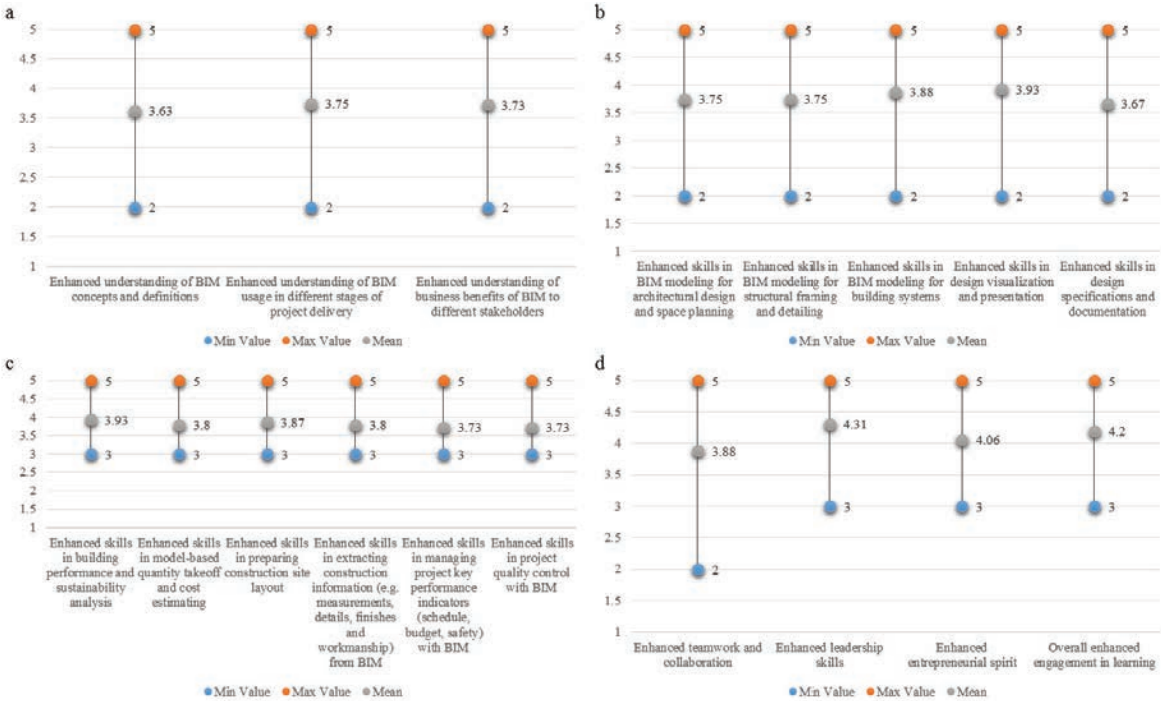


Fig. 6. Perceived impacts (5-point Likert scales with 1: strongly disagree to 5: strongly agree) of experiential and project-based learning on core SLOs: (a) BIM fundamentals; (b) BIM for design communication; (c) BIM for problem-solving; (d) other essential SLOs.

## 5. Conclusion

By leveraging the SMUD tiny solar house competition, construction management faculty at Fresno State have been undertaking a comprehensive curriculum and pedagogy redesign to investigate synergies of BIM, sustainability living and student learning engagement. The overarching goal apparently resides in designing and sustaining a robust and responsive undergraduate curriculum that can better prepare students for the rapidly transforming industry environment; and can cultivate future workforce that have the competency desired by emerging trends such as BIM and sustainability. The experiential and project-based learning pedagogy is evaluated and implemented in this project, and initial student learning data was collected. The results have shown some promising trends and patterns, while more comprehensive assessment will be needed at the end of the competition. Lessons learned from this project are expected to be shared among the construction management education community and with engaged industry organizations. Future work will be dedicated to establish a prototype of experiential and project-based learning for BIM and sustainability education in a primarily teaching institution with enhanced student participation from minority and other underrepresented population.

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