Chapter 17

Advanced Materials, Artificial Intelligence, and Sustainable Technologies for Energy and Environmental Engineering
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AI in Structural and Construction Engineering

Fuad Abaszadeh[1], Taleh Asgarov[1], Shafi Danyalov[2], Rashad Ismibayli[2], Ahila A[3] ✉, Malikov Ziyodullo Abdurayim[4] ✉, Abduraxmonov Muhammad Sulaymon[4] ✉, Rabbimov G'iyosjon Mehriddin[4] ✉

[1]National Aviation Academy. Baku, Azerbaijan.

[2]Azerbaijan University of Architecture and Construction. Baku, Azerbaijan.

[3]Department of ECE, Sri Sairam College of Engineering. Anekal, Bangalore.

[4]Teaching Assistant, Department of Software Engineering, Faculty of Artificial Intelligence and Digital Technologies, Samarkand State University. Uzbekistan.

ABSTRACT

The creation of the artificial intelligence (AI) became a remodelling instrument in structural and construction engineering, offering the new ways of analysis, design, and management. In the simple engineering course, machine learning, deep learning, and optimization algorithms can be deployed to make a decision based on the data with AI. In order to get structural design and analysis, AI increases the accuracy of load prediction, stress distribution and structural behavior modeling. With more precise and faster results, complex algorithms are used with the finite element analysis. The construction materials industry is one of the areas that will be assisted by AI in predicting the mechanical properties, optimization of mixes, and sustainable development of materials. AI makes its entry into the construction management to ensure a successful planning, resource allocation, and mitigation of risks and integration with BIM systems. The concept of structural health monitoring can be enhanced with the assistance of AI sensors data analysis to identify the initial damages and anticipate the maintenance. As AI brings about robotics and automation, the construction industry is revolutionizing with autonomous drones, robotic systems, and technologies along with 3D printing. The result of such developments is a reduction in the degree of human error, enhanced efficiency, and enhanced safety. Despite the inconveniences of the data quality, transparency, and the ethical issues, AI continues to expand the engineering sphere. The future trends reflect the increasing association of the digital twins with sustainable construction, as well as AI, as the bedrock of the contemporary engineering.

Keywords: Artificial Intelligence; Structural Design; Construction Materials; Health Monitoring; Robotics; Automation; BIM; Digital Twins.

INTRODUCTION

One of the most potent technologies that will transform the engineering spheres in the future is called artificial intelligence (AI). Efficiency, precision and lifecycle sustainability of a project can be improved by using AI in construction and structural engineering. The ancient approaches can be limited in data processing, risk control and optimization, which AI can execute with the assistance of complex algorithms. The recent direction of more intensive application of machine learning, deep learning and data-driven models has shifted the architectural analysis, design and construction management. Besides that, AI assists in the forecasting features that enhance the infrastructures security, cost-efficient operation, and reliability. AI is finding its way in the construction industry, especially with the increasing use of robotics in the sector, automation and digital twins. The given chapter will discuss the basic, practice, challenges and future of AI and practices of its application to structural and construction engineering. One of the most critical spheres is biomedical engineering that can be improved with the assistance of AI due to the power of diagnostics and personal approach. To mention but a few, AI algorithms will get an opportunity to enhance the quality of radiological diagnosis with favorable image processing algorithms to detect the multiple complex patterns and anomalies that can be ignored by a human radiologist and advance the quality of care and health of the patients.[1] This innovation enhances the delivery procedure within the healthcare sector and streamlines the healthcare systems and is a manifestation of aligning the healthcare requirements with technological enhancements. Furthermore, AI is also making its way into the sphere of education, and especially engineering courses. Maybe, AI will assist in simplifying the teaching process and creating smart educational tools and methods that can empower learners. It can not only help to find answers to one of the engineering issues but may also improve the practices of instructions.[2] Educational applications of AI can offer educational experience that is personal and will create a scenario where it will be possible to keep up with individual students, and, therefore, enhance the output of the educational process, on the whole, in the sphere of engineering. This is equivalent to the fact that structural engineering of the flexible models is required, which is capable of supporting the complex structures and loading conditions. And continuing on the relevance of AI in structural arrangements, any type of engineering undertaking is simplified through the software that streamlines the design procedure. The algorithm of the NSGA-II that Wang et al. applied to optimize the centrifugal pump features may be seen as an example of the strategy that can be effectively undertaken to enhance the features of the structural parts (stability and efficiency) which is one of the characteristics of the performance.[3,4] Therefore, the further evolution of AI-based optimization-based tools in the sphere of structural engineering may be linked with the current efforts to make the performance of the systems in the conditions of the large range of loading scenarios and with the subsequent enhancement of their service life. Among the most evident positive aspects of AI in the construction sector, one can also note the possibility to optimize the effectiveness of different stages of the material use. The inverse design can also be applied using AI technologies to maximize a desired property of an inverse designed material. It would be based on the need to identify the most appropriate material compositions that can be utilized in special needs in special use and, consequently, improve the output and sustainability of the materials applied to the same.[5] Moreover, the AI-related solutions were also discovered to improve the lifecycle management, in which the professionals are enriched with the control of the time of a schedule, cost-effectiveness, and the sophisticated safety monitoring working on a civil engineering project.[6] Artificial intelligence (AI) is another evolutional technology, which is making its way into structural and construction engineering. The existing design and management strategy usually entail dealing with big data and moving systems. With the help of AI, one can learn with data, process new circumstances, and make optimized judgments. The later findings of the carbon-based nanomaterials confirm the significance of the more complex modeling to the prediction of the material and structure behavior.[7,8,9] Due to this, AI is not merely another kind of technology, but a need in the modern-day construction. In addition, AI implementation within the construction management supports the project schedule and budget management, not to mention quality and safety. According to Xu and Guo, the possibility to regulate schedules and monitor health has led to the application of AI to the process of simplifying various processes to increase the resilience and safety of the infrastructures created. The performance of the project with the help of upgraded data analytics and real-time monitoring is one of the primary spheres where AI can be helpful. Liu highlights the point that the Building Information Modeling (BIM) can be used in the development of the smart site safety management system because of opportunities of its connection with the Internet of Things (IoT) technologies. This system divides the site safety management regarding various dimensions, therefore, making the risk management and safety completer and more efficient. Thanks to the help of data analytics, the project managers will manage to set a realistic standard, make smart decisions and, ultimately, enhance the level of management in the long-run, which will, in its turn, be disproved in an empirical manner, since the idea of smart technologies being not just a reality, but also extremely versatile in the construction industry.(10) Zhang study lays emphasis on the BP neural networks to ascertain the probability of structural collapse of the scaffolding systems. Through the use of the wireless strain sensors and the implementation of a finite element analysis (FEA), the presence of a robust framework that would be able to aid the process of discovering instability modal of the systems of structural system will be uncovered.(11) The benefits of integration are that early failure detection is possible and enhancing the safety of the construction situation. Besides it, Vaghela and Bayandor pay attention to the application of machine learning algorithms in SHM of sheet metal assemblies. Their experiment shows that it is beneficial to train custom neural networks on the data presented in an FEA simulation, which covers the different assembly processes, like riveting and welding. Not only is this approach economically friendly, but furthermore, it has been used as an indicator of a new direction of even greater diagnostic capabilities in the case of structural health monitoring applications.(12) These developments are the bright stars of what machine learning can do to simplify the process of collecting data, thus, making the outcomes of the monitoring more genuine. The technologies will play a crucial role in the successful migration of the automated spaces within the buildings where manual roles can be incorporated into the already developed ones.(13) Not only the issue of the human manpower replacement is linked to the application of robot system, but the betterment of the man-robot collaboration to increase the productivity and the construction time. Such possibilities can also be related to the emergence of the Internet of Things (IoT) technologies that could enable the robots to feel and respond in the surrounding environment in a productive manner that the automated working process could be simplified.(14) As an example, such systems will be efficient in controlling the construction situation as they will be able to determine the most significant parameters mentioned in the example, which are the steel bar layout and concrete quality that will be at the center of maintaining the already discussed norms and construction safety.(15) This has been a combined practice that has been strategic given the trend of prefabrication and modular construction that ultimately produces more customization and automated construction practices.(16)

Fundamentals of AI in Engineering

The use of calculational devices to replicate the decisions and the learning processes of human beings is known as engineering Artificial intelligence. The most frequently used ones are machine learning, deep learning, natural language processing, and expert systems, all of which make the analysis more accurate. AI in the engineering field is a field of a lot of dependence on quality data gathered through simulations, experiments or real-time monitoring systems (table 1).

Through such datasets, it is possible to come up with predictive models that can capture the trends and generate successful predictions. Neural networks are the optimization algorithms, genetic algorithms, and are often used in solving some of the engineering complex problems. The application of AI in structural engineering has the potential to automate computationally demanding components of a project (e.g. design optimization of many variables). Besides, the AI-enabled software is also released to assist the engineers with the design, testing, and validation of the models on the software platform.

Table 1. Fundamentals of AI in Engineering

Concept	Description	Application in Engineering
Machine Learning (ML)	Algorithms that learn patterns from data to make predictions or classifications	Predicting loads, stresses, and performance of structures
Deep Learning (DL)	Subset of ML using neural networks to model complex nonlinear relationships	Modeling nonlinear structural behavior and material properties
Expert Systems	Rule-based systems that mimic human decision-making for problem-solving	Providing guidance in construction management and design validation
Optimization Algorithms	Techniques like genetic algorithms and neural networks to solve complex problems	Optimizing structural design, resource allocation, and energy efficiency
Data-Driven Decision Making	Using large datasets to generate insights, forecasts, and guide design decisions	Supporting risk assessment, planning, and real-time decision support
Integration with Engineering Tools	Embedding AI models into CAD, BIM, and simulation software for enhanced use	Assisting engineers in design, simulation, and structural health monitoring

The concepts of AI in engineering sector, in their turn, are substituting a new paradigm of automated decisions and autopilot. The application of Artificial Intelligence (AI) in automating engineering tasks, creating better decisions, and additional system efficiencies have also remodeled different engineering fields. It is not only limited in biomedical engineering but can be applied to neural networks and wireless communications technologies among others, which demonstrate its versatility and the ability to transform the world. It has transformed the way the researchers process the neural data by using the AI and more specifically machine learning (ML) in neural engineering. This data requires smart designs, which are difficult to identify in the traditional system of analytic work, but machine learning is equal to the task, and it is absolute to the development of the profession. As the ML approach is more broadly applied to the field of neural engineering, it is important to assure high-levels of research validity and reproducibility to make the results and the manner in which they can be applied to the field more plausible.[17] These principles are needed to guarantee proper integrations of the AI technologies into the neural engineering studies. The other field that AI has influenced is communication engineering, and deep learning models are becoming a potent signal processing tool. These models are effective in non-linear mapping of large complex signal environment like a large MIMO (Multiple Input Multiple Output) system. The systems also make it possible to retain the high-performance levels even under the problematic conditions because of the communication technologies and AI and extend the scope of the sphere of the wireless communication application.[18] Machine learning, deep learning and data-driven systems on which AI engineering is founded, have the potential to be predictive and optimizing. The trained neural network can help to estimate the structural loads, the degradation of the materials and system failure based on the engineering dataset.[19] The construction management and hero allocation of the construction decisions have been applied using expert systems. The examples of the computational tools, applied to functionalized nanomaterial, may include that of the predictive research which was later validated by the experimental evidence.[20,21,22,23] Just like materials informatics, AI engineering can automate the process and make it less expensive in terms of trial and error. Digital-based devices, i.e. BIM and IoT also use AI, which enhances the application of AI to real-time monitoring and adaptive control.[24] Finally, the AI and engineering partnership is not a mature area and it is still in the baby stages. The possibilities of AI in enhancing better systems, self-driving car and material discovery, carry grave concerns on safety and performance guarantees. The necessity of finding a solution to those issues is one of the most important challenges that should be taken into consideration in the future to make the potential of collaboration between AI and engineering-related operations to be utilized to its fullest.[25] As it has been noted, research and development will be required in the future to ensure that AI applications are streamlined in the different engineering sectors. To sum up, the application of AI in the engineering sector can not only assist in improving the current system and strategy, but also a new field of research and implementation in other spheres reveals itself. The possibilities of the AI in health care sector, education, neural analysis, communication, engineering industry, and so forth, are enormous. Designing complex structures optimized to a particular purpose, including biomechanical application, has been among the most useful fields where AI has contributed. A different experiment conducted by Omigbodun et al.[26] demonstrates that lattice structures such as Gyroid design can work, although they can be optimized with AI to maximize the mechanical properties (tensile and compressive strength) when implemented as medical implants. The designs will be more efficient and thermo-stabilized since the reduced Graphene Oxide (rGO) and calcium hydroxyapatite (cHAP) are advanced materials that will be incorporated in the designs as per their literature. Moreover, AI can be used in material science a science of high dimensional and multifactorial data, which is a crucial central process to efficient biomaterials. Jiang and others confirm by pointing out that through the assistance of AI, hydrogel, precision in drug-delivery systems would become possible. Their results manifest the usefulness of machine learning in the de-correlation of multi-dimensional interactions between the material structure and structural performance among other factors that warrant the use of machine learning in structural and biomedical engineering.[27]

AI for Structural Design and Analysis

The use of AI in the structural design and analysis has transformed the accuracy and speed of the visual engineering calculations. Through the AI-based models, engineers are able to predict the behavior of structures when the load on the structure varies most accurately. Machine learning has been used to optimize the design parameters, which include the use of materials, load distribution and structural stability. Deep learning can also capture more non-linear behavior of complex structures (table 2). The AI-based finite element analysis saves on a significant amount of time but is precise enough to compute the large-scale projects. Moreover, AI can help in the creation of hybrid solutions, which are founded on conventional and information-driven analytic algorithms. This type of integration gives a tradeoff between theory validity and application. The result is that now the amount of designs engineers can deliberate is increased at reduced time lines and eventually efficiency and safety of construction works is achieved. The artificial intelligence (AI) embarked in designing and the analysis of the structure is a drastic revolution on the way engineering is being practiced. The entry of AI algorithms in other sub domains of structural engineering has resulted to improved design, construction management and development of certain new materials. The applications of AI to efficiency and future-proofing civil infrastructure are quite significant in multiple publications that mention that it can be implemented on a wide scale. In addition, AI can be used to design optimization and structural health monitoring (SHM) of civil engineering projects lifecycle. Xu and Guo provide a broad overview of the application of AI in civil engineering in streamlining the procedures involved in the design of all phases within the development of an infrastructure.

They demonstrate how AI does not only strengthen the design schemes but the construction management practices as well because it helps to find innovative solutions that can adequately address the already existing, engineering-related issues.[6]

Table 2. AI for Structural Design and Analysis		
Aspect	**AI Approach**	**Benefits**
Load Prediction	Machine learning models trained on historical and simulated data	Improved accuracy in forecasting structural responses
Stress and Strain Analysis	Deep learning algorithms for modeling nonlinear behaviors	Better understanding of complex material and structural behavior
Finite Element Integration	Hybrid models combining AI with finite element methods (FEM)	Reduced computational time with reliable outcomes
Optimization of Design Parameters	Genetic algorithms and reinforcement learning for parameter tuning	Efficient resource use and cost-effective design solutions
Generative Design	AI-driven generative design creating multiple design alternatives	Innovative and sustainable designs with multiple options
Risk Assessment	Predictive analytics to identify potential failures and risks	Enhanced safety and proactive mitigation of structural failures

The potential of machine learning procedures in resolving the issue of real-time structural problems, including aeolian vibrations on transmission lines, are tremendous. Studies conducted by Jia et al. reveal that the two approaches can be successfully applied to anticipate failures and make structures more resilient, which are the supervised learning and the deep learning. This is one of the indications that AI may be used to overcome the gap between the abstract knowledge of the realm of engineering and real, practical knowledge.[28] Predictive modelling and simulation with AI have revolutionized the structural design and analysis. They are the predictive properties of the machine learning-based methods of predicting the load reactions, the stress fields, and the non-linear material reactions.[29,30,31] Direct direct integration of the deep learning and finite element techniques makes computation processes quicker. Generative design with AI is provided to engineers with the choice of a tradeoff between costs and performance. The possibility of projecting the structural and electrical behavior conditioned by the use of computational tools is substantiated by the studies on carbon nanotubes and graphene oxide.[32,33] These applications suggest the relationships between AI-inspired model-based developments and materials. All in all, the design results can be made safer, more efficient and stronger with the help of AI. Finally, according to the scientometric survey conducted by Sood, there is a growing significance of the ICT-on-the-rise-based data mining tools in the structural design and performance measurement. The study of machine learning models will be instrumental in transforming the approach on how the building is designed, constructed, and serviced as well as revolutionizing the accepted way of doing things in the field of civil engineering.[34] To conclude, in a word, AI is transforming structural design and analysis processes in a sense that, they can maximize on materials, predictive maintenance, and advanced model process, which allow to optimize the efficiency and overall performance of the process across different engineering fields.

AI for Structural Design and Analysis

Generative design beyond the conventional structural computations are also other uses of AI in the field of structural engineering. Generative design tools that rely on artificial intelligence can be used to automatically produce a range of design solutions, based on specified constraints and objectives. These designs are also evaluated, according to the performance, cost and sustainability, and the engineers are able to choose the best solutions. Besides this, the principle of reinforcement learning is also emerging so as to maximize adaptive structures that can react dynamically to external forces such as wind or earthquakes. AI-based simulations help identify the vulnerable sectors in constructions before they are constructed and this lowers the risks and costs involved. The technologies contribute to the life-cycle assessments as well, ensuring that the long-term durability and the maintenance are put into consideration when designing (table 3).

Table 3. AI for Structural Design and Analysis

Aspect	AI Approach	Benefits
Generative Structural Design	AI-driven generative design tools producing multiple structural options	Explores innovative solutions beyond human imagination
Adaptive Structures	Reinforcement learning for structures that adapt to external loads	Creates adaptive and resilient structures with dynamic performance
Life-Cycle Assessment	AI-enabled life-cycle modeling for durability and sustainability	Ensures long-term sustainability and reduced maintenance costs
Multi-Objective Optimization	Machine learning and genetic algorithms for trade-off optimization	Balances cost, safety, sustainability, and efficiency simultaneously
Seismic and Wind Response Prediction	Deep learning models analyzing structural responses under dynamic loads	Improves resilience against earthquakes and extreme weather conditions
Integration with BIM/ Digital Twins	AI models embedded into BIM and digital twin frameworks for real-time analysis	Enables continuous monitoring and real-time optimization of structures

Besides the classical modeling, AI is now applied to generative modeling, adaptive structures and life-cycle modeling. The reinforcement learning enables structures to change dynamically in response to external forces like seismic forces and wind.(35) The deep learning simulations can be used to predict long-term prediction of the durability and performance of the material in different environmental conditions. Graphene oxide and sulfur-doped materials adaptive behavior has been investigated and can be related to the AI-based optimization models.(31) One of the promises of the AI-based life-cycle analyses is the reduction of the maintenance and sustainability cost. At any given time, continuous monitoring and optimization can be practiced in the implementation of AI on BIM and digital twins carried out by the engineers.(32) In this, AI introduces the element of structural design to the proactive and adaptive and future-proof engineering. Therefore, AI is not a support technology, but a component of the innovation in the building design. The use of Artificial Intelligence (AI) in the civil engineering field can be implemented as AI application in the building design and analysis field and can revolutionize the industry. The ability to predict the forces on the members of structural elements (steel tubes) is one of the most significant innovations. More recent developments are based on the fact that machine learning (ML) algorithms can analyze and predict structural health monitoring (SHM) data and forces on members, and have been shown to be effective in comparison to more conventional approaches. Li and Chung provide data concerning the use of AI in such applications, as this is an indication that the generation of massive amounts of numbers, the accelerations in the processing power, and the development of more advanced neural nets and machine learning algorithms are all intriguing phenomena in the field of structural analysis and design.(36) Lastly, large-scale redesigning and analyses can also be redesigned with the help of AI. The predictions and optimization machine learning tool can enable the engineers to maximize the accuracy and validity of structural analysis. It is also noticeable that these smart systems will be shaping the future of civil engineering as it will aid in overcoming the maze of the modern designing complexities.

AI in Construction Materials

The AI implementation in the construction material engineering has transformed the idea of designing, testing, and the use of materials. Mechanical properties such as strength, elasticity and durability may be predicted with high accuracy using AI-based predictive models. When it comes to concrete technology, AI could be utilized to assist in streamlining the mix proportions to produce the best performance and with minimal impact on the environment. When it comes to steel and composite, AI algorithms can find defects, estimate fatigue life, and suggest an improvement procedure (table 4).

Table 4. AI in Construction Materials

Aspect	AI Approach	Benefits
Concrete Mix Optimization	Machine learning models for predicting optimal mix ratios and strength	Higher performance and cost-effective concrete with reduced trial errors
Steel and Composite Materials	AI algorithms for analyzing fatigue life and structural integrity	Improved reliability and longevity of steel and composite structures
Material Property Prediction	Predictive modeling of durability, elasticity, and mechanical properties	Accurate forecasting of material performance in various environments
Defect Detection and Quality Control	Computer vision and deep learning for real-time defect identification	Enhanced safety and reduced production costs through automated QC
Sustainable Material Development	AI tools to design eco-friendly and energy-efficient material compositions	Supports green engineering and reduces carbon footprint in construction
Smart and Nanomaterials	ML techniques to accelerate discovery and application of nanomaterials	Enables advanced functionalities in smart materials and innovations

Image recognition systems based on AI are extensively used in the quality control of processing. In addition to this, machine learning is also advanced in the creation of nanomaterial and smart materials, which makes it easier to discover sustainable solutions to construction. The results of these novelties are not only the improved structural reliability, but it is also related to the environment-friendly and energy-efficient construction. The application of Artificial Intelligence (AI) to the construction materials sector is of tremendous interest because of multiple advantages, issues, and future opportunities. Creating more effective and efficient construction processes, AI will complement data analysis and design and sustainable practices management. Nonetheless, even with such innovations, it is extremely difficult to adapt AI to the existing manufacturing systems and construction projects. Most construction companies are equipped with ready-made systems; that is why the implementation of AI becomes an intricate process and requires significant investments in the modernization of the infrastructure and training of employees. Even more problematic is the fact that the discontinuation of the traditional way of conducting business predetermines the shift to AI-driven systems. As such, AI practices concerning data collection, format and benchmarking standardization are critical measures towards ensuring that AI utilization is as efficient as possible, especially as the number of increasingly more IoT devices and smart sensors entering the world continues to rise to provide real time feedback.[37] Applications of AI in materials engineering are used to predict the mechanical properties of materials and a material process is designed to optimize the product. Machine learning will allow them to predict the concrete strength, and create mixes that, in a way, can be sustainable.[23,38] The fatigue life and performance of steel and the composite materials are identified with the help of AI algorithms. One of the most valuable examples of how the simulations based on AIs can be utilized to get a more accurate understanding of the electrical, thermal, and mechanical characteristics is the simulation of doped graphene oxide and CNTs.[39,40] The other one is the computer vision which enhances detection of defects in the processes of manufacturing of materials. Moreover, thanks to the use of AI, the process of getting nanomaterials with certain properties will become faster, and the invention of high-tech composites that can be implemented in the modern construction process will become possible.[9] This mixture increases the safety, performance and environmental sustainability. The ethical aspect of AI in the construction is also to be considered. With the deployment of AI technologies that can maintain the indigenous construction methods and lead to the success of sustainable construction, the issue of cultural appropriation and ethical implementation of algorithms becomes even more visible. The AI can come in handy in recovering the ancient techniques and merging with the latest material science in the case studies, thereby rescued the cultural heritage and facing the dilemma of sustainability in the modern world. These studies reveal the necessity of the moderate solution according to which the local culture would be respected and the ethical values would be upheld in the use of AI.[41] Since the sphere is constantly changing, it is also probable that the study will continue to reveal the answers to the questions that remain unanswered when it comes to the implementation of AI in construction materials, which will also be the validation of the importance of technology in the future of the sphere. Such developments imply that AI is not a developmental process, but one of the most crucial aspects that can transform the way the construction and material science may be undertaken in the future.[5,42] Overall, AI integration into the building materials can hold revolutionary possibilities of efficiency, sustainability, and novel design, but only when the serious challenges that need to be addressed with caution to allow the use of AI in the construction process are met in an ethical and productive way.

AI in Construction Management

One of the fields in which AI is already demonstrating the most viable advantages is the construction management one. Project schedule analysis and optimization of resource distribution and delays reduction are used to put the AI algorithm into practice. The managers can make decisions using the machine learning tools to predict the cost overruns and the safety risks. It is also possible to connect to Building Information Modeling (BIM) and coordinate, and conflict detection between teams working on the project in real-time. The management of supply chains by using AI-applicable tools also helps to predict the demand and supply of materials and delivery time. AI-based surveillance at the workplace can be used to secure the safety of the people working in the place as they will know when situations are dangerous. Automated reporting and documentation simplify the administration procedures since they reduce the human workload. The role of AI in construction management in most cases provides efficiency, transparency and safety to modern projects. The artificial intelligence (AI) has taken the place of the revolution of the sphere of construction management because it is the paradigm shift in the way of working with the projects which is one of the factors of the sphere in general. The introduction of AI technologies will assist to provide more efficiency, security, and decision-making through the lifecycle of the construction, which is a significant change in planning, implementation, and control of the projects. It goes hand in hand with the findings of the recently issued report according to which it was mentioned that the AI technologies will allow detecting the faults in the civil engineering and predicting the lifecycle in the most efficient manner by which the risks and the performance will be minimized and maximized.[42] Mammoth AI applications in construction management are used to smooth out resources, schedule and risk estimation. With the connections to the BIM and IoT, it would have the potential to provide real-time information and connectivity with the project teams.[24,43] Clouds also make it possible to store data on the construction process and perform analytics on a large scale.[44] The creation of advanced nanomaterials monitoring is expressed in a similar way as the AI-based infrastructure diagnostic and predictive models of failures.[9,31,45,46] The construction management process can be made more flexible and efficient, minimizing uncertainties, and ensuring that the process is more transparent, with the help of AI-driven tools. Thus, similarly to how AI has helped achieve success in governance in the management of infrastructures, it can also help project managers to navigate complexities in the construction process. The human-AI interplay is also important in the project success in the agile project management. According to the findings of the experiments conducted by Cui[47], the effectiveness of agile practices that leads to the successful project delivery in the large-scale construction setting is mediated by the connection between human intuition and AI competences. This is a reflection of why collaborative systems between human and artificial intelligence agents should be developed and could significantly increase the benefits of agile approaches. This aspect of this integration is significant in the complexity of the mega construction projects conquering, and also strategies to enhance the process of the project management. Moreover, the availability of Generative AI (GAI) technologies opens up the further possibilities of enhancing the quality of the services and the results of the projects in the mega construction projects. They are also expedited in regard to technological transformation and this is noteworthy since it falls under the improved service delivery mechanisms which is vital given the high stakes and magnitude of such undertakings in the society like telecommunications in China. This amalgamation of digital technology and service quality meant biases on the notion that the approaches that construction managers pursue would have to be modified to the modifications in the technological setting at any given moment. In conclusion, the application of AI in construction management is multifaceted, and it means that it is possible to make improved decisions with the help of data, better manage security, and improve the cooperation of people and AI. As the construction industry continues to take its shape, it will be necessary to embrace such technological advancements to ensure that the industry is still in its developmental stages and to ensure that competitive advantages are upheld in carrying out projects.

AI in Structural Health Monitoring

The infrastructure structural health monitoring (SHM) is important to security and performance of the infrastructure in the long term. AI has potential to improve SHM because it is comparatively more effective than traditional systems to process big volumes of sensor data. The use of AI can identify anomalies and reveal damages and disturbances at the earliest stage. Deep learning algorithms are effective especially at detecting defects that are hidden and vibration pattern and acoustic signal detection. AI is used to come up with predictive maintenance, which minimizes common failures and increases building life cycles. Drones with image recognition AI-based visual inspection systems are used to automatically identify cracks, corrosion or deformations. The practices are very effective in minimization of inspection cost and enhancement of safety as the human beings are not subjected to hazardous situations. Thus, AI-based SHM is one of the pillars of active infrastructure management. The concept of integrating artificial intelligence (AI) in structural health monitoring (SHM) is proving to be a valuable addition to improving the security and reliability of different buildings. The latest developments into data-driven methods have shown a magnitude of potential on optimization of the structural assessment using machine learning algorithms, sensors, and computation simulations. Meanwhile, Liu et al.[10] consider an important forward to be the one that incorporates some level of health monitoring because it becomes possible to diagnose faults in real-time with the introduction of deep learning algorithms. They offer a description of how the technologies of convolutional neural networks (CNNs) and recurrent neural networks (RNNs) might prove to be more effective and more effective at supervising and offering essential basis of fault control and decision dynamics in structure applications. These AI processes are groundbreaking, and predictive maintenance with real-time data is one of the possible uses of these methods in the future, which can avert expensive integrity failures of infrastructures.

Alongside this, a study have already created an evidence-based structural health monitoring framework, including wireless strain sensors, FEA, and machine-based learning algorithms to identify the scaffold instability modes, which echoes the prospects of the integration of different AI applications in SHM systems. They suggest that risk reduction in falls as the result of applying the corresponding technologies is considerable, thus, the overall safety of the construction site where the scaffolds are installed in large amounts is increased.(11) To sum up, AI application in structural health monitoring is not just a possibility to facilitate the culture of safety proactivity, but it also formed more efficient analysis opportunities, that is the multi-dimensional issue of infrastructure maintenance. It is turning SHM into an efficient, and trustworthy discipline by integrating machine learning, real time data collection and creation of novel forms of analysis that have enormous implications to the security of the populace and structural integrity. One of the most helpful AI implementations in the field of construction engineering is structural health monitoring (SHM). The sensor measurements are processed in real-time by artificial intelligence algorithms, which attempt to recognize anomalies, cracks and damaged material.(31,48) The applications of machine learning can forecast preventative maintainability and lessen sudden failures and optimize the infrastructure. AI-based vision systems on drones assist the inspections which are safer. The graphene oxide and doped CNTs study is a good example demonstrating the possibilities of intelligent sensing systems in SHM.(33,49) Together with AI analytics, such materials can be applied to identify the weak points in the structure in advance. The AI ownership within SHM promotes resilient infrastructure, adaptive infrastructure and cost-efficient infrastructure.

Robotics and Automation in Construction

The current robotics and automation based on AI is transforming the traditional approaches to construction by bringing new efficiency and accuracy. Autonomous robots are used in the repetitive tasks like laying bricks and welding as well as handling materials. The prefabrication and onsite construction is changing with the use of AI-powered navigation on the drones to surveil, inspect and monitor the progress of the site. These developments do not only shorten the project time, but also decrease the number of human errors, and enhance safety. AI-based robot systems can adjust to the dynamic environment of locations. Moreover, human workers can be assisted by collaborative robots (cobots) to overcome conditions of hard or dangerous work. The merging of robotics and AI, and construction-related technologies is an indicator of a new era of the construction industry that can be traced back to automation, sustainability, and resilience. The construction industry is an area where robotics and automation are being integrated as a way of improving efficiency and safety in addition to precision. The construction site dynamics require the robotic systems, which are able to measure the space variables and dynamically adjust with time. Research has established that high-tech construction robots with a high-quality sensor and managerial system are able to accomplish proper tasks like painting walls and placing glasses and maintain high quality and compliance with the rules of the construction.(14) Also, construction activity complexities tend to be a factor continually requiring advanced automation to obtain the highest efficiency. The recent bibliometric analysis indicates that the role of smart technologies in construction has been increasing recently, and it requires automatic solutions that can optimize the construction process, as well as safety and real-time monitoring of the infrastructure.(13) The advancement of AI-based robotics and automation has altered the existing mode of practice of construction. These autonomous robots carry out repetitive jobs including welding and constructing a wall in a highly precise way. AI-based drone technology may be utilized in the realm of surveying, inspection and safety control.(50) The prefabrication and sustainable construction practices are innovative and made through AI-based 3D printing. They can be compared to the works with nanomaterials, when AI and automation are employed in an attempt to accelerate the discovery and implementation.

[9,51] Cobots will also help in making the work environment a better place to work because they are deployed to work with heavy or dangerous tasks. Adaptive control can also be applied to the systems of a robot to control it with digital twins. All of these changes are indicative of the future when AI-powered robotics will guarantee efficiency, strength, and sustainability of the construction process. Deep learning is very useful in improving the capabilities of the robot.[52,53,54,55] Study established that it has led to the creation of intelligent identification and analysis tools, which employ deep learning to transform the construction industry into a performance. Such systems make the necessary information accessible with real-time data acquisition and processing, which promotes automation of construction projects and the intelligence of such systems in general.[15] In addition, the advance in materials science that has adopted additive manufacturing has left a subsequent impact on automation in building.[56,57,58,59] The strategies that have resulted in the potential of recycling and reusing the materials, specifically, plastic waste, are not only helpful in ensuring that the environment is sustainable; they can also result in decreasing cost and enhancing efficiency of construction.[16] Finally, convergence of robotics, automation and intelligent systems in the construction industry is transforming the industry in terms of efficiency, precision and sustainability.[60,61,62,63] Such inventions can help support the needs of complex initiatives and lead to the creation of a more resilient and innovative environmental of building. Since the process of technology implementation is continuously changing, the possibility of better results in the construction can become clearer.[64,65]

CONCLUSIONS

AI is depicted to possess the potential of changing structural and construction engineering in an important manner. It provides the fresh outlook in the design, analysis and management, and transgresses the barriers to the traditional approach. Machine learning and deep learning will enable the engineer to obtain a higher degree of precision of his or her model of the complex structural behaviors. The design of a solution is cheaper and more sustainable as AI provides optimization. Predictive modeling can be applied to construction materials, where the achievement of a better-quality control and creation of new materials is possible. The management of the construction can be greatly assisted by the AI-based planning, scheduling, and risk analysis. The surveillance of the structural health turns into an effective process, as the AI-powered sensors and predictive-based maintenance plans are used. The more safety, less human resource consumption and increased productivity is provided through robotics and automation by AI. Such development opens possibilities of stronger and more viable infrastructure. The problems of the data reliability, its transparency, and ethical approval, however, persist. The resolutions to the difficulties will be essential in the eventual deployment of AI in the engineer practices. The AI and digital twins developed on the basis of BIM will raise a new era of intelligent construction systems. Green engineering and energy efficient infrastructure is another area where the future of AI will be seen to operate. Anyway, AI is a disruptive trend characterizing the future structural and construction engineering.

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AUTHORSHIP CONTRIBUTION
Conceptualization: Fuad Abaszadeh, Taleh Asgarov, Shafi Danyalov, Rashad Ismibayli, Ahila A, Malikov Ziyodullo Abdurayim, Abduraxmonov Muhammad Sulaymon, Rabbimov G‘iyosjon Mehriddin

Data curation: Fuad Abaszadeh, Taleh Asgarov, Shafi Danyalov, Rashad Ismibayli, Ahila A, Malikov Ziyodullo Abdurayim, Abduraxmonov Muhammad Sulaymon, Rabbimov G‘iyosjon Mehriddin

Formal analysis: Fuad Abaszadeh, Taleh Asgarov, Shafi Danyalov, Rashad Ismibayli, Ahila A, Malikov Ziyodullo Abdurayim, Abduraxmonov Muhammad Sulaymon, Rabbimov G‘iyosjon Mehriddin

Drafting - original draft: Fuad Abaszadeh, Taleh Asgarov, Shafi Danyalov, Rashad Ismibayli, Ahila A, Malikov Ziyodullo Abdurayim, Abduraxmonov Muhammad Sulaymon, Rabbimov G‘iyosjon Mehriddin

Writing - proofreading and editing: Fuad Abaszadeh, Taleh Asgarov, Shafi Danyalov, Rashad Ismibayli, Ahila A, Malikov Ziyodullo Abdurayim, Abduraxmonov Muhammad Sulaymon, Rabbimov G‘iyosjon Mehriddin.