Investigating the Need for Forensic Engineering Graduate Program to Meet the Growing Workforce Demand

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Abstract

Forensic engineering is a growing career choice in the civil engineering discipline for the evaluation of structural failures and poor structural performance of houses damaged in a natural disaster, deteriorating infrastructure, and maintenance of the built environment. However, most of the forensic engineers in a professional role for field investigations are structural engineers who may or may not have developed forensic skills during their academic careers. This study aims to: (1) investigate bachelor's in construction management programs in 72 American Council for Construction Education (ACCE) accredited institutions to identify the accessibility to forensic engineering-based courses; (2) identify essential forensic engineering skills that students lack; and (3) investigate students' interest to pursue a forensic engineering career. The results of this study indicated that forensic engineers need specific skills and competencies to objectively analyze the causes of failure using the collected evidence, including (a) technical competency; (b) legal knowledge including technical vocabulary and legal procedures; and (c) interpersonal skills including the ability to communicate technical information to the people from non-engineering background. However, the student survey results indicated that many students lack such skills and there is a pressing need to teach them those skills in graduate programs. Additionally, the results highlighted that only 4 out of 72 ACCE institutions which consist of 5.6% of the accredited degree programs offered courses that are related to forensic engineering. With growing concern for climate change impact and deterioration of infrastructure such as bridges and buildings, the workforce demand for forensic engineers is expected to increase. The findings of this study are directed to engineering education administrators and interested parties in the current state of forensic engineering education to suggest that universities need to allow construction management and civil engineering students to develop forensic engineering skills and help them become successful in their professional careers.

Keywords: Forensic Engineering Education, Technical and Investigative Skills, Graduate Program

Background and Motivation

Forensic engineering refers to the evaluation of failures or other performance problems in components, design, and structures using available evidence [1], [2]. The goal of this discipline is to identify problems in built structures and/or elements, understand the causes of failure, and solving them, thus improving the quality and safety of structures, and making them serviceable [2]–[4]. Forensic engineering not only includes the investigation of catastrophic failures, such as the collapse of a structure due to a natural disaster, but also structural issues during construction or throughout the structure's design service life, and the evaluation of components that do not perform as intended [2], [4]. It is a multidisciplinary field that requires both technical and forensic competency. Thus, it requires (a) technical competency; (b) legal knowledge including technical vocabulary and legal procedures; (c) detective skills; and (d) interpersonal skills

including the ability to communicate technical information to people from non-engineering backgrounds [2].

Educational institutions in the United States do not offer forensic engineering programs due to several reasons: (1) it is a multidisciplinary discipline instead of a standard engineering discipline including technical competency, legal knowledge, and interpersonal skills; (2) it is not well-known outside the field; and (3) the demand of forensic engineers is less in comparison to standard engineering disciplines, including civil, mechanical, and electrical [1]. In fact, courses on forensic engineering are not widely offered [5]. Thus, many engineering graduates have limited or no exposure to forensic engineering skills, including investigative skills, construction techniques, material analysis, architectural systems, and structural systems [1], [5]. Only a few American Council for Construction Education (ACCE) accredited bachelor's degree programs under construction management and civil engineering curricula offer courses related to forensic engineering. Delatte (2012) highlighted that the Technical Council on Forensic Engineering (TCFE) has established and promoted forensic engineering educational activities over the past three decades and has made significant progress in the last decade [4]. Since its establishment, TCFE has published several books and conducted a series of workshops for faculty of graduate and undergraduate education within the U.S. and in an international location. However, these workshops and training are yet not accessible to engineering graduates indicating that there is still a growing demand for forensic engineering courses to support future workforce and help them develop necessary skills before working on the site.

Forensic engineering investigations as well as learning from engineering failures are responsible for significant improvements in structural safety, including after natural disasters [6]–[8]. Natural disasters expose individuals to damages, loss of housing, and ultimately loss of lives. Hence, there is a pressing need for forensic engineers that can effectively and safely evaluate structural failures and poor structural performance of houses and deteriorated infrastructure [1], [5]. As such, integrating courses pertaining to this discipline is of utmost importance to engineering and construction education. The goals of this study are to (1) investigate Construction Management and Civil Engineering bachelor's programs to identify the accessibility to forensic engineering courses; (2) identify essential forensic engineering skills that students lack; and (3) investigate students' interest to work in the forensic engineering field. This study will benefit educational institutions by helping them recognize the need for forensic engineering education as well as students who will gather new skills which will help them become more successful in their professional careers.

Methodology

This research adopted an exploratory approach to: (1) investigate accessibility to forensic engineering-based courses in the universities; (2) identify the gap in students' forensic skills in engineering and construction; and (3) investigate students' interest to pursue a forensic engineering career. The following section discusses the survey design and the statistical test used for the analysis of the obtained survey data.

Survey Design

The survey questionnaire included multiple choice and Likert scale questions related to socio-demographic background, students' motivation, students' current skill level, and students' likelihood to pursue a forensic engineering career. The survey design was guided by three main research questions: (1) How many universities are supporting students to develop forensic engineering skills; (2) What are the factors that influence students' interest to pursue forensic engineering career; and (3) What are gaps in students' forensic skills that need to be improved? The authors conducted the survey using an online Qualtrics link and distributed it to two courses including Sustainable Approach to Construction in the Department of Construction Management and Finite Element Methods in the Department of Civil and Environmental Engineering.

An ordered Probit Regression Analysis

To determine students' interest in a forensic engineering career, the study utilized a statistical method, ordered probit regression analysis. It is a suitable analysis for a categorical dependent variable. It is conducted to determine which independent variable has a statistically significant effect on the dependent variable, as well as to determine how well the model predicts it [9], [10]. An ordered probit regression analysis is the selected method for the collected data, as this analysis is fit for the generalization of cases of more than two outcomes of an ordinal dependent variable (a variable with potential values such as poor, fair, good, or excellent). Therefore, since an ordered logit model estimates the probability of the dependent variable to be only one, the ordered probit regression model was the best fit for this study. The dependent variable was defined as *students' interest in a forensic engineering career*, while the independent variables were the following: *availability of practical course material, interest to learn and operate forensic engineering technology, accessibility of the forensic curriculum within the university, students' attitude towards complex problem solving, students' interest in forensic concepts, and pedagogical approach used in the course*. The ordered probit regression model utilizes these parameters through the following equation:

$$y_i^* = X_i\beta + \varepsilon \tag{1}$$

Where y_i^* is a latent variable measuring the students' likelihood to pursue forensic engineering career 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 student's interest in forensic engineering career is not perfectly predicted by the regression equation. Kockelman and Kweon (2002) highlighted that y_i is a continuous measure of the potential occurrence of an event [11]. Based on this theory, this study categorized y_i on a continuous Likert scale i.e., very unlikely, unlikely, and likely to statistically measure the students' likelihood to pursue or show interest in a forensic engineering career and avoid any biases. Additionally, these categories were the best fit for the dependent variable obtained from the survey data. Therefore, students' interest in a forensic engineering career, y_i is determined from the model as follows:

$$y_i = \begin{cases} 1\ if\ -\infty \leq\ y_i^* \leq \mu_1\ (Very\ Unlikely) \\ 2\ if\ \mu_1 \leq\ y_i^* \leq \mu_2\ (Unlikely) \\ 3\ if\ \mu_2 \leq\ y_i^* \leq \mu_3\ (Likely) \end{cases} \tag{2}$$

In equation 2, the partial change in y^* with respect to X_i is β_i units. This implies that for a unit change in X_i, y^* is expected to change by β_i units, holding all variables constant. Furthermore, the significance test uses the t-score to describe how the mean of the data sample with a certain number of observations is expected to behave. On the other hand, the P-value indicates the confidence level, in terms of correlation, of each variable to the dependent variable. The confidence interval in the analysis is assumed to be 95%; thus, the area under the curve (z) is obtained as 1.96.

Results and Discussion

Figure 1 shows the overall socio-demographic information of 48 students from Sustainable Approach to Construction in the Department of Construction Management and Finite Element Methods in the Department of Civil and Environmental Engineering. Students from different socio-demographic backgrounds participated in the study, which included: (1) 34 Hispanic and 14 non-Hispanic; and (2) 36 white, 2 African Americans, 8 Asian, 1 Native American, and 1 more than one race. Additionally, 50% of the students are currently working outside the university, and most of the students were found to be local students. It is worth noting that most of the student participants are either graduate students (GS) or senior undergraduate students (SUS) indicating that their higher-level education could affect their interest in a forensic engineering career. Cross-tabulation analysis of the data indicated that seven GS, three SUS, and one junior undergraduate student (JUS) have considered forensic engineering as a career path. On the other hand, four GS, nine SUS, and three JUS have not considered forensic engineering as a career path. The rest of the students have not heard about forensic engineering careers before.

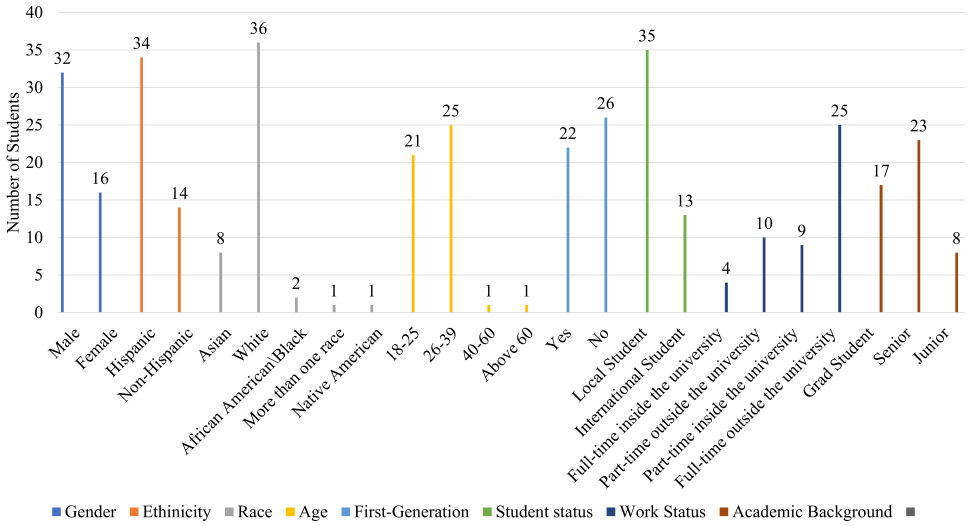

Figure 1. Students' Socio-Demographic Background, n=48

Current State of Forensic Engineering Courses

Forensic science is a scientific field that represents a natural expansion of different existing disciplines such as engineering, chemistry, biology, geology, and anthropology among others [12]. The American Society of civil engineers (ASCE) defined the forensic engineering profession as establishing practices and methods to reduce the number of structural failures [13]. Forensic engineering is a multidisciplinary field since structural failure can occur in different locations including dams in the river, buildings on the land, and tunnels in the underground transportation system. Since the scope of this research is focused on investigating forensic engineering curricula in Construction Management (CM) and Civil Engineering (CE) programs within U.S. universities, the courses that may be related to other disciplines of forensic science such as fire investigation from other departments have not been included in this research. This study investigated the American Council for Construction Education (ACCE) accredited 72 bachelor's degree programs under CM and CE curricula to assess how these programs integrated courses that are relevant to forensic engineering. This method was selected to examine how future construction workforces are being trained to tackle challenges pertaining to forensic engineering topics. The authors investigated all the courses and their descriptions specified in each institution's course catalog under the CM and CE bachelor's programs to identify courses that integrated forensic engineering topics. The first step of collecting data for this study was to look for courses that included the keywords "forensic engineering", "applied forensics", and "forensic engineering and risk management" in the title. The second step involved identifying courses that did not include "forensic engineering" within their titles. Therefore, the authors conducted keywords-search within the course descriptions which include "construction defects forensics", "building failure", "product liability, repair, and restoration", "materials conservation", "structural failures and rehabilitation" and "Technical Council on Forensic Engineering (TCFE)" to further analyze the concentration of the courses.

As shown in Figure 2, only 4 out of 72 programs offered courses that are relevant to forensic engineering, including: (1) Alfred State College, which offers the course "Masonry Restoration" [14], Florida International University, which offers the course "Concrete Problems: Prevention, Diagnosis and Resolution" [15]; Northern Kentucky University, that offers the course "Construction Renovation and Restoration" [16]; and Purdue University, that offers the course "Introduction To Disaster Restoration And Reconstruction Management" [17]. These courses focused on: (1) the preparation and restoration of damaged masonry structures; (2) prevention, diagnosis, and resolution of concrete production, testing, construction, and performance; (3) renovation and restoration of current structures along with historical construction; and (4) restoration and reconstruction procedures of disaster-impacted projects, business management practices, requirements of disaster restoration and reconstruction management contractors. The findings indicated that there is a gap within engineering education to incorporate forensic engineering topics within the curricula which can in turn hinder the process of creating a dynamic and skillful future forensic engineering workforce.

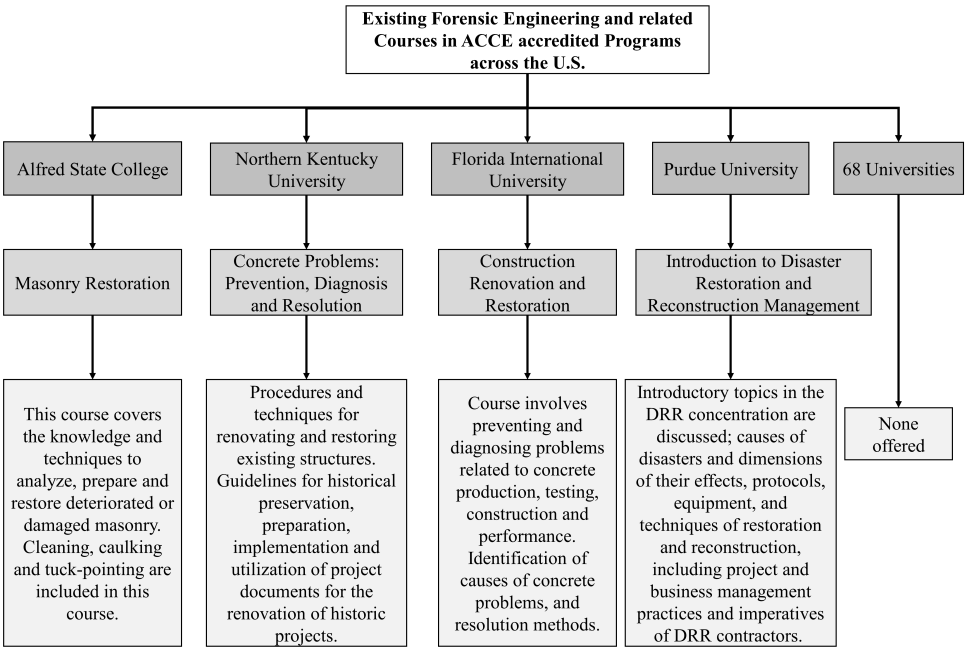

Figure 2. Flowchart showing types of forensic engineering courses offered by American Council for Construction Education (ACCE) accredited bachelor's degree program across the U.S.

Quantitative Analysis

The ordered probit regression model addresses the second research question regarding factors that impacts students' interest in a forensic engineering career. Table 1. provides the results of the ordered probit regression model for the student's interest to pursue a forensic engineering career, with a Pseudo R^2 value of 0.26. The P-value of availability of practical course material, accessibility of the forensic engineering curriculum within the university, students' attitude towards complex problem solving, students' interest in forensic concepts, a practical pedagogical approach used in the course, and students' interest to learn and operate forensic engineering technology are 0.319, 0.0005, 0.012, 0.049, 0.0005, and 0.509 respectively. Since the values of accessibility of the forensic engineering curriculum within the university, students' attitude towards complex problem solving, students' attitude towards solving a complex problem, students' interest in forensic concepts, and practical pedagogical approach used in the course are less than 0.05, it can be concluded that the hypothesis pertaining to the existence of the true relationship between dependent and independent variables is correct. Thus, the data is statistically significant. In Table 1, $\boldsymbol{\mu}_1$ and $\boldsymbol{\mu}_2$ are the coefficients of the ordered probit model with the values -0.42 and -0.8. This value is the threshold that reflects the predicted cumulative probabilities at covariate values of zero. Based on the obtained results of regression analysis, higher accessibility of forensic engineering curriculum within the university (β= -6.35), students' positive attitude toward solving complex problems (β= 1.04), higher interest in forensic concepts (β= -1.21), and practical pedagogical approach used in the course (β= 6.35) will increase students' interest to pursue a forensic engineering career.

Table 1. Coefficients and P-Value from Ordered Probit Analysis for the Students' Interest in Forensic Engineering Career

Variables	Coeff. (β)	Std. Error	Z	P-Value
Availability of practical course material	0.55	0.55	1.00	0.319
Accessibility of the forensic engineering curriculum within the university	-6.35	0.61	-10.43	0.000
Students' attitude toward solving a complex problem	1.04	0.41	2.51	0.012
Students' interest in forensic concepts	-1.21	0.62	-1.97	0.049
Practical pedagogical approach used in the course	6.35	0.69	9.17	0.000
Interest to learn and operate forensic engineering technology	0.39	0.59	0.66	0.509
$\boldsymbol{\mu}_1$	-0.42	0.86		
$\boldsymbol{\mu}_2$	-0.80	0.87		
Number of observations				48

Box plots are one of the most common methods for graphically analyzing the distribution of data sets. The authors utilized box plots to address research question 3 which aims to investigate the gap in students' forensic engineering skills. The box in the box plot typically includes the interquartile range of the dataset, i.e., values between the 25th and 75th percentile. A dark horizontal line represents the median value in the box. A whisker or line extending above and below the box indicate the largest and smallest observed values. Students provided ratings on a five-point scale where 1 represented "Not Lacking" and 5 represented "Extremely lacking." As shown in Figure 3, students extremely lack communication skills (e.g., oral and written communication to allow for adequate articulation, communication, and writing of reports of the causes of failure), and investigative and detective skills to gather information, discover important facts, and generate conclusions, as indicated by the median value of 5. On the other hand, students' legal knowledge (e.g., technical vocabulary and legal procedures), structural engineering knowledge, and professional experience have a median value of 4 indicating that they lack skills in these areas as well. Therefore, it is clear from the box plots that there is a gap in students' forensic engineering skills. As such, forensic engineering courses with practical pedagogical approaches should be accessible in the university to the students as indicated by the ordered probit model.

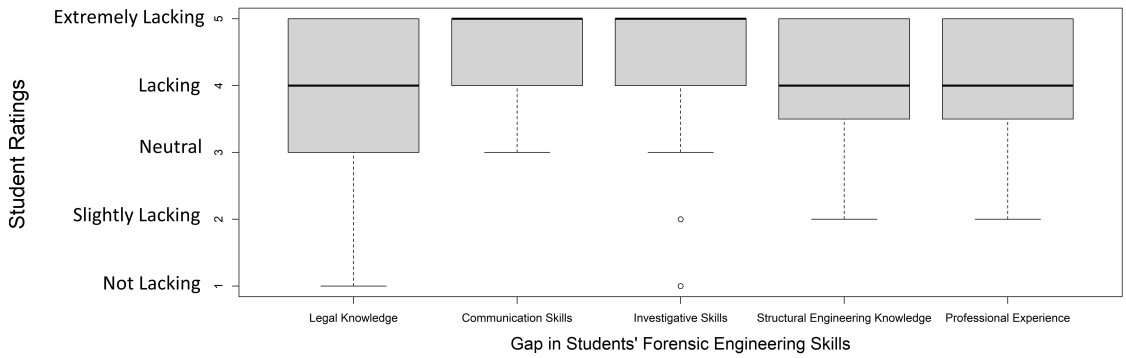

Figure 3. Box plots showing a gap in students' forensic engineering skills.

Limitation and Future Work

One of the study's limitations is that the research has been conducted in a Minority serving institution. This indicates that 90% of the sample size in the study includes a minority population. Therefore, future studies could focus on investigating the research in several institutions with a diverse student population from different socio-demographic backgrounds.

Conclusion

Forensic engineering is a challenging discipline where engineers are expected to investigate structural failures, litigation support, quality control, complex problem-solving, and structural damage repair. Past studies conducted in the early 2000s, indicated that many graduating workforces have only limited or no exposure to forensic skills, including investigative techniques, construction techniques, material analysis, architectural systems, detailing, and structural systems. Due to the growing demand for forensic engineers, this study investigated if any progress has been made in academia to improve the forensic skills of the future workforce. To achieve this goal, the authors analyzed 72 ACCE accredited bachelor's programs in the U.S. to identify the accessibility to forensic engineering courses. The results indicated that only 4 universities offered courses that are relevant to forensic engineering.

The ordered probit regression analysis results indicated that higher accessibility of forensic engineering curriculum within the university, students' positive attitude towards solving complex problems, higher interest in forensic concepts, and practical pedagogical approach used in the course will increase students' interest to pursue a forensic engineering career. Furthermore, the results of this study highlighted that students significantly lack skills in forensic engineering, including legal knowledge, communication skills, investigative and detective skills, structural engineering knowledge, and professional knowledge. As such, incorporating curricula that include those topics will significantly contribute to students' professional success. The findings of the study are directed to field professionals, instructors, engineering education administrators, and individuals who are interested in the current state of forensic engineering education.

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