GUEST EDITORS' INTRODUCTION

AI Applications in Structural/Construction Engineering

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Structures such as high-rise buildings, highway bridges, and subway stations are a vital part of our lives, but few people stop to think much about them. In fact, few of us give much thought to any of the infrastructure we have come to rely on so heavily to support our modern lives. It is not common these days to read about a structural collapse. Such collapses might occur during devastating earthquakes or ferocious hurricanes, but in most circumstances we expect large structures to be safe and remain functional over their lifetimes—even though the lifetime of a large structure usually exceeds the lifetime of its designers. In fact, many might not even know that the construction industry is the largest of all international industries, generating about 15% of the Gross National Product (GNP) of most countries. Only when structures fail, as in San Francisco in 1989 and Kobe in 1995, do we realize their importance to our society and its economy.

Structural infrastructure is prevalent and fundamental in our society; hence, you might be tempted to believe that designing, constructing, and maintaining structures is straightforward and simple. Not so. The design stage of large structures can consume years of effort. The person who begins a structural design project is usually not the one who completes it. Indeed, structural design, construction, and maintenance tasks are not trivial, especially since we never have enough knowledge about the behavior of structural systems and structural materials. We need to consider the complexity of each structural problem. For example, how do we select a structural form or shape to provide a desired structural behavior where many uncertainties in the loads, material strengths, and soil conditions influence behavior?

We hope that this special track will illustrate to you the difficult problems facing structural and construction engineers and the potential for AI to help them develop our vital structural infrastructure.

Designing a structure involves many iterations of several knowledge-intensive steps. The following tasks provide examples of such steps:

- **Designers must determine the structure's functional requirements** (for instance, how many people will use the structure and for what purpose?).
- **Designers must understand the environment**—the soil conditions, the seismic activity, and the wind loadings—where the structure will be built. Sometimes social and political factors are also important.
- **Designers usually generate various alternatives for the structure**, such as alternative structural configurations, component sizes, and material selections. They must predict behaviors such as stresses, deflections, and vibrations, as well as costs (for example, development and maintenance) under great uncertainty. Modeling these structures and making predictions about behavior and cost also requires a large amount of experience and knowledge.
- **From these early predictions, designers develop more detailed designs of a few alternatives**. Owners use these detailed designs to acquire bids from construction companies for building the structure.
- **Construction companies use their expertise to predict how they will build the structure**, what resources they will use, how much it will cost, and how long it will take to build it.

During the construction process, construction managers constantly must respond to unexpected delays and changing economic conditions to remain on time and within the estimated budget. Often they must modify their detailed schedules and resource allocations to accomplish this.

Once built, owners must monitor the structure for signs of deterioration, maintain it when deterioration occurs, and modify it to accommodate new functions. Determining when and which structures are maintained with limited resources is a major issue for organizations and municipalities with a significant structural inventory.

Thus, structures are complex to design, and expensive to build and maintain. Moreover, they affect the lives of many people; a single structural failure has the potential to take lives. When creating computer-aided tools for assisting structural and construction engineers, we must consider several aspects of this domain. First, all knowledge needed to perform a given task is not easily acquired or represented. Second, structural engineers and construction companies have a strong professional and legal responsibility to society when creating the built environment, and they must be able to understand and make professional assessments of the knowledge used by their computer-aided engineering tools. Third, many structures are "one of a kind," but engineers can apply components and concepts in one design to other designs; hence, design case bases are extremely valuable. Fourth, structural life cycles are measured in decades or centuries. Finally, the context in which the structure must perform is never completely known; engineers and construction companies must manage uncertainty throughout the design and construction processes.

Some of the aforementioned design and construction knowledge cannot be modeled completely. This leads to a requirement for interactivity, where users provide the context-dependent interpretation of what is not modeled. Interactivity is not due to certain tasks being too hard for computational models. Rather, interactivity is necessary because the knowledge needed to complete certain structural engineering tasks cannot be modeled completely.

Some of the knowledge is standardized in codes of accepted practice. The profession acquires this knowledge over a period of time; changes to the codes usually occur after major catastrophic structural failures. Often, provisions of codes of practice become ambiguous during their development, as their authors strive for consensus.

A strong professional responsibility reinforced by local and national laws exists within this domain. Hence, engineers must understand and assess, using their own professional judgment, all information offered by computer-aided engineering tools. They are legally responsible for all decisions they make, with or without a computer. In our society, structural collapse is—and historically has been—unacceptable. Society has a very low tolerance for structural failure, as opposed to inferior product performance in other areas of engineering, such as indoor
environmental controls. Therefore, all recommendations made by computer-aided engineering tools must be clear and understandable, and modifying their knowledge bases must be easy.

As already stated, structures are built over years and are used for tens or hundreds of years. Errors in design or construction are often expensive. Unfortunately, some structural engineering tasks occur under conditions of nearly complete uncertainty. For example, we can measure what lies below the ground surface only at points; a complete subsurface picture is always too expensive to acquire. In addition, structural loads and overload conditions are never known exactly; designers must estimate them on the basis of other experiences with the location and the intended use of the structure. Nevertheless, each new major storm or earthquake can exceed these expectations. In any given structure, hundreds or thousands of people would be injured or killed in the event of structural collapse. This immense responsibility forces the construction industry to be conservative users of new technology. Changes take years—even generations—to occur.

In an industry where proven success is a requirement, few engineers latch onto fads. Fortunately, AI is coming out of the fad stage, and understanding of appropriate and effective uses of AI is increasing. The next 10 years should witness a tremendous increase in the applications of AI in this field. Because the contribution to the GNP is so large, the potential gain from using such technology is great. Imagine if computer technology could slice just one of those 15 percentage points off the GNP. This is not only possible; it is beginning to happen now. The reason the penetration of advanced computer applications in this field is low is that all these conditions contribute to what are very hard problems. We are just beginning to offer appropriate tools for such tasks. The articles in this special issue are representative of how engineers can effectively use AI in this field.

Six articles are part of this special track: three in this issue and three in the next. They describe applications of various AI techniques and methods to different stages of the engineering/construction/maintenance process. The three articles in this issue describe applications of AI to design and modeling. While great progress has been made in algorithms that analyze a structure, formal representations of the knowledge needed to model real structures and interpret the behavioral results derived from that model are lacking. The article by George Turkiyyah and Steven Fenves describes a knowledge-based framework that assists modeling and model interpretation tasks of structural engineering.

The design of a structure is actually the design of many interacting subsystems and components—for example, the structural system; the enclosure system; and the heating, ventilating, and air conditioning system. A given structure design is usually a unique combination of the possible forms for each of these component systems. Nevertheless, in some cases, engineers can benefit from component designs used in previous structures, and use them in subsequent designs as well. Making use of past design cases in the design of a new structure is the subject of the article by Mary Lou Maher, which discusses several incarnations of a case-based structural design system.

Due to a structure's complexity (as it consists of many interacting subsystems), its design involves many different disciplines. The article by Renate Fruchter discusses a computer-based collaborative design environment where the different participants in the conceptual structural design process can interact using a shared graphical description of the design.

The three articles in the next issue describe applications of AI in construction, condition monitoring, and maintenance-resource allocation. The article by Philip Dunston, S. "Ranji" Ranjithan, and Leonhard Bernold describes the development and use of a neural network for predicting the amount of spring-back in a reinforcement bar. Engineers must account for this measure in setting the bending angle in a rebar bending machine. The article by Paolo Salvaneschi, Mauro Cadal, and Marco Lazzati describes four decision-support systems that they developed to help monitor dams and maintenance and to assess the seismic risk of buildings. Finally, the article by John Kunz, Yan Jin, Raymond Levitt, Shouli-Dahu Lin, and Paul Teicholz describes a system they developed to help process-plant owners perform plant maintenance only as needed, rather than on a regular basis whether that maintenance is needed or not.

In presenting this special track of articles, we hope to show the breadth of applications of AI in the field of civil and structural engineering. These articles represent a small sample of the effort underway; many other exciting applications exist. From the applications we have included, it is easy to see that AI plays and will play a strong role in providing computer-aided support for this complex and challenging problem of design, delivery, and maintenance of structures.

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