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Engaging Engineering Students with the Stakeholders for Infrastructure Planning

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Abstract: Construction projects should be planned and executed in a way that minimizes the inconvenience to the local community. For that, it is crucial to incorporate public opinion by engaging them in the decision-making process. However, the public is generally involved indirectly in the planning of infrastructure projects through information-sharing reports and meetings, which have not shown to be very effective. This paper presents the findings of a case study as a hands-on experience for graduate engineering students toward engaging the public in the feasibility assessment of a real-world rehabilitation project. The case study involves the application of a simple additive weighting (SAW) multi-criteria decision-making (MCDM) approach to the assessment of various dimensions of the proposed rehabilitation alternatives. As a part of the MCDM framework, public opinion is sought to determine the relative importance of various criteria in making the final decision. The steps and processes of the case study are summarized and proposed in the form of a framework for engaging both students and the community members in the planning of construction projects. The case study and the framework serve as a structured introductory exercise for raising awareness in the students about the impact of public opinion on the planning of construction projects, and the existence of methods that can help them articulate participatory processes. This structured exercise is replicable for future researchers. It is expected that the application of the approach pursued in this study will help promote a culture of accommodating public engagement among engineering students as future engineers in the long term.

Keywords: multi-criteria decision-making; engineering education; public engagement; unmanned aerial vehicle

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1. Introduction

The primary goal of the construction industry is to enhance the quality of life of community members and serve the common welfare by providing physical facilities and infrastructure systems based on public needs and values [1]. Therefore, construction projects should be planned and executed in a way that minimizes the inconvenience to the local community [2,3]. However, there are often unexpected impacts of a project or action on others, called "externalities" [4]. To eliminate negative externalities, it is crucial to incorporate public opinion by engaging with them in the decision-making process. Regarding public engagement, an old concern should be addressed: can the general public have a major influence in planning decisions? [5].

Past examples in the literature have questioned the effectiveness of the required public engagement processes in transportation projects [6]. Several past studies [7,8] asserted that formal public engagement processes were generally "rituals designed to satisfy legal requirements" and that engineers were not adequately involved in community concerns [9,10]. If community concerns remain overlooked, future scholars and practitioners will continue to consider public engagement irrelevant to their practice [11]. One dominant perception is that engineering is about technical problem-solving, which precludes engineering students from engaging with public welfare concerns [12–14]. In the long term, such practices and perceptions can lead to failure in the consideration of community concerns and in the broader impacts of engineering projects on society [15]. Therefore, the onus is on undergraduate and graduate students to interrupt the cycle of oblivion and to develop a culture of accommodating public engagement [11].

This explains the need for an integrated framework to educate students and future engineers on how to get the public involved in the planning of construction projects. To address this need, this study proposes a framework for educating engineering students to engage the public in the planning of construction projects. This is followed by a case study that involves the engagement of engineering graduate students with the public in the feasibility assessment of various alternatives for a construction project (Suda Wall, Hamilton County, IN, USA). Throughout the case study, students were trained to adopt multi-criteria decision-making (MCDM) to engage community members in the decision-making process.

The case study and the introduced framework serve as a structured introductory exercise for raising awareness in the students about the impact of public opinion on the planning of construction projects, and the existence of methods that can help them articulate participatory processes. This structured approach is replicable for future researchers. The applications of the approach pursued in this study promote a culture of public engagement among engineering students, which can reduce the negative externalities of construction projects in the long term.

2. Background

Construction projects can incur various unintended or uncontrolled damage or social costs to the nearby society [16]. Economists [17,18] define social costs as "the overall impact of an economic activity on the welfare of society. Social costs are the sum of private costs arising from the activity and any externalities". The main issue with considering social costs in the design and planning stage of projects is that social costs are borne by the public rather than the project participants, and affected communities are not engaged in the planning and management of the projects [19]. The social costs are called "Negative externalities", when an act from an individual causes harm to other members of the society, who do not get compensated for the negative impact [20].

Complexities in quantifying the intangible effects of project externalities that also consider monetary evaluations have led to the development of several multi-criteria evaluation methods [21,22]. As a powerful decision-aid tool, multi-criteria decision-making (MCDM) models are becoming more accepted for assessing the feasibility of construction projects, as they allow for the consideration of multiple and occasionally conflicting criteria [23]. MCDM methods also provide the opportunity for considering the interests of various stakeholders [21,24]. For instance, the analytic hierarchy process (AHP) method [25] and ELECTRE [26], allow stakeholders to have their own criteria and preference [21].

Table 1 shows previous examples of the application of MCDM approaches to planning and feasibility assessments of various alternatives for civil engineering projects. In this table, the methods used by the authors as well as the means for public engagement are illustrated.

Table 1. Current research on public involvement in MCDM.

Authors	Application	Methods	Public Involvement Strategy
(Arroyo & Molinos-Senante, 2018) [27]	Selecting appropriate wastewater treatment technologies.	Choosing-by-advantages approach (CBA)	Indirect: Adding public acceptance criterion in the planning stage.

Table 1. *Cont.*

Authors	Application	Methods	Public Involvement Strategy
(Heravi et al., 2017) [28]	Selecting sustainable industrial building options.	Multi-criteria group decision-making, ELECTRE, grey system theory, ordered weighted averaging	Indirect: Considering social aspects in the planning stage.
(Yoon et al., 2009) [29]	Infrastructure systems assessment.	Analytical system for planning of infrastructure rehabilitation (ASPIRE)	Indirect: Considering social/political aspects in the planning stage.
Pellicer et al. (2016) [30]	Teaching graduate students on the sustainability of design and construction of infrastructure alternatives.	MCDM—AHP	None: General public is not among the stakeholders. Graduate students in construction field acted as experts.
(Zheng et al., 2016) [4]	Externality assessment of hydropower projects.	Input-output model for externalities	Indirect: Considering public benefits and negative externalities in the planning stage.
(Macharis et al., 2010) [21]	Turning Flanders into a top mobility and logistics region by 2020.	Multi-actor multi-criteria analysis (MAMCA), analytic hierarchy process (AHP)	Direct: Engaging various stakeholder groups using survey questionnaire to determine weights of the introduced criteria.
(Yoon et al., 2019) [31]	Wastewater infrastructure system planning.	MCDM-CBA—life cycle cost analysis-equilibria of power	Indirect: Quantifying the monetary impacts on the community.
(Büyüközkan & Karabulut, 2017) [32]	Comparison of thermal power with three renewable energy sources.	MCDM-AHP—VIKOR	Indirect: Considering social aspects in the planning stage.
(Ribas et al., 2019) [33]	Multi-criteria risk assessment of a large hydroelectric project	Fuzzy analytic hierarchy process (FAHP)	None: General public is not among the stakeholders.
Salas and Yepes (2022) [34]	Prioritizing the maintenance of different public facilities	MCDM—AHP	Direct: Engaging a team of 12 experts to determine weights of the introduced criteria.

As can be seen in Table 1, the main approach for considering the public involvement is through an indirect rather than a direct strategy, by adding criteria that consider the public needs. Yoon [31] adopted an equilibrium of power approach to demonstrate the benefits of construction projects to the community. However, it did not quantify the importance of the criteria based on the opinion of the local community. Another study on environmental and community risks of solar power plant construction sites in Australia considered the noise and dust when considering the impacts of the project on the community. However, the community was only engaged during the construction phase, and the agenda and minutes were published [35]. The table and these instances show that only on rare occasions, the public is directly involved in the planning of infrastructure projects. This is while the past research suggests that engagement approaches such as information sharing reports and meetings are not very effective [8].

This can be attributed to the dominant perception that engineering is about technical problem-solving, which precludes engineering students to consider both public welfare concerns and the broader impact of engineering projects on society [12–15]. In fact, a longitudinal study [36] on the public welfare beliefs of 326 engineering students at 4 US academic institutions: MIT, the Franklin Olin College of Engineering, Smith College, and the University of Massachusetts–Amherst, showed that the engineering students' perceptions of public welfare, in terms of their professional and ethical responsibilities and social consciousness, declined significantly over the course of their engineering education.

A more recent study [37] conducted 26 in-depth interviews with students at one public and one private university in the US. The outcome showed that the engineering students had difficulty justifying the value of non-technical work and integrating community knowledge into projects. For instance, one student mentioned that "I am an engineer—I don't know how to talk to people!", leading to the conclusion that engineers are not qualified to participate in surveys with communities. Another student emphasized their preference to have technical work rather than writing assignments: "I am an engineer! Give me something engineer-y!" These instances show that several students still stress technical aspects for defining the boundaries of engineering knowledge and practice, and tend to ignore community engagement [37].

In the past few decades, student-centered and collaborative learning approaches such as problem-based learning, project work, and guided small group work have become more common in higher education systems [38]. As the first step of problem-based learning, the students are first presented with the problem, and the learning needs are cooperatively identified under the guidance of the tutor. This is followed by a cycle of self-directed study, applying the obtained knowledge to addressing the problem, and summarizing the learned material. To be successful in engineering education, problem-based learning requires discussions guided by the teacher, problem-solving tutorials, as well as small group work. Interactive or co-operative learning facilitates student knowledge acquisition as well as the acquisition of the skill to improve their own knowledge [38]. Including case studies and discussion activities in the curriculum keeps students engaged with the ethical dimensions of their work [39].

Accordingly, this study presents the findings of a case study that involves the education of graduate engineering students for engagement with the public through the feasibility assessment of a real-world rehabilitation project in a team-based collaborative setting. As elaborated in the discussion section, the steps and processes of the case study are then summarized and proposed in the form of a framework for engaging both students and community members in the planning of construction projects through case studies.

3. Methodology for Case Study

The case study was conducted during the spring semester of a three-credit graduate-level civil engineering course, infrastructure planning, at Purdue University from January to May 2020. Twenty students were enrolled in the course and there were 3 h sessions once per week throughout the semester. The case study intended to provide hands-on experience with the planning, analysis, design, development, and feasibility study of the *Walden Ponds Project, Hamilton County, Carmel, Indiana, United States.* Students were divided into 4 groups of 5 students voluntarily. Each group evaluated certain dimensions of the problem and was assigned particular objectives to fulfill. They are demonstrated in Table 2.

Table 2. Student grouping and objectives.

Group	Objectives
Technical	• Collect data regarding technical issues • Identify constraints and issues around the project and the site • Provide the design team with recommendations for addressing drainage, i.e., dewatering, erosion control, and drainage, and retaining wall rehabilitation alternatives
Design and construction	• Collect basic information for design and schedule such as equipment and traffic condition • Provide specifications and design details
Planning and feasibility	• Identify constraints and issues around the project and the site • Identify the scope of project and work definitions • Determine cost estimates, schedules, risk, and logistical issues for each alternative
Social and environmental	• Collect data regarding social and political issues • Identify the relative importance of different criteria based on public opinion • Determine the benefit score for each alternative

In the case study, the students were engaged with the representatives of the homeowners' association (HOA) from the Walden Ponds community at Hamilton County to identify best-value solutions for the rehabilitation of an old retaining wall and improving the stormwater system in the county. An overview of the methods that the students used in the case study are discussed in the remainder of this section.

The students were asked to work in a team-based setting throughout the semester to interact with the owners of the project, who were the HOA representatives from the Walden Ponds community, to (1) understand the needs and concerns of the community, (2) identify current constraints of the project and conduct primary field testing, (3) engineer alternative solutions for the problem, (4) evaluate the benefits of each of the alternatives based on the social, technical, and economic aspects of the project and provide the best solution of design and schedule for performing the project, and (5) present the final outcome to the client in the form of a presentation and a final report, and come up with the "best value" alternative in coordination with the project owner. These steps are shown in Figure 1, which summarizes the methodology for the case study.

As Figure 1 shows, the community is involved in Steps 1, 4, and 5 of the decision-making process. Furthermore, as color-coded in the figure and discussed in the following sub-section, each of the student groups were responsible for certain steps carried out for the case study.

3.1. Step 1: Problem Definition

One of the class sessions was assigned to engage the students with representatives of HOA from the Walden Ponds community. During the session, HOA representatives made a presentation to the students about the problems, needs, constraints, and resources. There were two major objectives for the decision-making process: to identify solutions for (1) retaining wall rehabilitation and (2) drainage management. This step helped the students to get greater insights into owners' needs, concerns, constraints, and resources.

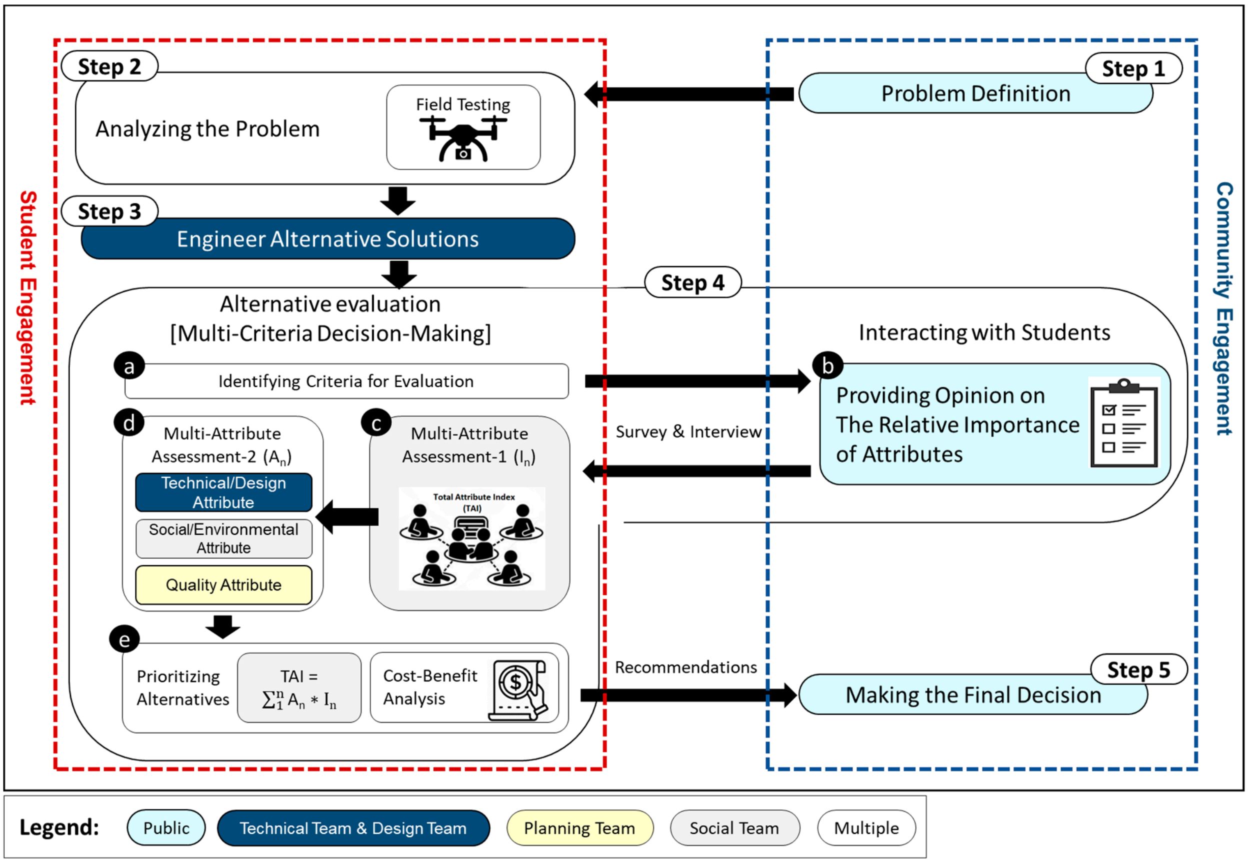


Figure 1. Methodology for case study.

3.2. Step 2: Analyzing the Problem and Field Testing

To further evaluate the site conditions, the leaders of the groups, who were nominated by the group members, did a site visit with the course instructor, project advisors, and HOA members. During the site visit, students evaluated the site conditions and documented the damages caused by the drainage problem to the retaining wall. The leaders of the groups were then tasked with communicating the outcomes of the site visit with the rest of their own teams.

Another part of the site visit was dedicated to data collection using unmanned aerial system (UAS), also known as drones. The collected data was used for generating 3-dimensional maps of the area. The data collection was conducted during the site visit by the course instructor with technical assistance. However, the group leaders and other students who were interested, had the chance to observe the process. DJI Mavic Pro, equipped with a 12 MP (Mega Pixel) RGB camera, was used to perform aerial surveys over the study area. Images collected from the DJI Mavic Pro were processed using a structure from motion (SfM) software—Agisoft Metashape Pro Version 1.7.6 (https://www.agisoft.com (accessed on 10 March 2020))—to generate 3D point clouds, digital surface models (DSM), and orthomosaic images. The surveyed coordinates of the GCPs were used in the SfM process to generate accurate geospatial data products that were used in an alternative proposal and evaluation.

3.3. Step 3: Engineer Alternative Solutions

After the site visit, the technical team was asked to identify possible alternative solutions for solving (1) the drainage problem, and the (2) retaining wall rehabilitation. The design team worked on providing design specification for the alternatives proposed by the technical team.

3.4. Step 4: Alternative Evaluation

The students were instructed to use MCDM to evaluate the identified alternatives. A considerable portion of the syllabus was dedicated to environmental assessment and different multi-criteria methods for the feasibility assessment of construction projects, including the analytic hierarchy process (AHP) [25], choosing by advantages (CBA) [40], and simple additive weighting (SAW) [41]. Since the purpose of this case study was to educate the students, SAW, which is the most simple, transparent, and user-friendly MCDM method and is even well-known to decision-makers, was selected [42]. Furthermore, a recent case study [43] on different MCDM methods such as simple additive weighting (SAW), weighted product method (WPM), and the analytical hierarchical process (AHP), showed that the outcomes of these methods are highly correlated.

All the groups were involved in conducting a multi-attribute assessment to evaluate the proposed construction alternatives for the identified problems based on both quantitative and qualitative assessments. To that end, several key attributes, A_n, which are the characteristics of the proposed alternatives, were used for the comparison of the alternatives. Each of the attributes, A_n, was weighted based on its relative importance, I_n. These two components, i.e., I_n and A_n, were then used to form a measure for the benefits associated with each alternative, the TAI:

$$Total\ Attribute\ Index\ (TAI) = \sum_{n=1}^{N} (I_n \times A_n) \quad (1)$$

To determine the *TAI*, it is necessary to (1) identify the criteria, (2) identify solution alternative scores with respect to each criterion, and (3) determine the weight for each criterion, as discussed in the following sub-sections.

3.4.1. Step 4-(a): Identifying Criteria

To identify appropriate criteria for comparing the suitability of the identified alternatives, the students were guided to conduct a literature review on the criteria commonly used in MCDM frameworks to incorporate a wide range of aspects. As discussed later in the results, these criteria include technical/design, quality, and social/environmental.

3.4.2. Step 4-(b), (c): Multi-Attribute Assessment–1 (I_n)

Multi-attribute assessment–1 (I_n), is a qualitative analysis used to identify the relative importance of various attributes in the view of the targeted community members, stakeholders, or decision-makers. This allows for the incorporation of public opinion (e.g., the relative importance of different factors in selecting the best construction alternative) in the decision-making and planning process of the projects.

To determine the relative importance of the considered criteria in the decision-making process (I_n), the social team was tasked with and guided through designing a brief survey questionnaire, to ask for the opinions and suggestions of the residents of Walden Ponds community. The survey was designed online on Qualtrics XM. To make the collected data unidentifiable, no personal information was collected in the survey questionnaire. The main purpose of the survey was to ask the two most important criteria in the view of Walden Ponds community. The results were aggregated automatically by Qualtrics, and linear scaling was used to determine the relative importance of each criterion based on the number of times it was selected by the respondents. Despite its simplicity, linear scaling provides reasonably accurate results for metric development [44–46]. This step requires public engagement, which results in the consideration of their opinion in the decision-making process.

3.4.3. Step 4-(d): Multi-Attribute Assessment–2 (A_n)

Multi-attribute assessment–2 (A_n) consists of three different analyses to determine technical/design, quality, and social/environmental attributes. Through multi-attribute assessment–2 (A_n) the available alternatives are compared with each other in a hierarchical fashion. Under each attribute, there are a number of dimensions, and each dimension is quantified based on a set of metrics. For instance, as elaborated in the next sub-section, the technical attribute has three dimensions, i.e., safety, logistic needs, and project duration. Logistic needs of each alternative are quantified based on three metrics, i.e., equipment needs, space requirements, temporary structures. After assigning metric scores and calculating dimension scores, the students used a geometric average formula to determine the attributes, A_n, based on the associated dimensions, D_m [47]:

$$A_n = \left(\prod_{m=1}^{M} D_{nm}\right)^{\frac{1}{M}} \tag{2}$$

where M is the number of dimensions, and n refers to alternative n. This formula assumes equal weights for the dimensions of each criterion. For instance, noise pollution and vibration caused by construction equipment are two dimensions for the social/environmental criterion. The weight of these two dimensions were considered to be the same. However, the weight of the social/environmental criterion in the overall benefit for an alternative, i.e., *TAI*, was determined using the survey questionnaire, as discussed in the previous section. It should be noted that the survey questionnaire only asked for the relative importance of the criteria and did not cover the importance of the dimensions under each criterion. This limitation can be addressed in future research studies.

Different student groups were involved in identifying the technical/design, quality, and social/environmental attributes for each alternative, as described below.

Technical/Design Attribute (T_i)

The objective of this analysis was to select the alternative that created minimal risk, constraints, as well as logistic issues and construction duration. The design and planning teams worked together to determine the overall technical/design score of each alternative i, T_i, based on safety risk (S_i), logistic needs (L_i), and duration (D_i), of the drainage and retaining wall rehabilitation alternatives using Equation (3):

$$T_i = C_T \times (Safety\ Risk\ (S_i) \times Logistic\ Needs(L_i) \times Duration(D_i))^{-1/3} \tag{3}$$

where C_T is a normalization factor to convert the technical/design scores given to alternatives to lie between 0 and 1. It should be noted that since higher safety risks, logistic needs, and duration are negative characteristics, a negative exponent has been used in Equation (3). The design team evaluated the risk and safety issues, while the planning team focused on evaluating the construction and logistic issues.

Safety Risk (S_i)

The design team was instructed to conduct a risk analysis to evaluate the type and the nature of the risks to the workers and the residents of the nearby communities for each alternative. Students in the design team quantified risk as the product of severity and chance of the potential adverse consequences (e.g., exceeding capacities such as the failure of the structure or overflow of the drainage). The severity and chance of adverse consequences were quantified with numbers, taking integer values between one and four [48,49]. Accordingly, the final risk score for each alternative was obtained by multiplying the score of chance and severity by subjective scoring of the proposed alternatives with respect to different risks (e.g., exceeding capacities such as the failure of the structure or overflow of the drainage). The final risk score for each alternative was obtained by summing over the product of the scores of the chance and severity of the risks for that alternative.

Duration (D_i)

To estimate the duration of the work, the planning team first developed the work breakdown structure (WBS). Next, the quantity and duration of the construction works associated with each task listed in the WBS were determined using standard data referenced in RS means [50]. In the end, the critical path method was used to determine the total construction duration based on the inter-dependency of the tasks using Microsoft Project.

Logistic Needs (L_i)

Construction might not go according to the plan due to site-specific and design-specific issues faced during the construction. According to Patty and Denton [51], equipment requirements and unforeseen work are the major areas of unforeseen project costs. Therefore, the planning team was asked to conduct a logistic assessment. The students identified three important factors, i.e., equipment needs, temporary structures, and storage requirements, and ranked the alternatives based on these three criteria.

Quality Attribute (Q_i)

The design team also evaluated the durability of each of the alternatives over the long term. To that end, the students in the design team used the same risk assessment approach used for characterizing safety risks. They compared the alternatives based on three durability risks, i.e., risk of overflow, risk of structure failure, and erosion. They determined the durability risk, and then the quality attribute for each of the alternatives using Equation (4):

$$Q_i = C_Q \left(Durability\ Risk_i\right)^{-1} \quad (4)$$

where C_Q, is a constant to convert the scores assigned to alternatives so that the maximum quality score for the alternatives becomes equal to 1.

Social/Environmental Attribute

The social team was asked to conduct a social/environmental analysis to determine the level of disturbance that each of the proposed alternatives will cause to the residents. The students leveraged the findings of experimental studies on the level of noise [52,53] and vibration [54,55] made by construction equipment to quantify the level of disturbance associated with the construction of the proposed alternatives. To that end, the social team used the type of machinery used for the construction activities and the duration of each activity to determine the generated level of noise and vibration. The list of activities and the duration of each activity were taken as inputs from the planning team.

The calculated noise and vibration were used to determine the social/environmental attribute, SE_i, of each alternative, as shown in Equation (5):.

$$SE_i = \left(\frac{C_{SE}}{\text{Vibration } (V_i) \times \text{ Noise}(N_i)}\right)^{\frac{1}{2}} \quad (5)$$

where C_{SE} is the normalization factor so that the highest score is 1.

3.4.4. Step 4-(e): Benefit-Cost Analysis

The objectives of this analysis are twofold: (1) to determine the costs of each alternative, and (2) to leverage the *TAI*, the costs, and to identify the best alternative for drainage management and retaining wall rehabilitation. To address these two objectives, first, the planning team conducted a financial analysis to calculate the construction costs of each alternative. Next, the social/environmental team conducted a cost-benefit analysis to identify the best solution.

Cost Estimation

For cost estimation, the planning team used RS means software's cost database, WBS, and the construction schedule to estimate the costs. Based on the assumptions made by the students, the finalized costs include materials costs, labor costs, overheads and profits (O&P), and equipment costs in USD in 2018.

Benefit Analysis

Once the attribute scores of each alternative were determined through Step 4, the social/environmental team used Equation (6) to weight these attributes by their associated level of importance determined through multi-attribute assessment-1 (I_n) to calculate *TAI*, which serves as the basis for comparing alternatives.

$$TAI_i = \left(I_T \times T_i + I_{SE} \times SE_i + I_Q \times Q_i\right) \quad (6)$$

where T_i, S_i, and Q_i are the technical, social/environmental, and quality scores of alternative *i*. While I_T, I_S, and I_Q are the associated weight of these three attributes in decision making. It is worth mentioning that these weights are determined based on multi-attribute assessment-1 (I_n), which involves asking the relative importance of these factors in the view of the public through a survey questionnaire.

Having the costs associated with each alternative, the social/environmental team conducted an incremental analysis to evaluate the impact of incremental increases in the costs on the gained benefits. The incremental or marginal analysis is a simple approach that assists decision-makers by providing a visual representation of benefit versus cost trends [31]. It involves the evaluation of the differences between two options from diverse benefit and cost aspects [56]. After sorting alternatives based on their costs, decision-makers decide whether the marginal benefits are worth the marginal costs [57].

3.5. Step 5: Making the Final Decision

The ordered list of alternatives and the incremental analysis results were then communicated with the HOA representatives in a meeting to determine the final alternative. During the meeting, the instructor described the overall flow and the distribution of the feasibility assessment among student groups. This was followed by presentations given by all members of each student group. During the presentation, the students described their assumptions, logic, and details of multi-attribute assessment-1 and multi-attribute assessment-2. The presentation was concluded by the cost-benefit analysis and incremental analysis results.

4. Case Study Results

This section elaborates on the outcomes of the case study conducted by the students. The students were engaged with the representatives of the homeowners in the Walden Ponds community throughout the semester to identify the best-value solutions for the needs of the residents.

4.1. Step 1: Problem Definition

As discussed, one of the class sessions was assigned to engage the students with the HOA representatives. The representatives communicated their needs and concerns with the students. The Walden Ponds subdivision, Carmel, IN, was developed in the 1980s on the site of a former outdoor movie theater. Overall, the subdivision is approximately 38 acres with 145 single-family houses. The existing retaining walls made by timber were projected to have a 70-year life. Nevertheless, in the middle of its lifespan, the timbers have deteriorated prematurely due to the water clogging in the absence of stormwater drains. There were, hence, two major objectives for the decision-making process: to identify solutions for (1) retaining wall rehabilitation and (2) drainage management.

The HOA representatives also mentioned the resources for the project, e.g., funding and management resources to do a mass mailing for the residents, funding for transportation of the students to do a site visit, and supplemental funding for necessary data acquisition or other activities. In addition to the presentation, the HOA representatives talked about the different dimensions of the project, e.g., social, technical, and planning, with the respective group. This helped the students get more insights into the problem and the owner's needs and constraints.

4.2. Step 2: Analyzing the Problem and Field Testing

As discussed, the leaders of the groups were then tasked with communicating the outcomes of the site visit with the rest of their own teams. Figure 2 shows the pictures taken through site investigation. As Figure 2a shows, the wooden wall has deteriorated significantly. In some cases, supplemental wood posts have been installed to maintain the integrity of the retaining wall, as shown in Figure 2b. Additionally, there was a risk of a retaining wall failure due to the loss of anchoring. This would lead to a landslide which, in turn, could cause damage to at least four houses that are located remarkably close to the retaining wall. Due to the unappealing look of the wall and water logging in the absence of stormwater drains, there was a risk for the property values to dwindle.

(**a**) (**b**) (**c**)

Figure 2. Site Investigation. (**a**) Water intrusion (1); (**b**) support post; (**c**) water intrusion (2).

Another part of the site visit was dedicated to the data collection from drones. A total of 646 images were collected on these flights on 29 February 2020. Since the onboard GPS of the Mavic Pro was not accurate enough to generate precise aerial maps, eight ground control points (GCPs) were surveyed using a survey-grade Trimble R10 real time kinematics (RTK) GPS (Figure 3).

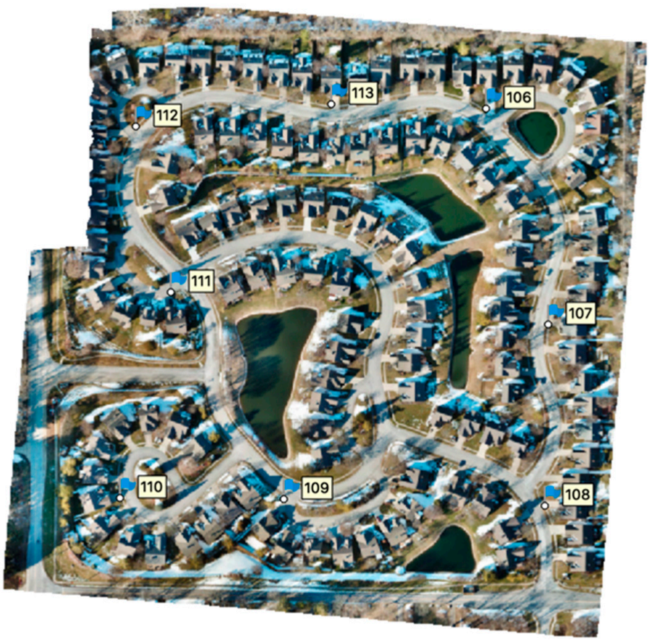
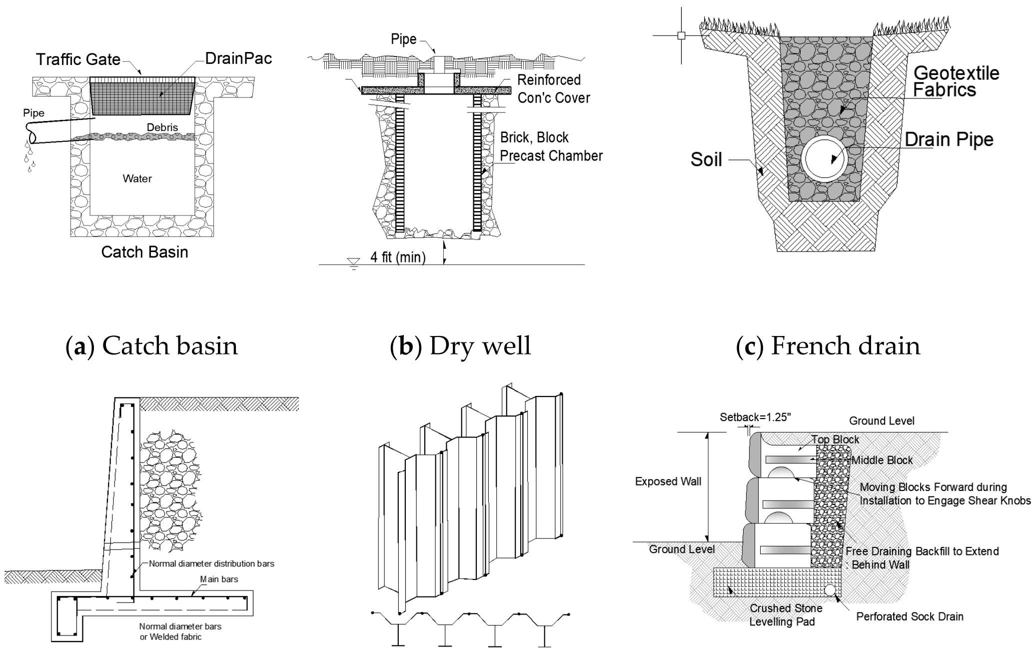


Figure 3. Spatial distribution of GCPs over the study area.

The generated fine spatial resolution 3D aerial maps were used for the technical/design analysis, to extract the geometric dimensions and identify the amount of work for particular drainage management alternatives.

4.3. Step 3: Engineer Alternative Solutions

After the site visit, the students had regular meetings with their instructor in their technical team, to communicate their issues and concerns and finalize the solution alternatives for solving (1) the drainage problem and (2) retaining wall rehabilitation. As Figure 4 shows, three different alternatives were proposed for each of the problems.



(**a**) Catch basin (**b**) Dry well (**c**) French drain

(**d**) Concrete cantilever retaining wall (**e**) Steel sheet piles (**f**) Redi-Rock wall

Figure 4. Proposed solutions for drainage management and retaining wall rehabilitation.

4.4. Step 4: Alternative Evaluation

Students were instructed to use simple additive weighting (SAW) MCDM to evaluate the identified alternatives. To conduct the MCDM, it is necessary to (1) identify the criteria, (2) identify solution alternative scores with respect to each criterion, and (3) determine the weight for each criterion. To that end, the student groups worked with each for the different tasks, as described below.

4.4.1. Step 4-(a): Identifying Criteria

The students were asked to identify the criteria for comparing the identified alternatives based on the existing MCDM frameworks and studies. For brevity, only a couple of the references reviewed by the students are provided as samples.

A review study of 105 hydropower plant feasibility studies used 3 broad criteria, i.e., technical, economic, and social/environmental [58]. A study regarding the environmental and community risks of a solar power plant construction sites in Australia [35] considered technical (e.g., transport of supplies to site and site access), social (e.g., disruption to the community and community acceptance), and environmental (e.g., noise, dust and air quality, drainage, and water management) criteria. The community was engaged only during the construction phase, and the agenda and minutes were published [35]. Another study on sustainable building assessment/certification recommended including noise pollution in the decision-making process [59].

Students selected the attributes and dimensions related to their focus based on the literature. As Table 3 shows, the identified criteria consider a wide range of aspects. As the table shows, the alternatives are compared based on the criteria in a hierarchical fashion. Under each criterion, there are a number of dimensions, and each dimension is quantified based on a set of metrics. For instance, the technical criterion has three dimensions, i.e., safety, logistic needs, and project duration. The logistic needs of each alternative are quantified based on three metrics, i.e., equipment needs, space requirements, and temporary structures.

Table 3. Criteria selected by the students.

Criteria	Dimension	Metric	Associated Student Team
Technical	Safety	• Excavation failure • Trip and fall • Collapse	Design team
	Logistic issues	• Equipment needs • Space requirements • Temporary structures	Planning team
	Project duration	NA	Planning team
Quality	Durability	• Risk of overflow • Failure of the structure • Erosion	Design team
Social/ environmental	Disturbance to local community	• Vibration • Noise	Social team

4.4.2. Step 4-(b),(c): Multi-Attribute Assessment–1 (I_n)

As discussed, to determine the criteria weights in the decision-making process (I_n), a brief survey was designed by the social team and was distributed, with the assistance of the HOA representatives, among the Walden Ponds community. The survey consisted of multiple-choice questions and a total number of 135 responses were collected. In addition to multiple-choice questions, the opportunity for providing comments was also provided so that the respondents could share their suggestions or extra information related to the question as well as the project, such as potential candidate sponsors for the project. Table 4 summarizes a selected number of survey questions and their associated target. Question 1 was aimed at identifying the relative importance of the criteria identified in previous stages, while the second question was asked for fundraising purposes.

Figure 5 shows the response of the participants to the first question of the survey. As demonstrated in Figure 5, safety, quality, and disturbances have been selected as the most important factors in 48, 43, and 9 percent of the responses, respectively. These ratios (0.48, 0.43, and 0.09) were used to determine the relative importance (I_n) of the criteria of technical, quality, and social/environmental factors in Equation (1).

Table 4. The survey questionnaire.

Scope	Description	Target
Social and environmental	Q1. Please choose the two factors that are most important to you (a) safety (b) quality (c) disturbance	Priorities
Financial	Q2. Which payback period would prefer for bearing the expenses incurred due to the repair or rehabilitation of the Suda wall? (a) one-time payment (b) bi-weekly (c) monthly (d) annual	Funding/financing options

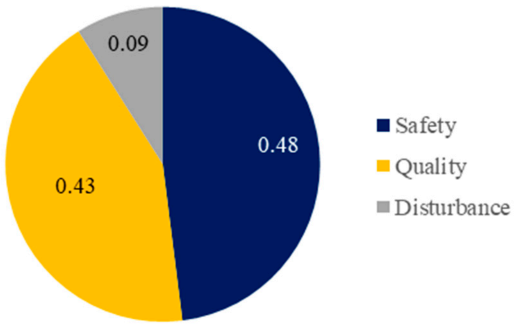


Figure 5. Priorities of the respondents.

The benefits of alternatives with respect to the considered attributes, A_n, were then determined through multi-attribute assessment–2 (A_n).

4.4.3. Step 4-(d): Multi-Attribute Assessment–2 (A_n)

This section presents the outcomes of the multi-attribute assessment–2 (A_n), which was aimed at identifying the benefits of each alternative. The multi-attribute assessment–2 (A_n) consists of three different analyses to determine technical/design, quality, and social/environmental attributes.

Technical Attribute

The design and planning teams worked together to determine the overall technical/design score of each alternative i, T_i, based on the safety risk (S_i), logistic needs (L_i), and duration (D_i) of the drainage and retaining wall rehabilitation alternatives using Equation (3).

Safety Risk

To evaluate the type and the nature of the risks to the workers and the residents of the nearby communities for each alternative, the design team conducted a risk analysis. To that end, the students in that team assigned a subjective score to the severity and probability of various potential risks, i.e., excavation failure, trip and fall, and collapse. The final risk score for each alternative was obtained by multiplying the score of chance and severity of the proposed alternatives (Table 5).

It is worth mentioning that more advanced tools such as virtual reality and augmented reality can be used for characterizing the workers' safety during the construction period [60–62].

Table 5. Technical/design analysis–safety risks associated with each alternative.

Problem	Dimension	Metric	Alternative 1			Alternative 2			Alternative 3		
			French Drain			Catch Basin			Dry Well		
			Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)
Drainage	Safety	Excavation failure	3	3	9	3	3	9	4	3	12
		Trip and fall	2	2	4	2	2	4	2	2	4
		Collapse	3	2	6	1	3	3	1	3	3
		Total			19			16			19
Retaining Wall			Concrete Wall			Steel Sheet Piles			Redi-Rock Wall		
			Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)
	Safety	Excavation failure	3	4	12	2	3	6	3	4	12
		Shoring risks	3	4	12	3	4	12	3	4	12
		Failure of the wall	1	4	4	1	4	4	2	4	8
		Total			28			22			32

Duration

The planning team used Microsoft Project and RS means [50] to determine the duration of construction for different alternatives. Table 6 shows the duration of the French drain as a sample. For the sake of brevity, the duration of the retaining wall rehabilitation alternatives as well as a sample schedule chart, is provided in Appendix A.

Table 6. Technical/design analysis–duration of each activity for French drain alternative.

Description			Qty.	Unit	Daily Output	Duration (Days)	Adjusted Duration (Day)
1.	Excavation (excavating, trench or continuous footing, dense hard clay, 3/8 C.Y. excavator)	Main	179.0	B.C.Y.	132.00	1.36	2.00
		Arterial	98.94	B.C.Y.	132.00	0.75	
2.	Pipe laying (public storm utility drainage piping, corrugated metal pipe)	Main	1611.0	L.F.	330.00	4.88	8.00
		Arterial	890.50	L.F.	330.00	2.70	
3.	Backfill (excavating, trench backfill, 1 C.Y bucket, minimal haul, front end loader)	Main	110.25	L.C.Y.	200.00	0.55	1.00
		Arterial	38.80	L.C.Y.	200.00	0.19	
4.	Soil compaction and finishing		-	-	-	1.00	1.00
	Total duration					10.43 days	12 days

Logistic Needs

The students identified three important factors, i.e., equipment needs, temporary structures, and storage requirements related to logistic needs. They ranked the alternatives based on these three criteria, as summarized in Table 7.

Table 7. Technical/design analysis—logistic needs.

Problem	Dimension	Metric	Alternative 1	Alternative 2	Alternative 3
			French Drain	Catch Basin	Dry Well + Catch Basin
Drainage	Logistic needs	Equipment needs	3	1	2
		Space requirements	3	1	2
		Temporary structures	2	1	3
		Total	7	3	8

Table 7. *Cont.*

Problem	Dimension	Metric	Alternative 1	Alternative 2	Alternative 3
			French Drain	Catch Basin	Dry Well + Catch Basin
			Concrete wall	Steel sheet piles	Redi-Rock wall
Retaining wall	Logistic needs	Equipment needs	1	3	2
		Space requirements	1	2	3
		Temporary structures	3	2	1
		Total	5	7	6

Overall Technical Score

The students in the design and planning teams determined the final technical/design score for each alternative, as shown in Table 8. It is worth mentioning that the constant values in the formulas, i.e., 8.77 and 16.95, are for normalizing the overall technical scores between 0 and 1.

Table 8. Technical/design analysis—overall score.

Problem	Dimension	Alternative 1	Alternative 2	Alternative 3
		French Drain	Catch Basin	Dry Well + Catch Basin
Drainage	Safety	19	16	16
	Logistic needs	7	3	8
	Duration	12	14	15
	$8.77/(\text{safety} \times \text{logistics} \times \text{duration})^{0.33}$	0.754	1.000	0.702
		Concrete wall	Steel sheet piles	Redi-Rock wall
Retainingwall	Safety	28	22	32
	Logistic needs	5	7	6
	Duration	98	42	25
	$16.95/(\text{safety} \times \text{logistics} \times \text{duration})^{0.33}$	0.712	0.915	1.000

Quality Attribute

The design team evaluated the durability of each of the alternatives over the long term based on three durability risks, i.e., risk of overflow, risk of structure failure, and erosion. They determined the durability risk, and then the quality attribute for each of the alternatives using Equation (4). The outcomes are summarized in Table 9. *The constant* C_Q, 12.05, is multiplied to normalize quality scores between 0 and 1.

Social/Environmental Attribute

The social team used the type of machinery used for the construction activities and the duration of each activity to determine the generated level of noise and vibration. The list of the activities and the duration of each activity were taken as inputs from the planning team. As a sample, Table 10 summarizes the noise (in dBA) and vibration (quantified by the peak particle velocity reported in "in/sec") for the French drain.

Table 9. Quality attribute of each alternative.

Problem	Dimension	Metric	Alternative 1			Alternative 2			Alternative 3		
			French Drain			Catch Basin			Dry Well		
			Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)
Drainage	Durability	Risk of overflow	2	2	4	2	2	4	2	2	4
		Failure of the structure	3	3	9	1	3	3	1	3	3
		Erosion	2	4	8	2	4	8	1	4	4
		Durability risk			21			15			11
		10.99/(durability risk)			0.528			0.736			1.000
Problem	Dimension	Metric	Concrete Wall			Steel Sheet Piles			Redi-Rock Wall		
			Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)
Retaining Wall	Durability	Material deterioration	1	2	2	3	2	6	2	2	4
		Failure at joint	1	4	4	1	4	4	1	4	4
		Foundation settlement	2	3	6	2	3	6	3	3	9
		Durability risk			12			16			17
		12.05/(durability risk)			1.000			0.759			0.711

Table 10. The level of noise and vibration of French drain.

Option	Activity		Adjusted Duration (days)	Noise			Vibration		
				Equipment	Intensity (dBA)	Total	Equipment	PPV + (in/sec)	Total
French drain	Excavation (excavating, trench or continuous footing, dense hard clay)	Main line	2.00	Excavator	78.25 *	156.5	Excavator/loader/backhoe	0.008 ***	0.016
		Arterial		Excavator	78.25 *				
	Pipe laying	Main line	8.00	Movable crane	77 **	616	Crane	0.007 ***	0.056
		Arterial		-					
	Backfill (excavating, trench backfill, 1 C.Y bucket, front end loader)	Main line	1.00	Excavator	78.25 *	78.25	Excavator/loader/backhoe	0.008 ***	0.008
		Arterial		Excavator	78.25 *				
	Soil compaction and finishing		1.00	Vibrating roller	76.07 *	76.07	Vibratory compactor	0.209 ***	0.209
			12.00			926.8			0.29

+ Peak particle velocity, * based on [52], ** based on [53], *** based on [63].

It should be noted that the estimates for the noise and vibration were measured at a specific distance from the machinery, which is appropriate for comparison purposes. Repeating the same procedure for the remaining alternatives and using Equation (5), the social/environmental scores of the alternatives are determined by calculating the geometric average of the noise and vibration produced by each alternative, as demonstrated in Table 11. Like the technical and quality scores, the social/environmental scores were scaled between 0 and 1 using constant multipliers, i.e., 16.37 and 29.66.

Table 11. Social/environmental scores.

Problem	Attribute	Dimension	Alternative 1	Alternative 2	Alternative 3
			French Drain	Catch Basin	Dry Well + Catch Basin
Drainage	Social/environmental	Noise	927	1008	1081
		Vibration	0.289	0.305	0.303
	16.37/[(Noise × Vibration)$^{0.5}$]		1.000	0.904	0.934
			Concrete wall	Steel sheet piles	Redi-Rock wall
Retaining Wall	Social/environmental	Noise	7887.52	449	3439.5
		Vibration	0.58	1.96	0.49
	29.66/[(Noise × Vibration)$^{0.5}$]		0.439	1.000	0.723

4.4.4. Step 4-(e): Benefit-Cost Analysis

Once T_i, SE_i, and Q_i were determined, the social/environmental team used Equation (6) to calculate the *TAI* for each alternative as the basis for comparing alternatives. Using the TAI and the costs associated with each alternative, the social/environmental team conducted a cost-benefit analysis to identify the best solution. To do that, the social team used the cost estimates provided by the planning team.

Cost Estimation

For brevity, only the cost estimates for drainage are presented in Table 12. A summary table for the costs associated with the retaining wall alternatives is provided in Appendix A.

Table 12. The estimated costs for drainage management solutions.

Drainage Type	Item	Quantity	Cost/Unit ($)	Total Cost ($)
Catch basins	18″ Catch basins (2 openings)	52 nos.	160	8320.00
	4″ Corrugated pipes	1880 feet	61.5/100 ft.	1156.20
	4″ Corrugated pipes Couplers	19 nos.	4.2	79.80
	4″ Inlet/outlet T fittings	32 nos.	6	192.00
	4″ Elbow fittings	20 nos.	5.7	114.00
	Drain excavation	52 catch basins + 2800 ft. drainage line	123.71/yd^3	22,960.18
				$32,822.86
Dry wells	NDS flo-well	2 nos.	73.4	146.8
	Surface drain inlet with grate	2 nos.	31.85	63.7
	Landscape fabric (4′ × 200′)	1 roll	45	45
	4″ Inlet/outlet T fittings	2 nos.	6	12
	Excavation cost	2 wells + drainage line of 60 ft.	123.71/yd^3	16,225.06
				$16,492.5
French drain	EZ drain	2500 feet	50/50 feet	2500.00
	4″ Corrugated coupling	50	4	200.00
	4″ Corrugated end cap	18	3	54.00
	Excavation costs	2500 ft. drainage line (1.5′ × 2′)	123.71/yd^3	34,167.00
				$36,921.00

Benefit Analysis

The benefit of each alternative was measured based on the TAI, which was determined based on the technical/design, quality, and socio-environmental scores, weighted by their relative importance obtained from the survey questionnaire. Table 13 shows the TAI for each alternative.

Table 13. The benefits associated with the evaluated alternatives.

Problem	Attribute (A_n)	Weight (I_n)	Alternative		
			French Drain	Catch Basin	Dry Well + Catch Basin
Drainage	Technical and design	0.48	0.754	1.000	0.702
	Quality	0.43	0.528	0.736	1.000
	Socio-environmental	0.09	1.000	0.904	0.934
	TAI	1	0.679	0.878	0.851
			Concrete wall	Steel sheet piles	Redi-Rock
Retaining wall	Technical and design	0.48	0.712	0.915	1.000
	Quality	0.43	1.000	0.759	0.711
	Socio-environmental	0.09	0.439	1.000	0.723
	TAI	1	0.811	0.856	0.851

Figure 6a,b show the application of the incremental analysis to the selection of the best solution for drainage management and retaining wall rehabilitation, respectively. The vertical axis shows the TAI, while the horizontal axis shows the cost on a logarithmic scale. The costs are shown on a logarithmic scale to increase the readability of graphs.

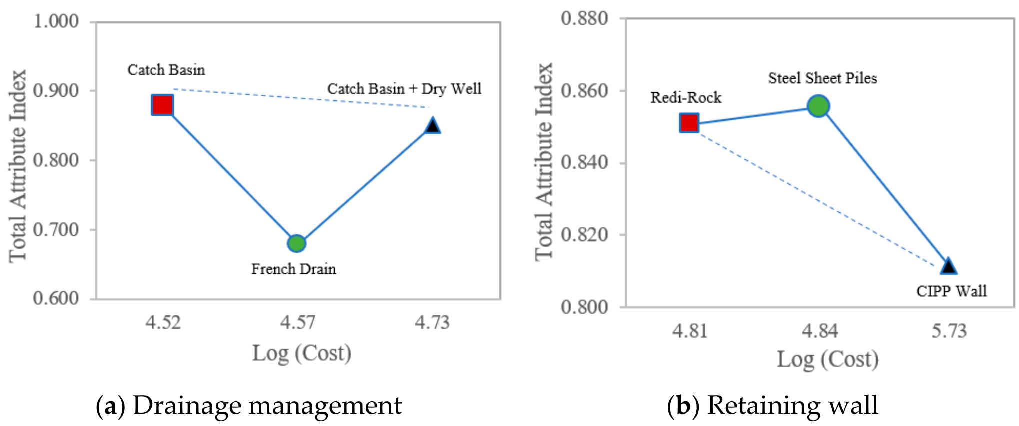


Figure 6. Final alternative comparison.

As Figure 6a shows, the catch basin was proposed as the most appropriate solution for drainage management, as it has the highest benefit and the lowest cost. Regarding the retaining wall alternatives shown in Figure 6b, steel sheet piles turned out to be the alternative, with the highest benefit for retaining wall rehabilitation. However, Redi-Rock was the second-best alternative and had relatively lower costs. In this condition, the final decision becomes dependent on several factors, including the amount of money the county was willing to spend on solving the drainage issue. In the face of budget limitations, Redi-Rock can be seen an acceptable alternative with more affordable costs. Furthermore, presenting the advantages of each alternative with respect to each of the criteria, i.e., technical/design, quality, and social/environmental, would assist the decision-makers in making a more informed decision. To that end, the results of a more detailed incremental analysis were communicated to the owner, as discussed in the next section.

4.5. Step 5: Making the Final Decision

The prioritized list of alternatives as well as the incremental analysis results were communicated with the HOA representatives in the last session of the course to determine the final alternative. Figure 7 shows the detailed incremental analysis for each attribute of the retaining wall alternatives.

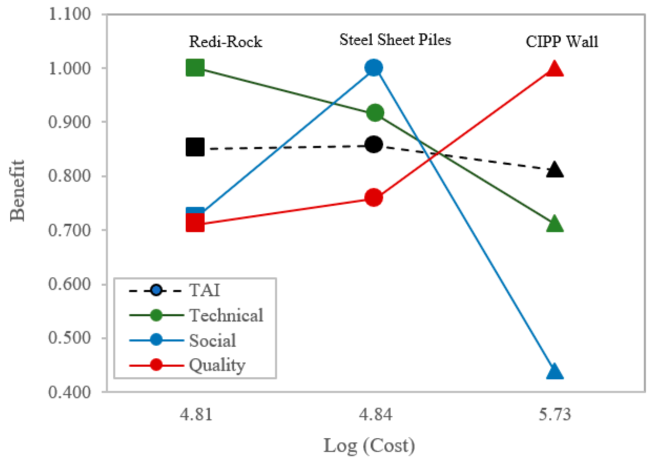


Figure 7. Incremental analysis for retaining wall alternatives.

As it can be seen in Figure 7, steel sheet piling had the highest TAI and social/environmental score, signifying that it would be the lowest inconvenience to the public. This alternative also had an acceptable durability over the long term. However, the risks that might occur during the construction were higher for this alternative as it involved pile driving, which could initiate z landslide or settlement for the buildings in the vicinity. This shows that engineers are more competent than the general public in elaborating on the social impacts of their work [36]. These insights were communicated to the HOA representatives and there were follow-up discussions with the owner, students, and the instructor. The owners decided to opt for the Redi-Rock alternative.

5. Proposed Framework for Students and Community Engagement

As discussed in the previous section, during the case study, the students were instructed to work in a team-based setting to provide recommendations for a construction project. During the process, the students learned to collaborate and communicate with each other as well as the owner of the project, and the HOA representatives from the Walden Ponds community, as an essential element of the decision-making process. Throughout this unique hands-on experience, the students were encouraged to engage the public in the decision-making process, not only through the consideration of social and environmental factors, but also through the incorporation of their opinions and judgments via the survey. This attitude can follow the students in their future careers as engineers.

Successful repetition of such an instruction approach can promote community engagement and reduce the negative externalities of construction projects in the long term. To that end, the utilized approach is presented in the form of a framework for educating engineering students to engage with the stakeholders for infrastructure projects. Figure 8 shows the proposed framework.

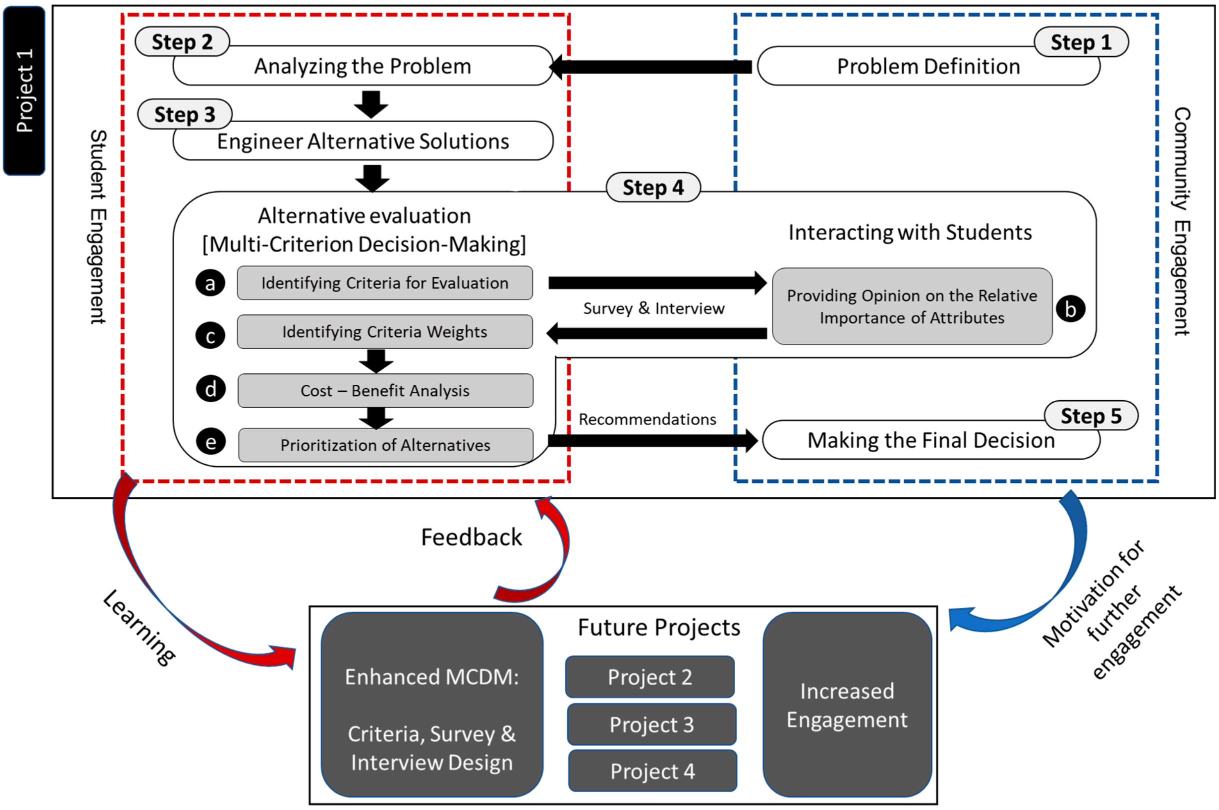


Figure 8. The proposed framework for engaging students with the stakeholders for infrastructure planning projects.

As Figure 8 shows, the steps of the proposed framework are (1) problem definition, which is initiated by the community to understand the needs, requirements, and constraints of the project, (2) analyzing the problem, (3) engineer solution alternatives for the problem, which involves the identification and engineering design of various alternatives, (4) evaluation of various alternatives with respect to several aspects, e.g., social, technical, and economic, while considering the public opinion with regards to the relative importance of the considered aspects, and (5) presenting and communicating the outcomes of the alternative evaluations to the client, while highlighting key advantages and disadvantages of the proposed alternatives, and determining the "best value" alternative in coordination with the project owner.

As demonstrated in Figure 8, the community is engaged in the decision-making process in three different steps, i.e., Steps 1, 4, and 5. The representatives of the public play a key role in communicating their problems, needs, constraints, and resources to the students in Step 1. In Step 4, public opinion on the relative importance of various criteria is acquired through a survey questionnaire. Lastly, in Step 5, the outcomes of the project such as the cost-benefit and incremental analysis results, are communicated to the public or their representatives.

The primary difference of the proposed framework from the existing body of knowledge is its ability to incorporate the needs of the community members in the decision-making process. Similar work such as Pellicer et al. [30] have also demonstrated procedures to include the preferences of the community members in infrastructure planning projects. However, in their case, the students only acted as community members and provided preferences. Whereas, in this work, the community members were actually engaged in the decision-making process. For enhancing the community engagement of engineering students, Segalàs et al. [64] made two recommendations, that (1) courses need to have a stronger focus on the social and institutional aspects of the projects and that (2) courses must apply a constructive and community oriented pedagogical approach.

As explained earlier and shown in Figure 8, the proposed framework incorporates these two recommendations. On the other hand, Wolcott et al. [65] suggested having a capstone project on the community engagement in the engineering curriculum to raise awareness on community engagement. The proposed framework also includes course projects for community engagement. In a nutshell, the proposed framework has commonalities with few existing frameworks on public engagement in infrastructure and planning and teaching community engagement to engineering students [66]. However, it builds on the existing frameworks in two major ways. First, it provides a step-by-step approach for raising awareness in students about the impact of public opinion on the planning of construction projects, and the existence of methods that can help them articulate participatory processes. This structured approach is replicable by future researchers. Furthermore, the framework offers a feedback loop, which provides the groundwork for the assessment of its improvements through its application to future projects. On one hand, such improvements can be in the form of an enhanced MCDM framework, criteria selection, survey and interview design, etc., as well as the training of future students to acquire the necessary set of skills and gain the attitude and behavior to engage the public in the decision-making process. On the other hand, observing their impact on the final decision can encourage the public to engage in future projects.

6. Conclusions

This study leverages the findings of a case study on the feasibility assessment of a real-world rehabilitation project to propose a framework for raising awareness among undergraduate and graduate engineering students toward increased engagement with the public. The case study served as an introductory exercise intended to raise awareness in the students of the impact that public opinion might have on the planning of construction projects, and to provide hands-on experience on the application of the existence of methods that can help them articulate participatory processes. In the case study, engineering graduate students collaborated with the instructor and the HOA representatives in a team-based setting. The case study intended to provide hands-on experience with the planning, analysis, design, development, and feasibility analysis. The students were divided into four groups of five students voluntarily. Each group evaluated certain dimensions of the problem. Throughout the case study, the students were engaged with the HOA representatives to identify the best-value solutions for the rehabilitation of an old retaining wall and improving the stormwater system in the community. The benefit analysis involved the determination of the benefits of each alternative with respect to technical/design, quality, and socio-environmental aspects. The determined benefits were then weighted based on the opinion of the residents of the Walden Ponds community and integrated into a benefit index, the *Total Attribute Index (TAI)*. The students communicated the outcomes of the alternative evaluation and incremental analysis to assist the HOA representatives to select the best-value option depending on the level of their available budget, as well as the trade-offs between social, technical, and quality aspects of various alternatives.

The approach used for the case study is then generalized in the form of a framework for educating engineering students to engage with the stakeholders for infrastructure projects. The proposed framework comprises five steps: (1) problem definition, (2) analyzing the problem, (3) engineer solution alternatives, (4) alternative evaluation, and (5) making the final decision. In the proposed framework, the public is engaged in the definition of the problem, the evaluation of the proposed alternatives, and making the final decision. Including public opinion in the quantitative weight of the MCDM facilitates reducing the negative externalities of construction projects in the long term.

The case study and the framework serve as an introductory exercise for raising awareness in students about the impact of public opinion on the planning of construction projects, through a step-by-step MCDM framework for incorporating public opinion in the feasibility assessment of an infrastructure project. This structured approach is replicable for future researchers. Furthermore, the framework offers a feedback loop, which provides the groundwork for the assessment of the observed improvements as a result of its application to future projects. Such improvements can be in the form of (1) an enhanced MCDM framework, criteria selection, survey, and interview design, etc., (2) training of future students to acquire the necessary set of skills and gain the attitude, and behavior to engage the public in the decision-making process, and (3) encouraging the public to engage in future projects.

Observing the impact of the feedback loop requires a longitudinal study, or at least a pre- and post-training evaluation after a course involving such case studies. Therefore, there is a need for developing a more thorough framework that includes an element for evaluating the effectiveness of the proposed approach in the training of students in the design and development of participatory processes for the planning of construction projects. This can be an opportunity for future research in this area. It is expected that the application of such comprehensive frameworks would help to interrupt the cycle of oblivion and promote a culture of accommodating public opinion among engineering students as future engineers in the long term.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Figure A1. Drainage layout for French drain.

Table A1. The construction work and duration of the alternatives for retaining wall rehabilitation.

Alternative	Activity	Quantity	Unit	Daily Output	Adjusted Duration
Sheet piling	Compaction of loose soil	-	-	-	1
	Utility drainage piping wyes/tees	100.00	Ea.	15	7
	Twisted pair cable (for sliding prevention)	100.00	C.L.F	7	15
	Hammering of sheets into place	1530.00	V.L.F.	540	3
					25 days
Redi-Rock	Excavation (1/2 CY excavator)	770.37	B.C.Y,	540	2
	Subgrade	2500.00	S.F.	800	4
	Assembling (flatbed trailer or boom truck)	8168.00	S.F.	205	40
	Backfilling	577.78	L.C.Y	650	1
					46 days
Concrete wall	Excavation	770.4	BCY	540	2
	Concrete 300 ksi (structural concrete gravity retaining wall)	7949.21	Ft^3		
	Footing	3656.64	Ft^3	125	30
	Wall	4292.57	Ft^3	125	35
	Cutting, bending, and placing of rebar	121.37		8	15.0
	Formwork (Pr.) (exterior shutter)	13,937.5	Ft^2		
	Footing	3484.38	SFCA	305	12
	Wall	10,453.13	SFCA	305	35
	De-shuttering	13,937.50	SFCA	1000	14.0
	Curing	139.38	C.S.F.	55	3.0
	Back filling	577.78	L.C.Y.	650	1
					98 days

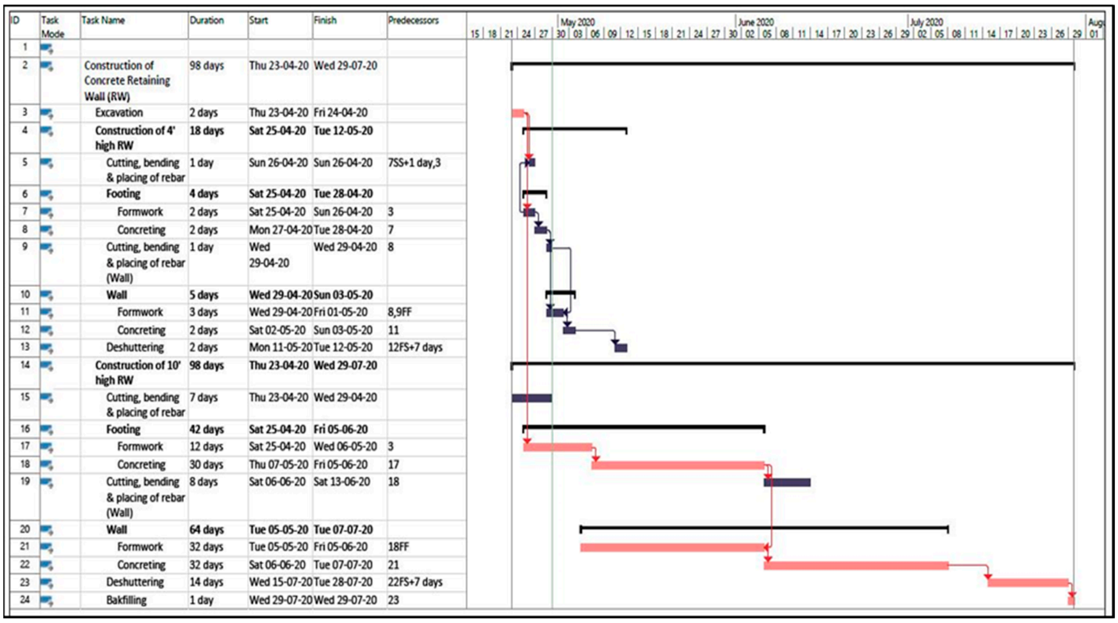

Figure A2. Sample schedule: the concrete wall alternative.

Table A2. The estimated costs for the construction of the retaining wall alternatives.

Alternative	Item	Qty.	Unit	Total Costs
Redi-Rock	Stone blocks, cut stones (28″ × 60″ × 96″)	153	Ton	$47,259.84
	Subgrade	2500	S.F.	$11,700.00
	Drainage piping underdrain fabric	100	Ea.	$4997.00
				$63,956.84
Sheet piling	Sheet piling, high strength steel piling, 50,000 psi	153 (32.2 tons)	Ton	$2244.66
	Steel plate (structural) for connections and stiffeners	1000	S.F.	$12,100.00
	Utility drainage piping wyes/tees	100	Ea.	$40,812.00
	Steel bolt, hex head, plain steel	1000	Ea.	$4500.00
	Twisted pair cable (for sliding prevention)	100	C.L.F	$9350.00
				$69,006.66
Concrete wall	Concrete 300 ksi (structural concrete gravity retaining wall)	7949.21	Ft^3	$68,303.69
	Rebar A36 (beam bolsters for reinforcing steel)	121.37	klb	$85,190.00
	Formwork (Pr.) (exterior shutter)	13,937.5	Ft^2	$336,912.00
	Pip underdrain wrapped 4″ (erosion control underdrain)	772.5	Ft	$42,976.70
				$533,382.39

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