Building the Future: Applications of Artificial Intelligence in Civil Engineering

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ABSTRACT

Artificial intelligence (AI) gives classical civil engineering (CE) a new life and ways to innovate by giving it more complex mathematical frameworks and algorithms. The new AI methods can improve and update a lot of complicated, time-consuming and hard work in design, building and inspection. The physical machine learning can help solve many problems and find new laws in the field of CE by combining the data paradigm with physical principles. On the other hand, artificial intelligence based solutions may often help civil engineers to solve problems more quickly and easily. This paper talks about new theories and methods that have been developed for using artificial intelligence in civil engineering. The smart science and technology in CE greatly improve the current levels of digitalization, informatization, automation and intellectualization. This paper gives a systematic review and summary of the most recent advancements in AI in civil engineering (CE) for the entire life cycle of civil structures and infrastructure. These advancements include intelligent architectural design, intelligent structural health diagnosis and intelligent disaster prevention and reduction. A number of examples are given for intelligent architectural art shape design, structural topology optimization, computer vision-based structural damage recognition, correlation-pattern-based structural condition assessment, machine-learning-enhanced reliability analysis, vision-based earthquake disaster evaluation, and dense displacement monitoring of structures under wind and earthquake. The discourse concludes with an examination of the potential of sentient science and technology in the context of future CE.

Keywords Artificial Intelligence, Machine Learning, Civil Engineering, Structural Health Monitoring, Predictive Maintenance, Real-Time Monitoring, Data-Driven Decision-Making, Infrastructure Management, Sustainability

Introduction

Artificial Intelligence (AI) is the term used to describe the simulation of human intelligence in machines that are intended to perform tasks such as problem-solving, reasoning and learning. AI makes it easier to make decisions automatically, improves the accuracy of designs and makes construction work more efficient in civil engineering. As infrastructure gets more complicated standard engineering methods are no longer enough to deal with problems relating to cost, safety and sustainability. AI is emerging as a disruptive technology that has the potential to revolutionize the field (Aydin & Sari, 2021).

The use of artificial intelligence (AI) in civil engineering has changed the way infrastructure is planned, developed, built and maintained in a precise way. AI gives us sophisticated capabilities to deal with these changing problems as civil infrastructure gets more complicated and the need for smart, sustainable and cost-effective systems grows. The Machine learning (ML), deep learning, fuzzy logic and evolutionary algorithms are some of the new tools being used to simulate non-linear behaviors. This make the best use of resources and make structures safer with speed up construction processes (Ghosh et al., 2020; Zhang et al., 2021).

AI is especially useful for things like monitoring the health of structures, analyzing geotechnical data, managing construction projects, predicting how materials will behave and managing traffic and transportation systems (Abbas et al., 2021). For example, machine learning models can look at sensor data in real time to find cracks or stress buildup in bridges. The optimization algorithms can make construction project scheduling and budgeting more accurate (Min et al., 2022). The AI-powered decision support systems are also becoming essential for building smart cities and long-lasting infrastructure since they make predictive analytics and intelligent automation possible.

Nasirian et al. (2020) have identified several significant obstacles to technological adoption, including data quality, model interpretability and the absence of domain-specific datasets. This review looks at and combines current developments in the use of AI in civil engineering, pointing out both the benefits and drawbacks and suggesting future research paths that can help bridge the gap between AI theory and real-world engineering. As cloud computing and the Internet have grown, the amount of data has grown at an incredible rate. The different kinds of data are created at different points in the life cycle and big data technologies that can help to manage this data well (Motawa., 2017). Recently, the science of artificial intelligence has come out with a new machine learning technology called deep learning (DL). This is possible because of big improvements in data collection and processing hardware. The main benefit of deep learning is that the multilevel features are not made by engineers but by a common learning process (Huang et al.,2018). This article will talk about where different AI techniques came from and what the newest uses and breakthroughs are in different areas of civil engineering.

Intelligent Optimization Methods in Civil Engineering:

Artificial intelligence is a field of study that focuses on the investigation and application of the laws governing the activities of human intelligence. After 50 years of progress, it has become a very important topic across borders. Today, this technology is used in a lot of different areas, like expert systems, knowledge base systems, intelligent database systems and intelligent robot systems. The expert system is the oldest, biggest, busiest and most successful area. It was called "the knowledge management and decision-making technology of the 21st century." In civil engineering, a lot of problems especially in engineering design, construction management and program decision-making were affected. Civil engineering has a lot of problems, especially in engineering design, construction management and program decision-making. These problems were caused by a lot of uncertainties that could only be solved with math, physics and mechanics calculations and the experience of professionals. The AI has its own advantages over other technologies. It can tackle hard problems like an expert by copying the experts. Overall, artificial intelligence has a lot of potential uses in civil engineering (Lu et al., 2012).

Table 1: The roll of AI in Civil Engineering.

AI Technique	**Application Area**	**Key Contribution / Outcome**	References
Reinforcement Learning, Neuro-Fuzzy Systems	Adaptive civil engineering structures	Implemented self-diagnosis, shape control, and modeling complex systems in tensegrity structures	(Adam and Smith, 2008)
Neuro-Fuzzy Systems	Durability prediction of SCC	Predicted SCC durability under sodium sulfate exposure	(Bassuoni and Nehdi, 2008)
Artificial Neural Network (ANN)	Concrete compressive strength prediction	Predicted 28-day compressive strength of SCC and HPC with fly ash	(Prasad et al., 2009)
Back-Propagation Neural Network	Slope failure assessment	Demonstrated effectiveness in predicting slope failure	(Lee et al., 2009)
Fuzzy Expert System	Tunneling case studies	Developed expert system rules from expert input	(Shaheen et al., 2009)
AI Prediction Models	Soil property prediction	Predicted MDD and UCS of cement-stabilized soil	(Das et al., 2009)
Computer Simulation	Civil engineering education	Assessed teaching of linear scheduling using simulations	(Forcael et al., 2011)
Ontology-Backed Software Applications	Software design for civil engineering	Proposed methodology for evolving ontology-backed applications with Java proof-of-concept	(Krcaronemen and Kouba, 2012)

The function of expert systems in the special connections and cases is a notable effect, as each project has its own generality and individual character due to a multitude of uncertain factors and complex influence factors in civil engineering. In the last 20 years, the civil engineering field has made a lot of progress with the development and use of expert systems. They are mostly used for project evaluation, diagnosis, decision-making, prediction, building design and optimization, project management construction technology, road and bridge health detection and a few other areas. Figure 1 is showin some Application AREAS of AI in building and construction industry.

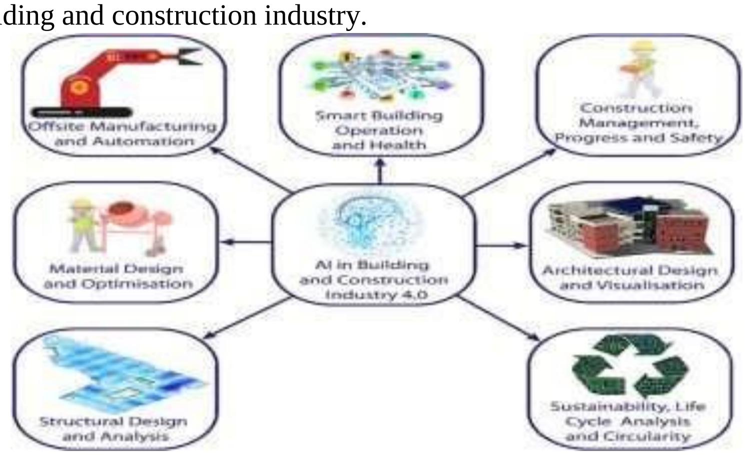

Figure 1: Application AREAS of AI in building and construction industry (Baduge et al., 2022)

Structural Health Monitoring:

Structural Health Monitoring (SHM) is essential for the preservation of the safety and longevity of critical infrastructure including buildings and bridges. Artificial intelligence (AI), especially machine learning (ML) is very important for analyzing a lot of sensor data to figure out what's going on in real time. The Artificial Neural Networks (ANNs) and Convolutional Neural Networks (CNNs) are algorithms that are frequently employed to identify stress patterns, fractures and anomalies in structures (Min et al., 2022). These tools make it possible to do predictive maintenance which helps stop big problems from happening. The current Convolutional Neural Network (CNN)-based methods have limitations in terms of pixel-level accuracy which is essential for the automation of pavement fissure detection. Zhang et al. (2017) came up with a CNN-based architecture called CrackNet as shown in Figure 2 and 3 that can automatically find fractures in three-dimensional asphalt pavement. There are five layers in CrackNet that has more than a million parameters that were learned during the learning process to make sure that each pixel is correct. An enhanced CrackNet architecture known as CrackNet II that was proposed to enhance learning performance and ability (Zhang et al., 2018). It has fewer parameters and a deeper architecture with more hidden layers.

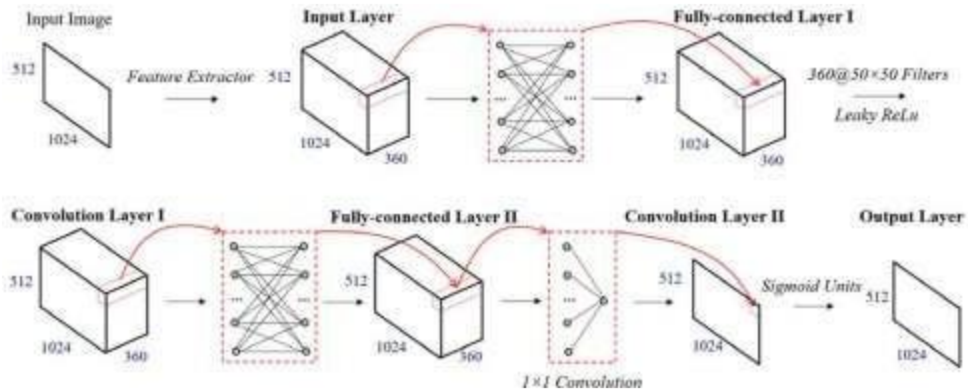

Figure 2: Architecture of CrackNet (Zhang et al. (2017)

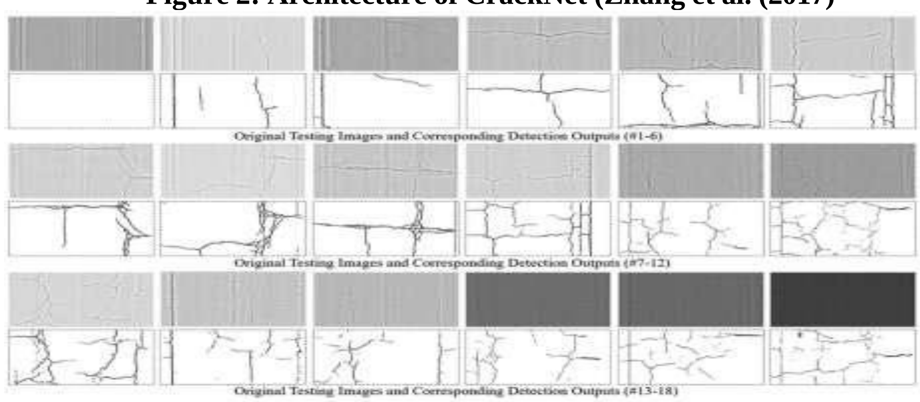

Figure 3: Typical testing images correctly classified by CrackNet (Zhang et al., 2017).

AI in Construction Management:

The enhancement of scheduling, cost estimation and risk mitigation is a significant contribution of AI to construction management. The Natural Language Processing (NLP) and reinforcement learning methods let us look at unstructured data like contracts and reports. AI-powered solutions like Autodesk BIM 360 let people work together and get more done by tracking issues, finding clashes and analyzing projects in real time (Alreshidi et al., 2022).

Geotechnical Applications:

In geotechnical engineering, AI is used to model how soil and structures interact in complicated ways and to predict geohazards like landslides and soil liquefaction. The deep Learning models, Decision Trees (DTs), and Support Vector Machines (SVMs) have been implemented to predict slope stability, bearing capacity, and settlement (Zhou et al., 2020). Both in terms of speed and accuracy, these methods are better than classic empirical methods.

Smart Infrastructure and Transportation:

Smart cities have made AI an essential part in managing traffic and planning cities. The AI algorithms are used by Intelligent Transportation Systems (ITS) to improve traffic signals, predict traffic jams, and handle accidents. For example, AI models that use real-time sensor and GPS data make route planning better and cut down on travel time and emissions (Mohajerani et al., 2021).

Sustainable Design and Material Optimization:

AI makes it easier to plan buildings and infrastructure that are good for the environment. The most energy-efficient and cost-effective solutions are selected by generative design and optimization algorithms which evaluate thousands of design permutations. Artificial intelligence (AI)-powered Life Cycle Assessment (LCA) tools evaluate the environmental consequences of a variety of construction methods and materials (Lu et al., 2022).

Artificial intelligent algorithms and its applications in civil engineering

Civil engineering is among the numerous engineering disciplines that have been transformed by artificial intelligence (AI). Artificial intelligence algorithms emulate human intellect in order to execute tasks such as pattern recognition, decision-making and learning. AI has made the design, building, and upkeep of infrastructure smarter, safer and more efficient in civil engineering.

Genetic algorithm:

The Genetic algorithms (GAs) are a well-known type of evolutionary algorithm that mimics the Darwinian idea of evolution and the survival of the fittest in optimization. It is very useful in civil engineering, however there are many things that need to be investigated and improved. The evolutionary algorithm in civil engineering has made a lot of development but this study doesn't address a lot of the ways it can be improved because it has grown so quickly. Some ways to make genetic algorithm methods better are to adjust the genetic algorithm component or the technology it uses, to employ the hybrid genetic algorithm, the dynamic adaptive technology, nonstandard genetic operators or the parallel genetic algorithm. The genetic algorithm has gotten better over the past few years and it has added many new mathematical tools and taken civil engineering as its most recent application. We can predict that the genetic algorithm will be used more widely and effectively in civil engineering as computer technology improves. Senouci and Al-Derham devised a model for scheduling linear building projects that uses a genetic algorithm to optimize many objectives at once. The model enables construction planners to generate and assess optimal or near-optimal construction scheduling plans that reduce both project time and cost (Senouci and Al-Derham, 2008).

Artificial Immune Systems:

Artificial immune system (AIS) uses theoretical immunology, observed immune functions, concepts, and models to get the adaptive immune system of a living thing to work on solving the many difficulties that come up in real-world engineering optimization. This method employed both the evolutionary algorithm and the least-squares method to find structures that could work and the right constants for those structures. The new method fixes the problems with the old and artificial neural network-based methods that have been used in the past to study civil engineering systems. Dessalegne and Nicklow used an artificial life algorithm that came from the artificial life paradigm. The multi-reservoir management model that came out of this worked well on a part of the Illinois River Waterway.A variety of immune algorithms have been proposed by realization form in accordance with the characteristics of the immune system's diversity. The immune system features of the application exploration are still in their early stages, so there are many ways to improve the algorithm design such as how to implement the algorithm, how to choose parameters, how to talk about the theory and how to use the immune system in civil engineering applications (Dessalegne and Nicklow, 2012).

Genetic Programming:

Genetic programming is a programming model that employs the principles of biological evolution to address intricate optimization problems. A Scientists group came up with a novel empirical model to figure out the base shear of flat steel buildings that are hit by earthquake loads. They did this by combining genetic programming (GP) with simulated annealing (SA) in a unique way termed GP/SA (Aminian et al., 2011). Hsie with friends came up with a new method called "LMGOT" that combines the Levenberg Marquardt (LM) Method and the genetic operation tree (GOT). The GOT uses the idea of the genetic algorithm, which is a well-known way to solve discrete optimization problems, to make operation trees (OTs) that show the structure of the formulas. The results provide a simple way to forecast how long pavement transverse cracking will last and they also suggest that the LMGOT was a good way to make a precise crack model. The neural networks and genetic programming were used by Cevik and Guzelbey to come up with two plate strength formulas that can be used on metals having nonlinear stress-strain curves, such aluminum and stainless steel alloys. The suggested formulas make it possible to find the buckling strength of rectangular plates using Ramberg-Osgood parameters (Hsie et al., 2012). There are various algorithms that are efficiently used in construction department as shown in table 2.

Table 2: Some other Evolutionary Algorithms and their uses in Construction.

AI Technique	Application in Construction	Outcome	Authors
Evolutionary Algorithm	Optimization in structural systems	Developed an algorithm capable of identifying both global and local minima; validated with examples	(Caicedo and Yun, 2011)
Evolutionary Algorithm ("Electimize")	Construction engineering optimization	Mimicked electron flow; evaluated globally and locally; demonstrated strong convergence and exploration	(Khalafallah and Abdel-Raheem, 2011)
Evolutionary Polynomial Regression (EPR)	Stability analysis of soil and rock slopes	Introduced EPR-based model to assess slope stability	(Ahangar-Asr et al., 2010)
Evolutionary Polynomial Regression (EPR)	Nonlinear parameter interaction in civil systems	Applied EPR to model complex nonlinear interactions between engineering variables	(Rezania et al., 2008)

Artificial Neural Networks:

Artificial Neural Networks (ANNs) are the type of computer model that is based on how the human brain is built and operated. They are made up of layers of nodes or "neurons" that are connected to each other and learn how to process data by changing weights. The ANNs are great at finding complex nonlinear relationships in big datasets, which makes them useful for many engineering jobs, such as recognizing patterns, making predictions and classifying things (Haykin, 2009). In civil engineering, ANNs have become more popular because they can model complex things like how materials behave, how structures get damaged, geotechnical properties and construction performance metrics that regular math modeling can't be always effective. ANNs are a useful tool for making decisions and improving design, building and maintenance processes since they are flexible and strong.

The Potential surface settlement is one of the most dangerous things that can happen when digging tunnels for infrastructure. It is important to accurately anticipate the maximum settlement on the surface (MSS) to lower the risk of surface failure. It is suggested that a hybrid model of an artificial neural network (ANN) and particle swarm optimization (PSO) be used to forecast MSS induced by digging along the Karaj subway's line 2. The bridges should be built with safety and durability in mind in order to keep costs down (Hasanipanah et al., 2016). Another scientist used artificial neural networks (ANNs) to make an integrated multi-objective harmony search that cut down on the time it took to run the finite element model used in deck analysis (Garcia-Segura et al., 2017). The best design for the post-tensioned concrete box girder road bridge takes into account the cost, the overall safety factor, and the time it takes for the bridge to start to corrode.

In a simple way, an artificial neural network (ANN) is a technical version of a biological neural network. Its major job is to create a useful artificial neural network model based on the way biological neural networks work and the needs of real-world applications. It also has to design a learning algorithm that goes along with it and mimic some of the smart things that the human brain does. Finally, it is put into action in a way that fixes real-world problems. Figure 4 shows a three-layer feedforward network. It has input layers, hidden layers and output layers. The number of independent variables is in the input layers while the answers to the problems being examined are in the output layers (Basheer, I. A.; Hajmeer, M. 2000).

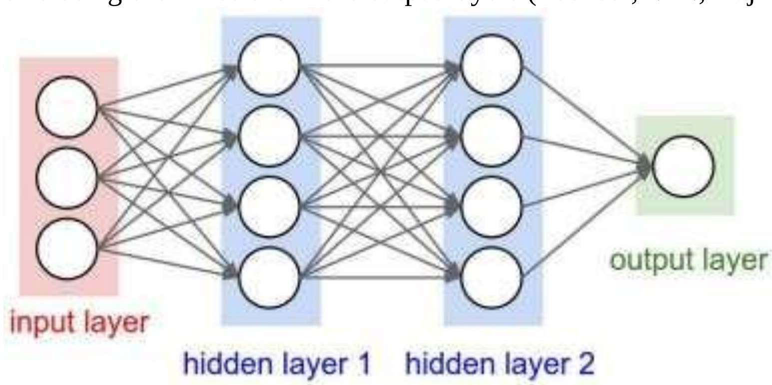

Figure 4: Three-layer feed forward network (Schröder et al., 2018)

The Fiber Reinforced Polymers (FRP) are often used to strengthen and make ductile Reinforced Concrete (RC) under passive confinement. A model based on artificial neural networks (ANN) was shown that could estimate the compressive strength of FRP-constrained concrete (Casardi et al. 2017). The proposed model creates an analytical link without taking into account the usual effectiveness parameter, which is different from other models. The Glass fiber-reinforced polymer (GFRP) bar reinforced concrete constructions last longer than reinforced concrete products. It is very important to test how well GFRP bars stick to concrete in order to develop and build polymer-matrix composites (PMCs). Another idea was to use a combination of artificial neural networks (ANNs) and genetic algorithms (GAs) to forecast how strong the link between GFRP bars and concrete would be. This is because ANNs are good at nonlinear mapping and GAs are good at searching the whole space (Yan et al., 2017).

Big data- Construction waste analysis:

The High-performance computing and large-scale data storage are becoming more important for analyzing construction waste. It is hard to use typical methods to store big data sets and process the data in real time for complicated analysis. A big data architecture for construction refuse analysis was proposed to manage and analyze this unprecedented data (Bilal et al., (2016). There are hundreds of pictures and videos shot during construction, but most of them rapidly become useless without proper planning documents and time. Another research talked about how big visual data could be used with BIM to keep an eye on construction performance and quickly add notes and reports on the construction of different applications, such as talking about problems with communication about progress, quality, and safety (Han et al., 2017).

Construction site management:

It is a challenging endeavor to guarantee personal safety in the construction industry due to the dynamic and intricate work conditions that exist on-site. At the present time, the computer vision methods that keep an eye on where workers are and recognize targets may need lengthier processing times. In this context, a research created hybrid deep learning model that combines convolutional neural network (CNN) and long short-term memory (LSTM) to automatically find risky behaviors of workers on construction sites (Ding et al., 2018). The CNN model is utilized on each frame to get the spatial data from the video and the LSTM network is used to make sense of the temporal information from the continuous frames. It takes a lot of time and effort to manually pick rebar's from the data collected by ground penetrating radar (GPR) on concrete bridge decks. A theory came up with a system for automatically finding and locating rebar that used deep convolutional neural networks (CNNs) and image processing technology. First, the image processing tools find the pixels that might contain the rebar peak (Dinh et al., 2018)]. After that, the GPR scans are used to get the windowed images around the possible pixel. Finally, a trained CNN solve this problem and proved to be more efficient network.

Conclusion:

The use of Artificial Intelligence (AI) and Machine Learning (ML) in civil engineering is a big change that makes these technologies very important for solving some of the field's hardest and most data-heavy problems. The engineers can go from reactive to predictive frameworks in civil engineering by using AI and ML. This makes infrastructure management safer, cheaper, and more adaptable to changing conditions. The AI and ML have the ability to change civil engineering in many important ways, such as predictive maintenance, structural health monitoring, traffic optimization, and environmental impact assessment. These apps make it easier to make decisions, let you keep an eye on things in real time, and let you take care of maintenance needs before they become problems. This helps keep infrastructure from breaking down and makes operations run more smoothly. For example, ML's capacity to look at huge datasets and find patterns that point to possible structural problems before they get worse is a huge help for predictive maintenance. AI-driven methods in Structural Health Monitoring (SHM) use neural networks, anomaly detection, and predictive analytics to give timely information about the state of important structures including bridges, tunnels, and tall buildings. These features move infrastructure management toward a data-driven approach, where constant monitoring and quick action lower maintenance costs, lengthen the life of assets, and make them safer. In the same way, reinforcement learning algorithms change traffic lights in real time depending on data from the road which helps reduce traffic jams and make the roads safer. Artificial intelligence algorithms and neural networks have been used in civil engineering for decades. The deep learning is a useful technique in the age of big data because it can fully use the vast amounts of information that big data holds. So, using big data and deep learning together will be a new area of research in civil engineering artificial intelligence.

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