

# Artificial intelligence techniques applied to civil engineering problems

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**Abstract:** Artificial Intelligence (AI) is a branch of computer sciences that studies the creation and design of machines capable of solve problems by itself, basing its behavior in the human brain. The methods for modeling and optimizing complex structure systems require huge amounts of computer resources; and artificial-intelligence-based solutions can provide valuable alternatives for solve problems efficiently. This article provides an overview of different techniques of AI, like expert systems, artificial neural networks, fuzzy systems and genetic algorithms; used to solve Civil Engineering problems.

**Key words:** artificial intelligence; neural networks; construction; reinforced concrete; beams

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## 1 Introduction

Research into Artificial Intelligence (AI) has been developing since the term "Artificial Intelligence" was first used in 1956. Many authors have attempted to define it since then. Perhaps the simplest and most comprehensive definition is: "The study of mental faculties through the use of computational models" [1]. This discipline combines such diverse fields as information theory, psychology, linguistics, and neurophysiology. The goal of AI is to create machines that think and act like humans; to do this, researchers create situations that make the computer think and adjust parameters depending on the response obtained.

AI is divided into four categories [2]:

1. Systems that think like humans: These systems attempt to emulate human thinking; for example, artificial neural networks.
2. Systems that act like humans: These systems try to act like humans; that is, they imitate human behavior; for example, robotics.
3. Systems that think rationally: These systems attempt to imitate the rational logical thinking of humans; for example, expert systems.
4. Systems that act rationally: These systems attempt to rationally emulate human behavior; for example, intelligent agents.

In each of these categories, tools have been developed that enable problem solving in a wide range of disciplines. This is due to an inherent characteristic of AI, which is that since its inception it has been geared toward solving problems for which equations have no possible analytical or numerical solution; and therefore, it can be applied to solving a multitude of problems in different disciplines [4]. One of the disciplines that has benefited from computational development is civil engineering. Numerous advances have been made in this field thanks to the application of computational techniques in

solving problems specific to this science.

The problems that arise in the construction of an engineering project are subject to a series of changing factors, which make it very difficult to predict the final result using traditional methods. Some of these factors, such as site conditions and material quality, among others, mean that the structure must be constantly checked for possible faults. These problems cannot be solved with the help of mathematics, physics, and mechanical calculations alone, but also depend on accumulated previous experience.

Although buildings are designed to be long-lasting, they often exist in harsh environments that affect their structural integrity. Predicting their useful life is far from a simple problem due to the many internal changes in the structure itself, as well as often uncertain external causes. In many cases, the intensity and type of parameters (e.g., load, environmental conditions, etc.) are largely unknown in nature and magnitude. Traditionally, it has been assumed that routine visual inspections would determine deterioration or damage early enough to allow for necessary actions or repairs to be carried out. But sometimes this is not enough.

This article presents some AI techniques that are used to obtain immediate results on the health of a structure. It also compares the techniques explained and analyzes future trends in this field as applied to civil engineering.

## **2 Material and method**

Due to the large number of unpredictable factors, each civil engineering project has its own individual characteristics. Over the last 20 years, with the development and application of expert systems, many advances have been made, especially in the areas of project evaluation, diagnostics, decision-making, prediction, design, and optimization.

The main AI techniques applied to problem solving in civil engineering are shown below.

### **2.1 Expert systems**

An expert system is a computer application that emulates the reasoning of an expert in a specific domain. It is a set of programs that, based on knowledge, possesses information from one or more experts in a specific area. They are built by obtaining this knowledge from a human and encoding it in such a way that a computer can apply it in similar situations [4].

Applied to the field of civil engineering, expert systems have been created for the design of concrete mixes and their constituents. These systems eliminate the tedious procedure of referring to the figures and tables of international construction standards every time the exact amount of cement, water, sand, and aggregates in concrete per cubic meter needs to be known [5].

Expert systems have also been created to design soils subjected to axial loads, to determine the load-bearing capacity of columns, to arrive at the ideal design for floor beams, among others. Several computer programs have been created with the aim of assisting in decision-making. Some of these programs are Rule Master, Insight 2+, and VP Expert.

It is important to note that an expert system does not replace a human expert in the field, as the latter are able to learn quickly from mistakes, have common sense, and are also very easy to have a fluid conversation with—characteristics that are almost impossible to achieve in a computer program.

### **2.2 Artificial neural networks**

An Artificial Neural Network (ANN) is an information processing system based on the way the nervous system of animals works. They are therefore electronic or computational models based on the neural structure of the brain [6].

ANNs are a method of solving problems, either individually or in combination with other methods, for classification, identification, diagnosis, optimization, or prediction tasks where the data/knowledge balance leans toward data and where, in addition, there may be a need for runtime learning and a certain tolerance for failure. In these cases, ANNs adapt dynamically by constantly readjusting the weights of their interconnections [7]. The mathematical basis for structuring an

ANN is based on Kolmogorov's theorem, presented by Kurkova [8], such that from three layers (input, hidden, and output), any continuous function in an interval can be approximated to the desired level, making the multilayer network a universal function approximator [9].

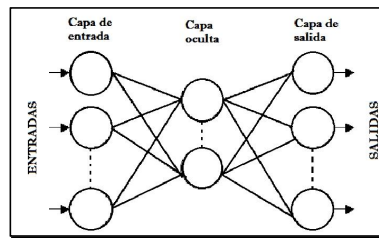


Figure 1. Structure of an Artificial Neural Network [10]

The need to use ANN models in the field of civil engineering is due to the large amount of data obtained from laboratory tests and the limited time available to analyze it. The idea is therefore to train a network with this data and get it to learn automatically, so that when new data is introduced, it can predict behavior based on previously obtained knowledge.

Sanad and Saka [11] proposed an ANN to predict the ultimate shear strength of reinforced concrete beams with large spans. To do this, they took as neurons in the input layer the characteristics of these structural elements, such as the size and depth of the beam, the width of the steel, the beam span, among others. An estimate of the resulting force was obtained as a neuron in the output layer according to the input data. The resulting value was compared with other existing methods, showing better results. Since then, numerous researchers have modified the structure of the network to try to obtain values closer to those obtained in real tests. Some studies changed the number of neurons in the input layer [12], others changed the training algorithm [13], while the most recent ones have increased the number of hidden layers [14].

Another application of ANNs in construction is to estimate the load-bearing capacity of corbels. As with deep beams, the characteristics of these elements are taken as neurons in the input layer. Kumar and Barai [15] developed an ANN to predict damage in this type of structure.

Other ANN models have been developed to estimate the elasticity of concrete [16], the load-bearing capacity of columns [17], the compressive strength of concrete [18], and to determine the velocity-strength relationship of concrete [19].

The results achieved show that ANNs can be a valuable tool for predicting the strength of concrete and its properties with an acceptable margin of error.

### 2.3 Fuzzy systems

Fuzzy logic is a computational paradigm that provides mathematical tools for representing and manipulating information in a way that resembles human communication and reasoning processes [20]. This type of logic takes two random values, but they are contextualized and refer to each other. Thus, for example, a person who is 2 meters tall is clearly a tall person, if the value for a short person has previously been taken and set at 1 meter. Both values are contextualized to people and refer to a linear metric measurement. Thus, the theory based on fuzzy logic is presented as an adequate theory for representing the uncertainty that exists in the meaning of all words [21].

Systems based on fuzzy logic have had many applications in the field of civil engineering. Zarandi, Türksen, Sobhani, and Ramezani-pour [22] developed a fuzzy neural network to predict the compressive strength of concrete. As a result of this research, the FPNN-Type1 software was developed, which is a valuable support tool for professionals in the field.

Cheng, Tsai, and Sudjono [23] developed a fuzzy neural inference system that mimics the decision-making process to facilitate this action for experts in the field of geotechnical engineering.

One of the most important fuzzy systems was presented by Sobhani and Ramezaniapour [24]. It estimates the useful life of reinforced concrete bridge decks. It has four fuzzy modules to quantify exposure conditions, deck signals, current corrosion density, and corrosion ratio. The results show that the estimated lifespan is better than that obtained by probabilistic methods.

Bianchini and Bandini [25] proposed a fuzzy model to predict pavement performance, using standard parameters collected by agencies to characterize the conditions of existing pavements. The results of this model were superior to those obtained by the linear regression model in terms of approximation accuracy.

Based on the above, it can be said that fuzzy systems can be used when the complexity of the process in question is very high and there are no accurate mathematical models, for highly nonlinear processes, and when definitions and knowledge are not strictly defined (imprecise or subjective).

#### 2.4 Genetic algorithms

A genetic algorithm is a recurrent and stochastic process that operates with a group of potential solutions known as a genetic population [26]. Initially, this population is generated randomly, and the solutions evolve continuously after consecutive stages of crossover and mutation. Each individual in the population has a value that is associated with its adaptation, according to its ability to solve the problem. This value, which must be obtained individually for each potential solution, constitutes quantitative information that the algorithm will use to guide the search. The process continues until a predetermined stopping criterion is reached, which can be a maximum number of iterations or no changes in the population.

Senouci and Al-Derham [27] presented an optimization model based on genetic algorithms for linear planning of a construction project. This model allows engineers to generate and evaluate an optimal or near-optimal construction plan with the aim of minimizing project time and cost.

The construction of temporary facilities during the development of a building is a very important task. Sites such as warehouses, workshops, offices, and bathrooms must be located near the work being carried out. Depending on the size, location, time, and nature of the project, these requirements may vary. Li and Love [28] presented a system based on genetic algorithms that provided a solution to this problem, which had a significant impact on project cost savings.

Rabuñal, Puertas, Suarez, and Rivero [29] developed a genetic algorithm to predict rainfall behavior in an urban settlement. The novelty of the proposed method lies in the combination of two artificial intelligence techniques: genetic algorithms and ANN. This project demonstrated how these two techniques can work together to solve the problem.

### 3 Results and discussion

All the research mentioned above demonstrates the advantages of AI techniques over other problem-solving methods. Expert systems are very efficient when there is enough time for a human expert to input all their knowledge. They are also very reliable, as they are not affected by external conditions such as fatigue, pressure, etc. ANNs, on the other hand, are suitable for applications where there is no identifiable model that can be programmed a priori, but where a basic set of input examples (previously classified or not) is available. The structure of an ANN is parallel, so if it is implemented with computers or special electronic devices, responses can be obtained in real time. One advantage of ANNs is that they create their own representation of the information internally, relieving the user of this task. In addition, they are fault-tolerant, responding acceptably even if partially damaged.

Fuzzy systems are used to model nonlinear systems of arbitrary complexity. They can be constructed based on expert experience. They can be combined with conventional control techniques. One advantage of this technique is that the input data can be imprecise and the system will still function.

Finally, genetic algorithms are proven to be effective when calculating non-derivable (or very complex) functions. They can be used in virtually all branches of science, such as robotics, bioinformatics, software engineering, industrial processes, and the financial sector, among others.

There are no rules or parameters that indicate which technique to choose to solve a given problem. However, there are situations in which some of these techniques have advantages over others.

In the field of civil engineering, the applications of AI techniques are relatively new, so a greater boom in the use of these methods is expected. Work is currently underway combining several of these techniques, taking advantage of the qualities of each one. One trend is the development of expert systems for decision-making by architects, with learning through ANNs. Other research opts to use genetic algorithms for learning and ANNs to decide the behavior of the system. Finally, some researchers choose to use expert systems or ANNs to reinforce the initial heuristic rules of any control system based on fuzzy logic.

#### **4 Conclusion**

This article summarizes the intelligent technologies used in civil engineering. Many applications of AI techniques in this field were analyzed. The trends that should be followed in order to create more robust and fast-learning systems were analyzed. AI methods can help inexperienced users solve engineering problems, but they can also help expert users improve the efficiency of the processes they perform. AI is changing all the time, the application of computational methods in all branches is already a fact, and the field of civil engineering has a great future for its application.

#### **Conflicts of interest**

The author declares no conflicts of interest regarding the publication of this paper.

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