Future of Civil Engineering Education: Trends and Challenges

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Abstract
This paper examines stakeholder satisfaction with civil engineering academic curricula and their preparedness for current and future challenges. It discusses emerging technologies, major infrastructure issues, the role of sustainable practices, essential skills for future engineers, and overall satisfaction with the profession. An extensive survey was designed to gather valuable feedback from diverse stakeholders within the field of civil engineering. The survey encompassed a wide range of participants, including students, trainees, academics, and civil engineers with varying levels of experience and professional roles. The survey was conducted through LinkedIn and social media networks. A total of 68 responses (mostly from Middle East) were collected. Among the participants, about 57% were academics, offering educational insights, while 40% were engineers from various industry roles. Most respondents had over 10 years of experience in civil engineering, with approximately 8% having less than 5 years, bringing fresh perspectives from emerging professionals. Participants emphasized the importance of sustainable development for the future of civil engineering. The survey highlighted that essential skills for future engineers include proficiency in innovative software, effective management, and advanced technological expertise. Additionally, about 74% of participants expressed concerns that current academic programs do not sufficiently prepare the next generation to tackle anticipated global challenges.

Keywords: Civil Engineering, Challenges, Curriculum, Sustainability, Future Trends

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Introduction

In today's rapidly changing technological landscape and amidst the numerous challenges faced by communities worldwide, such as climate change, resource scarcity, poverty, the need for sustainable development, and digital transformation, it is imperative to continually review and revise academic curricula to ensure they remain relevant and responsive to the evolving demands of society. Among the various academic disciplines, engineering curricula, particularly civil engineering, hold a position of high priority in this regard.

Civil engineering curricula must be continuously updated to equip students with the knowledge and skills necessary to tackle the pressing challenges faced by communities. It is crucial to bridge the gap between academic theory and real-world industrial practices and trends. This responsibility lies jointly with educational institutions and industry stakeholders. In this regard, Abdul Karim (2016) proposed a new course "Principles of Management, Finance and Entrepreneurship" to be added to the revised curriculum of civil engineering. Other elective courses were offered with possibility of having Entrepreneurship Minor Program before graduation of students of college of engineering. These skills are needed and welcomed by students. Another initiative aimed at bridging the gap between academia and industry was undertaken by Saint-Petersburg Polytechnical University (Tuchkevich et al., 2015). This initiative involved reaching out to well-established companies and prominent employers in the civil engineering field, with the objective of providing valuable resources and opportunities for both students and faculty members.

There is ongoing research addressing the need for updating the engineering education to include the new concepts and utilize the evolving technologies to meet the demands of the changing world (Duderstadt, 2008; Graham, 2018). Engineering education 5.0 is a newly introduced concept that describes a forthcoming educational framework connected to a perspective of engineering education marked by an ongoing requirement for development for achieving a future that is both environmentally sustainable and socially compassion-ate. Lantada (2020) characterized several key features of the Engineering education 5.0 including dynamic and continuously evolving, personalized for joint personal and professional development, combining knowledge-based and outcomes-based approaches, sustainability focused, holistic, guided by ethics, collaborative and open source, involving international experiences, including external academic internships, supported by project-based learning activities, technology-supported and artificial intelligence-aided, oriented to lifelong learning, enjoyable for enhanced results, and Equitable.

Building Information Modeling (BIM) is a robust tool in the construction industry that utilizes planning and cost and provides visualization of the executed construction tasks over a period of time (Wang et al., 2014). Construction 4.0 is the integration of advanced technologies and digitalization in the construction industry. These technologies include connected systems of sensors, intelligent machines, mobile devices, and innovative software applications. Examples of these technologies include utilization of drones for surveying and inspecting construction sites, advancements in additive manufacturing, such as 3D printing, implementation of 3D scanners to allow for the creation of digital models of intricate structures, using Global Positioning System (GPS) and Radio Frequency Identification (RFID) to track materials, equipment, and workers (Gerbert, 2016; Hilfert & König, 2016).

A research group from Faculty of Engineering at the University of Porto have high-lighted two essential aspects of the teaching practices employed: the Construction Sites of the Future,

which involved a laboratory-based education initiative, and the Digital Products Catalogue, which aimed to support Project-Based Learning in Construction. The intended learning outcomes of these initiatives included enhancing knowledge of innovative solutions, developing skills to implement actions in the con-text of Industry 5.0, and fostering human-centered and sustainable attitudes and values. According to their findings, the incorporation of Project-Based Learning and Laboratory-Based Education initiatives, complemented by teaching in Project Management, Information Technology, and Sustainable Building, provides a robust pathway towards Engineering Education 5.0. As a result, they have devised a plan to gradually integrate and evaluate these topics within the existing curricular units to-wards Civil Engineering 5.0 academic path (Calvettia, 2024).

Nearly 200 research papers from the period of 2009 to 2020 were reviewed and analyzed to gain deeper insights into the prevailing trends and identify any gaps or areas requiring further research in the area of Construction 4.0 (Perrier et al., 2020). They observed a strong connection between research on Construction 4.0 and the construction phase itself. Furthermore, they concluded that the most extensively researched topics revolve around the management processes associated with quality, risk, and health and safety. These topics can be introduced to the students in their undergraduate study in relevant fields.

Methodology

A survey was designed to seek the feedback about the current challenges and future trends of the civil engineering in both aspects; the educational curriculum and the profession itself.

The survey included a variety of questions to gather comprehensive insights about civil engineering and civil engineers. It started with general questions about the participant's occupation, role, and experience, followed by technical multiple-choice questions on the monetary value and salaries of civil engineers. The survey also explored the emerging technologies and challenges that have the most significant impact on the future of civil engineering, the importance of sustainable development for civil engineering careers, the skills needed for the next generation of civil engineers, and the adequacy of current civil engineering academic programs. Additionally, it included open-ended questions asking civil engineers to address and face future challenges, explain how emerging technologies can transform the field, discuss the vital role of sustainable practices, and provide any other helpful thoughts or suggestions.

Different stakeholders including students, academics, and civil engineers with different roles and experience within the civil engineering field participated in the survey. A total number of 68 participants have participated through direct emails, social media, and professional websites. This sizable dataset provides a robust foundation for analysis and allows for statistically significant conclusions to be drawn. The geo-graphical scope of the survey encompassed several regions, namely North Africa, the Gulf region, South Asia, and North America. This deliberate selection of regions ensured a diverse range of perspectives and experiences, taking into account variations in civil engineering practices, regulations, and challenges across different parts of the world with a majority from North Africa and Gulf region.

By incorporating these different viewpoints, the survey aimed to generate insights that would be applicable in various international contexts. Approximately 57% of the participants were academics, who brought their specialized knowledge and educational perspectives to the

survey. Their insights provided valuable input from an educational standpoint, shedding light on the latest research, trends, and emerging practices within the field of civil engineering. The remaining 40% of the respondents were practicing engineers, representing a diverse range of roles such as site engineers, office engineers, and construction project managers. This diverse representation of professionals with hands-on experience in different aspects of civil engineering adds depth and richness to the findings. Their practical insights and real-world experiences con-tribute to a more comprehensive understanding of the challenges, opportunities, and best practices within the industry.

Overall, the extensive survey successfully captured a global perspective on civil engineering by incorporating participants from different regions and professional back-grounds. The dataset obtained from the survey, along with the diverse representation of stakeholders, lays a solid foundation for in-depth analysis and meaningful conclusions regarding the current state of civil engineering.

The survey seeks feedback on the emerging technologies that will significantly impact and transform the field, the major future challenges facing the profession and how to address them, the importance of sustainable practices in shaping the future of civil engineering, the skills required of future civil engineers, and the adequacy of current academic curricula.

Results

The results of the survey questions are shown in Figures 1-6. According to the participants, the emerging technologies mentioned, such as 3D printing, artificial intelligence, and machine learning, have the potential to transform the field of civil engineering. These technologies offer various benefits, including reducing construction time and cost through efficient design and simulation models. They also promote environmental sustainability by using new construction materials and reducing CO_2 emissions. Additionally, these technologies enable better prediction of infrastructure performance over time. As shown in Figure 1, the participants selected the artificial intelligence and machine learning to be the most needed emerging technology with a percentage of 60.3%. In the second stage, the 3D printing and new construction materials received 57.4% of the selection of the participants. Overall, the emerging technologies can improve the quality, efficiency, and economic viability of civil engineering projects. By incorporating these technologies, civil engineering can become more advanced, easier to manage, and more environmentally friendly. It may also lead to changes in construction practices, such as the use of new materials and increased automation.

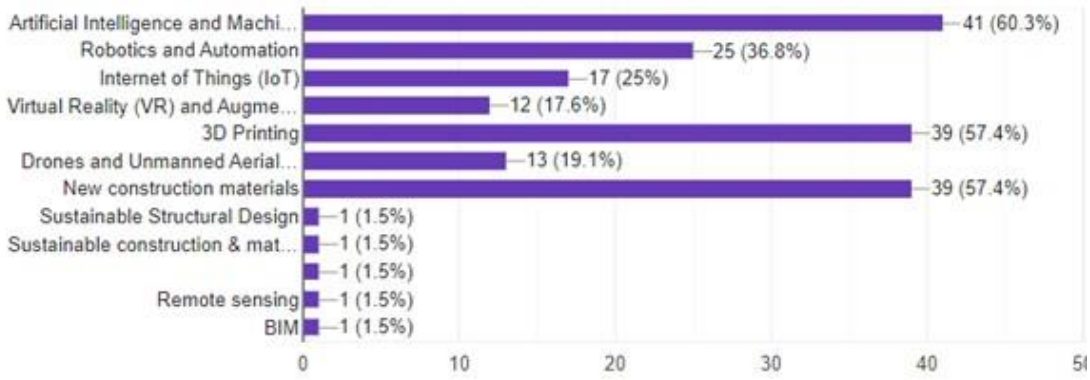

Figure 1: Most Significant Emerging Technologies for Future Civil Engineering

Figure 2 depicts the most challenges that civil engineers can face and need to address them in the future. According to the survey results, these challenges are aging infra-structure, climate change and extreme weather conditions, and population growth, respectively. In order to address the challenges and requirements in civil engineering, incorporating new technology, devising innovative construction materials, and considering urban and social needs are crucial. Advanced technologies combined with the expertise of civil engineering professionals can effectively respond to these challenges. Governmental strategies, study, analysis, education, and training play important roles in implementing these solutions. Sustainability, continuous monitoring of structures, and strict measures against violations are essential considerations. Brainstorming, research, and continuous skill enhancement are necessary for progress. Additionally, addressing transportation obstacles, environmental changes, and population growth are important factors in designing and maintaining resilient and sustainable infrastructure. A comprehensive plan that includes assessment, deliberate design, and collaboration can help meet the increasing demands of growing populations.

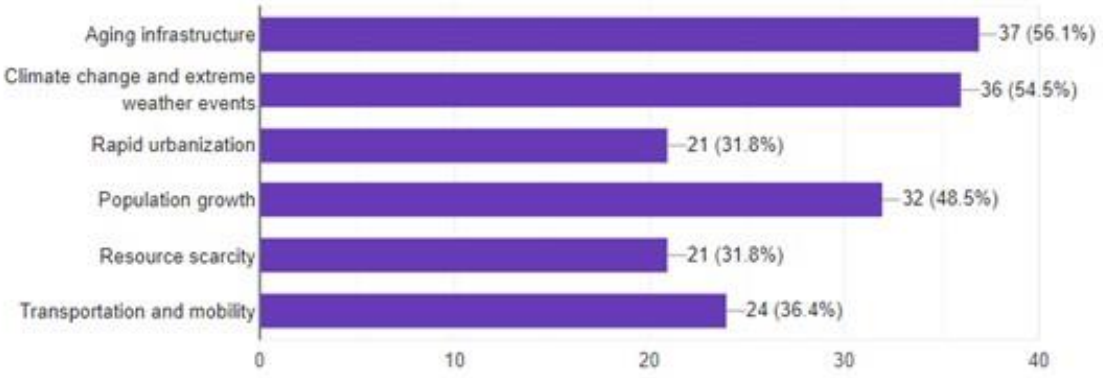

Figure 2: Significant Challenges Expected to Face Civil Engineers in the Future

Around 33% of the participants classified the sustainable development as extremely important aspect for the future of civil engineering and 24.8% categorized it as very important, as shown in Figure 3. Sustainable practices, such as using recycled materials, minimizing waste, and adopting clean energy, are important for reducing green-house gas emissions and addressing climate change. The use of sustainable and natural materials, finding alternatives to concrete, and implementing innovative engineering management approaches are important considerations. Energy conservation, sustainable energy regimes, carbon emissions, and recycling are key areas of focus. The role of civil engineers in improving the quality of life for others is important, although they may not always receive adequate benefits in return. Water management, life-cycle assessment, waste reduction, climate resilience, and the use of software and construction methods are additional aspects to consider. BIM, renewable energy, green materials, smart design, water management, and circular economy principles are expected to shape the future of civil engineering. Additionally, the use of auto-mated machines and robots is becoming more prevalent in the field. Participants were asked about the necessary skills for the future generation of civil engineers to effectively address upcoming challenges. The findings revealed that the most preferred skill was the application of innovative technical software and tools, which received 69.7% of the votes. Managerial skills ranked second, with a percentage of 59.1%. Other notable skills mentioned included advanced technological proficiency (54.5%), effective communication (53%), and teamwork and collaboration (50%). The survey also emphasized the importance of data analysis and ethical/social awareness. Figure 4 provides a visual representation of the survey results.

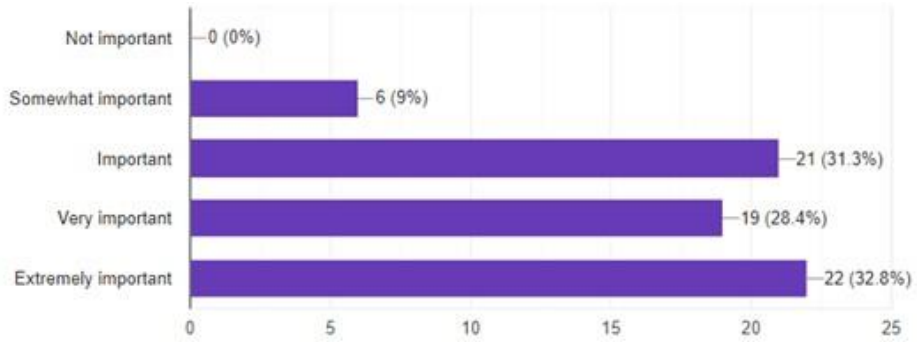

Figure 3: Importance of the Sustainable Development on the Future of Civil Engineering

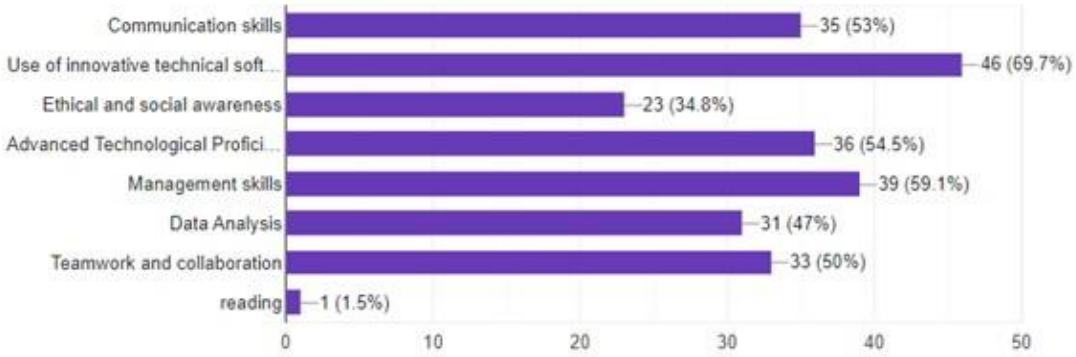

Figure 4: Skills Needed for the Future Civil Engineers

Based on the perspectives of the survey participants and in response to the changing world and its associated challenges, a majority of participants believe that the existing civil engineering curriculum should be revised to adequately prepare future generations for the role of civil engineers. As indicated in Figure 5, 74.2% of the respondents expressed the opinion that the curriculum requires improvement, while 13.6% considered the current curriculum sufficient without any need for changes. Figure 6 provides a list of topics that should be incorporated into the current educational curriculum of civil engineering in order to enhance its effectiveness. The most highly prioritized topic, selected by 73.1% of participants, was emerging technologies such as Building Information Modeling (BIM), 3D printing, robotics, drones, and new construction materials. Other significant topics that should be considered include sustainability and green infrastructure (62.7%), smart cities and the Internet of Things (IoT) (38.8%), data science and analytics (35.8%), and virtual design and construction utilizing virtual reality and augmented reality (34.3%). Additional areas of interest included the legal aspects of engineering, licensure and professional practice, and field training.

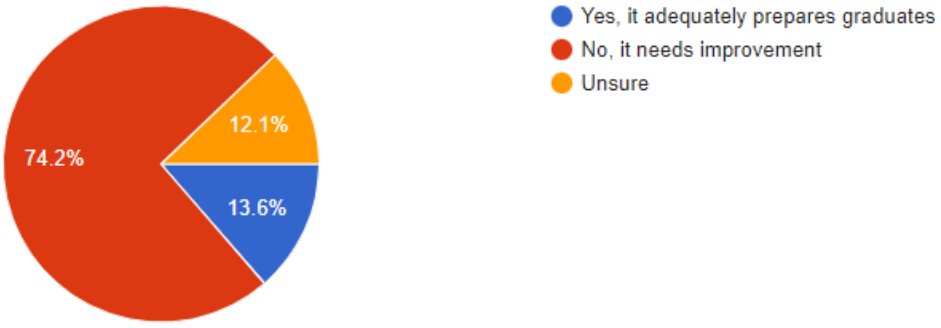

Figure 5: Does Current Civil Engineering Curriculum Adequately Prepare Graduates?

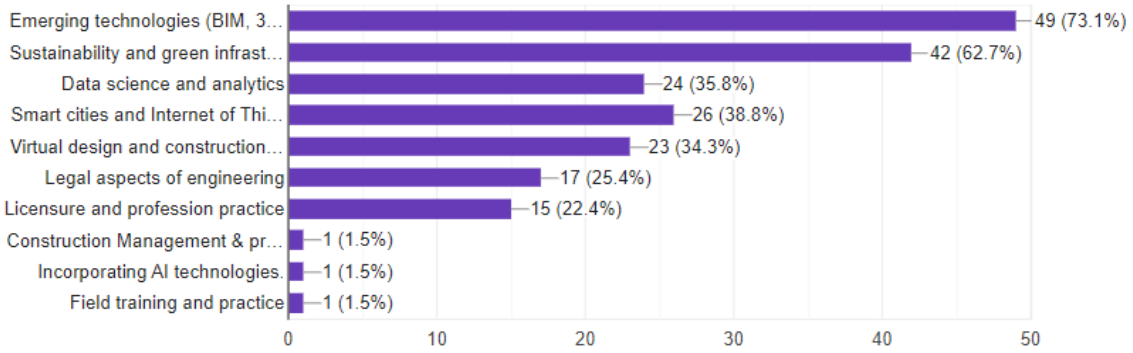

Figure 6: Topics Should Be Included in the Educational Civil Engineering Curriculum to Prepare the Graduates for the Future Challenges

Conclusion

The topic of the future of education is a subject of active research that garners significant attention from researchers. Civil engineering, as a discipline, requires constant updates to adapt to evolving global changes and to incorporate emerging technologies utilized by advanced companies in the field. To gather valuable insights, a survey was conducted involving 68 participants who represented various stakeholders in the civil engineering field. These participants included students, trainees, academics, and civil engineers with diverse levels of experience and professional roles. Based on the survey findings, it was determined that certain emerging technologies will have a substantial impact on civil engineering in the future. These technologies include artificial intelligence and machine learning, 3D printing, and the utilization of new construction materials. Participants expressed their insights regarding the most significant challenges that civil engineers are anticipated to encounter in the future. These challenges include addressing aging infrastructure, mitigating the effects of climate change, and accommodating population growth.

The participants emphasized the importance of sustainable development for the future of civil engineering. Regarding the essential skills for future civil engineers, the survey revealed that proficiency in innovative technical software and applications, effective management skills, and advanced technological proficiency are highly valued. It was noted that approximately 74% of the participants expressed concerns that current academic programs are insufficient in preparing the next generation of civil engineers to effectively confront the future challenges that are expected to arise globally.

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