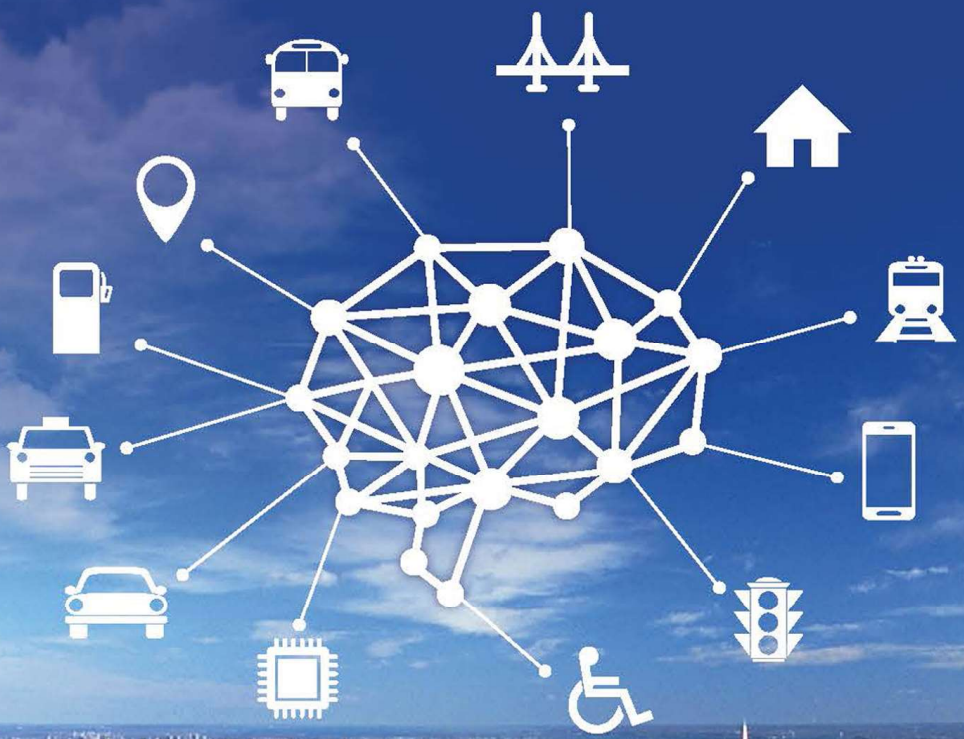
Leveraging Artificial Intelligence in Engineering, Management, and Safety of Infrastructure

M.Z. NASER (*ed.*)



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Dedication

To the hard-working engineers around the world,
To the future of civil and environmental infrastructure,
&
To the convergence of domains.

#TheFutureisAI

Preface

Artificial Intelligence (AI) continues to transform our lives on a daily basis. Advancements on the AI front can only be described as lightning-fast, especially when compared to what we are accustomed to in our civil and environmental engineering (CEE) discipline, one of the most classical and perhaps oldest engineering disciplines. Such rapid advancements, while admirable, their applications often struggle to find a home in CEE. This is possibly due to the fact that AI represents facets that can be foreign to us. For example, AI relies on coding—an exercise that is rarely covered in our curriculum. AI, and for the most part, remains a blackbox that can be hard to visualize—unlike many of the methods favored and practiced by our engineers. Most importantly, our discipline has been thriving and possibly, with presumably little credit to AI.[1] Thus, it is not surprising that we are a bit careful about embracing AI.

Thus, the prime motivation behind this edited book is to present our community with a series of successful stories to counter the above and set the stage for a foundation for AI. This book not only hopes to narrow the knowledge gap between AI and CEE but also to ease the transition into a future CEE; one where AI works hand-in-hand with engineers. It is our hope that this book charts a path to how AI can help re-shape our domain; to one that is modern, resilient, and intelligent. We anticipate the showcased chapters and case studies to be seen as evidence of the potential of AI. We hope that these studies become benchmarks that our readers can refer to and, most importantly, extend to more complex problems.

In parallel, this edited book also aims to address the following pivotal question; given that infrastructure is a massive investment that is expected to last for decades, then *how can we leverage AI in engineering, management, and safety of our infrastructure?*[2] Throughout a journey spanning 18 chapters and over 400 pages, we hope that we were able to show a glimpse of the potential of AI to our discipline. Each chapter is tailored to address a particular dimension to the aforenoted question. Each chapter is also crafted by experts in their niche area to highlight how various AI methods can be created, tweaked, and applied to problems relating to infrastructure. Most chapters are designed to be a standalone document that is comprehensive and

[1] For a more in-depth discussion on engineering, philosophical and educational aspects pertaining to these items, please refer to the following works as well as (Lin and Huang, 2015; Martínez-Barrera et al., 2015; Sacks et al., 2020; Thai, 2022) those by yours truly and co-authors (Naser and Ross, 2022; Naser, 2021; Naser, 2021).

[2] And hence, the title of this edited book!

encompass of a detailed cases study to the most extent, and some were dedicated as key references/reviews to give our readers the best of two worlds.

A primary objective of designing the internal structure of this book was to be as inclusive and diverse as possible in terms of the invited contributors, as well as topics covered—without any substantial compromises. We are proud to announce that we have contributions from Africa, Asia, Australia, Europe, and North America. A good portion of our chapters includes or is led by minorities, under representative groups, and early careers/Post-docs. While our contributors from South America could not make it to this edition, we are confident that future editions will be able to highlight a more inclusive and diverse body of works.

We start this edited book with a review on convolutional neural networks and their applications in civil infrastructure led by Onur Avci, Osama Abdeljaber, Serkan Kiranyaz, Turker Ince and Daniel J. Inman. This review outlines the latest advancements in AI in infrastructure. Then, Yifan Gao, Vicente A. González, Tak Wing Yiu and Guillermo Cabrera-Guerrero present their work on identifying construction workers' personalities. This chapter explores prominent AI models for the safety of construction workers in big projects.

Chapters 3 and 4 (led by Ahmad N. Tarawneh and Eman F. Saleh and Iman Mansouri, Jale Tezcan and Paul O. Awoyera, respectively) describe procedures to create novel AI models for designing structural elements and predicting properties of construction materials. Vafa Soltangharaei, Li Ai and Paul Ziehl in Chapter 5 further our discussion onto how AI can be adopted as a tool for condition assessment of structures and in Chapter 6, Diana Andrushia, Anand, N., Richard Walls, Daniel Paul T. and Prince Arulraj compliment this track with a case study on crack detection via AI.

We take a deep breath to continue our reviews on AI in Chapter 7 (where Islam H. El-adaway and Rayan H. Assaad lead the discussion on recent advancements with regard to construction engineering and management and safety). Their review is augmented with an equally impressive analysis with a scientometric spin by Zhanzhao Li and Aleksandra Radlińska on the use of AI as a design tool for concrete construction materials (Chapter 8).

Koosha Khorramian and Fadi Oudah provide us with an in-depth introduction and discussion on AI for attaining reliable structures via active learning kriging in Chapter 9. Then, William Locke, Stefani Mokalled, Omar Abuodeh, Laura Redmond and Christopher McMahan (the authors of Chapter 10) present a thorough Bayesian analysis for multilevel damage classification and identification of bridges.

Chapters 11–15 are dedicated to successful works that scaled AI to system-levels and infrastructure. For example, in Chapter 11, Andrew Fahim, Tahmid Mehdi, Ali Taheri, Pouria Ghods, Aali Alizadeh and Sarah De Carufel paint a vivid picture of how AI and Internet-Of-Things (IoT) can be valuable for international and large-scale monitoring of concrete across various site jobs. Haifeng Wang and Teng Wu (Chapter 12) present a detailed analysis of how deep learning can be enhanced through domain knowledge to predict the nonlinear response of structures. In Chapter 13, Hayder A. Rasheed, Ahmed Al-Rahmani and AlaaEldin Abouelleil present a novel synergistic approach that combines numerical simulations with AI to create a new tool for bridge girder damage detection. Zadid Khan, Sakib Mahmud Khan, Mizanur Rahman,

Mhafuzul Islam and Mashrur Chowdhury (Chapter 14) elevates the discussion by exploring the role of AI in transportation cyber-physical systems. Chapter 15 (co-authored by Amir H. Behzadan, Nipun D. Nath and Reza Akhavian) discusses the added value of AI to the construction area from the lens of the Future of Work.

The last three chapters are dedicated to the merit of adopting AI to overcome the unique hazard of fire. Unlike other hazards, fire can break out anywhere and anytime. Yet, building codes have not matured enough in this often forgotten area. Thus, these three chapters showcase the potential of AI in overcoming such a bottleneck from a practical, research, and futuristic look into the problem of fire in infrastructure. For example, in Chapter 16, Yavor Panev, Tom Parker and Panagiotis Kotsovinos articulate the use of AI in structural fire engineering design applications. Chapter 17, as led by Srishti Banerji, presents a case of using AI as a tool to establish the response of construction materials under elevated temperatures. Finally, this book ends with Chapter 18, where Xinyan Huang, Xiqiang Wu, Xiaoning Zhang and Asif Usmani highlight the application of AI in smart tunnels from a fire perspective.

Note to Readers and Instructors

We believe that this edited book will be valuable on a number of fronts. For example, the dedicated review chapters (Chapters 1, 7, 8, and 14[3]) can deliver the latest information on the frontier of AI and CEE. These chapters are a good starting point for readers of varying backgrounds on AI (e.g., little or advanced knowledge). Personally, I like to assign these chapters to senior undergraduate students interested in AI, as well as to graduate students who are planning/carrying out research on AI. Students who are looking for some exciting projects might find these chapters worthy of their time. Equally, I also like to refer my industry colleagues and practicing engineers to such chapters to introduce them to AI-based solutions and proofs of concepts that can be extended to other problems.

All other chapters are designed to present the reader with a collective background on their particular problems and adopted AI methods in sufficient detail. Admittedly, these chapters also home references to more complete works that can be visited for additional information. In some instances, some chapters might include links to codes and/or datasets that readers/students might like to view and apply. In all cases, our contributors have displayed interest in sharing their codes upon reasonable request. Please feel free to reach out to us shall you have any questions.[4]

This edited book emphasizes six areas within CEE. Namely, structural engineering, structural health monitoring, construction management and safety, construction materials, transportation engineering, and fire engineering. Other areas such as geotechnical engineering, environmental engineering, pavement engineering, and others were not left out of negligence but rather due to limitations and constraints imposed by the COVID-19 pandemic. We hope to showcase works

[3] Please note that Chapters 9 and 15 are two special hybrids in which they contain a good amount of introduction/review and a detailed discussion as well.

[4] In addition, please feel free to visit my website for additional codes, datasets, and AI-based applications [https://www.mznaser.com/fireassessmenttoolsanddatabases].

from the aforenoted areas, as well as others, in future editions of this book. On a more positive note, many, if not all, the explored AI methods in this edited book are equally applicable to other areas.

A Series of Thoughts and Advice from our Contributors

This is a collection of personal thoughts and advice collected from our contributors, as well as yours truly. For brevity, I will convey these thoughts in short sentences.

- Think of AI as a tool that can supplement and augment our existing knowledge and methods.
- While AI can help us on a variety of fronts, it, and just other methods, has its limitations.
- Keep an eye on details.
- Do not be afraid to try and use AI through coding or coding-less approaches.
- Get the fundamentals down. Teach yourself to see where AI can help you.
- Ask, how & why did AI arrive at such predictions?
- Ask, what does AI "see" that traditional methods do not?
- With technological advancements in sensors, cloud storage, and computing power, AI and data-driven approaches have become essential to determine the current structural condition and estimate the remaining service life of structures.
- Verify that the inputs to the ML model are representative of the dataset used for its training.
- Obtaining data under consistent environmental and operational conditions is probably the most important task when performing model updating with real system response data, as unknown sources of noise cannot easily be captured in a model.
- Sharing data and tools and standardizing AI application procedures will be a big step towards the development of a robust, data-informed construction intelligence ecosystem.
- Developing AI-based methods to form surrogate models in a reliability-based framework of analysis has opened the door for assessing the reliability of complex structural systems that otherwise was difficult or inefficient for us to quantify.
- AI offers unprecedented opportunities to retrieve and reveal remarkable patterns, trends, relationships, and knowledge from big data that can better help in managing civil infrastructure systems, construction engineering operations, and associated safety practices.
- The culture of openness, explainability/interpretability, and uncertainty quantification are important research gaps that need to be addressed in the AI-based civil engineering community.
- One of the challenges facing machine learning is over fitting. Make sure your model is generalized by selecting the appropriate training algorithm, dividing the database into training and validation datasets, and visualizing the effect of each of the variables.

- The confined tunnel is fatal in case of any fire event, so it needs an intelligent fire safety management system that combines AI, IoT, and digital twin to enable smart firefighting.
- Artificial Intelligence (AI) techniques allow the investigation of natural patterns between variables without assuming any preconception in terms of the mathematical structure of the data, which can have a considerable impact on the way that workers' safety behaviour can be predicted.
- Efforts toward sharing data and tools and standardizing AI application procedures are essential to foster the development of a robust, data-informed construction intelligence ecosystem.
- Finite element analysis is one of the most reliable tools to predict behavior of structural engineering systems. On the other hand, AI framework is one of the most promising tools to generalize efficient pattern recognition of complex phenomena. Therefore, the synergy of the two approaches holds great potential to accomplish effective solutions to a variety of open-ended problems in civil engineering.
- AI and big data should be viewed as accelerators of (rather than replacements to) human ingenuity and creativity.

A Look into How this Edited Book came to be

Finally, I would like to take the following few lines to reminisce and acknowledge the kind support of our contributors and CRC staff – for which, without them, this edited book would not have been possible. A special thanks go to my family, friends, students, colleagues, and my home school at Clemson University.

Let me start with a brief history of this project. The idea for this edited book came to light after a brief discussion with Vijay Primlani, an Acquisitions Editor at CRC. We set sail on this journey at the end of 2019 with a goal of completion within 18–24 months. Little did we know that a pandemic was on the horizon. I must admit that in the first few months of the pandemic, this project felt far away from seeing the light. Nevertheless, CRC's support and the trust of our contributors were tremendous. Despite this pandemic,[5] which unfortunately continues to exist as of the writing of this preface, our contributors and CRC staff managed to complete this book on time. Their hard work and persistence are acknowledged within the pages of this book. This is, and always will be, a true community effort. I am humbled to be part of this team and indebted to all of you.

M.Z. Naser
April 7th, 2022 Clemson, SC

[5] If you happen to read this edited in a few, or many, many years from now, you may/may not have witnessed the COVID-19 pandemic. A quick Google search can result in a brief look at our lives during the 2019–2022.

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