An Assessment of Students' Perceptions in Curriculum Development Integrating Entrepreneurship and STEAM with Designing Green (Bio-inspired) Roofs

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STRUCTURED ABSTRACT

CONTEXT: Over the past several decades, sustainability has reshaped engineering education and motivated scholars to implement it into academic curricula and research. Educating engineering students in sustainable (bio-inspired) design helps them to understand the impacts of their decisions on the environment and natural resources and empowers them to make positive changes. On the other hand, entrepreneurship enables students to learn how to spot, evaluate, and explore opportunities, build a prototype, and test it to design a project that satisfies clients' needs and aesthetic preferences. Unfortunately, educational institutions and researchers lag, particularly when integrating an entrepreneurial mindset with green building. Thus, this study emerged to overcome this contemporary interdisciplinary challenge and prepare green entrepreneurs and T-shaped engineers.

PURPOSE OR GOAL: This study aims to prepare future green entrepreneurs and T-shaped engineers by creating a curriculum that integrates entrepreneurship and STEAM with construction projects' sustainable (bio-inspired) design and assessing students' perceptions of this curriculum development. The guiding research question is: What are the assessment themes of students' perceptions of integrating entrepreneurship and STEAM with sustainability in a curriculum in which students design green (bio-inspired) roofs? These themes help to understand student voices and interpret the information they share at a deeper level toward continuous improvement to curriculum development. Subsequently, the researcher can gain more significant insights into educational effectiveness's who, what, and how.

APPROACH OR METHODOLOGY/METHODS: This study was conducted at the Civil and Environmental Engineering and Construction Management Department at a University in the United States. The study was a four-week assignment integrated into two senior-level courses: 1. the capstone project course in two semesters, 2. the pre-construction management course in one semester. This study uses participatory action research (PAR) as a data collection instrument. PAR is a qualitative approach in which researchers work collaboratively with the participant subject population to collect data, reflect and take action. Photovoice, commonly linked to PAR, is used to collect and explore qualitative data, give a unique depth of understanding to the research questions identified, and offer new insights and perspectives toward making improvements. Data obtained are analyzed using thematic analysis, a fundamental qualitative method for finding patterns within the data set using a step-by-step process.

ACTUAL OUTCOME: After analyzing the qualitative data, six core themes related to this study were identified, including (1) curriculum design, (2) students, (3) entrepreneurship, (4) sustainable (bio-inspired) design, (5) art, and (6) technology. Each one of these six themes includes subthemes.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY: This study fulfills a knowledge gap by researching a novel topic that contributes to advancing interdisciplinary learning experiences in engineering curricula. In addition to green roofs, this study can be applied to all other

components of green buildings and replicated by instructors of other institutions. This study concludes with recommendations for improving the curriculum design and student performance. It also recommends further studies in engineering education and the AEC (Architecture/Engineering/Construction) industry using other research methods and investigating this study topic in depth.

KEYWORDS: Sustainability, Entrepreneurship, Engineering Education

1. Introduction

According to the 2022 Global Status Report for Building and Construction, buildings are responsible for 34% of global energy consumption and 37% of energy and process-related CO2 emissions in 2021 [1]. However, the built environment also has the most significant economic potential for carbon dioxide emission mitigation compared to other sectors [2]. By 2050, projections reveal that two-thirds of the world's population will live in cities [3]. Green building has become increasingly crucial to sustainable cities' economic, social, and environmental development in this future urban vision. Engineering plays a significant role in achieving these sustainability goals. As a result, integrating green building concepts into engineering education advances students' knowledge and skills toward developing complex and transdisciplinary solutions to create sustainable cities and communities [4]. In addition, incorporating sustainability in the engineering curricula attracts many students seeking to build and maintain a better and safer planet for themselves and future generations [5].

On the other hand, STEAM (Science, Engineering, Math, Art, and Technology) is a meta-discipline and nontraditional pedagogical approach that integrates science, technology, engineering, art, and mathematics. STEM education enables students to solve real-world problems that are rarely solved using knowledge, tools, and skills from one discipline [6]. Also, this requires students to understand societal needs, critical and creative thinking skills, engineering-design thinking, and research and experimentation [7]. However, STEM is sometimes insufficient to explain a phenomenon or solve a problem. As a result, scholars have been trying to integrate STEM with other subjects such as environmental studies (sustainability), art, and entrepreneurship [8]. On the other hand, entrepreneurship education is defined by Torrance and Rauch as “the teaching of skills and cultivation of talents that students need to start businesses, identify opportunities, manage risk, and innovate in the course of their careers” [9]. Therefore, it is prudent to incline students toward adopting entrepreneurship as a tool for innovation and value creation, enabling them to discover, evaluate, and exploit business opportunities essential to economic growth [10].

Thus, this study is designed to challenge students to employ their intellectual gifts and combine these two rival concepts (sustainability and entrepreneurship), connecting them with STEM and art. Bioengineering improves the environment and increases the human quality of life by translating from nature into manmade designs to address complex challenges such as sustainability [11]. This study was conducted at the Civil and Environmental Engineering and Construction Management at a University in the United States. The study was a four-week assignment integrated into two senior-level courses: 1. the capstone project course in two semesters and 2. the pre-construction management course in one semester. In these two courses,

the students used bioengineering to inspire them to learn from a natural phenomenon, connect it to their project design, and contribute productively to climate change mitigation [12]. The main goal of this study is to assess students' perception of integrating entrepreneurship and STEAM with designing green (bio-inspired) projects using photovoice. Photovoice is a participatory action research strategy, an ethnographic and experiential technique combining photography and images, narrative and critical dialogue, and reflection to uncover social issues and promote change [13], [14]. In return, that will enable students to share information and allow interpretation processes at a deeper level.

1.1 Problem Identification

Sustainability is a complex problem and a decision-oriented endeavor that requires the expertise and integration of business, architecture, engineering, technology, community, policy, and law [15]. Subsequently, engineering curricula must cultivate an ability to recognize the importance of diverse knowledge to solve this emerging problem. In addition, in today's globally competitive market, engineers need to be T-shaped professionals developing an ability to leverage their disciplinary training and collaborate with others [16].

A T-shaped engineer possesses a breadth of expertise in a specific knowledge domain represented in the horizontal bar of the "T." On the other hand, the vertical part of the 'T' shows that the engineer has broad knowledge across various systems and intellectual and disciplinary cultures, such as sustainability, entrepreneurship, etc., [17], [18], [19]. Moreover, employers place high importance on hiring T-shaped professionals [16]. However, the problem is that engineering students are not good at being T-shaped. Also, training students to embody the T-shaped model is a slow and challenging process [20]. Unfortunately, educational institutions and researchers lag, particularly when integrating an entrepreneurial mindset with green building. Thus, this study is designed to overcome this contemporary interdisciplinary challenge and prepare T-shaped engineers by developing an engineering curriculum that adapts to the changing expectations of students and industry and assessing students' perceptions of this integration across multiple disciplines, including entrepreneurship, STEAM, and sustainability.

1.2 Study Overview

This study aims to prepare T-shaped engineers by creating a curriculum that integrates entrepreneurship and STEAM with construction projects' sustainable (bio-inspired) design and assessing students' perceptions of this curriculum development. The guiding research question is: What are the assessment themes of students' perceptions of integrating entrepreneurship and STEAM with sustainability in a curriculum in which students design green (bio-inspired) roofs? The study was a four-week assignment integrated into two senior-level courses: 1. the capstone project course in two semesters, including twelve students, and 2. the pre-construction management course in one semester, including seventeen students. In these two courses. These two courses teach students how to spot and define a business opportunity to create value for their community through sustainable building. Bioinspired design is also described and explained to enable students to connect nature with innovation to meet humans' needs and protect the planet. In addition, this course instructs them and prepares them to be capable of evaluating sustainable

features' esthetic and economic viability toward making an informed decision that benefits individuals, groups, and communities.

In addition, the student-scholar modality is utilized in this course by exposing students to a real-world project that stretches their knowledge and forces them to go and learn. As a result, this project develops students' critical thinking, problem-solving, research skills, and written and oral communication by creating a proposal encompassing multiple disciplines. The project's micro (the individual level) is directed at preparing a future independent researcher. On the other hand, the project's mezzo (the group level) enhances teamwork and collaboration across disciplines and offers a wide range of topics for discussion and research.

Finally, the outcome of this course is broadening students' participation, working collaboratively, and getting excited about and committed to solving interdisciplinary problems from sustainable, STEAM, and entrepreneurial mindsets.

2. Literature Review

2.1 Integrating Entrepreneurship and STEAM with Designing Green (Bio-inspired) Roofs

Previous research shows that green roofs mitigate summer temperatures, decrease indoor cooling load demand, and improve outdoor comfort. In urban areas, a green roof system is one of the sustainable solutions due to air temperature reduction, shield solar radiation shielding water runoff management, and urban heat island effect mitigation [21]. However, some drawbacks prevent green roof systems from spreading further worldwide. The plants' growing media (substrate layer) needs organic material essential for the growth and maintenance of vegetation. Also, other studies reveal that these organic materials often are a potential source of contamination for the water runoff of the roof due to the instability of organic matter [22], [23], [24]. Typical yard soil is used in green roofs in countries where commercial substrates are not available, which causes more challenges such as low water retention, additional weight not supported by a standard slab, and growing weeds [25].

Research also shows green roofs [22], [23], [24] [25], [26],[27] are more challenging in system installation, maintenance, and weed and root control than hydroponic systems [28]. Hydroponic systems used in green roofs are more efficient in rationalizing water consumption and chemical elements for the fertilization of plants [29], [30], [31]. The plant is provided with the substances it needs for its biological development in hydroponic systems.

In this study, students are asked to design green (bio-inspired) roofs as one of the requirements of their capstone project course and the semester project of the pre-construction management course. Integrating STEAM with their sustainable (bio-inspired) design is presented as a solution to overcome the challenges facing green roofs. Subsequently, these two-course projects force students to think outside the box as entrepreneurs, creating innovative solutions for real-world problems. Entrepreneurship, the engine of the economy and the source of creating new businesses [32], [33], [34], is known to focus on maximizing financial gains rather than environmental protection [35]. That presents another challenge to students when designing green

roofs for their construction projects. In other words, green entrepreneurship must be added to the vertical part of T-shaped engineering.

Green entrepreneurs operate businesses in a nonconventional way by integrating environmental awareness with entrepreneurship, shifting towards a new sustainable business paradigm, and creating innovative solutions to nourish the green economy [36], [37]. Thus, these two-course projects require students to adopt the green entrepreneurial mindset, which adds another challenge for students to overcome.

2.2 Current Approaches and Gaps

Over the last few decades, green roof systems have been explored and studied among construction techniques and innovative building envelopes to help reduce carbon emissions and optimize energy efficiency. Researchers have found that implementing soil-less crops or hydroponics into roofing is one of the solutions to overcome the drawbacks associated with green roofs, such as substrate and soil weight. In addition, hydroponic cultivations provide other benefits, such as increased crop production, reduced food transportation and waste, and improved food safety. Even though the hydroponic green roof has the potential to be a viable solution for green buildings, it is still a new terrain that requires further investigation and innovation [25]. Thus, the AEC (Architecture/ Engineering/ Construction) industry and engineering education encounter a real-world problem that must be tackled by integrating entrepreneurship and STEAM with green (bio-inspired) design. This integration is not only applied to green roofs but also to all components of construction projects.

Subsequently, engineering education must cope with the threats imposed by climate change [38] and employ the advent of cutting-edge technology to come up with feasible, sustainable solutions that save humanity and the Earth. Modernizing engineering curricula enhances the T-shaped engineering and instills the culture of integrating entrepreneurship and STEAM with green (bio-inspired) design among students. The pedagogical approaches and techniques must prepare future engineers who know what seems impossible today with sustainability, entrepreneurship, and STEAM is possible.

As Bill Gates stated, “When I first fell in love with computers as a teenager, they were enormously expensive, and only government and big companies could afford them. But my friends and I became obsessed with a wild idea. What could we do if there was a computer on every desk? And, now, the wild idea is quite tame. Billions of people not only have computers on their desks but even in their pockets. Now the world needs another breakthrough. In fact, it needs many breakthroughs. We need to set from 51 billion tons of greenhouse gases to zero while still meeting the planet’s basic needs. That means we need to transform the way we do almost everything. Our commitment to developing these innovations will be the difference between a future where we can live a healthier and more productive life and one where we are constantly dealing with human and financial crises at a historic scale. Entrepreneurs and investors have to build new businesses and change existing businesses.” [39].

Moreover, multiple governmental programs and non-profit organizations at the local, national, and global levels address and advocate for sustainability, STEAM, and entrepreneurship. However, no organization or program aims to integrate entrepreneurship and STEAM with

sustainability simultaneously. For instance, KEEN (The Kern Entrepreneurial Engineering Network) partners with more than 50 colleges and universities across the United States. KEEN focuses on teaching undergraduate students the entrepreneurial mindset (EM) so they can create personal, economic, and social value through a lifetime of meaningful work.

Also, in sustainability and specifically in the AEC industry, there are many government programs and non-profit organizations at the local, national, and global levels, such as U.S. Green Building Council, Engineers Without Borders (Designing Sustainable Solutions), and World Green Council.

Moreover, since the early 1990's many environmental and professional organizations, such as the American Institute of Architects (AIA), and accrediting agencies, such as the American Council for Construction Education (ACCE) and the National Architectural Accreditation Board (NAAB), have intrigued universities to offer sustainability courses and encourage students to engage in sustainability development.

2.3 Status in the Field

As emerging from conducting a thorough literature review, limited research has studied green roofs [25], and no previous research has been done to investigate the integration of entrepreneurship and STEAM with designing green buildings. Moreover, research has yet to examine the integration of entrepreneurship and STEAM with designing green buildings in engineering education. Thus, it is a novel area requiring extensive research in academia and the AEC industry. However, the literature review provides a holistic view of this study's topic.

Due to the potential benefits associated with green roofing systems, previous research has recommended conducting studies on green roof systems [26], [40], [41], [42]. Researchers studied the hydroponic green roof system in Asian and Middle Eastern countries and European countries, such as Spain, Portugal, Greece, and Germany [25]. However, a few studies have been searched in the United States for hydroponic green roof systems, as shown in Figure-1.

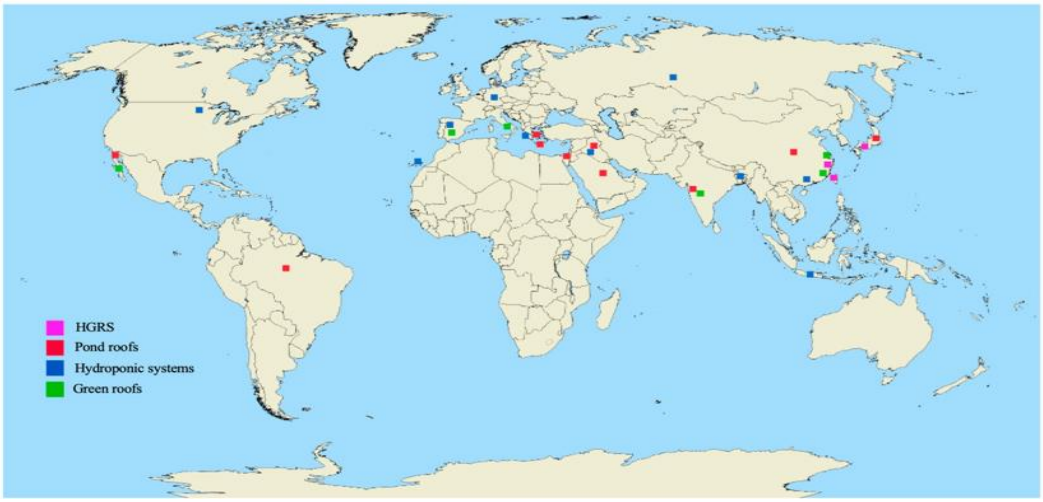

Figure-1: Geographic individuation of analyzed studies on hydroponic green roof systems, pond roofs, hydroponic systems, and green roofs [25].

The data and information provided by those studies are qualitative and fragmented, not providing deep insight and knowledge on this topic. Previous research has yet to study green roof systems' economic feasibility, constructability, operation, and maintenance. As a result, this topic is selected to engage students in this new topic as a part of their capstone projects and semester projects.

A previous study examined integrating innovation and entrepreneurship principles into the civil engineering curriculum. However, the research did not address the integration of entrepreneurship and STEAM with sustainability. Moreover, assessment rubrics were developed to evaluate students' outcomes [43] instead of employing photovoice as a research method that enables students to express their learning experience.

On the other hand, a study emphasizes that engineering and construction must head the call for sustainability. However, this research also refers to the need for more knowledge, time, or incentives for instructors to develop sustainable concepts in their course materials [44]. To overcome those barriers, case studies and modules are being added to curricula [45], [46]. Another study concludes that integrating sustainability into a capstone construction project enables a more profound learning opportunity than offering a separate course in sustainability [47]. Also, research shows that despite a constrained four-year curriculum, the United States Air Force Academy civil and environmental engineering students learn and apply sustainability concepts at multiple points during their -four-year program [48].

3. Methods

This study assesses senior students' perceptions of a four-week assignment incorporated into the capstone project course in two semesters and the semester project of the pre-construction management in one semester. During these four weeks, the students understand and learn how to integrate entrepreneurship and STEAM into designing green (bio-inspired) roofs for their construction project.

3.1 Intervention

Project Problem Statement

You are a green entrepreneur engineer; you want to create innovative solutions in designing and building green roofs compatible with the building types, locations, weather, vegetation, building codes, and other related issues in the United States of America. Your solutions must be sustainable (bio-inspired) design, conduct intensive research, meet the client's needs, expectations, and aesthetic preferences using art, generate profits, and be easy and feasible to construct, operate, and maintain. You must develop a 3D BIM (Building Information Modeling) as a prototype. Others must evaluate your module to get constructive feedback that enables you to improve your innovation.

Assignment Goal
The aim is not only to teach students how to integrate entrepreneurship and STEAM into designing green (bio-inspired) roofs but also to every building component of construction projects. It also improves students' verbal and written communication skills and enhances collaboration and teamwork. This assignment contributes to preparing today's students to be future green entrepreneurs and T-shaped engineers.

Knowledge and Topics Required
Before introducing this project, the knowledge and topics required to complete this assignment are scheduled to be covered in lectures. Green building concepts generally are introduced, and green roof systems are explained to students. Bio-inspired design is also demonstrated and supported by case studies connecting design with nature. Moreover, the topics of entrepreneurship, market analysis, and SWOT (Strengths, Weaknesses, Opportunities, and Threats) are presented, defined, and explained.

As illustrated in Table-1, the assignment is divided into four-week deliverables. This project accounts for 20% of the total course grade. It is individual homework. However, the students work in a group setting as this assignment is a part of their senior project.

Table-1: The Deliverables of Four-Week Assignments

WEEK #1: Research (25 points)	WEEK #3: 3D BIM Module (25 points)
1. Identify suitable locations in the USA.	1. Design the 3D green roofs using BIM software.
2. Identify materials for the green roof.	2. Place the green roof design on a 3D BIM module on a single-family home.
3. Identify types of vegetation.	3. Conduct constructability review.
4. Identify bio-friendly irrigation methods.	4. Get the feedback of at least three persons on the green roof.
5. Identify the maintenance methods throughout the life cycle of the roof and plants.	
6. Identify how to handle roofs with solar panels.	
7.Identfy the design criteria and constructability methods.	
WEEK #2: Market Analysis & Economic Feasibility (25 points)	WEEK #4: Final Deliverable (25 points)
1. Conduct market analysis (SWOT).	1. Spot areas of improvement in the design.
2. Perform cost estimate of the product design and construction.	2. Edit and finalize the design.
3. Study project's economic feasibility.	3.Submit a final report, PowerPoint slides, with the 3D BIM module.
	4. Conduct a 5-minute presentation.

Green Roof Designs
As demonstrated in Table-1, the project was created to enable students to unleash their creativity and be inspired by nature and art to find sustainable and economic solutions. The instructor explained to students the different types of green roofs. However, the students were asked to design roofs considering the unique circumstances of each location. The project location limits students' choices of roof design mechanics, selection of construction materials, and vegetation types. The goal is to find a creative way to design a cost-effective green roof throughout the life cycle of the roof and plants, minimizing the expenses related to maintenance. In a previous BIM (Building Information Modeling) course, the students employed Revit software to design a single-family house. The students used those houses to add green roof designs to them. Each

student created a 3D BIM module for a green roof design, placed it on a single-family house, and asked for feedback from three persons to spot areas of improvement, edit, and finalize the 3D BIM module of the green roof design.

3.2 Participants

Twenty-nine students participated in this study. This study included two female students and twenty-seven male students. Twenty-five are majoring in construction management, and four are in civil engineering. The photovoice format was shared with them to assess their perceptions of this study, which returned a response rate of 100%. Demographic data on the study participants indicated no differences in learners' perceptions based on gender or major.

3.3 Study Design and Data Collection Protocol

This study uses participatory action research (PAR) as a data collection instrument. PAR is a qualitative approach in which researchers work collaboratively with the participant subject population to collect data, reflect on it, and take action [49], [50]. Photovoice, commonly linked to PAR, includes photos supplemented with narrative or open-ended questions to further elicit understanding in a process coined photo-elicitation. In other words, photovoice is a qualitative method exploring the data and giving a unique depth of understanding to the research questions identified, offering new insights and perspectives toward making improvements [51], [52].

Similar to previous studies conducted in engineering education [53] [54], [55], three photovoice reflection prompts and two open-ended reflection questions were given to the students doing the course assignment. The students selected three pictures for each photovoice reflection prompt with (3-5 sentences) to demonstrate the selection of images and (3-5 sentences) to respond to the two open-ended reflection questions as described below:

1. Photovoice Reflection Prompt A (**Entrepreneurial Integration**): The entrepreneurial mindset is defined as "the inclination to discover, evaluate, and exploit opportunities." Explain how participating in the newly developed curriculum integrated the entrepreneurial mindset and lessons learned relevant to the entrepreneurial mindset.

2. Photovoice Reflection Prompt B (**STEAM**): STEAM (science, technology, engineering, arts, math) goes one step beyond the well-known STEM to acknowledge the importance of integrating the arts and humanities into more analytical coursework, such as that found within engineering. Art can be incorporated through pieces, processes, and movements. Explain how participating in the newly developed curriculum incorporated STEAM (specifically, the arts) and lessons learned relevant to STEAM (specifically, the arts).

3. Photovoice Reflection Prompt C (**Bio-Inspired Design**): Bio-inspired design uses the nature-focused context of sustainability, security, and/or biomedicine and health outcomes to motivate analogical thinking and improve the engineering design process. Explain how participating in the newly developed curriculum incorporated bio-inspired design and lessons learned relevant to bio-inspired design.

4. Open-Ended Reflection Question A (**Interdisciplinarity**): The interdisciplinary approach of integrating the entrepreneurial mindset, STEAM (specifically, the arts), and bio-inspired design has been shown to affect student engagement, motivation, and learning outcomes. How did this interdisciplinary learning experience affect your ability to engage with the newly developed curriculum?

5. Open-Ended Reflection Question C (**Connect to Real World**): What skills did you learn? Please consider both professional skills (e.g., communication, collaboration, etc.) and context-specific skills (e.g., topic area). Why are these skills important for engineers in the real world?

3.4 Data Analysis Procedure(s)

The data gathered by the researcher were analyzed using thematic analysis. Thematic analysis is a fundamental qualitative method for finding patterns within the data set using a step-by-step process [56]. After gathering data, the research themes were generated, and the report was written. The researcher used quotes from the collected data to present evidence supporting credibility, accuracy, and fairness [57].

4. Results and Discussion

After analyzing the qualitative data, six core themes related to assessing the students' perceptions of this study were identified, including (1) curriculum design, (2) students, (3) entrepreneurship, (4) sustainable (bio-inspired) design, (5) art, and (6) technology.

4.1 Curriculum Design

The instructional theme mainly addressed the course's curriculum design and pedagogical approaches, viewed as the principal area where the instructor makes direct and immediate changes when necessary to improve the course materials and students' deliverables. Here, two subthemes emerged.

Authentic Learning and Transferable Skills: Students identified their authentic learning outcomes after attending this course and doing their assignments. They obtained knowledge and skills transferable across domains and applicable to solving real-world problems. Examples of genuine learning quotes are presented below:

- *I **learned for the first time** about integrating bioengineering with* entrepreneurship. *I am thinking about engineering and design from a new lens right now.*
- *This course created **a better understanding of sustainability and how to integrate it into developments** that both improve the environment but also improve the comfort and beautification of the building*.

Pedagogical Approach: The students addressed the proper outcomes associated with the pedagogical approach of this course. The examples of quotes are presented below:

- *The professor gave **clear instructions** about what we must submit in each deliverable to complete the project.*
- *The entrepreneurship, market analysis (SWOT), sustainability, and art lectures **helped us to do the assignment.***

4.2 Students

The individual student theme highlighted particularly students' performance, interaction with teammates, and future career vision.

Collaboration and Communication: The students expressed their perception of collaboration and communication after working in a team setting to accomplish the project associated with this study. The examples of quotes are presented below:

- *The team dynamic provided a way for each team member to convey their strengths, and in places where they might have difficulties, **other team members** were able to **help them improve that portion of their work**.*
- *I **learned to communicate with my team members**, come up with different ideas, and overall having patience for a tedious project.*

Procrastination and Time Management: The students admitted the challenges they faced regarding time management and deadlines. The examples of quotes are presented below:

- *We **started extremely slow**, with a lot of time not being used adequately. **If we began this project at the pace we were in the final week** of the project it would have improved it greatly.*
- *The things that didn't go well **we did not take things seriously in the first week**. We **stressed-out** because of the deadline. I will be more **proactive**. I must ask questions to the professor to clarify things that they were not clear to me.*

Future Career The students comprehended the knowledge and skills they learned in this project would benefit their future careers. The examples of quotes are presented below:

- *Hopefully these **skills** will be very useful in the future, and I **can't wait to see what impact** or what this project's impact will help us to be successful.*
- *The resources and knowledge (entrepreneurship concepts, art, bioengineering, market analysis, clients' feedback, comparing and evaluating options, creating values, and making money) I gained during this project will be used **in my continuation as a professional engineer** and motivate me to continue my studies of **green issues** and master them for professional use from entrepreneurship mindset.*

4.3 Entrepreneurship

The entrepreneurship theme addressed how the students could think about their construction project from an entrepreneurial mindset.

Spotting New Opportunities: The students were able to spot opportunities necessary to the success of their project. The examples of quotes are presented below:

- *We are able to use the prompt **and identify what the client needs and what the buyer will want from t**his project and that's what we use to deliver our house production line.*
- *Based on the market analysis, I **tried to discover opportunities for our clients** in several profitable and appealing options.*

Inspiration: The students referred to the inspiration effect on their performance while doing the project designed for this study. The examples of quotes are presented below:

- *The bioengineering design **has inspired** me to think critically and find solutions from nature.*
- *I am **inspired** to connect my projects with nature.*

Creativity: The students stated that they found creative solutions to solve problems while doing the project designed for this study. The examples of quotes are presented below:

- *The main problem that arose was the complications with plant irrigation and using my problem-solving skills, I was able to develop the land around it and **create an efficient irrigation system.***
- *I decided to think outside the box and search, evaluate and **create bio-engineering solutions to save the planet without costing people many dollars**.*

Connection: The students described how they used the connection to find better solutions to their problems while doing the project designed for this study. The examples of quotes are presented below:

- *I discovered **how connecting nature** with projects can change the outcome and appeal to clients and be profitable at the same time.*
- *I tried to **connect the client's needs** with what is available in nature with **less human intervention in irrigation.***

4.4 Sustainable (bio-inspired) Design

The students demonstrated how bioengineering (sustainability) could divert the outcomes of their product to a better solution while working on this study's project. The examples of quotes are presented below:

- *This project showed me that some parts of **sustainability** are not on full display. Examples like how **native plants are used in green walls and roofs without the need to water them.***
- *This project created a **better understanding of sustainability** and how to integrate it into developments that both **improve the environment** but also improve the **comfort** and **beautification** of the building.*

4.5 Art

The students realized how art incorporation in their project positively impacts their product while working to deliver the project designed for this study. The examples of quotes are presented below:

- *It also shows how **art** can be incorporated in such projects that require lots of math and research, as well as shows the **beauty** in this type of work.*
- *I included **creative shapes** in the structural options that **children and adults find attractive.***

4.6 Technology

Efficiency, Productivity, and Creativity: The student emphasized how technology enabled them to be more efficient, productive, and creative while working to deliver the project designed for this study. The examples of quotes are presented below:

- *Working with BIM allowed me to **make changes fast** to reach to what is appealing to clients after getting the feedback. With BIM, I was able to be **creative** and **discovered many ways** to make my design attractive.*
- *For example, with **BIM** I designed different 3D modules and I was able to show them to other students, clients, and professors to get their feedback in my design.*

Interdisciplinary: The student illustrated how technology is a valuable tool to facilitate interdisciplinary while working to deliver the project designed for this study. The examples of quotes are presented below:

*The **interdisciplinary learning experience** allowed me to diverse my ability to utilize different technological resources to produce a product.*

- *Another technological web that helped us with our product design projects are **MS project, RSMeans Online (online software for cost estimate of construction projects), social media handles, and other known web.***

5. Summary of Themes

In summary, the qualitative analysis of photovoice data resulted in six core themes (Figure 2) related to assessing students' perceptions of integrating entrepreneurship and STEAM with designing green (bio-inspired) roofs in these two courses.

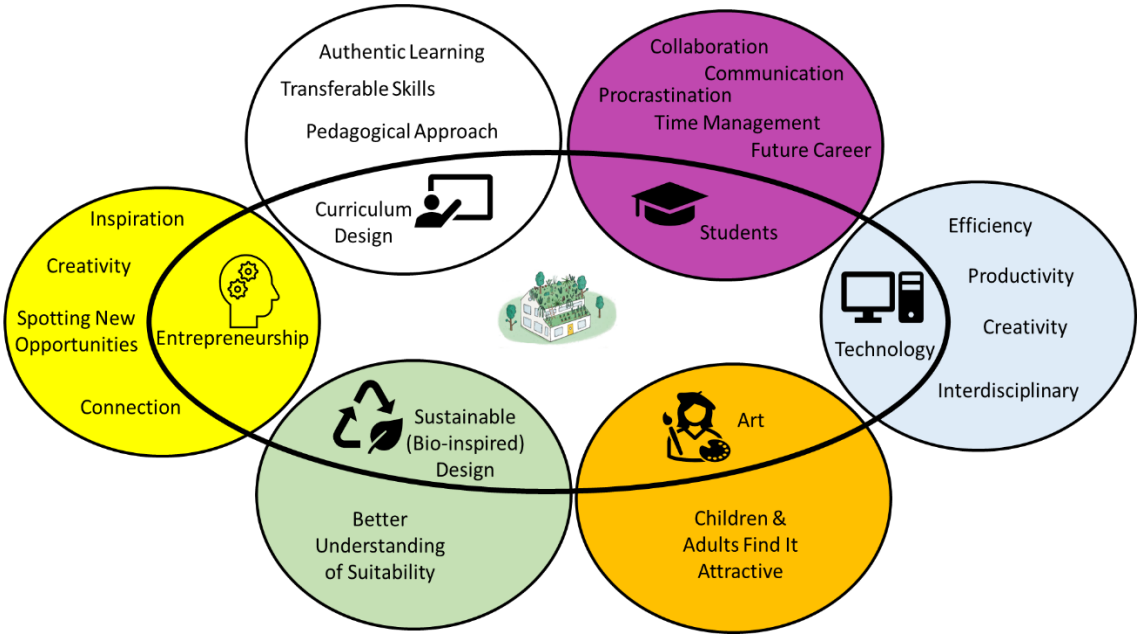

Figure-2: Summary of Themes
(Integrating Entrepreneurship and STEAM with Green (Bio-inspired) Design)
By: The researcher

The curriculum design theme and subthemes of the course are considered within the direct and immediate control of the instructors. Thus, new topics were identified by the instructor to cover before starting the project to make sure that students had the required knowledge to accomplish the assignment. The lectures on the new topics, including entrepreneurship, market analysis, and SWOT (Strengths, Weaknesses, Opportunities, and Threats), were presented, defined, and explained. As a result, the theme and subthemes align well with authentic learning experiences, allowing students to gain first-hand experiences of the constraints and challenges and to be involved in real-world topics or issues [58], [59].

The individual student theme is within the primary control of the students yet can be influenced by the institution and instructor. A real-world project, on the other hand, is time-consuming for instructors and students, requiring planning and structuring the curriculum and the activities associated with this project. With unexpected challenges and uncertainty, the real-world project can create significant anxiety for instructors and students [60], [61]. Based on this study's results, the instructor intends to make the following changes to overcome procrastination and improve time management: (1) develop a structure with clear guidance for a kickoff meeting assignment

and give it to the student before the project starting date, (2) assign time and a location for this kickoff meeting, (3) create a survey with each deliverable for self and peer evaluation, (4) provide students with a similar previous assignment with lessons learned.

In the entrepreneurship theme, the instructor plays a significant role in developing a curriculum integrating entrepreneurship with STEAM. The keywords shown on the subtheme results of this study (inspiration, creativity, spotting new opportunities, and connection) are in alignment with the 3CS (Curiosity, Connections, and Creating Value) of Engineering Unleashed prepared by KEEN (The Kern Entrepreneurial Engineering Network), [62]. Thus, the study results confirm previous research's findings on entrepreneurship's effect on students' gaining insights beyond the technical skills of their discipline and enabling them to be leaders and innovators facing the global challenges of the twenty-first century [43], [63].

On the other hand, the suitability theme adheres to the instructor's responsibility in educating students on bio-inspired design and integrating it into their project. Combining entrepreneurship with sustainability is achievable despite its challenges and associated barriers. However, thinking outside the box and borrowing solutions from nature allows engineers to create green buildings that are environmentally friendly and economically feasible. The theme results align with the literature and highlight how bio-inspired design encourages transdisciplinary problem-solving, promoting connections and applicability to most (if not all) engineering disciplines, such as civil engineering [53]. In addition, the theme results show how teaching the integration of entrepreneurship with sustainability positively impacts students' learning experience and mindset towards these two rival concepts.

Also, the curriculum of this study is designed to bring art to the STEM classroom. Art is categorized into three types: (1) art pieces, (2) art process, and (3) art movement. Generally, buildings and landscapes are art pieces for designers and art processes for engineers [64]. However, the art theme addresses how this study brought students' attention to the value added to their project when incorporating art in STEM. The art theme results agree with the literature that art integration can enhance STEM learning by making it more relevant to students [65], capturing their interest, activating and reifying neural networks [66], and deepening their understanding of the arts and core content.

Finally, the technology theme and subtheme echo how incorporating technology in STEAM advances and modernizes students' learning experiences. The keywords (efficiency, productivity, creativity, interdisciplinary) expressed in the technology theme and subtheme align with the positive impact of BIM (Building Information Modeling) and cutting-edge technology on construction projects. The students developed 3D BIM modules for their project. BIM and cutting-edge technology enable the entire project team to work effectively and efficiently in planning, designing, constructing, and managing projects. Data and information are gathered from the design, construction, operation, and maintenance phases and then combined in digital virtual models. Simulations are run on these virtual models that imitate the virtual reality of the design and construction to make sound decisions, generate innovative solutions, choose the best alternatives, and improve project performance and productivity before starting construction. [67], [68].

6. Conclusion

6.1 Response to Research Question/Objective and Summary of Main Takeaway

This study aimed to integrate entrepreneurship and STEAM with designing green (bio-inspired) roofs in two senior-level courses: 1. the capstone project course in two semesters, 2. the pre-construction management course in one semester. It was a firsthand experience for students to integrate entrepreneurship and STEAM with sustainability. In this authentic learning experience, the students were exposed to a real-world project and communicated, collaborated, and reflected to develop critical thinking and problem-solving skills. Thus, the curriculum meets the study's goal of preparing future green entrepreneurs and T-shaped engineers. Subsequently, this study fulfills a knowledge gap by researching a novel topic that contributes to advancing interdisciplinary learning experiences in engineering curricula. In addition to green roofs, this study can be applied to all other components of green buildings and replicated by instructors of other institutions.

Participatory action research (PAR) was used as a data collection instrument. Obtained qualitative data collected by utilizing photovoice were analyzed using thematic analysis. Six core themes related to this study were identified, including (1) curriculum design, (2) students, (3) entrepreneurship, (4) sustainable (bio-inspired) design, (5) art, and (6) technology. Each one of these six themes includes subthemes. The themes and subthemes were discussed, summarized, and depicted in Figur-2. Also, the results of the themes and subthemes align with the literature emphasizing the positive impact of integrating entrepreneurship and STEAM with green (bio-inspired) design on students' learning experience.

6.2 Implications for Practitioners (Lessons Learned)

Improving Teamwork Dynamic and Time Management Issues:
Based on this study's results, the instructor intends to make the following changes to overcome procrastination and improve time management: (1) develop a structure with clear guidance for a kickoff meeting assignment and give it to the student before the project starting date, (2) assign time and a location for this kickoff meeting, (3) create a survey with each deliverable for self and peer evaluation.

Discussing the Previous Projects:
The instructor intends to improve the curriculum by providing students with a similar previous assignment with lessons learned.

Green Entrepreneurship and T-Shaped Engineering: Based on the rewarding outcome of this study, in addition to STEAM and technology already included in the instructors' curricula, the instructor intends to continue incorporating sustainable (bio-inspired) design and entrepreneurship.

6.3 Specific Entrepreneurial Skills Students Developed through the Curriculum

For the first time, this project considered and adopted the teaching of innovation/entrepreneurship integrated with sustainability in a Civil and Environmental Engineering and Construction Management Program. As a result, this study laid the foundation for creating learning environments that foster innovation, entrepreneurship, and sustainability in that department. Moreover, integrating entrepreneurship and sustainability into the curricula of that department has made the students think about the design and execution of construction projects from an entrepreneurial/innovative and sustainable mindset. The study also assessed the students' entrepreneurship and innovation competencies and perceptions.

6.4 Limitations, Future Research, and Recommendations

The limitation of this research is that it only used photovoice under the umbrella of participatory action research (PAR) to evaluate students' perceptions of the curriculum design. Future research is recommended in academia and the AEC industry using other research methods to assess students' perceptions.

In conclusion, since the curriculum is the most logical place to educate about and adapt to the changing expectations of students and industry, this study recommends improving engineering education by integrating entrepreneurship and STEAM with green (bio-inspired) design. Concisely, I recommend targeting the four undergraduate student levels at the AEC academic institutions. Subsequently, these institutions must develop a framework identifying and describing the topics (knowledge) and (skills) necessary for integrating entrepreneurship with sustainability. Metrics must also be created to measure the outcomes of this integration to evaluate, improve, and advance the curricula integrating sustainability with entrepreneurship. In addition to integrating entrepreneurship with sustainability in engineering education programs, similar frameworks can be created to incorporate entrepreneurship with other themes to enhance diversity, promote ethics, and uplift economies.

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