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Board 69: Learning Sustainable Development Through Integrative Design Process (a Case Study)

Dr. Xi Wang, Drexel University

Xi Wang is an Assistant Teaching Professor of Construction Management at Drexel University. She received her Ph.D. and M.Eng both in Civil Engineering, from the University of Kentucky and Auburn University. She is licensed as a Professional Engineer and LEED Green Associate. She is teaching a range of courses in construction management and will be assisting capstone design projects that directly serve regional construction firms. Her research interests include technology adoption in workforce development in the construction industry, sustainable developments in construction education, and learning motivation for student success in engineering education.

Kathleen M Short
Dr. Christine Marie Fiori

Dr. Christine Fiori is the Department Head of Engineering Management Studies and the Program Director of the Construction Management Program at Drexel University where she teaches courses in Project Controls, Equipment Applications and Economics, and Stra

Learning Sustainable Development through Integrative Design Process: A Case Study

Abstract

The integrated design process is a highly collaborative approach to designing sustainable built environments that operate efficiently. It is a process by which all design variables that affect one another are considered together. In recent decades, the industry has increasingly demanded engineers be equipped with the skills to apply sustainability in building and construction projects. Universities are starting to emphasize sustainability concepts in various engineering programs. Because industry standards are becoming higher, students should learn in their courses to be aware of what constitutes green design and have some experience putting it into practice. As a critical approach to creating a green building, the integrated process plays a vital role in sustainability education. It guides students to implement green building design knowledge in real projects and eventually enhances their in-depth understanding of sustainability. This paper presents a semester-long project in an undergraduate-level course that required students to adopt the integrated design approach to design a house that will be used as an educational center for sustainability. The project was completed in multiple phases, from hosting a charrette for conceptual design to running an energy consumption test for the final detailed design. A standard sustainable design rubric evaluated students' designs, and their engagement and learning outcomes were also evaluated at the end of the course. The feedback shows that students were highly motivated to learn the integrated design process and sustainability from the project. This project will be a pilot study to develop an educational module on green building design for engineering educators.

Keywords: Integrative Design, Sustainability, Green Buildings

Introduction

Public demand has increased in recent decades to balance environmental, social, and economic outcomes within sustainable development [1]. Engineering professions from industries and accreditation boards have required that engineering graduates be able to think and design for sustainable development. Subsequently, the integration of sustainable development has become a relevant topic in higher education, and increasingly, universities are attempting to take responsibility as agents in promoting sustainable development principles [2][3]. Sustainable developments are complex environmental and societal engineering challenges, which means that solving such challenges will require students to possess a creative skillset and mindset. Integrative design thinking, a human-centered design approach, has recently gained traction as an advanced approach to innovation that identifies environmental and societal needs and integrates them with technological and economic feasibility [4]. It encourages multidisciplinary teamwork and creates a favorable environment for collaboration.

The literature defines design thinking as a unique problem-solving approach that creates value and achieves innovation [5]. Universities can contribute significantly to fostering the transition toward a sustainable society by developing knowledge and preparing students for their future roles [6]. Meanwhile, it also comes with challenges to integrating sustainability into the engineering curriculum, such as gaining student awareness of sustainable development and providing practical experience for students [7]. Thus, a course term project is introduced and discussed in-depth for the following purposes: 1) to understand pedagogical elements that might affect students' learning experience of sustainable development; 2) to demonstrate the potential of integrative design thinking for fulfilling the learning outcomes related to sustainability and 3) to suggest a teaching strategy to overcome challenges of applying integrative design process in sustainability learning. The students who worked on these projects are junior undergraduates majoring in Construction Management from the College of Engineering. Data related to this project has been collected, including extensive design documentation and models, the feedback of the instructor, peer evaluation regarding designs, and self-assessment of learning outcomes.

Integrative Design in Sustainable Buildings

Building systems are interdependent and require collaboration and creative thinking across disciplines. In the creation of a building, a need is identified, and a concept of the structure emerges and is then developed in detail and tested. In a traditional design process, the Architect, Engineers, and Contractor complete their processes separately and then pass their work along. Conventional building systems are planned and installed independently [8]. Traditional design can be understood as a linear process, but sequential work routines may be unable to support any adequate design optimization efforts during individual phases, which could lead to higher project costs [9]. Integrative design considers and optimizes the building as an integral system for its lifespan. This can be achieved when all project actors collaborate across disciplines and agree on decisions jointly from the beginning.

The integrated design process emphasizes the iteration of design concepts early [9]. Participants contribute their ideas and technical knowledge collectively and in the early stages. For the early design phases, concepts must be worked together for all design issues. For example, the concepts of energy and construction erosion control are not designed complementary to the architectural design but as integral parts of the building very early [10]. Considering the complexity and high demand for optimization of sustainable building design, the integrative design process brings interdisciplinary experts and stakeholders together for an inclusive collaboration whose focus is achieving the project's sustainable design goals [12][13]. Sustainable developments, especially green building design, aim to identify opportunities to achieve synergies across disciplines and building systems throughout the planning and design phases and beyond [10]. For example, decision-making about building shape, orientation, and insulations relies on knowledge from multiple disciplines. These building envelope strategies impact heating and cooling loads and are a function of thermal comfort and daylighting. With an integrated design process considering these numerous benefits, the building is more likely to perform as intended and achieve projected energy and cost savings.

The integrative design process, in advance, analyzes how different systems impact each other and how to make choices that consciously improve the efficiency of a project. The integrative design process becomes critical to green building design or any other sustainable development. The approach could enhance design quality and improve sustainability performance [14]. Increasing evidence shows that sustainable developments, especially green building projects, can be cost-effective when an integrated design approach is applied [15]. Even though the initial phase of the integrative design could be time-consuming, the later stages will take less time and end up with a fast delivery schedule overall.

In general, the integrated design process includes early charrettes with the client and users, collaboration with the architect, engineer, owner, green consultant, and contractor throughout the design process, and a full-day pre-design charrette with stakeholders from all design disciplines, including local officials, community representatives, and LEED experts [10]. The primary outcome is setting design goals to guide further detailed designs. Using energy simulation tools informed the decision to integrate site parameters, solar orientation, water, stormwater system, thermal envelope, lighting, window performance, heating and cooling supply systems, ventilation, and air distribution in such a way that all of these systems are working together and achieving design goals. Figure 1 is a workflow chart showing the generic process of integrative design.

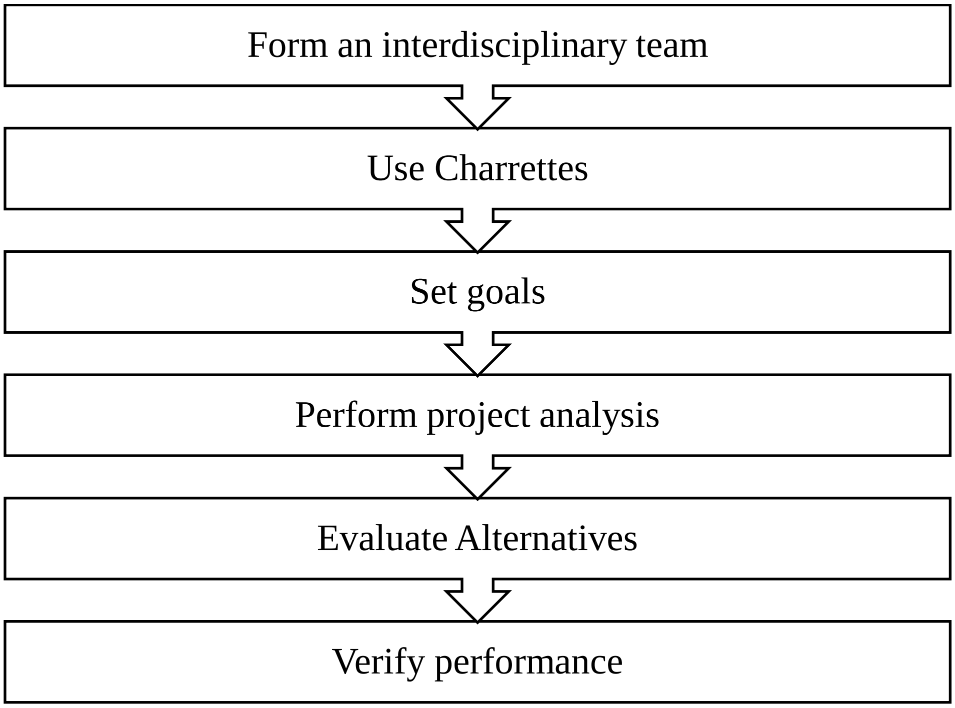


Figure 1. Overview of the Integrative Design Process [10].

Descriptions of the Course Project

Students learn the integrative design process through lectures and a semester-long project from an intro-level sustainable development course. This course gives an overview of green designs and sustainable practices in building construction. The course covers technical topics and requirements of a nationally recognized rating system, Leadership in Energy and Environmental Design (LEED), specifically focusing on Green Building Design and Construction. Students are introduced to basic building designs and systems related to sustainability. Additionally, they learn about green design topics such as site plans, water and energy efficiency, material and resource usage, environmental quality, and renewable energy sources. As an outcome of the course, students can assess and incorporate green technologies and designs into building projects. Considering the course timeline, the project is designed to simplify the integrative design process. Students are tasked to design a sustainable, practical, aesthetically pleasing home that complies with the requests of a client who is the course instructor by using selected software programs (e.g., SketchUp, Revit, Cove tool, etc). The design must include all essential features of a home, including windows/doors, roof, site plan, and all appropriate fixtures (i.e., toilets and showers). In addition, the home should be LEED certified, smaller than 1,200 sq ft, and less than $800,000. A total of 22 students are in this class, and they are divided into six groups. First, each group plans and leads a charrette at the beginning of the term. Each student was asked to play a specific role in a multi-disciplinary team, such as an architect, civil engineer, etc. A Charrette sets the ground stage for the success of the integrative design. Charrettes builds consensus, formalizes the project expectations, streamlines the design process, and sets the team up for success by supporting and setting specific goals. A charrette allows project actors to share their perspectives at a time when their inputs can still be easily incorporated into the design. Table 1 shows a sample charrette agenda developed by students. By the end of the term, students submit the site plan, construction site erosion and sediment control plan, floor plan of the house, a list of primary building materials and cost, 3D model of the building, LEED score sheet, and energy simulation report. In addition, each group gives a 20-minute oral presentation of their design in front of the whole class. Figures 2 to 7 are examples of deliverables submitted by a team. This team built silt fences around the site's edges to keep sediment from washing away during rainstorms. They used sediment traps or basins to catch and hold sediment-laden water. Grass and quick-growing plants will be planted on exposed dirt to keep the soil in place. Rain gardens and permeable pavements are applied to handle stormwater on the site, which helps prevent erosion. For the structure of the building, this team used FSC-certified wood and recycled steel and cellulose insulation, sheep wool, and eco-friendly foam for the insulation materials. Fiber cement siding, reclaimed wood, and recycled bricks are used for the exterior of the building. In addition, double- or triple-glazed windows with frames made of uPVC or treated wood are selected to increase energy efficiency. In addition to the features mentioned, students added a green roof, low VOC paints and flooring materials, low-flow water fixtures, and solar panels integrated with the HVAC system in their design to achieve their sustainable goals. To test their choices of materials and green features, students used an online energy simulation tool (cove.tool) to help them decide on the optimal design details. For example, this group of students referenced state codes to determine the R-value of windows and tested the solar panel angles and other parameters used for building envelop materials. R-value is one of the common indicators used to measure how well building insulation can prevent heat flow into and out of the home [11]. Figures 5 and 6 are example reports from the energy consumption simulation. The simulation results show the different values of Energy Use Intensity (EUI) which is used to measure the energy performance of building design options. After all the detailed design, students completed the LEED score sheet, as shown in Figure 7.

Table 1. A Sample of Charrette Agenda Developed by Students

Sustainable Design Topics	Discussion Question
LEED goals:	Which level of LEED would your team like to reach (target points) for the building?
Site, Stormwater, and Water Strategies:	Where will the project be located?
	How will the building design take advantage of climatic factors and passive systems?
	What is the water budget for the building?
	How and where can stormwater be managed on-site?
	What low-water flow fixtures will be used in the plumbing system?
Energy Strategies:	What is the energy target?
	How can occupancy patterns and uses be considered in the building design?
	What are the HVAC needs?
	Is daylighting the primary source of illumination? How will it be controlled?
	What is the inventory of plug load equipment for this building, and how can we optimize plug load energy use?
Indoor Environmental Quality:	What recycled, reused, or salvaged materials might be used in construction?
	How can nature be incorporated into the building?
Operations and Maintenance:	What operational considerations need to be made?
	How will energy use and generation be tracked and verified?
	Will the building connect with and contribute to the community? How?

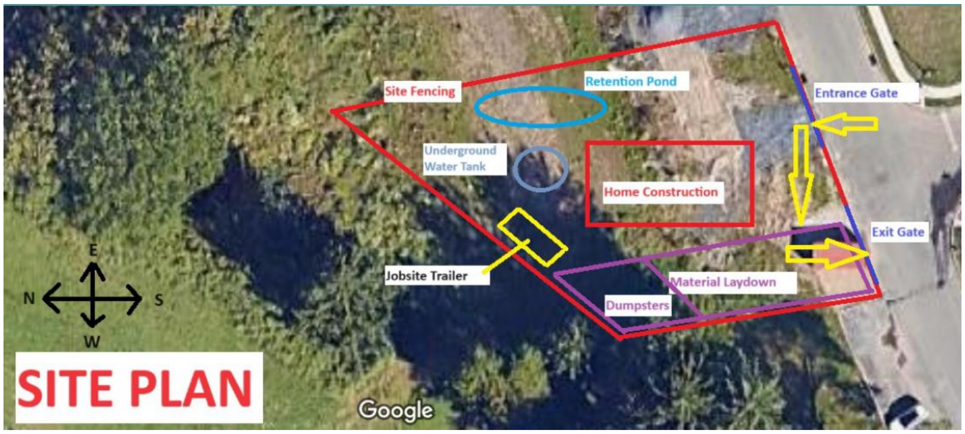


Figure 2. A Site Plan of the Green Building Project Designed by a Student Team

Figure 3. A 3D Model of the Building and Site designed by a Student Team in SketchUp

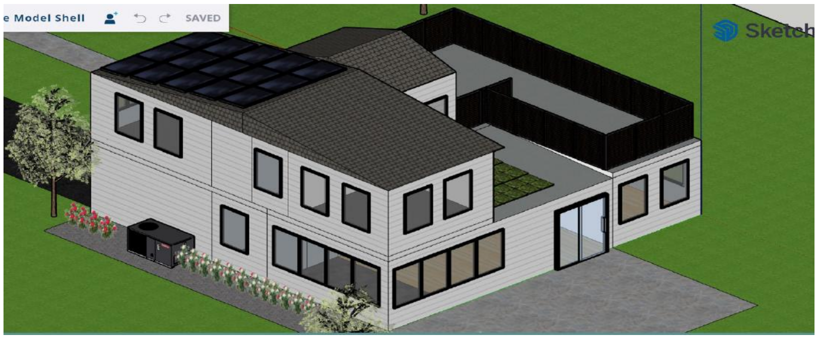


Figure 4. A 3D Model of the Green Building Project Built by a Student Team in SketchUp

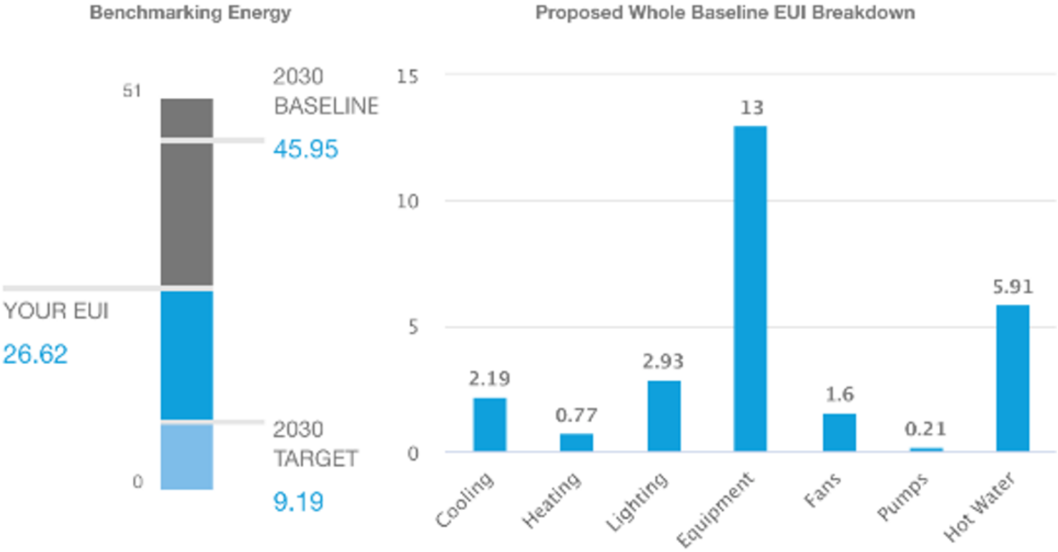
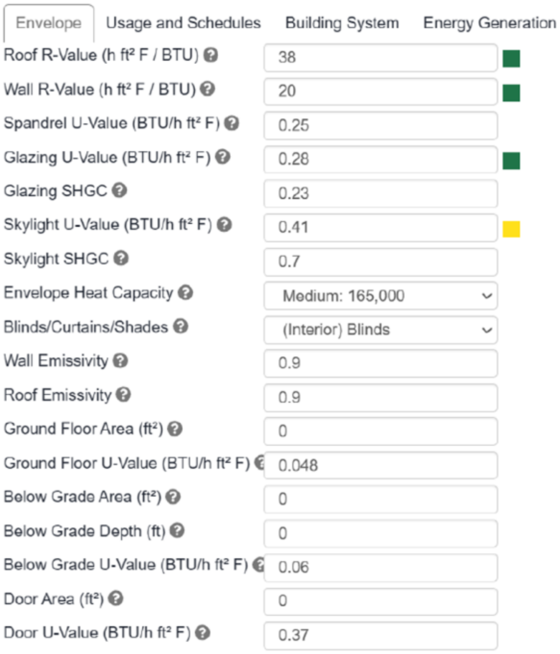
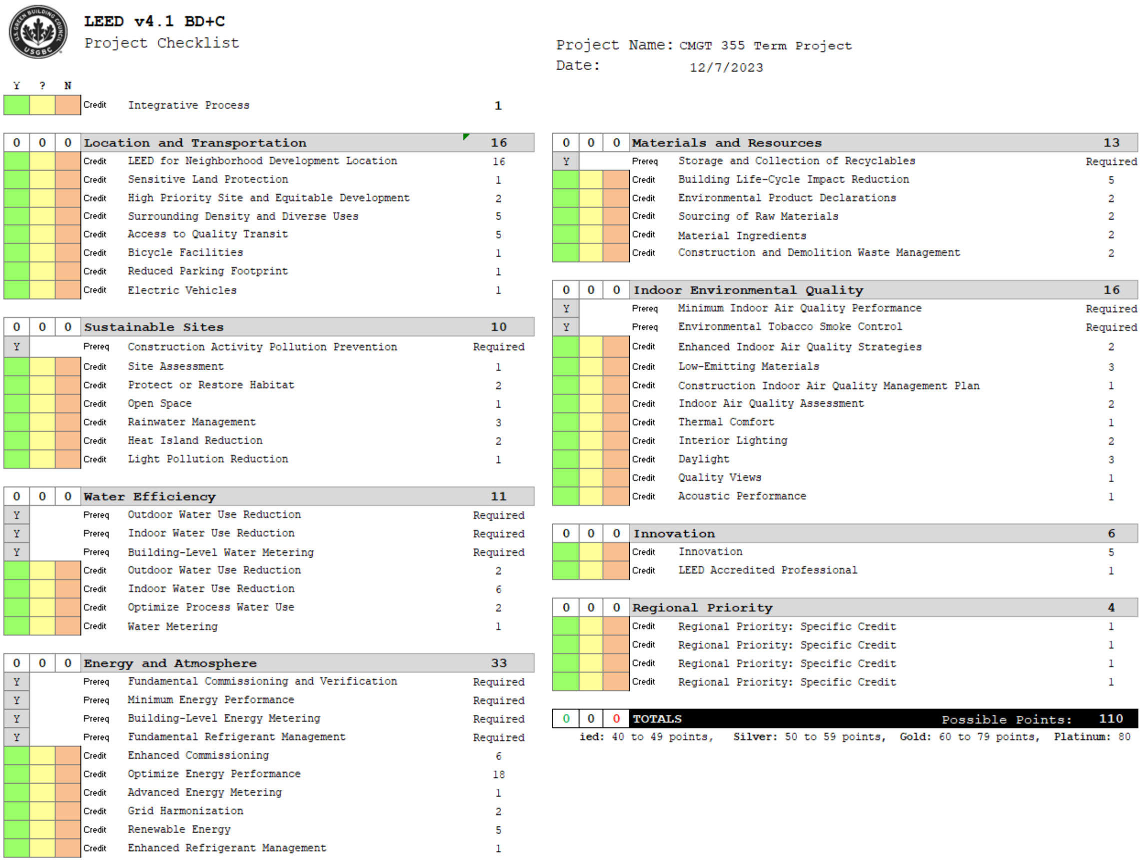


Figure 5. Energy Simulation Results in cove.tool



Roof R-Value (h ft² F / BTU)	38	🟩
Wall R-Value (h ft² F / BTU)	20	🟩
Spandrel U-Value (BTU/h ft² F)	0.25	
Glazing U-Value (BTU/h ft² F)	0.28	🟩
Glazing SHGC	0.23	
Skylight U-Value (BTU/h ft² F)	0.41	🟨
Skylight SHGC	0.7	
Envelope Heat Capacity	Medium: 165,000	
Blinds/Curtains/Shades	(Interior) Blinds	
Wall Emissivity	0.9	
Roof Emissivity	0.9	
Ground Floor Area (ft²)	0	
Ground Floor U-Value (BTU/h ft² F)	0.048	
Below Grade Area (ft²)	0	
Below Grade Depth (ft)	0	
Below Grade U-Value (BTU/h ft² F)	0.06	
Door Area (ft²)	0	
Door U-Value (BTU/h ft² F)	0.37	

Figure 6. Alternative Materials Testing by an Energy Simulation in cove.tool



LEED v4.1 BD+C
Project Checklist

Project Name: CMGT 355 Term Project
Date: 12/7/2023

Y	?	N			
			Credit	Integrative Process	1

0	0	0		Location and Transportation	16
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site and Equitable Development	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Electric Vehicles	1

0	0	0		Sustainable Sites	10
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1

0	0	0		Water Efficiency	11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Optimize Process Water Use	2
			Credit	Water Metering	1

0	0	0		Energy and Atmosphere	33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Grid Harmonization	2
			Credit	Renewable Energy	5
			Credit	Enhanced Refrigerant Management	1

0	0	0		Materials and Resources	13
Y			Prereq	Storage and Collection of Recyclables	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Environmental Product Declarations	2
			Credit	Sourcing of Raw Materials	2
			Credit	Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

0	0	0		Indoor Environmental Quality	16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1

0	0	0		Innovation	6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

0	0	0		Regional Priority	4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

0	0	0	TOTALS	Possible Points:	110

ied: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80

Figure 7. LEED Score Sheet [19]

Assessment of Student Learning

Self- and Peer-Assessment

A practical method for assessing student abilities to engage in sustainable design is essential. Surveys and rubrics have been proven effective in assessing students' learning effectiveness [16]. To ensure that students understand the complexity of sustainability topics and apply their knowledge in the design process, a sustainable design rubric has been proven helpful in capturing their sustainable design abilities. In this project, students are required to use the rubric published in the existing literature [19]. This sustainable design rubric is a tool for evaluating project results, identifying areas for improvement, and justifying design decisions throughout a project's duration. The worksheet is used for students and instructors to record ratings based on a 3-point scale. The first column identifies a criterion and provides a short definition. In the second and third columns, students list their design ideas and one alternative design idea. In the last column, the instructor and students enter the total points earned out of 3 for each criterion. If a team uses both quantitative and qualitative evidence and multiple analysis methods to support their design decisions which reflects long-term thinking, they could earn 3 pts. Table 2 shows the design evaluation rubric. The design work of each group was assessed by both the instructor and their peers following the same sustainable design rubric shown in Table 2. Peer evaluation is an effective collaborative learning strategy [19]. Related to self-assessment, peer evaluation encourages students to critically examine peers' work and reflect on the meaning of quality work in general, primarily when consulting a detailed rubric as a guide. Students themselves provide feedback to one another, while the instructor focuses on more targeted guidance toward a learning outcome. Through peer evaluation, students ultimately learn to better self-assess themselves, which pays dividends throughout their academic and professional careers [21]. In addition, students learn to examine diverse perspectives and assume greater responsibility in the learning process [22]. By adding an element of accountability and critical review, students are more likely to exert effort to ensure a positive peer review.

Course Evaluation Survey Results

Twenty-one students in this course completed a course evaluation survey at the end of the term. The first part of the survey measured students' perceived performance and understanding of the learning objectives related to sustainable developments before and after entering the course and project. Students rated how well they agreed with the statements on a 1-5 scale (1 = No Understanding; 5 = Complete Understanding). As shown in Table 3, overall, students' ratings of understanding of sustainable development significantly increased after completing the course and term project. In addition, a qualitative question was posed to the students to explore their feedback on the strength of the course. Most responses show an increased comprehension of the topics through the term project. The following are examples of students' comments regarding this course term project "*I liked learning about the different types of green building along with the simulated project assignments. I felt like I was more involved in a "competition" setting as opposed to a classroom,*" "*Learning about LEED and the green building design process was my personal favorite*", "*The best aspect was getting some practice learning the energy consumption simulation methods from the project*."

Table 2. Sustainable Design Rubric [17]

Criterion	Design	Alternative Design	Points
Environmental Category			
A1. Minimizes the use of non-replenishable raw materials; requires minimal energy input or uses renewable energy sources			
A2. Minimizes quantity of consumable waste (e.g., water, materials) output; manages quantity and quality (benign, usefulness) of waste			
A3. Protects or enhances natural ecosystems (water, air, soils, flora, fauna, etc.)			
Social Category			
B1. Identifies and engages stakeholders in the design process			
B2. Addresses needs of diverse stakeholders, acknowledging culture and other differences among individuals and groups			
B3. Protects human health and physical safety of users and society			
B4. Promotes human well-being and enhances the quality of life for users and society			
Economic Category			
C1. Evaluate the economic impacts of environmental design criterion			
C2. Evaluate the economic impacts of a social design criterion			
C3. Considers affordability for users and/or demonstrates cost competitiveness or cost reduction for client/sponsor			
C4. Evaluates economic costs and benefits to inform decisions			

Table 3. Assessments Results of Learning Outcomes [18]

Learning Outcomes	Before (Mean Rating)	After (Mean Rating)
Comprehend fundamental concepts of sustainable design and construction of buildings and civil infrastructure	1.93	4.24
Understand how public, private, and non-profit land and facility owners practice approaches to sustainable built environments	1.79	4.06

Comprehend elements of “green” projects to make informed decisions about siting, systems design, water use, energy use, materials selection, and life cycle determination	1.79	4.00
Quantify the environmental, social, and financial impacts of sustainable development	2.00	4.06

Discussion and Conclusions

Some lessons have been learned from this innovative term project experience and assessment results. These lessons provide some empirical suggestions for implementing sustainable development projects to maximize student learning effectiveness: 1) The design charrette was effective in this project to enhance collaboration and helped students’ general and specific knowledge related to their design projects. Based on the in-class observations and course evaluation feedback, students agreed that the charrette improved their understanding of green building design. In the future, the charrette preparation could be improved with input from industry professionals. In addition, a more in-depth lecture session or workshop about designing a charrette could help students be more prepared for practical discussions about their designs. Although a guideline is provided to students, many have never experienced a design charrette before. Some students spent extra time preparing all the questions for discussions. 2) It is essential to challenge students to move outside their comfort zone by involving them in challenging tasks that require them to apply the skills they learned in the classroom and research solutions for detailed design. Requirements are insufficient to capture their attention and motivate them to make a full effort. Through the projects, students experienced many facets of an actual green building project for the first time, such as energy consumption analysis, fundamental structural design, learning different design standards, and construction erosion and sediment management. Another was that the students experienced some frustration in trying to create an environmentally conscious development in a highly regulated jurisdiction whose goals are not entirely in sync with LEED principles. 3). Students learn to make trade-off decisions to optimize the design and meet all requirements at the same time. The integrative design is a collaborative practice requiring diverse abilities [20]. It requires communicating requirements and concepts and collaborating with diverse people to generate a feasible design. These collaborative abilities transcend boundaries within and outside the classroom. As discussed earlier, a green building is a complex system, and many design details are interrelated. The challenge is how to reach a compromise among the conflicting design requirements from different aspects of the building system. For example, students spend a decent amount of time selecting the material for the building envelope. Students had a lot of discussions on the balance between energy efficiency and lighting conditions. Students learn to use technology and software to run multiple tests. In addition, students consult experts from the industry about the problems. Students use their network from their internship experience to reach out to a ‘right’ person who has done similar projects before. Students learn to integrate theoretical and practical perspectives into their design during this process. 4) Student leadership has proven critical to the design work’s success and the team’s overall performance. The team leader determines the dynamics among participating students. Without a student leader with good personal efficacy and a solid technical background, students quickly felt overwhelmed due to the amount of details in the design process and the high demand for the time commitment. Students are more motivated to work if they have a peer who sets up plans, works alongside them, and encourages them the whole time.

The project also comes with challenges for the instructor. A green building or related sustainable development project typically requires different technical skill sets. A single faculty member might be unable to advise students on all aspects of sustainable building design. Thus, the faculty advisor must identify and build connections with necessary technical support for students. Additionally, the faculty advisor needs to follow up with students on the advice they receive from other resources to help them make correct decisions. That also supports timely and frank communications with students, which is essential.

Besides challenges, the project has some limitations. First, in practice, the integrative design requires a multidisciplinary team. Students from these courses are majoring in the same discipline, which could limit students' potential for designing capabilities. The project could be developed further as a joint project with more students from diverse technical backgrounds. Second, the project is not from a real design request. An actual client from the industry and community could primarily increase students' learning engagements and motivations. Some fundamental interactions with clients and stakeholders could encourage students to communicate effectively and become socially aware of the environmental impact of their designs, which can better prepare them for the global challenges they may face after graduation. It could help to enhance students' understanding of social issues and provide direct feedback on the value and effectiveness of the design they create. Through communications with the client, the design work can be perceived by students as something meaningful that will bring about tangible benefits to the community. It gives students incentives to improve learning when they believe that they are making a real difference to others through their work.

Despite the challenges and limitations, the project proved valuable, providing a solid foundation for incorporating sustainable development knowledge and skills in engineering education. The future of sustainable design will highly depend on institutions of higher education incorporating this knowledge and skills into the curriculum [23]. Academic institutions can contribute to the acceptance of sustainability in architectural and engineering design by offering courses and project opportunities in conjunction with well-established considerations such as ethics, economics, and structural integrity. The topic should be treated as a major consideration similar to protecting public safety in design. Ultimately, the objective should be to graduate a new generation of engineering, architecture, or management professionals capable of integrating sustainable development into real-world design projects.

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