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Integrating Sustainability KPIs in Construction Education for a More Responsible and Equitable Built Environment

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Abstract

The built environment plays a key role in achieving equitable and sustainable development. It is estimated that 33 percent of greenhouse-gas emissions, 40 percent of energy use, and 30 percent of natural resources consumption are related to construction activities. Sustainable development requires considering the triple bottom line as well as measurement methods to track environmental performance and the social impacts of construction activities. Sustainability key performance indicators (KPIs) are essential metrics used to track sustainability performance. Offering our future construction workforce knowledge about sustainability KPIs is fundamental to achieving a sustainable future. The goals of this research are to: (1) understand the gap in construction management (CM) students' knowledge related to sustainability KPIs and overall sustainability; (2) evaluate the significance of integrating sustainability topics, including sustainability KPIs, into CM curricula; and (3) determine the most efficient teaching methods and instructional tools for introducing sustainability KPIs into curricula, aiming to educate students and enhance their learning experience. To achieve these goals, this study surveyed 84 CM students at one of the largest minority-serving institutions (MSIs) in the United States. The results of this study highlight the gaps in students' knowledge regarding sustainability KPIs as well as the importance and potential methods to educating them about this fundamental topic.

Keywords: Equity, Sustainability; Sustainability Key Performance Indicators (KPIs); Construction Education; Sustainable Built Environment

Background and Motivation

The built environment accounts for approximately 33 percent of greenhouse-gas (GHG) emissions, 40 percent of global energy consumption, 30 percent of natural resources consumption utilization, 25 percent of water consumption, and 25 percent of solid waste generation [1], [2], [3], [4], [5], [6]. Therefore, the built environment pays a pivotal role in achieving equitable and sustainable development and attaining sustainable development goals (SDGs) remains a crucial objective for the construction industry.

Sustainable development aims to meet the current needs of society while ensuring that future generations can meet their own needs [7], [8], [9]. Achieving SDGs requires not only consideration of the triple bottom line's three pillars, encompassing social, economic, and environmental components, but also the use of measurement methods to track environmental performance and the social impacts of construction activities [6], [9], [10], [11]. Sustainability key performance indicators (KPIs) are crucial metrics for measuring and tracking sustainability performance [12].

Sustainability KPIs must consider the three dimensions of the triple bottom line to effectively monitor and evaluate the sustainability performance of construction projects. Environmental sustainability involves (1) resource efficiency and waste management, including reducing the consumption of natural resources and waste production, along with the reuse and recycle of materials, as well as considering material sustainability; (2) energy efficiency, which involves reducing energy use and incentivizing the use of renewable energy; (3) water management; (4) reducing GHG emissions as well as air, water, and noise pollution; and (5) land use and the impact on the biodiversity [6], [11], [12], [13]. Social sustainability involves evaluating the social impacts of construction projects and understanding their influence on how individuals live, work, engage in recreational activities, relate to one another, organize to fulfill their needs, and cope as integral members of society [14]. As such, social sustainability strives to ensure that the social impacts of construction projects result in positive outcomes, fostering equity, community engagement, preservation of neighborhood character, as well as enhancing the health, safety, and well-being of individuals, communities, and employees [12], [13], [14], [15]. Finally, economic sustainability involves the assessment and management of financial aspects. This pillar considers the life-cycle cost of construction projects and focuses on economic viability, profitability, financial sustainability, and corporate governance, which is crucial for the effective operation of an organization [12], [16], [17], [18]. Corporate governance involves setting rules, practices, and processes by which an organization is directed and controlled and helps to ensure accountability of management and transparent financial reporting [18].

Embracing sustainability KPIs in construction presents an opportunity to pursue long-term sustainability, increase operational efficiency, and enhance performance [19]. The successful and efficient implementation of innovation in construction relies significantly on higher education, since the future workforce plays a crucial role in achieving sustainability goals [20], [21], [22]. Hence, a paramount approach to achieving a sustainable future is to educate construction students on sustainable practices and sustainability KPIs. To this end, the goals of this research are to: (1) understand the gap in construction management (CM) students' knowledge related to sustainability KPIs and overall sustainability by surveying students at Florida International University (FIU), one of the largest minority-serving institutions (MSIs) in the United States; (2) evaluate the significance of incorporating sustainability topics, including sustainability KPIs, into CM curricula; and (3) determine optimal teaching methods and instructional tools for introducing sustainability KPIs into curricula, aiming to educate students and enhance learning.

Methodology

This study is guided by three research questions: (1) What gaps exist in the knowledge of sustainability KPIs among CM students? (2) How do CM students perceive the significance of learning about sustainability KPIs? And (3) What learning methods and instructional tools are most effective for integrating sustainability topics, particularly sustainability KPIs, into curricula to educate students and enhance their learning experience?

This study addresses these three research questions through surveying 84 CM students at FIU, one of the largest MSIs in the United States, to understand the gap in student knowledge related to sustainability KPIs. The administered survey included a demographic section and four questions. The first question aimed to identify how familiar CM students were with sustainability KPIs, as well as with the environmental impact of the construction industry, the challenges and costs involved in transitioning to sustainable construction, and the benefits of such transition. The second question intended to determine the importance of learning about sustainability KPIs for students and whether they think that this topic should be incorporated in CM curricula. The following question sought to identify the most effective teaching methods and instructional tools for educating and training students regarding sustainability KPIs and overall sustainability. The last question asked students to mention one or more economic, social, and/or environmental benefit of transitioning to a more sustainable built environment.

The authors conducted several statistical measures to assess the consistency, reliability, and adequacy of the sample size, including the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, the Bartlett's Test of Sphericity, and the Cronbach's Alpha test [23], [24]. The research employed a statistical ordered probit regression analysis to evaluate how several variables influence the dependent variable, which is the significance of incorporating sustainability KPIs curricula in CM programs. It is an adequate analysis conducted for a categorical dependent variable, aiming to identify which independent variables exert a statistically significant influence on the dependent variable. Ordered probit regression is suitable for generalizing cases with more than two outcomes of an ordinal dependent variable, which may have several potential values such as not at all important, slightly important, important, fairly important, and very important [25], [26]. The ordinal probit regression model incorporates these parameters through the following equation:

$$y_i^* = X_i\beta + \varepsilon$$

Where, y_i^* is a latent variable measuring the significance of incorporating sustainability KPIs curricula in CM programs for the ith participant; X_i is a (k x 1) vector of observed nonrandom explanatory variables; β is a (k x 1) vector of unknown parameters; and error factor (ε) captures the reality that the importance of teaching these topics is not perfectly predicted by the regression equation. Therefore, the observed importance towards this topic, y_i, is determined from the model according to:

$$y_i. = \begin{cases} 1\ if -\infty \leq\ y_i^* \leq \mu_1\ (Not\ at\ all\ important) \\ 2\ if\ \mu_1 \leq\ y_i^* \leq \mu_2\ (Slightly\ important) \\ 3\ if\ \mu_2 \leq\ y_i^* \leq \mu_3\ (\ important) \\ 4\ if\ \mu_3 \leq\ y_i^* \leq \mu_4\ (Fairly\ important) \\ 5\ if\ \mu_4 \leq\ y_i^* \leq \mu_5\ (Very\ important) \end{cases}$$

The partial change in y^* with respect to X_i is β_i units. This suggests that a one-unit change in X_i is anticipated to result in a β_i unit change in y^*, while keeping all other variables constant. Furthermore, the significance test employs the z-score to describe the anticipated behavior of the mean for a data sample with a specific number of observations. The P-value indicates the confidence level regarding the correlation between independent variables and the dependent variable. This research assumed a 90% confidence interval, and the associated z-score is determined to be 1.645. This implies that significance will be achieved at an alpha level less than or equal to 0.1.

Results

This section presents the results associated with the responses of 84 CM students at FIU. The research used a mixed-methods sequential explanatory design to collect and analyze quantitative and qualitative data from students. The recorded data included a diverse student group including

(a) 54 males, 25 females, 1 non-binary/gender fluid, one student that identified themselves as other and one student that preferred not to answer; (b) students from multiple races, including White, Asian, African American, among other; and (c) 54 Hispanic and 28 non-Hispanic students. The socio-demographic background is presented in Figure 1.

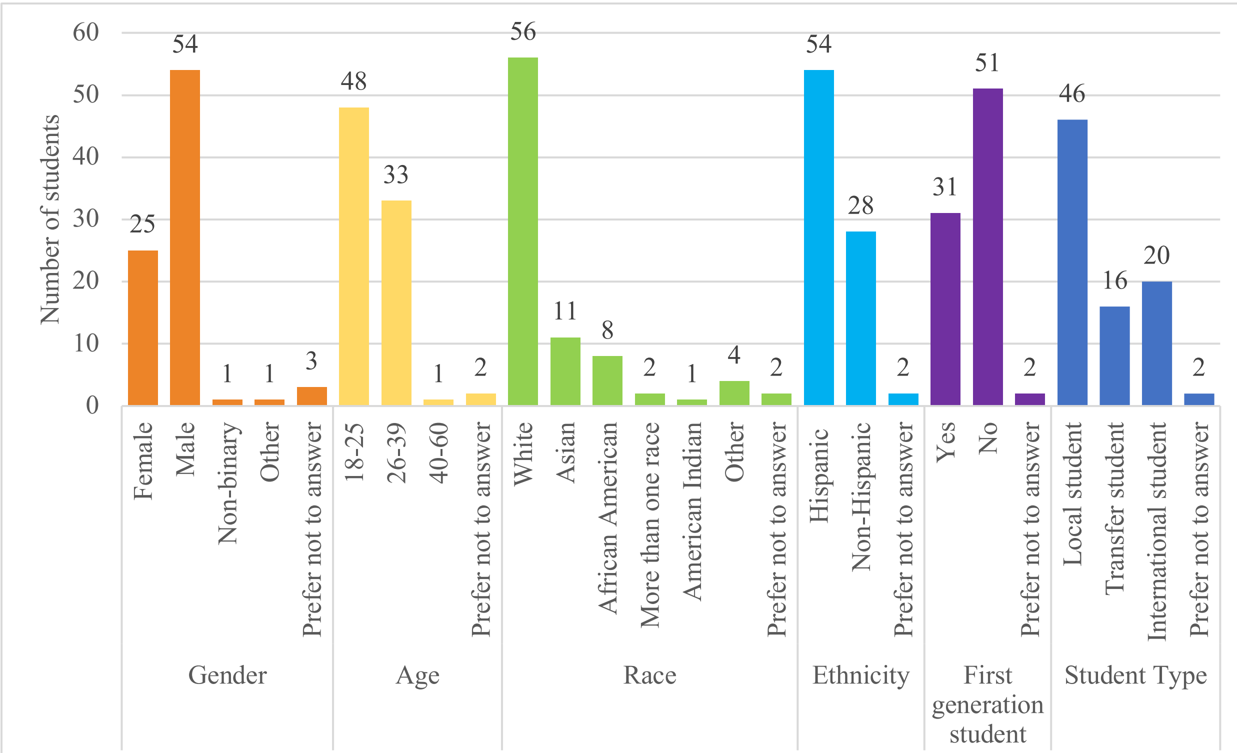

Figure 1. Students' socio-demographic background, n=84

The first question aimed to identify how familiar CM students were with sustainability KPIs, as well as with the environmental impact of the construction industry, the challenges and costs involved in transitioning to sustainable construction, and the benefits of such transition. According to the results of this study, presented in Figure 2, 77 students (92 percent), are aware of the environmental impact of the construction industry. Furthermore, 69 students (82 percent) are aware of the challenges and costs involved in transitioning to sustainable construction and 73 students (87 percent) are aware of the benefits of such transition. Additionally, 80 students (95 percent) consider that (1) environmental improvement is crucial for the construction industry; (2) CM education should teach sustainable construction concepts and practices, including KPIs; and (3) it is crucial that the present and future workforce have knowledge related to sustainability. Despite this, out of the 84 students surveyed, 44 students cannot define what sustainability KPIs are. This implies that more than 50 percent of students have no knowledge about sustainability KPIs.

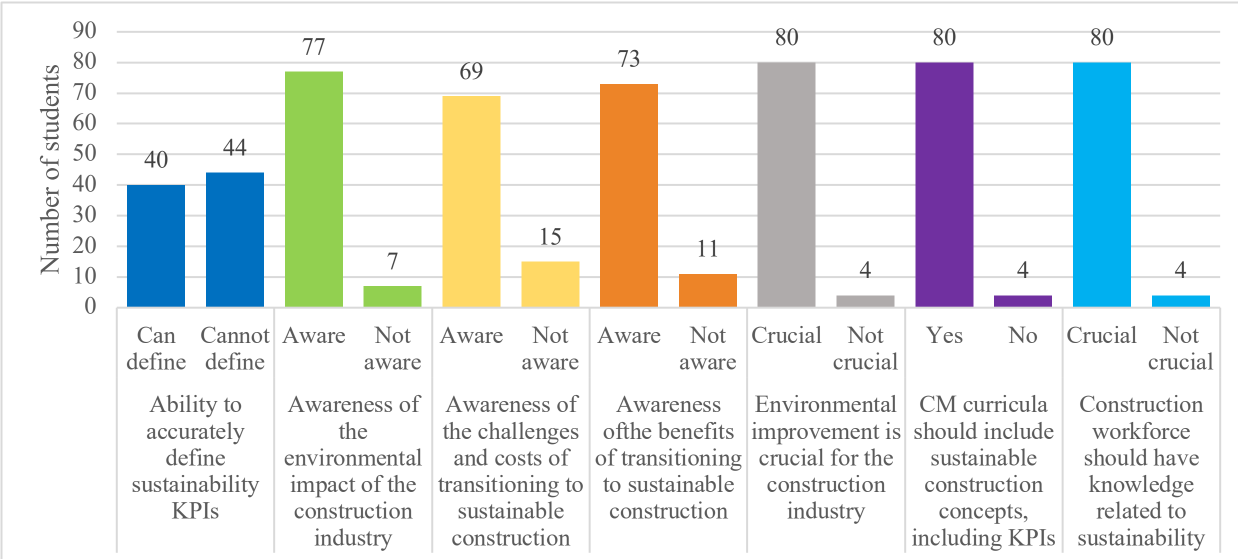

Figure 2. Students' perspective and knowledge of sustainable construction

The second question intended to determine the importance of learning about sustainability KPIs for students and whether they think that this topic should be incorporated in CM curricula. The results of this study, presented in Figure 3, show that (1) 35 students, around 43 percent, consider incorporating sustainability KPIs in CM curricula as very important; (2) 17 students, approximately 21 percent, consider it fairly important; (3) 25 students, around 30 percent, consider it important; (4) only 5 students, approximately 6 percent, consider it slightly important; and (5) zero students do not consider incorporating sustainability KPIs in CM curricula as not at all important.

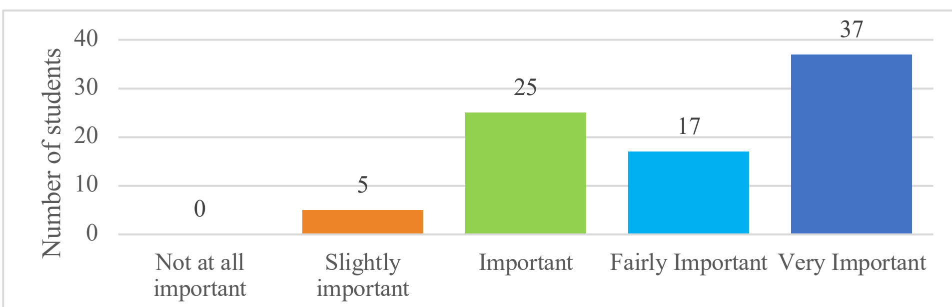

Figure 3. Students' perspective on the significance of incorporating sustainability KPIs in CM curricula

The following question asked students to rank, from 1 to 8, the most effective teaching methods and instructional tools for educating and training students regarding sustainability KPIs and overall sustainability. In this rank, 1 represented the most important teaching method and instructional tool, while 8 signified the least important one. The study results indicate that the most beneficial teaching methods and instructional tools to effectively educate and train CM students on sustainability KPIs and overall sustainability include (1) hands-on experience and on-the-job training, with mean scores of 2.10 and 3.56, respectively; and (2) in-person lectures, yielding a mean of 2.63. Other teaching methods and instructional tools that could be beneficial are group or individual projects and problem-based learning. These results are presented in Figure 4.

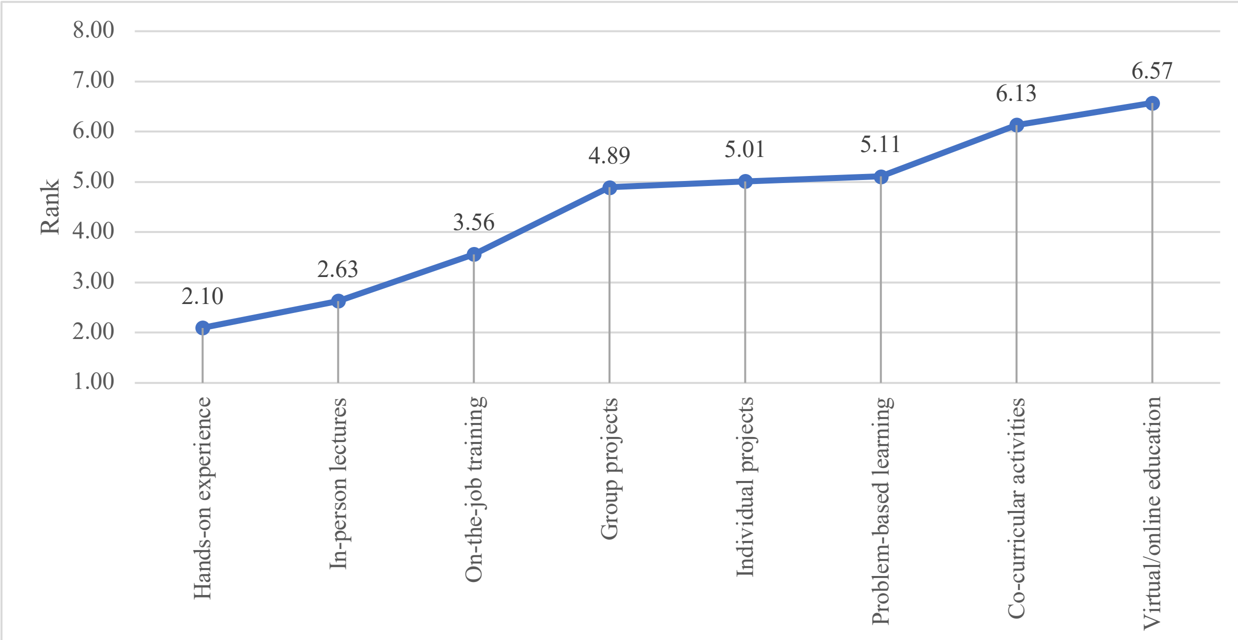

Figure 4. Ranking of teaching methods and instructional tools to effectively educate students in sustainability KPIs and overall sustainability

This study used diverse statistical tools including KMO, Barlett's Test of Sphericity, and Cronbach's alpha to evaluate the consistency, reliability, and adequacy of the data sample size using SPSS. The KMO value obtained was 0.719, exceeding the threshold of 0.6 for sample sizes under 100, indicating the adequacy of the sample size. The Cronbach's alpha value was 0.742. This value is greater than 0.7 which demonstrates that the sample size is reliable. Finally, Bartlett's Test of Sphericity assessed the correlation between variables, yielding a significance level below 0.001, indicating that the variables are not orthogonal.

Table 1 presents the results of the ordered probit regression model for the significance of incorporating sustainability KPIs curricula in CM programs, with a Pseudo R2 value of 0.0508. Three variables have P-values of less than or equal to 0.10, including (1) awareness of the environmental impact of the construction industry; (2) awareness of the benefits of transitioning to sustainable construction; and (3) environmental improvement is crucial for the construction industry. Therefore, it can be concluded that the data is statistically significant given that the hypothesis pertaining to the existence of the true relationship between the dependent variable, which is the significance of incorporating sustainability KPIs curricula in CM programs, and independent variables is correct. Additionally, $\boldsymbol{\mu}_1$, $\boldsymbol{\mu}_2$, and $\boldsymbol{\mu}_3$ are the coefficients of the ordered probit model with the values -0.33, 0.95, and 1.54, respectively. These values represent the predicted cumulative probabilities at covariate values of zero.

The study results indicate that CM students perceive sustainability KPIs and overall sustainability as highly significant for the construction industry. It can be inferred from the findings that students who are aware of the environmental impact of the construction industry (β=1.24) and those who are aware of the benefits of transitioning to sustainable construction (β=0.71) find it crucial to learn about sustainability KPIs and overall sustainability. Similarly, students who consider environmental improvement as crucial for the construction industry (β=-1.46) are very interested in learning about these paramount topics.

Table 1. Coefficients and P-Value from Ordered Probit Regression Analysis

Variables	**Coeff. (β)**	**Std. Error**	**Z**	**P-Value**
Ability to accurately define sustainability KPIs	0.01	0.28	0.03	0.975
Awareness of the environmental impact of the construction industry	1.24	0.25	4.95	0.000
Awareness of the challenges and costs of transitioning to sustainable construction	-0.16	0.43	-0.38	0.703
Awareness of the benefits of transitioning to sustainable construction	0.71	0.37	1.90	0.058
Environmental improvement is crucial for the construction industry	-1.46	0.54	-2.71	0.007
CM education should teach sustainable construction concepts and practices, including KPIs	0.59	0.46	1.28	0.200
It is crucial that the present and future workforce have knowledge related to sustainability	0.59	0.46	1.28	0.200
$\boldsymbol{\mu}_1$	-0.33	0.26		
$\boldsymbol{\mu}_2$	0.95	0.26		
$\boldsymbol{\mu}_3$	1.54	0.30		
Number of observations				84

An open-ended question in the survey asked students to mention one or more economic, social, and/or environmental benefit of transitioning to a more sustainable built environment. The recorded responses highlighted several benefits of such transition, including (1) fostering a safe, healthy, cleaner, and less harmful environment; (2) reducing GHG emissions and pollutants contributing to air, soil, and water pollution, as well as mitigating climate change; (3) preserving and protecting natural resources, including water, land, and biodiversity; (4) reducing waste through the use of sustainable building materials and practices such as recycling, reusing, and composting; (5) enhancing air and water quality; (6) improving the overall environmental impact from construction; (7) ensuring more efficient buildings, promoting energy, water, and resource efficiency, leading to cost savings on waste management, electricity, and water bills; (8) contributing to planet preservation for future generations, lessening the exhaustion of non-renewable resources and promoting the use of renewable materials and energy sources, such as solar and wind power; (9) increasing the value of buildings by building green buildings, given that studies indicate higher rents and lower vacancy rates of these buildings; (10) enhancing human health and well-being with a healthier indoor environment, better indoor air quality, natural light, and access to green space, as well as fostering a sense of community and place, promoting social cohesion and diversity, and improving the overall quality of life of occupants;

(11) conserving water through the use of efficient fixtures; (12) reducing the negative impacts of human activities on the environment; (13) supporting biodiversity and providing habitat for wildlife, helping to protect and restore ecosystems; and (14) lowering the total cost of construction and improving long-term financials.

Limitations and Future Work

The authors acknowledge certain limitations in this study: (1) the survey responses may be influenced by self-assessment and biases; and (2) this research was conducted at an MSI in the United States, limiting its generalizability to other educational institutions and affecting the scalability of the study. Future studies could explore additional demographics and encompass a broader student population by conducting this research in diverse educational institutions. However, FIU stands out as one of the leading and largest MSIs in the United States, thus making the sample representative of the minority population surveyed. Future research could also investigate students' familiarity with specific KPIs. Furthermore, incorporating varied learning methods and instructional tools, such as hands-on experience, on-the-job training, and problem-based learning, within a sustainability course might be beneficial to evaluate the most effective learning approach for educating students in sustainability topics, including sustainability KPIs. These data could help researchers and educational institutions in developing effective pedagogy to impart essential knowledge to the future construction workforce in these critical topics.

Conclusions

The construction industry has a substantial environmental footprint, underscoring the critical need for the industry to prioritize a shift towards a more sustainable built environment. The study's findings highlighted students' awareness of the environmental impact of the construction industry, along with the challenges and costs of transitioning to a more sustainable built environment, as well as the benefits of such transition. However, the results also highlighted (1) a knowledge gap among CM students concerning sustainability KPIs; and (2) the importance of providing the future construction workforce with knowledge of sustainability concepts, including sustainability KPIs. Therefore, educational institutions should incorporate pedagogical modules to complement sustainability courses, helping the future construction workforce in acquiring crucial knowledge and skills in these paramount topics. Furthermore, this research suggests that hands-on experience, in-person lectures, and on-the-job training are the most beneficial teaching methods and instructional tools for effectively educating CM students and enhance their learning experience.

The results from the ordered probit regression analysis revealed that three variables contribute to the significance of incorporating sustainability KPIs curricula in CM programs, including (1) awareness of the environmental impact of the construction industry; (2) awareness of the benefits of transitioning to sustainable construction; and (3) environmental improvement is crucial for the construction industry. These findings underscore the crucial need to educate the future construction workforce regarding sustainability KPIs and overall sustainability. Such knowledge is key for them to contribute to the environmental improvement of the built environment. The findings of this research are aimed at educational administrators and construction industry stakeholders who are committed to realizing a more responsible, equitable, and sustainable built environment.

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