Human Expertise and AI in Civil Engineering: Competencies for Responsible Engineering Practice

E. Volpe [1]
University of Florida
Gainesville, FL, USA
ORCID 0000-0001-5755-8142

D.R. Simmons
University of Florida
Gainesville, FL, USA
ORCID 0000-0002-3401-2048

K. Beddoes
Washington State University
Pullman, WA, USA
ORCID 0000-0003-2108-8884

Conference Key Areas: Digital tools and AI in engineering education; Engineering skills, professional skills, and transversal skills; Continuing education and life-long learning in engineering; Engineering ethics education

Keywords: *Responsible AI, Professional Competencies, AI in Civil Engineering, AI Ethics*

ABSTRACT

As artificial intelligence (AI) rapidly evolves, its integration into civil engineering presents both significant opportunities and challenges. Through a qualitative analysis of interview, survey, and reflection journal data, this study explores the perspectives of early-career civil engineers regarding the current and potential roles of AI in engineering practice. While AI is seen as a valuable tool for automating routine tasks and enhancing efficiency, concerns persist about its reliability, ethical implications, and potential overreliance. Participants emphasized the importance of maintaining human oversight, with AI serving as an aid rather than a replacement for engineering judgment. The study identifies key competencies essential for engineers to effectively and ethically integrate AI, including AI literacy, critical thinking, ethics, and cybersecurity awareness. As AI continues to influence the field, it is crucial to equip engineers with these competencies through education and ongoing professional development. The paper offers recommendations for integrating responsible AI practices into engineering education and the workplace, highlighting the need for continuous training in both technical skills and ethical decision-making. This research contributes to the growing literature on

[1] *Corresponding Author*
E. Volpe
Evolpe1@ufl.edu

responsible AI integration, providing insights that can guide the future workforce in navigating the complexities of AI-enhanced engineering practices.

1 INTRODUCTION

As AI technologies advance, questions arise about how these tools can be integrated into engineering practices without compromising human expertise. As such, there is a growing need for educational initiatives to prepare engineers with the competencies for responsibly utilizing AI (Decker et al. 2024; Liang et al. 2024). Research within civil engineering has highlighted several key ethical concerns surrounding AI, including job loss, data privacy, security, transparency, decision-making conflicts, trust, reliability, safety, surveillance fears, and liability (Liang et al. 2024). While civil engineering has historically been slow to adopt new technologies, there is now increasing focus on the ethical integration of AI. This shift is critical, given the significant impact civil engineering outcomes have on the built environment and society. This study explores the perspectives of practicing early-career civil engineers regarding the current and potential future roles of AI in their work. This study was guided by the following research question: How do early-career civil engineers perceive the integration of AI in engineering practice, and what competencies do they identify as essential for preparing for AI's integration into the field?

We employed a framework of competencies as a **sensitizing concept**, guiding our initial analysis while remaining open to new insights. The framework built on two existing sets of competencies. A study of construction industry leaders highlighted critical leadership-enabling competencies that engineering students should develop to ensure a smooth transition into construction and engineering careers (Simmons et al. 2020). These competencies include communication skills, professionalism, critical thinking and problem-solving, management, ethics and responsibility, big-picture thinking, humility, teamwork, collaboration, networking, and quality control (Simmons et al. 2020). Although originally developed for broader leadership contexts in civil engineering, these competencies align well with the skills and knowledge needed to promote responsible use of AI in civil engineering. Additionally, Decker et al. (2024) identified Responsible AI Competencies for Engineers, such as AI literacy, engineering literacy, software engineering ethics, engineering ethics, and AI ethics. Combining both sets of competencies provided a framework for understanding essential competencies for responsibly engaging with AI in civil engineering.

2 METHODOLOGY

4.1 Participants

Participants were 17 early-career engineers with up to 10 years of work experience in private and governmental civil engineering organizations across the United States. Their subdisciplines included traffic, transportation, environmental, systems, structures, and geotechnical. Three participants were recruited through convenience sampling; further details about those participants can be found in (Beddoes 2024). Fourteen participants were recruited through professional society listservs and social media postings; further details about those participants can be found in (Beddoes 2021, 2022, 2023, 2024).

4.1 Data Collection

Adopting a phenomenological approach, this study aimed to deeply explore participants' experiences with AI in the civil engineering industry (Creswell 2020). Qualitative data were collected through semi-structured interviews, open-ended surveys, and reflection journals. The survey prompts, reflection journal questions, and interview guides were designed to elicit in-depth responses from participants on their use (or non-use) of AI in their work and their perspectives what AI-related competencies practicing civil engineers need. Fourteen participants were asked to reflect on prompts such as: *"Have there been discussions about AI or the role of AI in your work?"* in qualitative interviews. Three participants were prompted with that and other prompts such as *"What kinds of things were people trying to use it for?"* and *"What knowledge skills or resources would be helpful to better understand AI in engineering?"* in their weekly reflection journals.

4.1 Data Analysis

To better understand the phenomenon under investigation, thematic analysis was employed to identify patterns in the data using a blend of deductive and inductive coding methods (Braun & Clarke 2006). We combined the leadership-enabling competencies outlined by Simmons et al. (2020) and the Responsible AI Competencies for Engineers by Decker et al. (2024) to create a conceptual framework for the deductive coding. Additionally, we used inductive coding to allow emergent codes to develop directly from the data. The first author conducted a line-by-line coding of all qualitative journal entries, survey responses, and interview data, assigning a priori codes such as descriptive, emotion, or process codes to extract meaning from the text (Saldaña 2013). These codes were then sorted into categories, and larger themes and patterns were identified across the data. The second and third authors engaged in peer debriefing with the first author, challenging interpretations until consensus was reached on the identified themes (Creswell 2020). This process aimed to uncover patterns across participants' experiences, offering insights into how early-career engineers are discussing, using, and learning about AI in engineering practice (Saldaña 2013; Creswell 2020; Braun & Clarke 2006).

3 RESULTS

3.1 Participant Identified AI Competencies

Competencies identified through inductive and deductive coding are listed in **Table 1**.

Table 1. Competencies Identified by Civil Engineers for Integrating AI into Practice

Communication	Ethics / Responsibility	Critical Thinking / Problem Solving	Management
Big Picture Thinking	Quality Control	Adaptability	People Focus
Cybersecurity	Continual Learning	AI Ethics	AI Literacy

Human-AI Collaboration	Data Management and Analysis	Risk Management	Change Management and Innovation

3.2 Themes Across Participant Narratives

Theme 1: AI as a Tool, not a Replacement for Civil Engineers

While the extent to which participants currently engage with AI in their work varied from "*No, AI can't impact our work*" and "*I've not heard any discussions on [AI]*" to "*Yes, we do have an AI committee*," the engineers in this study all discussed the potential future role they saw for AI in engineering. Some participants shared that their organization already had private, customized AI models that they were encouraging employees to engage with, while others had blocked all public AI platforms on company devices. Participants who were engaging with AI highlighted its potential to automate routine tasks like generating plans and conducting database searches. While AI is expected to streamline these processes, concerns remained about its ability to handle more complex tasks. Regarding design, many engineers believe it is too early for AI to make independent decisions but foresee it supporting the design process by automating data-heavy tasks and enhancing efficiency.

Participants frequently emphasized that AI is useful as a tool but should not replace the human expertise and decision-making required in engineering. There is a strong belief that AI should aid tasks (like coding or automating data analysis) but cannot replace critical human oversight, especially in tasks requiring professional judgment (e.g., reviewing designs, ensuring safety). One participant shared,

> *It [AI] is just a tool. You're still the responsible person. Your name goes on the document signed and sealed. You still gotta stroke the pen to sign off on this project is safe in accordance with the requirements of the codes, and you're responsible for it.[…]I actually see a lot of risk with AI in our profession, […]But to use it on the job means that [engineers a]re not thinking as much. They're relying on that tool to have […] essentially a crutch to give them an answer.*

This participant emphasized the importance of human judgment, knowledge of codes ethics, and basic engineering principles as things like AI become increasingly used.

Concerns Around Accuracy and Dependence

Many participants expressed concerns about the accuracy of AI and the potential for over-reliance on it. One participant expressed a concern at their organization, which did not encourage or use AI, sharing, *"The general use of AI is discouraged because people tend to just take what it gives without double checking the information*." Participants mentioned the need for thorough checks and balances to ensure that AI-generated outputs are trustworthy, especially in engineering tasks where precision is critical. One participant stated, "*It wasn't always correct or accurate, or it wasn't really a reliable source for us to use at this point."* Similarly, another participant said, "*I am also a bit wary of the accuracy and having to review it takes just as much time as doing it myself right now so I would prefer to just do it myself."* This statement reflects a concern about the reliability of AI, where the individual feels that reviewing AI-generated work for accuracy takes as much time as completing the task themselves. As a result, participants emphasized the importance of civil engineers developing strong critical thinking skills and the ability to critically evaluate AI-generated outputs. Often, they preferred to handle the task independently rather than relying on AI. Another participant contemplated the use of AI and the importance of professional engineers still conducting quality checks*, "Can [AI] be trusted to provide accurate and precise work? And that's where like we as professional engineers come in and do the QC [Quality Check]."*

Ethical Considerations and Cybersecurity

Across all participants, a strong pattern emerged on the ethical use of AI, particularly regarding privacy, security, and ensuring its responsible application in engineering tasks. Participants raised concerns about sharing proprietary or sensitive information with AI systems, especially generative AI tools like ChatGPT. One participant shared, *"I'm curious about ethics […] Can AI be trusted with confidential information? […] a lot of projects we do can be confidential."* Another participant, whose organization was not engaging with AI and had blocked all AI platforms, shared,

> *I mean [my organization] blocks ChatGPT on our laptops and everything, you know, so you can't access it right? Because we do have proprietary information, and you know, sensitive information from a client[…] But again, I don't know if it's the sensitive information that we deal with that's maybe keeping them from implementing something like that.*

This participant indicated that their organization was particularly concerned about cybersecurity and privacy, which may be the reason they were not engaging with AI tools at all. Other participants expressed similar concerns sharing that their companies had major concerns about protecting privacy and data.

All participants viewed AI as a tool, not a replacement for civil engineers. Participants expressed concerns about overreliance on AI, particularly regarding cybersecurity, privacy, and the protection of client data. While some saw AI as a valuable tool for tasks like checking work or analyzing large datasets, many raised concerns about the ethical, safety, quality, and security risks associated with its overuse.

Theme 2: Empowering Engineers: AI and Cybersecurity Training for the Future

Participants emphasized the importance of developing essential human competencies, to ensure users understand AI's limitations, ethical concerns, and the necessity of proper training. One participant shared,

> *The danger with that [using AI] is without understanding the concepts people could be lazy and rely too much on it. I think learning how to teach people to use it as a tool is an important step in ensuring that we grow along with it rather than being reliant on it.*

The concern expressed by this participant was that without understanding basic concepts of engineering and AI, people may become overly reliant on AI, so it's crucial to teach how to use it as a tool for growth and continue to build knowledge around engineering concepts.

One participant shared that at their civil engineering consulting firm,

> *[…]in consulting, literally, we sell time and it's going to take even more time to teach AI how to do something, but then over time it actually is way more efficient […] it's just the upfront, so I don't know, [we need] better understanding about how we can use it better … understanding ethics*

The participant highlights that while it may take time to teach AI to perform tasks and train engineers to engage with it, the long-term efficiency gained makes it worthwhile. However, as engineering consultants, they have limited time in practice to focus on this and they expressed a desire for skills in using AI efficiently and ethically. Another participant shared, "*I guess people are just lacking training*."

To ensure engineers can evolve with AI and avoid ethical concerns or overreliance, these participants called for more ongoing education and training on the topic. One participant even shared specific resources their company was providing,

> *Resources specifically […] lunch and learns and […] an IT AI seminar So we got to ask questions and [facilitators] gave us resources of like different AI tools that we could use inside and outside of work.*

The participants in this study emphasized the need for continuous education and training to help engineers effectively integrate AI into their practice while addressing its limitations, ethical concerns, and avoiding overreliance, highlighting the importance of ongoing support from researchers, educators, and organizations.

4 DISCUSSION AND CONCLUSION

Through a triangulation of qualitative data sources, this study explores a sample of U.S. civil engineers' perspectives on AI use in engineering and the competencies engineers need to responsibly integrate AI into engineering practice. The findings contribute to the growing body of literature on Responsible Artificial Intelligence (RAI) in engineering (Decker et al. 2024; Downey et al. 2024), offering context-specific empirical insights from practicing engineers that help identify responsible AI practices and competencies in civil engineering. Aligned with leadership-enabling (Simmons et al. 2020) and RAI (Decker et al. 2024) competencies, we identified 16 AI competencies in the data (see Table 1), suggesting future engineers will need a blend of technical, professional, and ethical competencies. This research builds on existing leadership and responsible AI competency frameworks, highlighting a growing need to focus on key competencies, such as ethics, quality control, people-centered thinking, and cybersecurity, as AI becomes more prevalent in the civil engineering workforce. While some of these competencies go beyond those previously identified, they contribute to a more holistic understanding of the knowledge, skills, and attributes that future civil engineers will need to navigate an increasingly technology-integrated profession. Two themes emerged from the data: (1) participants see AI as a tool, not a replacement for engineers and (2) training in AI and cybersecurity can empower future engineers. This work sheds light on the current uses of AI in civil engineering practice in the U.S., revealing concerns about cybersecurity, privacy, and the overreliance on AI as an engineering tool.

AI literacy emerged as a top competency, with 9 out of 17 participants expressing a desire for greater understanding, training, and skills related to the effective and responsible use of AI in civil engineering practice. In today's technology-driven world, AI literacy emphasizes the need for individuals to gain the knowledge and skills necessary to engage effectively with AI systems (Almatrafi et al. 2024). AI literacy encompasses the ability to critically assess AI technologies, collaborate with AI, and apply it effectively across different settings, such as online, at home, and in the workplace (Almatrafi et al. 2024). The competency of responsibility, also mentioned frequently by participants, is central to engineering education, as the rapid advancement of AI underscores the need to educate engineers about their role in both using and developing AI systems (Decker et al., 2024).

Based on these findings, recommendations for engineering educators and researchers include the introduction of RAI and AI literacy in educational settings to equip future engineers with these essential skills. Research and practice are increasingly offering strategies and tools for doing so; for example, one study found that engineering students gained familiarity with responsible AI practices through an AI competition activity (Downey et al. 2024). Recent literature highlights the exciting opportunities AI presents, with the potential to serve as a valuable tool when embraced responsibly (Plevris 2025; Uddin 2024). However, it is essential to educate students on the proper use of AI, advocate for its balanced and supplementary role in education, and emphasize the need for continuous evaluation and adaptation of these tools within the broader civil engineering field (Talha Junaid et al. 2024). This approach necessitates oversight, a deep understanding of AI's limitations, and the development of critical thinking skills to address its ethical implications (Talha Junaid et al. 2024). To further facilitate AI literacy, educators and trainers can focus on the core concepts of AI literacy identified by Almatrafi et al. (2024), including: recognizing AI tools and applications, understanding the basics of machine learning, using and applying AI to interact with machines and explore practical applications, evaluating and interpreting AI algorithm results, identifying potential biases, comparing different algorithms, and navigating ethical concerns related to the human-focused aspects of AI, such as fairness, accountability, transparency, ethics, and safety. Furthermore, students should be encouraged to critically discuss AI's role and its impact on engineering and society.

Participants in this study expressed concern that future engineers may not fully understand fundamental engineering concepts and professional ethics, illuminating a need for continued development of engineering students' skills in these two areas. While accredited engineering education programs include curriculum grounded in engineering basics, educators should continue to advocate and emphasize fundamental engineering concepts, skills, and knowledge even as basic courses compete with emerging technologies and AI-focused courses for curriculum space. However, it is also crucial to continually update and improve ethics education in engineering (AlSagheer & Al-Sagheer 2011; Polmear et al. 2019), especially as ethical issues around emerging technologies and AI arise. In the context of civil engineering in the U.S., it is essential to engage students with ethical guides such as the American Society of Civil Engineers (ASCE) Code of Ethics (ASCE 2020), and incorporate activities, case studies, and class discussions to encourage critical thinking about the application of ethical principles in AI practices. Additionally, engineering leaders should foster continuous, lifelong learning within their organizations as AI and technology rapidly evolve. By providing ongoing training, lunch-and-learns, seminars, and clear policies on ethical and responsible AI use, leaders can help advance the industry and ensure that AI is used in a responsible and effective manner.

In conclusion, this study contributes to the body of knowledge on civil engineers' perspectives regarding the role of AI in their profession, highlighting both its potential applications and the concerns it raises. Emphasizing the importance of pre-professional and continuing education in fundamental engineering principles, ethics, cybersecurity, critical evaluation of AI-generated outputs, and data management, these insights are vital for empowering engineers as critical thinkers. This foundation and ongoing support helps them navigate the transition to an AI-enhanced workforce while upholding strong adherence to engineering ethics and principles. The early-career civil engineers in this study offer valuable insights for shaping future educational practices in universities and workplaces that help engineers contribute to societal debates about technology development and use in an increasingly AI-driven world.

4.1 Limitations and Future Directions for Research

This study explores the experiences and reflections of a small sample population of practicing civil engineers in the U.S. The participants in this study are part of a larger, ongoing U.S.-based research effort on early-career civil engineers. We acknowledge the potential for selection bias due to purposive sampling, as these individuals were chosen for their continued involvement in related research. Additionally, we recognize that the findings reflect the localized, lived experiences of civil engineers working in the U.S. context. While not intended to be generalizable, the findings may be transferable to other individuals working in comparable fields. Future research should focus on exploring additional methods for training and educating engineers on computer science, AI principles, cybersecurity, and data management within engineering contexts.

5 **Acknowledgments**

The authors would like to gratefully acknowledge the participants for their thoughtful reflections and participation and interviews and surveys as well as the contributions made by Alison Bowers to edit and organize this paper. This work was supported by NSF #2414042 and NSF #2429274.

REFERENCES

Almatrafi, O., Johri, A., & Lee, H. (2024). A systematic review of AI literacy conceptualization, constructs, and implementation and assessment efforts (2019–2023). *Computers and Education Open*, *6*, 100173. https://doi.org/10.1016/j.caeo.2024.100173

AlSagheer, A., & Al-Sagheer, A. (2011). Faculty's Perceptions Of Teaching Ethics And Leadership In Engineering Education. *Journal of International Education Research (JIER)*, *7*(2), Article 2. https://doi.org/10.19030/jier.v7i2.4250

Beddoes, K. (2021). Examining Privilege in Engineering Socialization Through the Stories of Newcomer Engineers. *Engineering Studies, 13*(2), 158-179.

Beddoes, K. (2022). Gender as Structure in the Organisational Socialisation of Newcomer Civil Engineers. *European Journal of Engineering Education, 47*(1), 102-116.

Beddoes, K. (2023). Accounting for Occupational Identity Work in the Attrition of Newcomer Civil Engineers: A Theoretical Model. *Journal of Civil Engineering Education, 149*(3).

Beddoes, K. (2024). Five Years Later: Lessons and Insights from a Longitudinal Mixed-methods Study. *International Journal of Social Research Methodology, 27*(6), 805-810.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), Article 2. https://doi.org/10.1191/1478088706qp063oa

Code of Ethics. (2020). American Society of Civil Engineers (ASCE).

Creswell, J. (2020). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. SAGE Publications.

Decker, M., Schleiss, J., Schultz, B., Moreno, S. G., Stober, S., & Leicht-Scholten, C. (2024). Towards Responsible AI - Competencies for Engineers: An Explorative Literature Review On Existing Frameworks. *SEFI*. https://doi.org/10.5281/ZENODO.14256815

Downey, R. A., Rossi, M., & Schwaller, S. (2024). Rewarding Responsibility: Constructing a Responsible Artificial Intelligence Competition for Future Engineers. *SEFI*.

Liang, C.-J., Le, T.-H., Ham, Y., Mantha, B. R. K., Cheng, M. H., & Lin, J. J. (2024). Ethics of artificial intelligence and robotics in the architecture, engineering, and construction industry. *Automation in Construction*, *162*, 105369. https://doi.org/10.1016/j.autcon.2024.105369

Plevris, V. (2025). A Glimpse into the Future of Civil Engineering Education: The New Era of Artificial Intelligence, Machine Learning, and Large Language Models. *Journal of Civil Engineering Education*, *151*(2), 02525001. https://doi.org/10.1061/JCEECD.EIENG-2193

Polmear, M., Bielefeldt, A. R., Knight, D., Canney, N., & Swan, C. (2019). Analysis of macroethics teaching practices and perceptions in engineering: A cultural comparison. *European Journal of Engineering Education*, *44*(6), Article 6. https://doi.org/10.1080/03043797.2019.1593323

Saldaña, J. (2013). *The coding manual for qualitative researchers* (2nd ed). SAGE.

Simmons, D. R., McCall, C., & Clegorne, N. A. (2020). Leadership Competencies for Construction Professionals as Identified by Construction Industry Executives. *Journal of*

Construction Engineering and Management, *146*(9), Article 9. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001903
Talha Junaid, M., Barakat, S., Awad, R., & Anwar, N. (2024). Adopting the Power of AI Chatbots for Enriching Students Learning in Civil Engineering Education: A Study on Capabilities and Limitations. In A. Al-Marzouqi, S. A. Salloum, M. Al-Saidat, A. Aburayya, & B. Gupta (Eds.), *Artificial Intelligence in Education: The Power and Dangers of ChatGPT in the Classroom* (pp. 25–47). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-52280-2_3
Uddin, S. M. J., Albert, A., Tamanna, M., Ovid, A., & Alsharef, A. (2024). ChatGPT as an educational resource for civil engineering students. *Computer Applications in Engineering Education*, *32*(4), e22747. https://doi.org/10.1002/cae.22747
Volpe, E., & Simmons, D. (2024). AI's Visual Representation Gap: Redefining Civil Engineering Workspaces for Early-Career Women. *2024 ASEE Annual Conference & Exposition Proceedings*, 46536. https://doi.org/10.18260/1-2--46536