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Implementation of IoT and EIP in construction of Barapullah Bridge Project, New Delhi

Artificial Intelligence in Construction Projects

Artificial Intelligence in the Construction Industry: A Review of Applications in the Indian Public Sector

Artificial Intelligence Revolutionizing MEP Processes in Construction Industry

Predictive Maintenance and Managing Assets in the Construction Industry using Machine Learning and Deep Learning Techniques

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Artificial Intelligence Transforming in Construction Industry

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ARTIFICIAL INTELLIGENCE IN CONSTRUCTION INDUSTRY

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From President's Desk



I am delighted to address you through this esteemed technical magazine. The construction industry in India stands at the cusp of a revolutionary transformation, driven by the integration of advanced technologies, particularly Artificial Intelligence (AI). As we navigate through this era of unprecedented change, AI is emerging as a pivotal force, enhancing our capabilities, efficiency, and safety standards.

AI's role in optimizing project planning, resource allocation, and predictive maintenance is already reshaping our operational frameworks. The deployment of AI-powered drones and autonomous machinery is not only boosting productivity but also significantly improving site safety. Moreover, AI's ability to provide real-time data analytics is enabling us to make informed decisions swiftly, ensuring projects are completed on time and within budget.

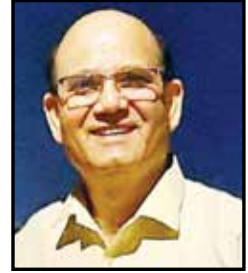
As we embrace these technological advancements, it is imperative to invest in skill development and continuous learning to harness AI's full potential. The Indian Buildings Congress remains committed to fostering innovation, sustainability, and excellence in our industry. Together, let us build a future where technology and human ingenuity coalesce to create resilient and sustainable infrastructure.

Let's grow with times.

A handwritten signature in black ink, appearing to be 'Ashok Kumar'.

(Maj. General Ashok Kumar, AVSM)
President, IBC &
Retd. Dir. General (Works), MES

From Editor-in-Chief's Desk



Embracing AI in the Construction Industry

Welcome to the latest edition of our esteemed journal, where we delve deep into the transformative realm of Artificial Intelligence in the Construction Industry. As Editor-in-Chief, it is my privilege to introduce you to a collection of insightful research, innovative methodologies, and forward-thinking perspectives that are shaping the future of construction through AI.

The integration of Artificial Intelligence into construction practices marks a significant paradigm shift from improving project efficiency and safety to enhancing decision-making processes. AI technologies offer unprecedented opportunities for growth and advancement. In this issue, we explore these transformative potentials across various facets of the industry.

One of the most compelling aspects of AI in construction lies in its ability to optimize project management and scheduling. By harnessing AI-powered predictive analytics, construction firms can anticipate project delays, optimize resource allocation, and streamline workflows with remarkable precision. This not only enhances operational efficiency but also minimizes costs and accelerates project timelines.

Moreover, AI is revolutionizing design and planning processes through generative design algorithms that can create and evaluate thousands of design options based on predefined parameters. This not only fosters creativity but also ensures that designs are optimized for functionality, sustainability, and cost-efficiency right from the outset. Such advancements not only elevate the quality of construction projects but also set new benchmarks for architectural innovation.

Safety, too, stands to benefit significantly from AI applications. With the ability to analyze vast amounts of data from sensors, drones, and wearable devices in real-time, AI can detect potential hazards before they escalate, thereby preventing accidents and ensuring a safer working environment for construction personnel. This proactive approach to safety underscores AI's role in mitigating risks and promoting a culture of workplace wellness.

Furthermore, AI-driven technologies are enhancing quality control and asset management throughout the construction lifecycle. From automated inspections using drones to predictive maintenance of equipment and infrastructure, AI empowers stakeholders to make data-driven decisions that prolong asset lifespan and optimize operational performance. This not only enhances the longevity of constructed assets but also reduces maintenance costs over time.

In academia and research, AI is fostering interdisciplinary collaborations that are driving innovation at the intersection of construction engineering and computer science. Through advanced machine learning algorithms and data analytics, researchers are uncovering novel insights into construction processes, material sciences, and urban planning.

As we navigate this era of rapid technological advancement, it is imperative for industry professionals, researchers, and policymakers alike to embrace AI as a catalyst for positive change in the construction sector. However, this journey is not without its challenges. Ethical considerations, data privacy concerns and the need for up-skilling the workforce to harness the full potential of AI remain pertinent issues that demand thoughtful deliberations and proactive measures.

In conclusion, this edition of our journal serves as a testament to the transformative impact of AI in the construction industry. Through rigorous research, insightful case studies, and thought-provoking perspectives, we aim to foster a deeper understanding of AI's role in shaping the future of construction. I extend my heartfelt gratitude to President IBC, Major General Shri Ashok Kumar, AVSM (Retd); Shri Rajeev Kumar Gupta, Member Secretary IBC for their useful suggestions and Shri V.R. Bansal Honorary Secretary, IBC and his team in bringing out this publication timely. I further extend our gratitude to our contributors, reviewers, and editorial team for their invaluable efforts in bringing this issue to fruition.

I encourage you, our esteemed readers, to engage critically with the content presented herein and to join us in exploring the limitless possibilities that AI offers for innovation, sustainability and resilience in construction. Together, let us chart a course towards a future where AI not only enhances construction practices but also enriches the lives and communities we serve.

Thank you for your continued support and enthusiasm for our journal. Here's to a future where AI and construction converge to create a built environment that is smarter, safer, and more sustainable than ever before.



(Dr. Om Prakash Tripathi)
Editor-in-Chief

Transforming Contracts: Gen AI and Blockchain in Construction Law

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IIT Delhi

Dr. Kumar Neeraj Jha

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Prologue

The construction industry, long characterized by its adherence to traditional practices, is undergoing significant transformation as it adapts to the digital age. This change has led to a growing exchange of digital information and assets without much regard to contractual stipulations, leading to various challenges, including data corruption, privacy breaches, and security vulnerabilities, that escalate into claims and disputes. Despite having a pivotal role in the management of projects, the contracting process and contracts themselves continue to be conventional and manual, lacking the necessary structure and intelligence to align with the industry's digital trajectory. Therefore, this research aims to investigate the emerging digital technologies comprising artificial intelligence (AI), blockchain-enabled smart contracts, Internet of Things (IoT), and Distributed Common-Data Environments (DCDE) in confluence towards the concept development for the "Next-gen Computable Contracts" that are both intelligent and secure. While AI holds promise in enhancing efficiency and speed, decentralization and automation through smart contracts and DCDE could foster trust and collaboration in the system. The underlying blockchain data structure is envisaged to enhance security and traceability throughout the process. The study paves the way for future research in the area of technology and law with enhanced automation and intelligence.

-Editor-

Introduction

Over the past decade, the construction industry has witnessed substantial change across various facets of its operations, driven by the increasing integration of information and communication technologies. Tools and technologies such as Building Information Modeling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML) algorithms and Decentralized Ledger Technologies (DLT), mainly blockchain and smart contracts are being increasingly adopted and explored for applications in various areas of construction, such as supply chain, automated payments, document and information management, and quality management, among others (Das et al. 2022; Erri Pradeep et al. 2021).

Despite these advancements, it is intriguing to note that the domain of construction law and contract management has largely remained resistant to significant technological changes. Construction contracts and their administration are a fundamental and quintessential component that essentially underpins the success of a construction project. However, their limited integration with digital technologies has impeded the industry's potential for automation and advancement.

Recently, researchers and industry are actively delving into the domain of “law tech” or “computational law” - the use of intelligent automation and digital tools in contracting practices and construction contracts. The most commonly deployed of these are AI tools for document management, information search and retrieval processes, and neural networks used for decision-making and outcome predictions. Another prominent area of focus has been contractual text analytics, where data analysis and ML techniques are applied to extract insights from text-based contract documents (Candaş and Tokdemir 2022; ul Hassan et al. 2022). Researchers utilize these methods to review contractual structures and forms, identify potentially problematic clauses, and assess risk-prone contractual terms (Iyer et al. 2002).

Blockchain-based smart contracts have recently been explored for the automation of contract terms and performance using deterministic codes. In early research, Mason (2017) introduced the term ‘smart legal contracts’, referring to legally enforceable smart contracts with embedded legal obligations in the standardized code. Later, McNamara and Sepasgozar (2021) proposed ‘iContracts’ and developed a theoretical framework exploring the concept and its possible implementation in the construction industry. Advancing the field, Cummins and Clack (2022) presented the concept of ‘computable contracts’ as objects that are understandable by both humans and computers. Their approach was based on the argument that ‘when contract terms and conditions are represented in highly structured data, computers are able to process them automatically with high accuracy.’ (SCCI 2020; Goodenough 2019). Gupta and Jha (2024) further built upon this concept towards the development of adaptive and dynamic contracts executed in a blockchain-based environment. Their research focused on creating automated smart contract templates for key FIDIC contract clauses, including Delay Damages and Price Variation.

While these studies have been pioneering in the research of contract automation, the process of developing, testing, and validating smart contract code poses various challenges. These include assessing the legality and operational accuracy of the code. Developing smart contract codes for complex legal agreements requires bridging the gap between legal and technical expertise. Understanding legal text semantics and pragmatics is crucial for building trust among stakeholders, including regulators, and promoting industry adoption of legally enforceable smart contracts.

By leveraging AI tools to foster efficiency and reliability in automation, combined with the security and transparency inherent in blockchain technology, there could be a fundamental shift in the preparation and execution of construction contracts.

Literature Review

Blockchain Technology and Smart Contracts

Blockchain technology, an advanced form of distributed ledger technology (DLT), stores and updates information chronologically in a decentralized manner (Turk and Klinc 2017). Each transaction is stored as a block linked to its predecessor via cryptographic hash values (Luo et al. 2019). Blockchain employs a consensus mechanism to validate transactions. Within the blockchain execution mechanism, smart contracts are digital programs and codes that self-execute based on consensus. (Szabo 1994; Gupta and Jha 2023).

Machine Learning, NLP, Neural Networks, and Gen AI

AI replicates human intelligence through artificial technologies to invent intelligent machines. It provides machines with access to objects, categories, properties, and the relationships between them to implement knowledge engineering, enabling machines to function and act like humans in various aspects (Gupta and Jha 2022). Machine Learning (ML) is a data-driven AI niche concerned with developing and using algorithms and statistical models that learn from datasets and generalize to unseen data, enabling computers to perform specific tasks without explicit instructions. ML uses three broad learning approaches: Supervised learning involves training models on labeled data, unsupervised learning deals with unlabeled data, and reinforcement learning focuses on learning through a system of rewards and punishments (Cummins and Clack 2022; Akinoshoe et al. 2020).

Natural Language Processing (NLP) is a subset of ML and AI that enables machines to interpret, manipulate, process, and generate text based on human language. It focuses on the interaction between computers and humans through natural language, allowing for more intuitive and effective communication with machines (ul Hassan et al. 2022). NLP often leverages ML algorithms, such as neural networks, to process and analyze language data. Neural Networks are self-learning ML algorithms structured similarly to how a human brain operates. They consist of layers of nodes (neurons) organized primarily in three layers: input layers, hidden layers, and output layers. Neural networks with many layers are known as deep neural networks, which form the basis of deep learning (Akinoshoe et al. 2020). These neural network algorithms are particularly adept at learning from large amounts of data and have been increasingly used in various industries, including construction, for decision-making, dispute resolution mechanisms (Chaphalkaret et al. 2015), safety management, progress monitoring, and 3D model reconstruction.

Further, neural networks provide the foundation for many advanced ML applications, including deep learning, significantly advancing their capabilities through the use of transformers and large language models (LLMs) such as ChatGPT from OpenAI (Ma et al. 2024). LLMs use deep learning systems, which are trained on extensive text data to produce human-like text; this leads to their use in applications like chatbots, virtual assistants, and content creation. Within the broader umbrella of AI, large language models (LLMs) and NLP could see some interesting applications in the domain of contract automation and administration.

These technologies collectively could advance the contract formation and execution process, enabling the automation and optimization of complex tasks across the contract lifecycle, thereby fostering innovation and efficiency (Rich 2018).

Next-Gen Intelligent Computable Contracts

In this section, we explore the seamless interaction of blockchain-based computable contracts with a range of advanced technologies and entities, including artificial intelligence, machine learning technologies, and the Internet of Things. This confluence could be significant in automating various aspects of contract creation, execution, and enforcement, thereby streamlining the contract management processes and adding substantial value to construction projects. A conceptual model visualising this approach is presented in Fig. 1.

This approach could impact and revolutionize contract management in two key areas:

Contract formation and drafting

The effective implementation of computable contracting relies closely on seamless integration and automation of the tasks. Computable contracts, equipped with machine-readable and self-executable code, have become essential to achieve this. This code developed to automate a particular contractual condition or task must accurately reflect the contract's content and intent, ensuring a precise connection between the code and the contractual text being translated (Gupta and Jha 2024). However, achieving this level of accuracy can be hindered by factors such as contract ambiguity, poor coding practices, or misunderstandings between legal and technical teams.

Generative AI presents a promising solution for enhancing the contract formation and drafting process. By leveraging technologies like LLMs and NLP, contract clauses can be automatically generated and optimized based on past projects and pre-defined criteria.

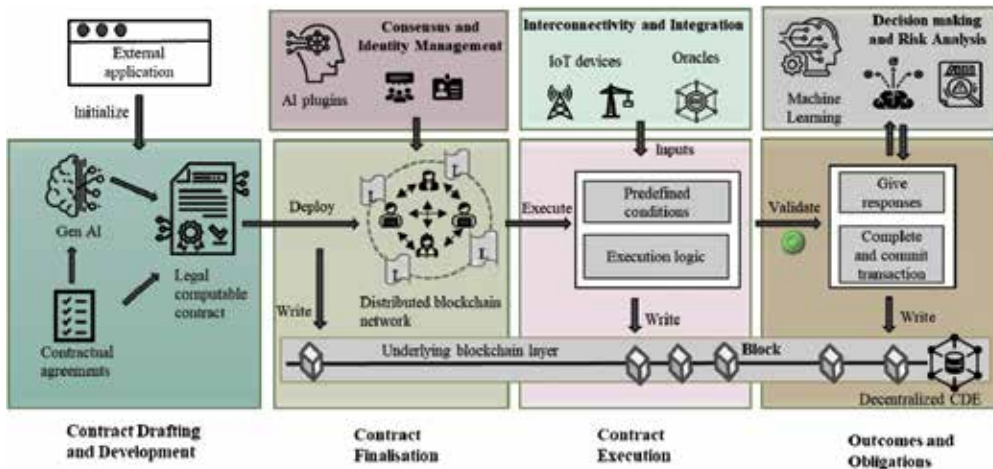


Fig. 1: Conceptual Model for the Next-Gen Intelligent Computable Contracts

These tools excel at extracting and clarifying contract content, including renewal dates and renegotiation terms, while also identifying contract types through pattern recognition. They could also facilitate further optimization of clauses according to project-specific requirements, streamlining the contracting process and reducing negotiation complexities. Moreover, trained AI tools can assist in extracting key variables such as clauses, dates, and involved parties, facilitating the identification of non-compliance and prompt resolution of unfavorable provisions (Ma et al. 2024; Candaş and Tokdemir 2022; Lee et al. 2019). Overall, the integration of generative AI in contract drafting could potentially enhance accuracy and consistency but also significantly reduce the time required to draft complex contracts.

Contract performance and administration

Trust and transparency play vital roles in automating contract performance and execution. Thus, a decentralized blockchain platform becomes indispensable to ensure the process

is trustworthy, secure, and reliable when automated (Gupta and Jha 2023). By providing an immutable and tamper-proof record of the dynamic states of the process, along with consensus-based approvals of transactions, a blockchain platform enables stakeholders in the legal system to connect and collaborate more efficiently (Cummins and Clack 2022; Msawilet al. 2022). It could reduce the possibility of human errors and help in data retrieval and tracking in a more accurate and faster way.

The integration of IoT devices with blockchain further enhances transparency and accountability by enabling real-time monitoring and reporting of project performance data. Smart contracts, operating on blockchain, can autonomously enforce compliance, trigger payments, and manage changes or disputes based on pre-defined conditions. Additionally, AI-driven analytics can offer insights into performance trends, provide real-time recommendations, and flag potential risks, enabling proactive management and informed decision-making. Fig. 2 illustrates the key technologies involved and highlights their attributes, that are instrumental in transforming contract management practices.

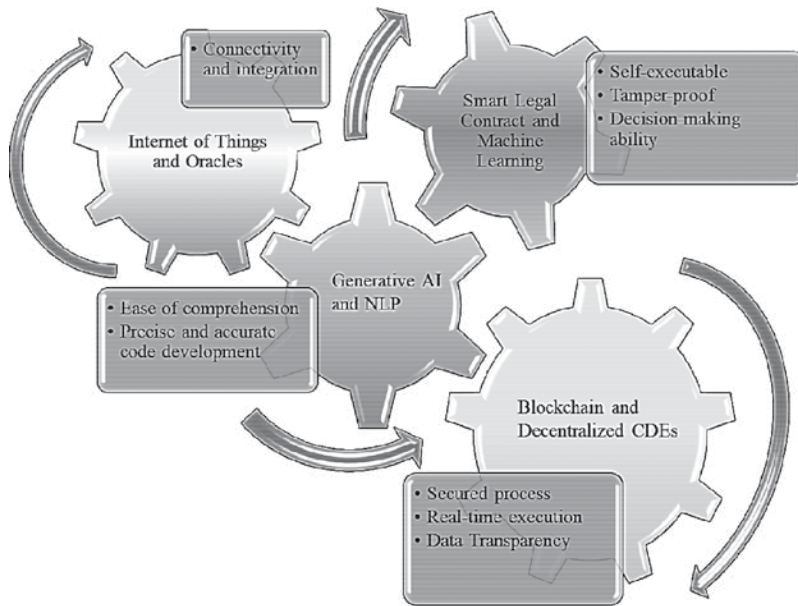


Fig. 2. Recent technologies with their respective roles in reforming the contracting practices

Next, we delve into some noteworthy applications of the proposed concept in the realm of construction contract management.

Dynamic and self-executing Contracts

Artificial Intelligence can be used to develop smart contract templates, which are self-executing contracts with the terms of the agreement directly written into code. NLP can assist in translating legal language into machine-readable code, ensuring that smart contracts accurately reflect the intentions of the parties involved (ul Hassanet al. 2021). Generative AI can facilitate dynamic contracting by continuously updating contract terms based on changing circumstances or pre-defined triggers (Ma et al. 2024). This adaptability

enables contracts to remain relevant and enforceable over time, particularly in complex or long-term agreements.

Decentralization of the project database

Decentralized Common Data Environments (DCDEs) integrate blockchain technology and Interplanetary File System (IPFS) to store records and large-sized files in a distributed and immutable manner (Jaskula et al. 2024; Tao et al. 2021). IPFS is an innovative protocol that offers a peer-to-peer distributed file storage system without a centralized server, thereby enhancing data availability and resilience. Traditional cloud-based storage solutions lack the necessary features to prevent alterations, deletions, access denial, and incorrect revision histories. To address these concerns, large files could be stored in IPFS and linked to the blockchain using content identifiers (CIDs) to ensure file integrity. Utilizing blockchain provides a decentralized, reliable, and transparent system for recording, updating, and maintaining the project records, with security and privacy ensured through cryptographic methods. This distributed and decentralized storage allows all stakeholders simultaneous access without intermediaries, fostering multi-disciplinary collaboration, reducing bureaucracy, and enhancing trust.

Interconnected and integrated digital and physical infrastructure

For a contract to be truly digital and automatable, it is essential that apart from being computable, it must also be integrated and interconnected with different project systems and databases that it refers to and interacts with, as and when conditions arise (for instance, digital wallets, project schedules, etc.). Integrating computable contracts with IoT and smart sensors could be pivotal in computable contracting serving as a secure and real-time data source for smart contracts (Singh et al. 2020; Gupta and Jha 2024). Further using AI and ML analytics, the project progress can be monitored closely, and relevant contractual obligations can be executed and enforced, such as automated payments, trigger actions or penalties in case of non-compliance. Oracles are services and mechanisms that provide external data to smart contracts on the blockchain. AI-powered decentralized oracles can collect, verify, and deliver real-world data to smart contracts, enabling them to execute conditional clauses based on dynamically changing information.

Decentralized Decision-Making and Dynamic Governance

Blockchain's decentralized nature allows decision-making processes to be distributed across a network of nodes, eliminating the need for a central authority. Generative AI algorithms can be deployed within this decentralized network to analyze data, propose solutions, or make predictions based on pre-defined rules or objectives. Blockchain networks rely on consensus mechanisms that allow stakeholders to validate and agree upon the state of the distributed ledger. Generative AI can enhance these mechanisms by providing insights, recommendations, or simulations to help stakeholders make informed decisions collectively. This could make decision-making processes more efficient, transparent, and resilient to manipulation or bias.

Risk Assessment

Generative AI can perform risk analysis, identifying suboptimal terms and clauses and potential risks and inconsistencies while reducing the risk of human error in contract

drafting and reviewing and suggesting amendments to mitigate risks. Risks are identified and allocated between contracting parties via the conditions of the contract that they have agreed upon, the provisions of law, or both. This lays the foundation for the course of action when a given risk materializes (Msawile et al. 2022).

Dispute Resolution

Blockchain provides an immutable and traceable record of events, ensuring secure, tamper-proof documentation. In case of delays or disruptions, it offers a verified chain of evidence, ensuring clear accountability and fair compensation without needing to re-verify or compile documents, thus streamlining dispute resolution. Additionally, the trace-back feature of blockchain can effectively address various issues such as errors, omissions, modifications to digital models, misplaced documents, pending approvals, and quality checks at their source. (Turk and Klinc 2017; Msawile et al. 2022; Gupta and Jha 2023). Furthermore, AI-driven dispute resolution mechanisms can be integrated into computable contracts deployed on the blockchain. These mechanisms employ sophisticated NLP and ML algorithms to analyze contract terms, communication logs, and pertinent data, enabling automated dispute resolution or arbitration (Parikh et al. 2019). Further, emerging developments in Gen AI and deep learning algorithms can be utilized to provide recommendations based on contract language, historical data, and legal precedents, offering valuable insights into effective dispute resolution approaches.

Conclusion

The integration of AI tools, IoT devices, smart contracts, and blockchain technology represents a significant advancement in the automation of construction contracts. NLP analytics and generative AI hold the potential to profoundly impact the creation and validation of smart contract codes, leading towards dynamic, transparent, and efficient agreements with a better comprehension of potential liabilities and ambiguities. Through deep analysis and understanding of language patterns and generative capabilities, we can develop robust smart contract codes that accurately reflect contractual agreements. Moreover, deploying these smart contract codes within a decentralized environment, with the consensus of all stakeholders, promises to enhance transparency and trustworthiness in the contract execution process. This integration could not only ensure precise adherence to contract terms but also facilitate real-time updates and adaptive responses to changing project conditions. Thus, it promises the potential to streamline processes, improve reliability, and instill greater confidence in the contractual agreements among all involved parties.

However, realizing the full potential of this integration requires addressing challenges related to scalability, interoperability, and regulatory compliance. Given the rapid advancements in AI technology, ensuring AI systems adhere to legal and ethical standards is crucial. Quality and bias in training data can impact the reliability of AI-generated content. Challenges also stem from the early stage of these technologies in construction, coupled with energy-intensive and scalability issues. Adequate training and skill development, along with computational resource allocation, are essential for effective adoption. Interoperability and compatibility hurdles further impede industrial implementation, while cultural resistance and skepticism underscore the need for a collaborative ecosystem transition. To mitigate these challenges, comprehensive cost-benefit analyses, enhanced security measures, and robust training programs are imperative for broader implementation.

While these advancements hold promise and intrigue, the authors advocate for a balanced approach in the contracting system, emphasizing the continued role of human intelligence alongside technology. Human oversight remains indispensable, with smart contract clauses incorporating legal text for reference in case of code malfunction. Dispute resolution mechanisms or human arbitrators could offer an exit route from automated systems, especially for decisions with significant consequences or requiring additional judgment beyond automated capabilities, ensuring a harmonious blend of human and machine capabilities.

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Artificial Intelligence Techniques in Construction Industry: An Overview

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Prologue

Artificial Intelligent system is defined as a software that is developed with one or more of the following techniques and approaches: (a) Machine learning approaches, (b) Logic- and knowledge-based approaches, (c) Statistical approaches, and (d) Optimization methods. Currently, the literature of information technology in construction is mainly focused on studying AI applications, related potentials, benefits, and trends. However, there is a gap in analysing the risks perceived by the construction experts. Without a clear and holistic understanding on the risks, it is not possible to act to create common policies and solutions to protect users and communities.

The paper is an exploratory work on AI in construction and its present status on adoption, benefits and risks. Literature review results shows that the application of AI in the most advanced construction practices is still limited and most applications cover process automation and process optimization during design. This paper reviews the state-of-art literature works carried out by researchers from around the world. The paper also discusses the research works carried out at CSIR-SERC based on AI application to structural engineering.

-Editor-

Introduction

Artificial intelligence exhibits a form of intelligence distinct from that of humans and animals, lacking the emotional depth inherent in organic intelligence. Since the emergence of artificial intelligence (AI) in the 1950s, it has sparked numerous hopes and aspirations. Insufficient digital expertise and technology adoption in the construction sector have been correlated with cost inefficiencies, project delays, substandard performance, uninformed decision-making, and compromised productivity, health, and safety standards. Coordinating construction projects proves challenging as each participant pursues their distinct spending goals and resource allocations. Consequently, a rigorous system of checks and controls emerges, necessitating extensive written documentation to record transactions among involved parties. This heightened administrative load largely stems from inadequate communication and collaboration among stakeholders. Among the most formidable challenges in the construction sector is ensuring a seamless flow of information among subcontractors, contractors, designers, clients, and other stakeholders. To address this hurdle, information

technology (IT) has effectively facilitated the integration of disparate information within the decentralized landscape of construction projects.

Artificial intelligence technologies are classified based on their ability to emulate human characteristics. Artificial intelligence can be broadly classified into the following categories:

1. Knowledge management and decision-making AI techniques
2. AI that depicts reasoning classification
3. AI that learning and interprets
4. other theories and some future trends

A common application of AI techniques in civil engineering includes the application of an artificial neural network (ANN) for predicting the compressive strength of various concrete mixes normal, high-strength, high-performance concrete (Prasad et al. 2009). Researchers have also worked on developed neuro-fuzzy based prediction of the durability of self-consolidating concrete to various sodium sulfate exposure regimes (Bassuoni and Nehdi, 2008). A recent review discusses different application of artificial intelligence techniques in construction industry (Abioye et al 2021). Chui (2017) demonstrated that AI can be used to initially gather data from diverse and reliable sources, leveraging the insights gained to make informed and adaptable judgments. It is widely understood that operations and maintenance constitute the bulk of the time and expenses throughout a facility's lifecycle, amounting to roughly sixty percent of costs by ensuring the safety and comfort of its users. Application of AI along with BIM-based techniques to manage operations and maintenance activities is expected to greatly enhance the output (Zabin et al, 2022). In recent years, artificial intelligence (AI) has significantly contributed to enhancing business operations, service processes, and industry productivity as shown in Fig. 1.

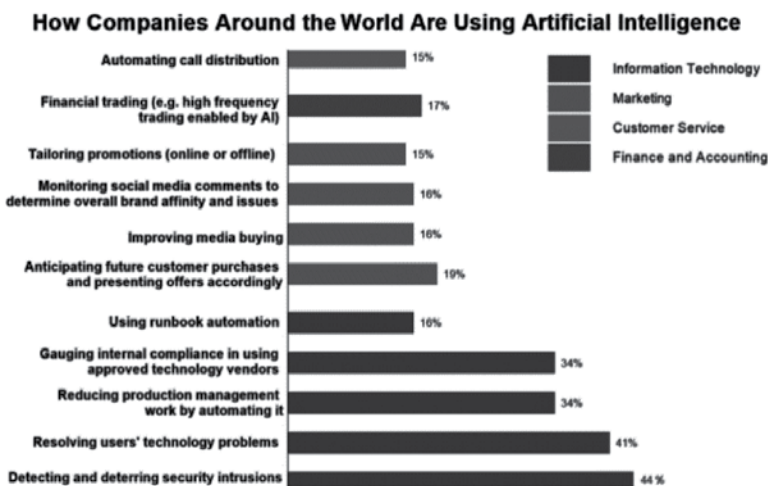


Fig. 1: Application of AI in various industries

Source: Ahmad et al, 2023

Artificial Intelligence Algorithms

Supervised and Unsupervised Learning algorithms

These algorithms mimic the human brain in its ability to learn from situations, analyse and interpret for a newer situation. The learning process could be supervised or unsupervised in real world conditions. Therefore, the algorithms which have been developed to mimic the learn and interpret concept of the human brain has been divided into supervised and unsupervised learning algorithms. Supervised learning methods rely on labeled datasets to generate predictions. This approach proves advantageous when the desired outcome or result is known beforehand. Unsupervised learning algorithms operate on unlabeled data. This method assigns labels to the unlabeled data by categorizing it or revealing its type, form, or structure. It proves useful particularly when the nature of the outcome is uncertain or undefined. Some of the popular algorithms include – artificial neural network, gradient boosting algorithm, support vector machine, k- Nearest Neighbors, Principal component analysis, machine learning, deep learning, and many more.

An artificial neural network (ANN) is a computational model inspired by the structure and functioning of biological neural networks in the human brain (Fig. 2). It comprises interconnected nodes (neurons) organized in layers, including an input layer, one or more hidden layers, and an output layer. Information flows through the network via connections between neurons, with each connection having an associated weight that modulates the signal. ANNs are trained using algorithms such as backpropagation, adjusting the weights to minimize the difference between the predicted and actual outputs during training.

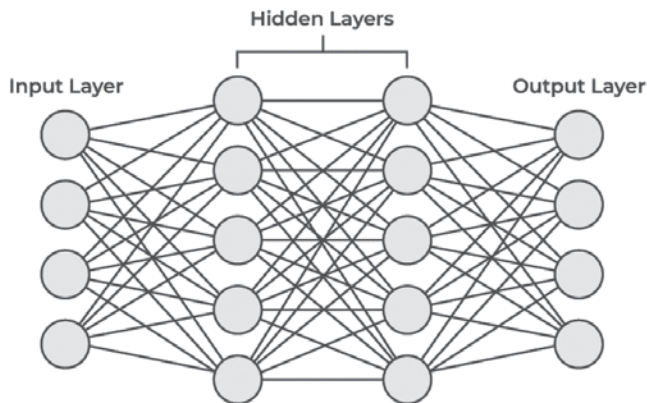


Fig. 2: Schematic of the neural network architecture

Source: <https://www.geeksforgeeks.org>

The support vector machine (SVM) algorithm is a supervised machine learning technique used for classification and regression tasks. It works by finding the optimal hyperplane that separates data points into different classes or predicts a continuous target variable. In classification tasks, SVM aims to find a hyperplane that maximizes the margin, which is the distance between the hyperplane and the nearest data points of each class, known as support vectors (Fig. 3). This hyperplane effectively separates the classes, and new data points can be classified based on which side of the hyperplane they fall on. One of the key

strengths of SVM is its ability to handle high-dimensional data efficiently and effectively, even when the number of features exceeds the number of samples. Additionally, SVM can handle both linearly separable and non-linearly separable data through the use of different kernel functions, such as linear, polynomial, radial basis function (RBF), and sigmoid kernels.

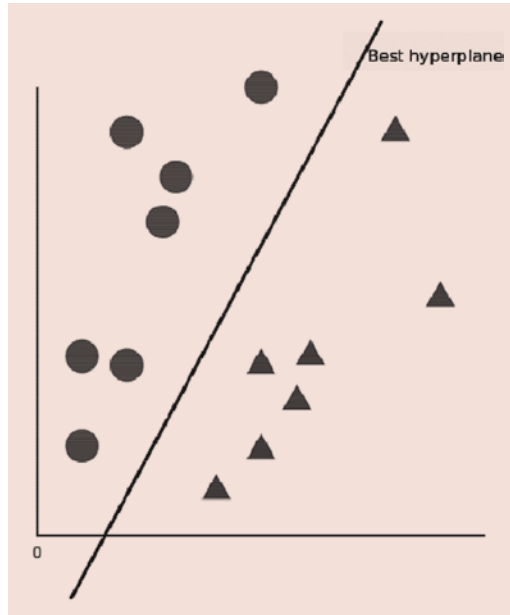


Fig. 3: Schematic of the hyperplane positioning in SVM

Source: <https://monkeylearn.com>

Logic based algorithms

Fuzzy logic is a computing paradigm based on degrees of truth rather than the usual true or false (1 or 0) Boolean logic on which traditional computing is based. It allows for handling the concept of partial truth, where an assertion can be true to a certain degree or false to some degree. Fuzzy logic is particularly useful in systems where uncertainties and ambiguities are present, such as in natural language processing, expert systems, and control systems. In fuzzy logic, variables can have a value that ranges from completely true to completely false, allowing for a more nuanced representation of data and reasoning (Fig. 4). It operates by defining membership functions that assign degrees of membership to elements of a set, determining the degree to which each element belongs to the set. These membership functions can be triangular, trapezoidal, Gaussian, or any other suitable shape depending on the application (Fig. 5).

Fuzzy logic systems consist of three main components: fuzzification, rule evaluation, and defuzzification. Fuzzification involves converting input data into fuzzy sets using membership functions. Rule evaluation applies a set of fuzzy rules to these fuzzy sets to derive fuzzy outputs. Defuzzification converts the fuzzy outputs back into crisp values or actions. Overall, fuzzy logic provides a way to model and reason with uncertain and imprecise information, making it valuable in various domains where precise mathematical models are difficult to obtain or where human-like decision-making is desired.

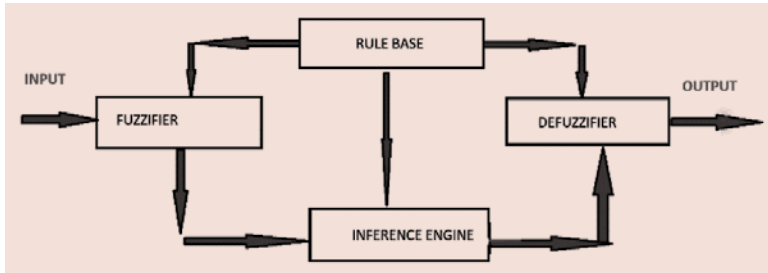


Fig. 4: Schematic of the fuzzy logic algorithm

Source: <https://www.geeksforgeeks.org>

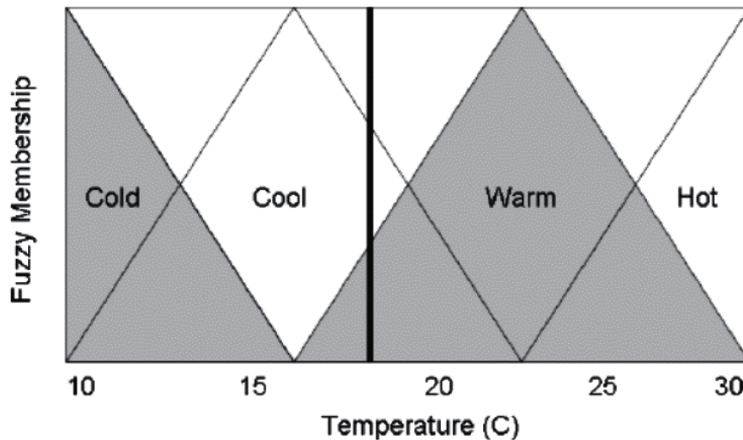


Fig. 5: Typical representation of fuzzy membership function

Source: www.researchgate.com

Optimization algorithms

Optimization algorithms are search algorithms and are classified into Linear, Binary, Interpolation, Jump, Exponential, and Ternary search algorithms. Optimization algorithms are used to identify the global maxima or minima of a problem. Some of the popular algorithms are Pattern Search Algorithm, Genetic Algorithm, Simulated Annealing Algorithm, Tabu Search Algorithm, Ant Colony Optimization Algorithm, Particle Swarm Optimization Algorithm, Differential Evolution Algorithm, and Harmony Search Algorithm. Particle swarm optimization (PSO) is a popular optimization technique inspired by the social behavior of bird flocking or fish schooling (Fig. 6). It is used to solve optimization problems by iteratively improving a population of potential solutions, called particles, based on their collective experiences. In PSO, each particle represents a potential solution to the optimization problem and is associated with a position and velocity in the search space. The movement of particles is guided by two main components: their own best-known position (pBest) and the global best-known position (gBest) discovered by the entire swarm.

During each iteration, particles adjust their velocities based on their current positions and their historical best-known positions. This adjustment is influenced by cognitive and social components, which represent the particle's tendency to explore its own best-known position

and the swarm's best-known position, respectively. As particles move through the search space, they converge towards promising regions, driven by their own experiences and the shared knowledge of the swarm. Through successive iterations, particles collectively explore and exploit the search space, gradually converging towards optimal or near-optimal solutions. The algorithm terminates when a termination criterion is met, such as a maximum number of iterations or achieving a satisfactory solution quality (Fig. 7). Particle swarm optimization is commonly applied to a wide range of optimization problems, including continuous, discrete, and multi-objective optimization tasks. It offers a simple yet effective approach to solving complex optimization problems, particularly in high-dimensional spaces or when the objective function is non-linear or multimodal.



Fig. 6: Swarm of birds flocking towards a destination

Source: <https://www.theweek.in>

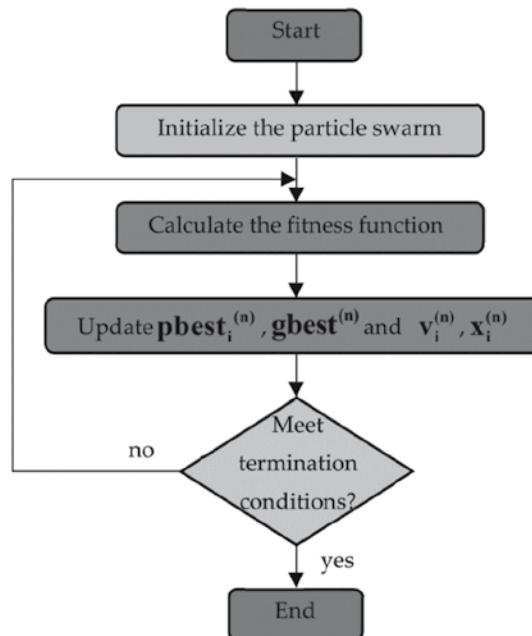


Fig. 7: Flowchart of particle swarm optimization algorithm

Source: www.reserachgate.com

Construction Materials

The main construction material popularly used in the construction industry is the cement. AI based decision making algorithms have been used for the sustainable manufacturing of cement (Ateş, et al 2021). Fig. 8 shows the schematic representation of neural network scheme. In the application of concrete, AI has been extensively used for investigating the applicability of sustainable supplementary cementitious materials (Asteris et al, 2022).

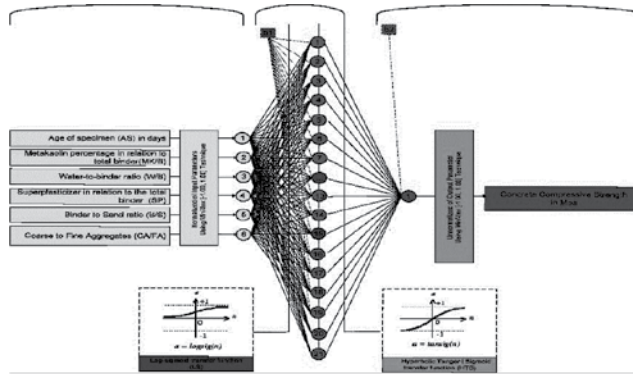


Fig. 8: Schematic of Neural network scheme used in the study

Source: Asteris et al, 2022)

Asteris et al, (2022) applied AI technique for investigating the durability characteristics of concrete. Researchers have investigated thermal conductivity of construction materials using AI techniques (Bienvenido-Hurtas et al, 2020). Agricultural byproducts contain naturally-occurring radioactive elements, posing potential radiation hazards to both people and the environment. Hence, this study examines the radiological properties of agricultural byproducts when used in building and construction materials, focusing particularly on their activity levels, as shown in Fig. 9 (Oyebisi and Alomayri, 2023).

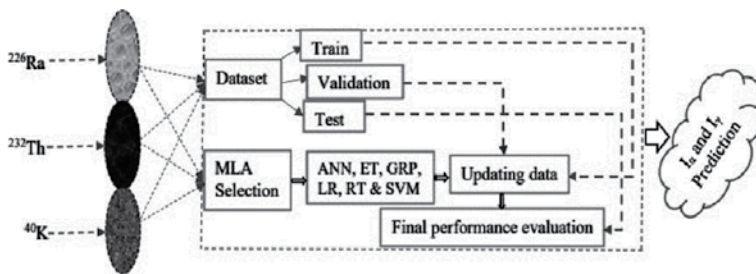


Fig. 9: Machine learning algorithms architecture

Source: Oyebisi and Alomayri, 2023

Geopolymer concrete is an innovative material that offers a sustainable alternative to traditional Portland cement concrete. It is made using industrial by-products, reducing the environmental impact associated with conventional cement production. Many researchers have investigated the mechanical properties of geopolymer concrete using AI techniques (Pazouki, 2022; Rathnayaka et al, 2024). AI techniques have also been used for the structural assessment of geopolymer specimen namely, crack detection and ultimate strength parameters (Rahman and Al-Ameri, 2023).

Construction Planning & Management

Construction planning and management is a multifaceted discipline that involves overseeing and guiding construction projects from inception to completion. The goal is to ensure that projects are completed on time, within budget, and to the specified quality standards

For best results, each project shall involve Detailed Planning, Stakeholder Engagement, Effective Communication, Regular Monitoring, Risk Management, Quality Assurance, and Flexible Adaptation. Planning in projects not only involves project planning but also planned and effective manpower utilization. Towards this, researchers are using optimization techniques for effectively utilizing of worker by considering their trade skill and learning capabilities (Xiao and Wang, 2018). In a more rigorous manner, problems involving multi objective, multi-scheduling and assembly line optimization is also becoming popular (Chutima and Chimrakhang, 2021). Consequently, artificial intelligence can effectively address complex problems in the construction sector.

Similarly, project management is a key parameter which influences the project success. Building Information Modelling (BIM) is a digital representation of the physical and functional characteristics of a facility (Zabin et al, 2022). BIM revolutionizes the construction industry by enhancing design quality, increasing efficiency, reducing costs, and fostering collaboration. BIM supports better decision-making and more sustainable practices in the construction and operation of facilities. Utilization of artificial intelligence along with BIM packages has shown effective improvement in the results (Wei, 2021). Researchers are also effectively utilizing artificial intelligence for managing quality control related issues and for controlling construction equipment activities. Such research works will soon bring about AI based automation in the construction industry.

3D Printing

3D printing technology, also referred to as additive manufacturing, has made considerable strides within the construction sector in recent times. This innovative approach involves creating three-dimensional objects layer by layer, using various materials such as concrete, plastics, or even metals. In construction, 3D printing offers numerous advantages, including increased speed of construction, reduced material waste, and the ability to create complex and customized designs with precision.

Artificial intelligence is applied in different ways towards enhancing 3D printing technology. Identifying the correct concrete mix properties is an intense area of research. Assessing the rheological properties of concrete for 3D printing is a tough research problem. Because of its intensity, evolutionary algorithm has been used to predict the rheological properties of fresh concrete (Nazar et al, 2022). Neural network technique has been used for predicting the printability characteristics of concrete (Marcucci et al, 2023). Recently, research on machine learning is gaining popularity. Machine learning has been applied to predict the compressive strength of fiber reinforced concrete for 3D printing (Alyami et al, 2024). AI also finds application in 3D printing robotics technology (Barjuei et al, 2024).

A single-story building with a ground floor and one upper level, spanning 700 square feet of built-up area, has been 3D printed by Larsen and Toubro's Kanchipuram facility. This

structure utilizes a unique concrete mix developed in-house, made from locally sourced conventional construction materials (Shivakumar, 2020). As the technology continues to advance, it holds promise for reshaping the future of construction, offering new possibilities for sustainable and efficient building practices.

Computationally Intensive Problems

Computationally intensive problems are those that require significant computational resources, including processing power, memory, and time. These problems are often complex and involve large datasets or require solving intricate mathematical models. Artificial Intelligence (AI) plays a crucial role in addressing these computationally intensive problems through various techniques and methodologies. Optimization techniques had been used for computing the minimum actuators required to actively control or reduce the earthquake drift in tall structures (Rama Mohan Rao et al, 2004; Sivasubramanian et al, 2005; Rao and Sivasubramanian, 2008; Rao and Sivasubramanian, 2008b). Recently, deep learning is gaining popularity for applications in civil engineering structures. Machine learning techniques have been effectively used in image processing for the identification of surface defects on concrete structures (Arulmozhi et al, 2023). Artificial intelligence gains popularity for application in health monitoring and damage identification (Gopalakrishnan et al, 2018). Artificial intelligence also finds applications in manpower allocation in construction industry (Xiao and Wang, 2018). It involves computing global optimal solution based on objectives like man hour, multi objective, multi-scheduling and assembly line (Chutima and Chimrakhang, 2021). Thus, artificial intelligence could solve rigorous problems in the construction industry.

Conclusion

This paper reviews and introduces to the application of artificial intelligence technologies in civil engineering. Presenting the recent research activities in the field of artificial intelligence is the focus of this paper. Based on these research findings, it outlines the prospects and development trends of artificial intelligence in this field. AI can assist inexperienced users in solving engineering problems, enhance the efficiency of experienced users, and facilitate experience sharing among team members through AI technology. AI technology will continue to evolve rapidly and has a promising future in civil engineering.

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Present and Future of Artificial Intelligence in Construction Industry

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Prologue

Time overrun, cost overrun and substandard quality of infrastructure projects lead to wastage of resources. Construction industry has been struggling hard to tackle time overrun, cost overrun, and quality including safety and health issues of the workers, low productivity and shortage of labour.

Artificial Intelligence is currently revolutionizing manufacturing industries, and entering into all walks of life including infrastructure development. Therefore, efforts are being made by researchers to adopt AI in construction industry, as it reluctantly adopts digitization.

The subfields of Alare machine learning, knowledge-based systems, computer vision, robotics and optimization. These have successfully been applied in other industries to achieve increased profitability, efficiency, productivity, safety and security however there are greater challenges in construction industry due to its scale of risks involved. The AI applications in the construction industry are presented in the paper describing challenges in the construction industry.

-Editor-

Introduction

Construction industry is one of the least digitized industries due to heavy dependence on unskilled and semi-skilled workers, innovative design of each project, particularly buildings, and perception of extra cost involved in digitization. It appears to be the mindset of the stakeholders rather than innovation which is preventing digitization in construction industry.

In last few years, construction of complex and high-rise structures is experiencing difficulty in monitoring, coordination of large number of services, and project management as such need of switching over to digitization is being felt. This has brought digitization in construction industry through monitoring software like MS Projects, Primavera, and Building Information Modelling (BIM). Also, robotics is entering into the construction and maintenance, particularly due to shortage of labour, inaccessible and risky tasks, and in repetitive works leading to curtailment of cost and delays ensuring quality.

Availability of data is ever increasing as such use of data and information is making IT to enter into every field and develop technologies based on selective data to provide accurate or almost accurate results. This has resulted into the reduction of interface with human

intelligence and has given birth to Artificial Intelligence. AI will enhance automation and provide competitive advantage compared to existing methods of digitization.

AI is going to be an integral part of the infrastructure creation and maintenance used in health and safety monitoring, cost estimation, supply chain, logistics process improvement, and risk prediction. Robotics will be used in many fields like site monitoring, performance evaluation, manufacturing of pre-cast components, management of construction materials, plants, and equipment, and maintenance management. Knowledge-based systems of AI will be used in tender evaluation, conflict resolution, net zero evaluation, sustainability assessments etc.

Definition of AI

AI is the study of “how to make machines do things” and defined as the simulation of human intelligence processes by machines, especially computer systems. It enables computers and machines to simulate human intelligence and problem-solving capabilities thus AI is computer science developing intelligent machines that can mimic human behaviour, encompassing machine learning and deep learning. AI involves development of AI algorithms, modelled after the decision-making processes of the human brain, that can learn from available data to make more accurate predictions. Thus, AI is capable of performing the tasks that historically only a human could do, such as reasoning, making decisions, or solving problems.

Types of AI

AI is generally divided based on capabilities and functionality of AI3 (Fig. 1). Based on capabilities, AI is categorised as; Narrow or Weak AI, General AI, and Super AI.

Narrow AI performs a dedicated task with intelligence and is the most common and currently available AI. It is only trained for a specific task as such it cannot perform beyond its field or limitations for example playing chess, purchasing suggestions on e-commerce site, self-driving cars, speech recognition, and image recognition.

General AI can perform any intellectual task like a human efficiency and think like a human by its own. Currently, there is no such system existing which can perform any task as perfect as a human being.

Strong or Super AI is a level of system intelligence at which machines could surpass human intelligence, and perform any task better than human with cognitive properties. It is still a hypothetical concept.

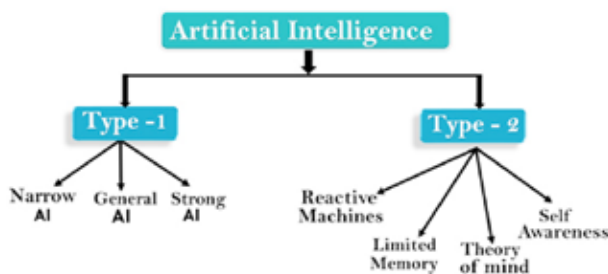


Fig. 1: Types of AI

Based on the functionality, AI can be categorized as; Reactive Machines, Limited Memory, Theory of Mind, and Self - Awareness

Artificial Intelligence Vs Human Intelligence

AI has been derived from human intelligence but is the outcome of many expert human minds which makes it superior to many of individuals. They have integration of ICT, and mechanical and electrical engineering hence AI-powered applications have faster execution speeds, higher operational efficiencies, better work efficiency, and better decision-making accuracy than many humans without much of physical fatigue. Human intelligence (HI) grows from adaptive learning and personal experience. Therefore, HI will still be able to overpower AI when it comes to adaptive learning even from the AI and experience over AI. In general, AI may have an edge over common HI however cannot go beyond expert human brains as human brain acquires knowledge by sense of understanding, reasoning, learning, and experience. Human brain and heart will always make HI superior to AI however with the development of AI, the risks from AI may be even on human brains and hearts. Robots will work on the data fed into it but not on common sense as humans can. Common sense continues to prevail in humans but not in AI as it does not understand "cause" and "effect" while humans do everything on the basis of "cause and effect" even though researchers are working on Deep Learning (DL), which works on the concept of the human reflex and nervous system, a neural network similar to the brain so that robots are taught to apply intelligence and knowledge to real-world scenarios.

AI is created by HI but it processes information faster, is highly objective, has better accuracy, based on optimization, and capable of doing task as per the designed system while HI created by divinity, is subjective, may be many a times less accurate but can easily adapt changes and do multitasking.

Subfields of AI

The major subfields of AI² are machine learning, computer vision, natural language processing, knowledge-based systems, optimisation, robotics, and automated planning and scheduling. Even though all the subfields are important in AI, robotics is entering the field of civil engineering at a faster rate. Robotics involves design, manufacture, O&M and other computer actions to carry out the desired activities. Use of robots⁴ in road works, construction and maintenance of nuclear installations, maintenance of transmission towers, railways, 3 D printing technology of houses, brick laying, plastering, formwork, casting of prefabricated houses, 3 D modular RCC construction etc are well known.

AI Applications in Construction Sector

Resource optimization and waste utilization

Green construction has become a necessity of today's construction, based on the concept of resource conservation, generation and optimization and waste utilization. It depends on diverse data obtained from different sources such as use of energy efficient, water efficient and waste efficient design, materials and construction practices, waste creation, reuse and recycle, and sustainability, requiring high-performance computation and computer processing. AI can help in analysing and selection of appropriate design, materials, and processes in

short time based on their availability, optimum cost, recyclability, and sustainability. Use of advanced AI techniques with BIM can also be used for the same.

Estimation and scheduling

The cost of a project depends upon many factors like design, selection of materials, processes, specifications, and scope of work. Any change in the same changes the cost. Therefore, BIM and other AI based techniques will provide updated cost immediately on change of any of the parameter affecting the cost. During rescheduling of any activity or deviations during execution, AI based techniques can provide updated estimated cost immediately on real time basis. AI will also enable to select best suited materials and methods for preparing the cost estimates and will go on rescheduling time and costing automatically based on the automated inputs, and even helping in monitoring and decision-making process during execution by providing cost of variations. Deep learning techniques can also aid in better predictions of financial resources, energy efficiency, water and waste efficiencies and even carbon footprint updates.

Construction site analytics

It is never possible to carry out one hundred percent manual inspections in a project. AI techniques will enable smart working and smart supervision at all the places simultaneously, integration of IoT sensors and other digital instruments and equipment resulting into quality, safety and higher productivity. A repository of design data, costing, specifications, contract data, accounts and financial resources, and thereafter generation, collection, storage and analysis of site data will provide deep insights for visualisation, monitoring and future modelling. Through AI techniques, a large volume of images, videos and other forms of data can be generated, compared, modelled, and used on construction sites and for future projects through the analysis being made from a faraway place in the office. AI techniques will thus optimise site performance in all key areas such as planning, design, safety, quality, schedule and cost.

Supply Chain Management (SCM)

SCM requires data related to materials, their transportation, their inventory and consumption at construction site in SCM and their test results, energy and water efficiency, initial cost, their replacement cost, maintenance cost, and performance etc. for mid-term reviews AI will benefit SCM in timely placement of orders, timely transportation, working and replacement at site simultaneously with minimum storage for which data may already be available in the repository. In prefabricated construction, AI will further be very useful as this will integrate design of mix, materials, sustainability, machinery requirement, processes, quality, HSE, storage of raw materials and finished products, their transportation and assembly at site, IoT-based real-time monitoring, risk involved, and cost implications for better decisions.

Health, Safety and Environment Analysis

Health and safety of workers, plants and equipment, site and indoor comfort conditions depend on site conditions, habits of workers, policy of the management, training, awareness, implementation measures, and cost of accidents. In future and robots may gradually take over construction and maintenance in risky conditions.

Use of advanced data analytics techniques of AI can predict its levels through which preventive measures can be taken. Data from different digital technologies like IoT sensors, UAV, CCTVs, digital photos, videos, plant and equipment and other IoT based devices at site can also be linked to control room, located at a desired place.

Contract Management

Construction contracts normally have large number of items, specifications, and conditions as such their management become very complex leading to mistakes, disputes and large financial implications. At present, with manual control, it is difficult as a contract involves bulky and multiple conditions, even duplicity of items and conditions. Sometimes, various sub-contracts are also included where co-ordination and time management become major issue leading to litigation costs, claims, project delay and loss of reputation as present contracts are heavily dependent upon on human intelligence, efforts and interpretation. Automation of the contract management system with AI will help in augmentation of the efforts and memory of contract managers for curtailing such mistakes and risks.

Another challenge in the contract management is measurements of thousands of items in a complex and high-rise construction project involving multiple services and new and innovative materials whose specifications are to be referred each time. In such cases, AI tools and techniques will help in contract management and better implementation. Further, AI will help to retrieve the data and information which can also be linked to the quality standards, acceptance criteria and resulting cost adjustments.

Communication and Voice User Interfaces

Communication and coordination between various stakeholders are very important, particularly with ongoing complex structures coming up globally and architectural and engineering design services being provided from distant places. Such services and other expert's advices are required from time to time and any delayed communication leads to wastage, delays in completion of work and cost overruns. Use of AI including communication through voice messages between different stakeholders immediately as per the requirements will help in curtailing such delays.

Quality and Audit System

Quality, accounting and finance are very important in any construction project. Quality is audited by supervisors, inhouse quality inspectors and third-party quality auditors. Owner and client make the assessment of the finances but when actual construction does not go as per the estimates and exceeds the assessment, finances remain idle one time and unavailable another time when required. AI tools and techniques can provide the updated requirements on real time basis as per the progress, site conditions and market fluctuation. AI will also help in quality and financial management.

Prefabricated structures

AI is very useful in the construction of prefabricated components and prefabricated modular structures which will help in achievement of quality, quantity and speed along with other

benefits. In future, more and more prefabricated structures in all types of infrastructure will be used hence AI will be adopted for cost optimization due to economy of scale.

Challenges in AI Applications

Adoptability of AI due to cultural issues

Adoption of “Change” in construction industry is very slow and adoptability of the digitization being least in construction industry, poses a challenge to AI in construction sector. The industry is managed by seniors at top who, more often, are not adaptable to new technologies easily due to their old knowledge. Similarly, contractors also do not adopt changes easily. As such, training is required at all levels.

Testing by a Multi-disciplinary Team

AI technologies to be deployed in the construction sector must be thoroughly tested which is possible by a multidisciplinary team of architects, civil, E&M, and IT engineers as cost of failure is very high. In future, it would be essential in government and private organisations both.

Facilities and Uninterrupted Internet Connectivity

Generally, construction sites are remotely located and lacking power, telecommunications and internet connectivity, leading to interruptions in power and internet connectivity. This will pose a serious problem in the use of AI on sites and interruption of AI tools and techniques, resulting into wastage and idle deployment of robots and other resources.

Security

Main issue of AI is security, its cost and intrusions, exploitation by hackers and cybercriminals also having large financial implications as a small mistake in construction process may lead to huge risk of quality, cost and delays, with a roll-over effect to the overall project time, disputes, interruption of supply chain, loss of goodwill etc.

Similarly, any mistake may lead to risk of safety of construction workers, safety of structure and huge cost of accidents and loss of lives to a contractor and owner. Also, it will be difficult to identify hackers and cyber-crime personnel due to large number of personnel required in a construction work, particularly employed occasionally.

High Initial Costs

Initial costs required in AI including in robotics will be high in its development, use and maintenance, as such, construction will have high initial cost. Initially AI may be best suited for prefabricated construction.

Ethics and Governance

It is only humans who can be made accountable and responsible, not the robots; therefore, adequate and proper regulations for AI governance will be needed.

Future of AI in Construction

Robotics, AI, and IoT will reduce infrastructure cost, help in virtual reality goggles, send robots at difficult, inaccessible and unsafe places carrying cameras to track the work as it progresses. AI will be used to plan the routing of complex electrical, plumbing and other services in modern high-rise buildings, and to track the real-time interactions of workers, machinery, safety, construction errors, and productivity.

Despite the predictions of massive unskilled and semi-skilled job losses, AI is unlikely to replace equal human workforce having technical jobs.

AI will make work easier but absolute safety will have to be ensured. AI will be useful in analysing large data for predictions of risks including mitigation of natural disasters.

Conclusion

1. AI in construction will help in design, planning, bidding, accounting and financing, procurement, construction, operations, asset management and business modelling, and in optimization of resources.
2. AI will be extremely useful in pre-fabricated construction.
3. AI will help in manufacturing sector for requirement of machinery in construction sector.
4. AI will help in analysing large available data and experience gained during construction hence will lead to higher accuracy.
5. AI will lead in losing unskilled and semi-skilled jobs while in creation of highly skilled and technical jobs.

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Advancing Structural Inspection through AR/VR: Drone-Assisted Flaw Detection in Civil Engineering

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Prologue

In the realm of civil engineering, detecting structural flaws such as cracks and water leakage in buildings poses a significant challenge. To address this issue effectively, the paper presents a system employing drones equipped with cutting-edge cameras and sensors to meticulously capture information on both the exterior and interior of structures. This data is then meticulously analyzed to construct a comprehensive 3D representation of the entire edifice, leveraging advanced artificial intelligence algorithms to precisely distinguish and pinpoint structural components and potential flaws. The resulting 3D model seamlessly integrates into a virtual reality (VR) environment, allowing observers to actively scrutinize and assess the structure. This innovative approach enhances the accuracy and efficiency of structural inspections, facilitates early detection of flaws, and reduces the costs and risks associated with traditional inspection methods, offering a robust solution to critical challenges in civil engineering.

-Editor-

Introduction

The preservation of structural integrity is paramount in civil engineering to ensure safety and durability. Traditional techniques for inspecting structures, such as visual evaluations and manual measurements, are time-consuming, labour-intensive, and often prone to human error. Additionally, these methods pose significant safety risks to inspectors, especially when dealing with tall or complex constructions. As urban infrastructure ages and new construction techniques emerge, there is an increasing demand for more efficient, precise, and safer inspection methods. Recent advancements in drone technology, artificial intelligence (AI), and virtual reality (VR) offer promising solutions to these challenges. Drones can efficiently and safely capture high-quality images and data from various perspectives, including inaccessible parts of a structure. AI, particularly convolutional neural networks (CNNs), can analyze these images to detect structural defects such as cracks and water leaks with remarkable accuracy. Furthermore, integrating these technologies with VR can provide engineers with an immersive and interactive platform to remotely inspect and evaluate structures. Despite the potential of these technologies, there is a lack of comprehensive solutions that integrate

drones, AI, and VR to facilitate structural inspections. Current methods do not fully leverage the capabilities of AI and VR, and face challenges in managing and integrating the vast amount of data collected by drones. This gap highlights the need for a unified system that can effectively acquire, analyze, and present structural data, providing engineers with a powerful tool for assessing structural integrity. Recent studies have begun addressing this integration. Park et al.¹⁸ explore the potential of combining UAV-based photogrammetry with AI-driven image analysis to enhance the accuracy of structural defect detection. Kwon et al.¹⁹ discuss using machine learning algorithms to process and interpret large datasets obtained from drone inspections, showcasing how AI can streamline data management and analysis. Wang et al.²⁰ investigate VR applications for remote structural inspections, emphasizing its ability to create immersive environments for detailed assessment and training. Building on this foundation, our research presents a cohesive system that employs drones equipped with advanced cameras and sensors, AI-powered image analysis, and VR visualization to improve structural inspections. The aim is to develop a reliable method for acquiring detailed structural information using unmanned aerial vehicles (UAVs), leveraging CNNs for accurate defect identification, such as cracks. The goal is to generate a comprehensive 3D representation of the inspected structure and integrate it into a VR environment for interactive examination and evaluation. This system aims to demonstrate the significant benefits of enhancing the precision, efficiency, and safety of structural inspections.

Literature Review

Phung et al. [1] review the application of UAVs in civil infrastructure inspections, highlighting their benefits in terms of accessibility, speed, and cost-effectiveness. Ellenberg et al.² discuss the use of UAVs for structural health monitoring, emphasizing their potential to reduce risks associated with manual inspections and improve data accuracy through advanced imaging capabilities. The integration of AI, particularly convolutional neural networks (CNNs), into structural inspections has significantly enhanced the ability to detect and analyze structural flaws. Yang et al.³ demonstrate the efficacy of CNNs in detecting cracks in concrete structures, showcasing the method's high accuracy and efficiency. Similarly, Cha et al.⁴ review the application of deep learning techniques in structural health monitoring, noting that CNNs can effectively identify and classify various structural defects. Recent work by Lin et al.⁵ highlights the application of hybrid AI models combining CNNs with other machine learning techniques to improve defect detection in steel structures, further showcasing the versatility of AI in structural inspections. Photogrammetry and Structure from Motion (SfM) are critical techniques for creating detailed 3D models of structures from 2D images captured by drones. Remondino et al.⁵ explore the use of photogrammetry and SfM in archaeological site documentation, which parallels their application in structural inspections by enabling the creation of accurate 3D models from drone imagery. Themistocleous et al.⁶ discuss UAV-based photogrammetry for the 3D modelling of historical buildings, highlighting the technique's precision and effectiveness in capturing structural details. Additionally, Xu et al.¹⁶ investigate the integration of photogrammetry with LiDAR technology to enhance the accuracy of 3D models in complex urban environments, suggesting a promising direction for improving structural inspections. VR offers an immersive and interactive platform for examining and evaluating structural data. Sacks et al.⁷ review the application of VR in construction safety training, illustrating how VR environments can enhance learning and inspection processes through immersive simulations. Chen et al.⁸ discuss the integration of VR with Building Information

Models (BIM) for building inspections, providing insights into the benefits and challenges of using VR for detailed structural assessments. Despite the individual advancements in drone technology, AI, and VR, comprehensive systems that integrate these technologies for structural inspections are still emerging. Existing inspection methods often fail to fully exploit the potential of these technologies due to challenges in data handling and integration. The proposed system in this research aims to bridge this gap by combining drones equipped with advanced cameras and sensors, AI-driven image analysis, and VR visualization to create a robust and interactive platform for structural inspections. The integration of multiple advanced technologies into a cohesive system for structural inspections has been explored in several studies. For instance, Koch et al.⁹ discuss the use of a combined approach involving UAVs, image processing, and 3D modeling for bridge inspections, demonstrating the potential for improved accuracy and efficiency in defect detection. Similarly, Rakha and Gorodetsky¹⁰ highlight the effectiveness of using drones and photogrammetry for rapid and detailed structural assessments, emphasizing the benefits of automated data collection and processing. Moreover, Sarmiento et al.¹⁷ examine the integration of UAVs with thermal imaging to detect subsurface defects in building facades, illustrating the expanding capabilities of drone-based inspections. While the integration of drones, AI, and VR holds significant promise, it also presents several challenges. One of the main obstacles is the processing and analysis of large volumes of data generated by drone inspections. According to Luo et al.¹¹ managing and analyzing this data requires sophisticated algorithms and significant computational power, particularly when integrating real-time processing capabilities. Additionally, ensuring the accuracy and reliability of AI models, as discussed by Li et al.¹² is crucial for the successful implementation of automated inspection systems. Another challenge is the seamless integration of VR into the inspection process. Research by Rezaei et al.¹³ indicates that while VR can enhance the inspection experience by providing immersive visualizations, it requires robust and accurate 3D models and intuitive user interfaces to be truly effective. Further more, the adoption of these integrated systems in industry faces practical challenges, including regulatory hurdles, initial setup costs, and the need for specialized training. The future of integrated systems for structural inspections lies in the continued development and refinement of these technologies. Advances in drone technology, such as longer flight times, better sensors, and improved data transmission capabilities, will enhance the efficiency and coverage of inspections. As AI algorithms become more sophisticated, their ability to detect and analyze subtle structural flaws will improve, making inspections more reliable. The role of VR is also expected to expand, with more intuitive and interactive interfaces that allow inspectors to explore and interact with 3D models in real-time. Research by Kim et al.¹⁴ suggests that the integration of augmented reality (AR) with VR could further enhance the inspection process by overlaying real-time data on physical structures, providing a more comprehensive understanding of structural conditions. In conclusion, the integration of drone technology, AI, and VR presents a transformative approach to structural inspections, offering enhanced accuracy, efficiency, and safety. The proposed integrated system addresses this need by providing a comprehensive solution for detailed structural assessment, early flaw detection, and interactive evaluation, ultimately contributing to improved infrastructure safety and maintenance. Future research and development efforts should focus on overcoming the current challenges and exploring new possibilities for integrating emerging technologies to further enhance the capabilities and applications of structural inspection systems.

Proposed System

The system architecture in Fig.1 specifically intended to seamlessly combine drones, data processing units, and virtual reality (VR) technology. This integration allows for efficient and thorough structural inspections. Essentially, the system comprises drones that are outfitted with sophisticated cameras and sensors. These drones are deployed to take highly detailed imagery of both the outside and inside of buildings. The drones are outfitted with advanced cameras that can capture images with exceptional accuracy and sharpness. In addition, certain sensors like LiDAR or thermal sensors can be used to collect more data for improved analysis. Subsequently, the gathered data is sent to a central data processing unit, where advanced artificial intelligence algorithms scrutinize the images to detect structural components and possible defects. These algorithms employ deep learning methodologies, namely convolutional neural networks (CNNs), to effectively segregate and categorize various elements of the structure, including cracks, water leaks, and other irregularities, with high precision. After the study is finished, the obtained data is utilized to generate a thorough three-dimensional depiction of the entire structure. This 3D model accurately represents the structural intricacies, allowing engineers and inspectors to visually examine the structure from various viewpoints and angles. Ultimately, the 3D model is smoothly incorporated into a virtual reality (VR) setting, allowing users to fully engage with the construction and actively examine and assess its soundness. VR technology offers an interactive platform for visualizing and interpreting structural data, hence improving the precision and efficiency of inspections.

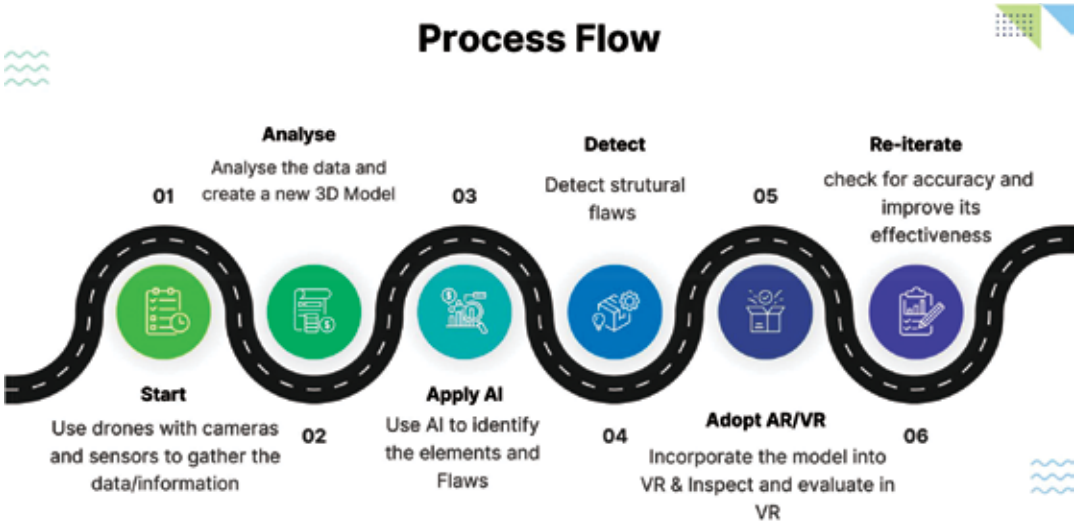


Fig.1: Process Flow

- Drone and Sensor Specifications:** Our technology employs drones with customized specs designed for structural inspections to collect data. An excellent option for this objective is the DJI Phantom 4 drone, renowned for its exceptional stability, agility, and superior image capabilities. The drones are outfitted with high-resolution cameras that can capture imagery with impeccable detail at the pixel level. In addition, thermal sensors can be used to identify temperature fluctuations that may suggest structural concerns, such as water leaks or insulation issues.

- **Data Collection:** The data-gathering procedure commences with meticulous planning and preparation, which involves selecting the target structure and ascertaining the most advantageous flight paths for the drones. The flight patterns are strategically planned to encompass the entirety of the structure's surface area, guaranteeing thorough data acquisition. While in flight, drones utilize their built-in cameras and sensors to acquire imagery. To provide comprehensive data coverage and eliminate gaps, a range of imaging techniques, such as grid patterns or overlapping sweeps, can be utilized. After the data gathering is finished, the imagery is sent to the central data processing unit for analysis. The collected data is later analyzed using advanced artificial intelligence algorithms to provide a comprehensive three-dimensional representation of the structure. This model is then incorporated into the virtual reality environment for the purpose of examination and assessment.

Image Processing and 3d Reconstruction

Photogrammetry is a method employed to derive three-dimensional data from two-dimensional photographs. Photogrammetry is essential in our proposed approach as it enables the creation of precise 3D models of structures by analyzing photographs taken by drones. Agisoft Metashape is a robust photogrammetry software that simplifies this procedure. Photogrammetry operates by examining intersecting pictures of an object from various viewpoints. The shared features in these photos are recognized, and their locations are utilized to calculate the three-dimensional coordinates of corresponding points on the object. Agisoft Metashape streamlines this procedure, enabling users to produce precise 3D models with minimal manual interaction. In our method, photogrammetry is utilized to capture a sequence of high-resolution photos of the structure from different perspectives utilizing drones equipped with cameras. Subsequently, these photos are imported into Agisoft Metashape, a software that scrutinizes them to detect shared spots and recreate the three-dimensional geometry of the structure.

Crack Detection Using CNNs

- **Preprocessing Techniques:** Before utilizing convolutional neural networks (CNNs) for crack identification, the collected pictures undergo multiple preparation procedures to improve their quality and applicability for analysis. Methods such as histogram equalization, contrast correction, and noise reduction are utilized to enhance image sharpness and emphasize structural characteristics. Furthermore, picture segmentation is carried out to separate regions of interest, directing the investigation towards pertinent areas and decreasing the computing burden. The preprocessing methods guarantee that the CNN model receives input data of superior quality, thereby enabling precise detection of cracks.
- **CNN Model Architecture:** To detect cracks, we employ a specialized convolutional neural network (CNN) architecture called U-Net. This architecture is designed to accurately recognize intricate structural features and is particularly successful for tasks

involving image segmentation. The U-Net architecture comprises an encoder, which utilizes convolutional and pooling layers to extract features from the input image, and a decoder, which reconstructs the segmented image by merging and up-sampling these features. This process results in a detailed map of discovered cracks. The inclusion of skip connections between corresponding layers in the encoder and decoder of the U-Net architecture helps to maintain spatial information and improve the accuracy of crack identification in segmentation tasks.

- **Training and Evaluation Process:** The Convolutional Neural Network (CNN) is trained using a dataset of photos that have been tagged and annotated with cracks. The dataset is divided into training, validation, and test sets to ensure a thorough evaluation of the model's performance. Data augmentation techniques, such as rotations, flips, and zooms, are utilized to enhance the model's resilience. The training approach entails minimizing a suitable loss function, such as binary cross-entropy, in order to instruct the model in identifying cracks. The efficiency of the model in detecting fractures is evaluated by assessing metrics like accuracy, precision, recall, and F1-score. These metrics provide complete insights into the model's performance and drive future modification.
- **Integration with 3D Model:** The CNN's output, which consists of a comprehensive map displaying identified cracks, is combined with the 3D model that was created by the photogrammetry procedure. Inspectors can visualize the positions and severities of the discovered cracks within the structural context by overlaying them on the 3D model. The inclusion of this technology improves the usefulness of the 3D model by offering practical information about the status of the building. This allows engineers to perform a comprehensive study and prioritize maintenance and repair activities based on the exact positions and characteristics of the observed fractures.

Integration to VR

To initiate the incorporation of VR, the first step is exporting the 3D model, together with the crack detection outcomes, from Agisoft Metashape in formats like OBJ or FBX to guarantee compatibility with VR systems. This process maintains the intricate structural data and annotations, allowing for precise representation in the virtual setting. The model is subsequently loaded into VR development platforms such as Unity 3D or Unreal Engine, where a realistic, interactive environment is constructed to simulate the physical structure. Users can utilize this interface to explore, magnify, rotate, and examine sections of the model. The interface also provides tools for calculating distances and emphasizing noteworthy locations. The inspection process is enhanced by interactive features such as the ability to annotate cracks, get extensive information about found faults, and collaborate in real time. These technologies offer engineers and inspectors a complete and engaging platform to conduct extensive structural assessments, enabling more informed decision-making and enhanced maintenance planning.

Advantages and Challenges

The suggested system provides several advantages, such as improved precision and efficiency in conducting structural inspections, early detection of defects, and decreased expenses and hazards in comparison to conventional approaches. By harnessing the capabilities of drones, artificial intelligence (AI), and virtual reality (VR), the system offers thorough and extensive assessments. This allows for preventive maintenance and prompt interventions, ultimately improving the safety and dependability of infrastructure. Nevertheless, the efficiency of the system might be influenced by various problems, including limitations in image quality, accuracy of AI algorithms, and performance of VR hardware. Pragmatic concerns such as the impact of weather conditions on drone operations and the requirement for specialized training for users also present difficulties. Mitigation techniques encompass the utilization of top-notch technology, ongoing enhancement of AI models using different datasets, and implementation of comprehensive training programs to guarantee efficient system operation and accurate interpretation of outcomes. These strategies optimize the advantages of the system while mitigating any drawbacks.

Conclusion

Precise identification and examination of structural defects are of utmost importance in the field of civil engineering to guarantee the safety and durability of infrastructure. The solution we propose combines cutting-edge drone technology, complex AI algorithms, and immersive virtual reality environments. This integration marks substantial progress in the field of structural inspections. By employing drones equipped with advanced high-resolution cameras and sensors, we may obtain intricate imagery of structures from various perspectives, encompassing both the outer and inner areas. By utilizing AgisoftMetashape, photogrammetry techniques may be applied to generate detailed 3D models. Additionally, the use of convolutional neural networks (CNNs) enables accurate identification of cracks and other structural defects. By incorporating these three-dimensional models into a virtual reality setting, engineers can create an interactive platform that allows for comprehensive examination and assessment of structures. This integration significantly improves the precision and effectiveness of the inspection process. This technology offers numerous advantages, such as better precision, early identification of defects, reduced costs, and improved safety for inspectors. Nevertheless, it is imperative to tackle obstacles such as image resolution, precision of AI models, and performance of VR gear. These obstacles can be reduced by using top-notch technology, improving AI algorithms, and offering thorough training for users. Our technology provides a strong and creative answer to important problems in civil engineering, leading to improved efficiency, effectiveness, and safety in structural inspections.

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Implementation of IoT and EIP in Construction of Barapullah Bridge Project, New Delhi

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Prologue

The construction industry stands at the forefront of a profound technological revolution driven by the widespread adoption of Internet of Things (IoT) technologies. Enterprise Information Portals (EIP) provide, a comprehensive platform for data integration across various organizational functions, viz. accounting, finance, human resources, and supply chain management. Leveraging Internet of Things (IoT) technologies facilitates real-time monitoring and management of construction assets, ensuring optimal productivity and quick mobilization of machinery.

The paper explains key features of EIP systems. The implementation of IoT and EIP technologies in the Barapullah Bridge project with real life usages is also presented. The paper provides useful insights in the effectiveness of IoT and EIP technologies in driving process improvement and asset management in the construction industry. The findings of the study will contribute towards betterment of industry practices and informing the policymakers and stakeholders about the transformative potential of emerging technologies in the construction industry.

-Editor-

Introduction

With the Indian construction industry poised to become the world's third-largest market by 2025, significant growth opportunities and challenges emerge. The government's substantial investment in infrastructure development, further underscores the sector's importance, with a budget allocation of Rs 11.11 lakh crore (\$134 billion) in the 2024-2025 financial year. This surge in infrastructure projects, coupled with substantial foreign direct investment (FDI), necessitates use of advanced technologies to streamline construction processes and asset management.

By integrating connected devices, sensors, and equipment directly into construction sites, IoT technology is fundamentally reshaping how projects are conceived, executed, and managed. This seamless integration facilitates the real-time collection and analysis of data, providing valuable insights that empowers the stakeholder in decision-making, optimize

resource allocation, and mitigate risks. The construction sector is set to reach previously unheard levels of efficiency, productivity and safety, as it increasingly utilizes the potential of IoT and EIP technology. In addition to changing conventional methods, these advancements are opening the doors for a more innovative future in the building industry.

Barapullah Bridge Project, New Delhi

Following the successful completion and appreciation of elevated road corridor of Barapullah Phase-I and Phase-II, now known as Baba Banda Singh Bahadur Setu, which connects AIIMS and Sarai Kale Khan, the Government of Delhi planned to extend the existing Barapullah corridor from Sarai Kale Khan to Mayur Vihar in East Delhi by crossing the Yamuna River. This extension is known as the Barapullah Phase-III project, a flagship initiative of the Government of Delhi.

The proposal for the Barapullah Phase-III project was approved by the UTTIPEC on August 22, 2013. The Delhi Urban Art Commission (DUAC) and the Yamuna Standing Committee approved the project on January 23, 2014, and May 27, 2014, respectively. The Barapullah Phase-III project features an elevated corridor from Sarai Kale Khan to Mayur Vihar, including a 550-meter extra dosed bridge over the Yamuna River. The total length of the elevated corridor is 3.8 kilometres. The project when complete will provide seamless, signal-free connectivity from Mayur Vihar in East Delhi to AIIMS in South Delhi.

The sanctioned cost of the project is ₹1,260.63 crores. The project commenced in April, 2015, was initially scheduled for completion by October 2017. However, delays occurred in the land acquisition, trees removal, shifting of overhead transmission lines etc. The present progress of work is 85% and is expected to be completed by June 2025.



Fig. 1: Aerial view of Barapullah Bridge Project

In 2021, IoT was installed in the Barapullah Bridge project. Before this implementation, log sheets and Excel data were maintained regularly, which was a time-consuming and error-prone process. In contrast, IoT integrates physical assets and IT systems by sending and

exchanging data over the internet. The IoT-enabled asset management software allows connected devices to communicate automatically and send information to the required destination without any human intervention. The EIP is being used in Barapullah Bridge project from 2015. The development and implementation of EIP system in the project has been done by the L&T Infotech.

Internet of Things (IoT) in Construction Industry

In construction industry, Internet of Things (IoT) refers to the integration of connected devices, sensors, and equipment installed on-site, allowing for real-time monitoring, data collection and analysis across the built environment over the internet. This integrated network of devices enables construction professionals to make more informed decisions, optimise resource utilisation, and limit risks. The adoption of IoT leads to increased efficiency, cost savings, and enhanced project outcomes.

Enterprises Information Portals (EIP)

An enterprise information portal has two main functions: integration and presentation. It must be able to access information from multiple and varied sources and manipulate that information through the portal. EIP enables organizations to automate and streamline various business functions viz, project management, procurement, finance, human resources, and more. By consolidating data and processes into a unified platform, EIP systems provide real-time insights, facilitate decision-making, and promote collaboration across various verticals. Enterprise Information Portals (EIPs) combine diverse company operations into a single platform, enhancing the revolutionary potential of the Internet of Things. These systems improve operational efficiency in construction projects by offering capabilities for project management, supply chain management, financial management, and inventory management.

EIP - Key Features

Asset Monitoring:

IoT sensors are deployed on the assets to collect and transmit real-time data regarding their condition, performance, and usage. These sensors can measure parameters such as

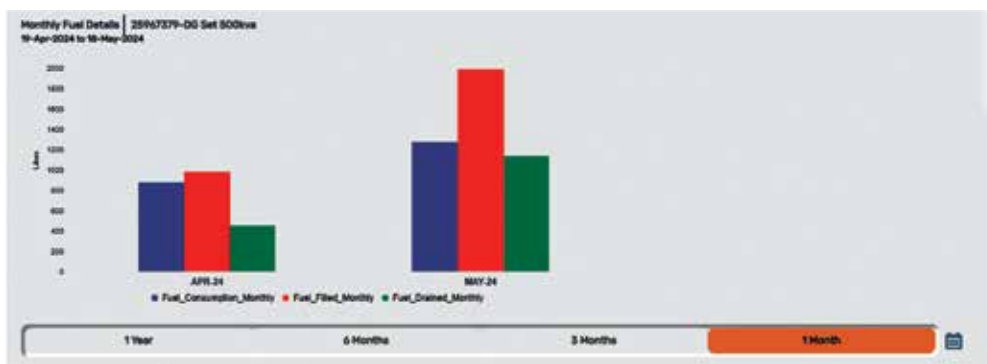


Fig. 2: Asset Monitoring Dashboard

temperature, pressure, vibration, location, fuel levels, and operational status. By continuously monitoring asset health and its performance; organizations can detect anomalies, predict potential failures, and proactively schedule maintenance activities to shorten costly downtime.

Asset Tracking:

IoT-enabled tracking devices, like RFID tags, GPS trackers, and Bluetooth beacons, provide accurate, real-time location information for assets throughout their lifecycle. This is important for large-scale operations, because minimizing loss and maximizing utilization depend heavily on the effective management of resources and equipment.



Fig. 3: Asset Tracking Dashboard

Optimized Asset Utilization:

IoT data analytics provide insights into asset utilization, helping organizations optimize resource allocation. By analysing usage, availability, and demand, they can identify underutilized assets; streamline workflows, and allocate resources optimally. This optimization, maximizes return on investment (ROI), reduces unnecessary spending, and improves overall efficiency.

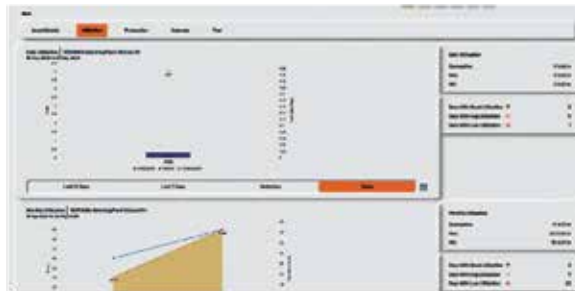


Fig. 4: Asset Utilization Dashboard

Asset Management :

Asset management using artificial intelligence is quickly replacing traditional techniques of spreadsheet management and record-keeping. By automating data collection and

communication, these systems greatly improve efficiency and accuracy while lowering errors and the amount of time spent on administrative duties. Asset management in an EIP involves a series of interconnected processes to ensure that assets are effectively acquired, utilized, maintained, and eventually disposed off or de-hired. Figure 5 gives process flow of asset management from vendor selection to disposal or de-hire.



Fig. 5: Asset Management using EIP

Project Management:

EIP systems in construction offer comprehensive project management modules, allowing stakeholders to oversee timelines, budgets, resources, and milestones. With features such as JCR, resource allocation tools, and progress tracking mechanisms, project managers can efficiently plan, execute, and monitor construction projects from inception to completion.



Fig. 6: Project Management Dashboard

Supply Chain Management:

EIP solutions offer a unified platform for supply chain management by seamlessly integrating procurement and inventory management procedures. By streamlining material sourcing, vendor management, and purchase order creation, this integration makes sure that procurement processes are in accordance with project requirements and demand projections.



Fig. 7: Supply Chain Management Dashboard

Financial Management:

Financial transparency and accountability are paramount in construction projects. EIP systems provide robust financial management functionalities, including budgeting, cost estimation, invoicing, and accounting. By integrating financial data with project management modules, stakeholders can monitor project expenses, manage cash flows, and mitigate financial risks effectively.

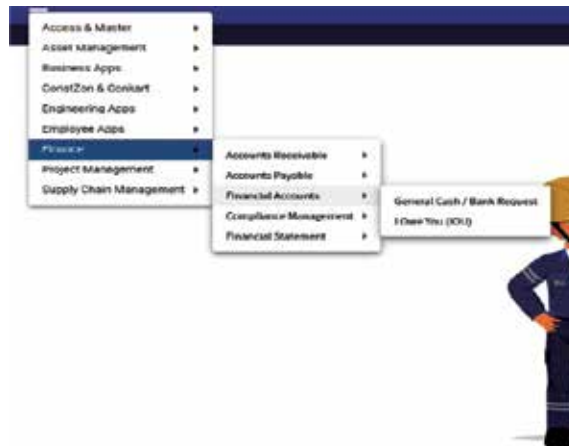


Fig. 8: Finance Dashboard

Inventory Visibility and Tracking:

EIP systems offer real-time visibility of inventory levels, locations, and movements, across construction sites, warehouses, and supply chain networks.

Demand Forecasting & Procurement Integration

EIP systems use sophisticated data analytics to make precise predictions about future material demand. The types and quantities of materials needed can be predicted by EIPs through the analysis of past consumption data, project timelines, and patterns. Project schedules are integrated into the forecasting models by EIP systems to ensure material availability at the appropriate time, preventing delays and guaranteeing project continuity. By assisting construction companies in more accurately planning their inventory needs, this predictive capability lowers the possibility of shortages or overstocking. Construction managers may proactively monitor and oversee procurement processes with the help of EIPs, which offer visibility into inventory levels, procurement progress, and supplier performance. This visibility aids in the detection of possible bottlenecks, the resolution of supply chain interruptions, and the guarantee that procurement adheres to project budget and schedule limitations.

Fig. 9 illustrates the reorder levels set within the EIP for various construction materials. Reorder level is a critical inventory management metrics that indicates the specific stock quantity at which a new order is placed automatically by EIP.

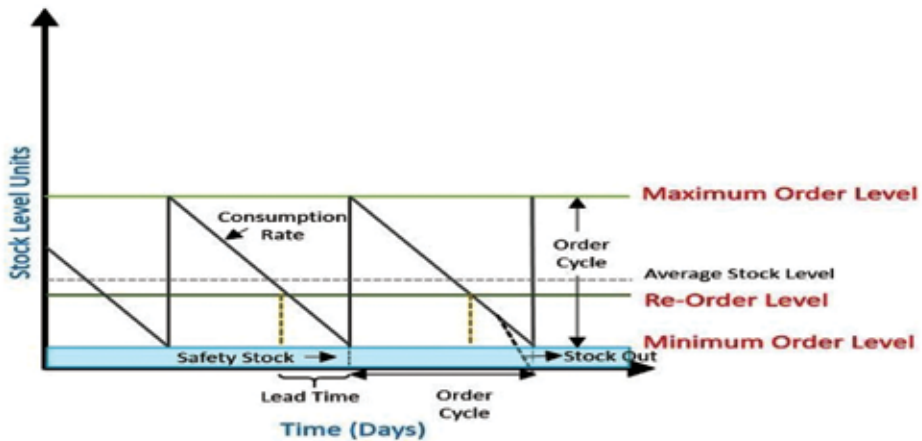


Fig. 9: Reorder Level in EIP

[Source ref. 2]

Maintenance (Periodic/ Predictive/ Preventive):

IoT-driven systems use machine learning and predictive analytics to analyse sensor data and predict asset failures. By monitoring performance metrics and identifying potential issues, organizations can predict when maintenance are needed and schedule accordingly. Through proactive scheduling of maintenance, equipment lifespan can be enlarged and unplanned downtime can be minimized by anticipating when an asset is likely to fail. This

shift from reactive to proactive maintenance reduces lifecycle costs and improves asset reliability.

Real Use of IOT and EIP in Barrahpullah Bridge Project

M-50 Concrete Production

Detailed comparison of various parameters in the manufacture of M50 grade concrete at Barapullah batching plant using IoT-enabled operations vis. a vis. conventional operation, is given in Table 1. IoT-enabled operations significantly reduce setup time from 1 hour to 0.5 hour and cut equipment downtime from two hours to one hour, while the time per batch is constant at twenty minutes for both ways. Due to this efficiency, the daily total operating time is reduced from 19.6 hours to 18.1 hours.

In the project, the requirement so far 95,371 cubic meters of M50 grade concrete has been consumed, further 16,208 cubic meters more concrete will be required for the project completion. In the M50 grade concrete, saving in production cost is projected of Rs 2.79 crore (1,11,579 cum @ Rs 250/- per cum). Similar savings are anticipated in other grades of concrete, amounting to approximately Rs 6.67 crore. Therefore, saving in the production cost of concrete alone will be of Rs 9.46 crores, which is approximately to the tune of 1% of the tendered cost of Rs. 964 crores.

Table-1: M50 Production data (Day)

Item	Conventional Operations	IoT-enabled Operations
Time per Batch	20 minutes	20 minutes
Setup Time	1 hour	0.5 hour
Equipment Downtime	2 hours	1 hour
Total Number of Batches	50	50
Total operating Time	19.6 hours	18.1 hours
Labor Cost per Batch	₹240	₹240
Materials Cost per Batch	₹10,000	₹10,000
Transportation Cost per Batch	₹2,000	₹2,000
Equipment Downtime Cost per Batch	₹2,000	₹1,000
Transportation Delays Cost per Batch	₹500	₹0
Total Cost per Batch of 6 cum	₹14,740	₹13,240
Total Cost for 300 cum in 16 hour per day	₹7,37,000	₹6,62,000
This comes out to a saving of Rs. 250/- per cum		

Automatic Purchase Order System for 3.15 mm electrodes

In the Barapullah Bridge project, EIP systems maintain detailed supplier databases with information on transactions, lead times, pricing, and performance. This enables well-informed decisions on supplier relationships, contract negotiations and vendor selection, ensuring attractive terms and reliable supply chains. Table 2, presents the implementation of an automatic purchase order system for 3.15 mm electrodes, integrating IoT and EIP systems. As the stock level approaches the reorder threshold level of 58,864 nos., the EIP system automatically generates a purchase order and sends it to the pre-approved supplier. The supplier receives the order and prepares consignment for the shipment of the required electrodes, ensuring timely delivery at the site. This automation eliminates manual intervention, reducing the risk of human errors and administrative delays. By reducing the blockage of money in inventory, the funds can be directed towards more critical activities at hand.

Table 2: Case Study 3.15 mm Electrodes

Description	UOM	
Annual Demand, D	Nos/Year	4,27,000
Cost per unit, C	Rs	4.5
Cost of placing an order / Setup cost, O	Rs	2,840.12
Lead Time, L	Days	7
Annual Holding and storage cost per unit, H i.e. 15.64%	perc.	0.70
Average daily demand, (D)	Nos	1170
Standard Deviation of daily usage	Nos	34.21
Standard Deviation for lead time	Nos	90.51
Desired Probability of Not stocking Out, p	Nos	0.95
Z-Value associated with 95% probability		1.64
EIP Calculations		
Optimum order quantity, Q	Nos	58,864
Reorder Point, R	Nos	8190
Safety Stock, SS = Z*Sd	Nos	148
Reorder Point after Safety stock	Nos	8339
Total Ordering Cost	Rs	20,602.26
Total Carrying Cost	Rs	20,602.40
Purchase cost	Rs	19,21,500
Total Annual cost	Rs	19,62,704

Monitoring of Transit Mixers

Location tracking and heat sensor enabled IOT sensors have been installed in all 22 nos. transit mixtures engaged in the project, which monitor their working hours as well as their movement. The movement and working details are readily available on the dashboard of the EIP system and the resource manager can easily track the productivity and take corrective actions according to the productivity of each asset.

Conclusion

EIP systems provide robust platforms for integrating data across various organizational functions such as supply chain management, project management, and finance, enhancing collaboration and efficiency. By leveraging EIP-driven demand forecasting and IoT-enabled asset management strategies, construction companies can reduce errors, optimize inventory, resource allocation, mitigate risks, improve project performance, and maintain competitiveness in a dynamic business environment.

The implementation of EIP and IoT technologies at the Barapullah Bridge project has led to a significant savings in the project. The case study of Barapullah Bridge project demonstrates transformative potential of IoT and EIP technologies, offering valuable insights for policymakers and industry stakeholders. Continued investment and adoption of these technologies will be crucial for driving sustainability, innovation, and economic growth in the construction industry, supporting India's infrastructure development goals.

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Artificial Intelligence in Construction Projects

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Prologue

The construction industry faces challenges like project delays, cost overruns, low productivity, inefficiencies, low profit margins and safety issues. Industry is reputed to be a slow adopter of technology but increasing demand for sustainable and efficient practices has led to growing interest in artificial intelligence applications. This paper investigates how Artificial Intelligence can potentially address these challenges, while trying to understand and adopt AI in the workflows. Some successful AI implementation cases, how they have impacted different areas of construction across the world are discussed.

Paper also briefly presents building of a custom knowledge base AI Assistant by leveraging ChatGPT for retrieval augmented generation and get responses based on shared knowledge base.

-Editor-

Introduction

India is currently experiencing rapid growth, driven by rising aspirations and demands for fast, efficient, and cost-effective infrastructure. The construction industry, however, faces numerous challenges such as cost overruns, project delays, poor quality, litigations, low productivity, labour shortages, health and safety concerns. Despite being one of the oldest industries, it remains one of the least digitised. The adoption of new construction technologies and the digitisation of workflows can significantly improve the industry's performance and overall efficiency.

The construction industry involves multiple stakeholders, each with unique workflows and standards, making technology implementation challenging. Additionally, various data types and isolated data silos that do not communicate, along with a large volume of unstructured data, further complicate the situation. This paper explores how Artificial Intelligence can address these issues by introducing innovative solutions and streamlining operations.

Artificial Intelligence in Construction

Artificial Intelligence refers to the capability of machines to perform cognitive functions typically associated with humans, such as problemsolving, conversation, knowledge retrieval, pattern recognition, and prediction. Machine Learning (ML), a subset of AI, involves training machines using algorithms on data, enabling them to make predictions and decisions.

Generative AI (GenAI) is a branch of AI, where systems generate new content, such as text, images, and videos, based on user prompts and trained data. In the construction industry, AI and ML can help manage and interpret the vast amounts of data generated, making it easier for end users to find relevant information. GenAI is already making significant strides by assisting construction professionals with tasks like image creation and conversational assistance, thereby enhancing productivity and decision-making processes.

Opportunities in Construction

AI has the potential to solve many challenges in the construction industry, improving efficiencies and boosting both the top and bottom lines while providing a better work environment. AI can be leveraged at all stages of construction, acting as a powerful partner for construction companies. Key areas where AI can offer significant benefits include:

Project Scheduling

Scheduling is critical and requires experienced professionals to plan and lay out dates and milestones for construction projects. A typical construction schedule is extensive, and professionals spend weeks to get it right. AI models trained on construction schedules can simulate multiple versions of a schedule, providing different schedule options, and thereby helping identify the most efficient one. This process, which typically takes weeks, can be completed in hours, saving time and costs. Moreover, AI can continuously optimise schedules in real-time, adjusting for any unforeseen delays or changes in project scope.

Design and Engineering

AI has been impacting the design process by enabling generative design methodologies. This involves creating numerous design options based on user-defined parameters such as budget, orientation, and materials. AI enhances this process, allowing designers to access a multitude of designs, improving decision-making and outcomes. Recorded improvements include up to 40% less material usage and lighter, cheaper, and stronger components. Furthermore, AI can assist in compliance with building codes and standards, ensuring designs are not only innovative but also adhere to regulatory requirements.

Cost Estimation and Bidding

The estimation process involves reviewing contract documents, design drawings, and specifications to create project estimates. By automating repetitive tasks like area and volume take-offs, AI minimises human errors and accelerates the estimation process. AI tools also analyse market data trends, enabling accurate and balanced estimates, thus improving the chances of successful bids. Additionally, AI can incorporate historical cost data and market fluctuations to provide more precise and dynamic cost predictions.

Project Management

Project management involves managing time, resources, and risks. AI models trained on historical data can predict risks, optimise resource allocation, and assist with time planning. AI tools can also act as assistants, retrieving data and insights from documents, generating

dashboards and reports, and helping project managers make informed decisions. By providing real-time analytics and predictive insights, AI enhances project managers' ability to proactively address issues and keep projects on track.

Progress Monitoring

Traditionally, progress monitoring involves manual data entry and reporting. AI, coupled with computer vision technology, allows for automated progress tracking using 360-degree cameras. These tools stitch site images to show progress over time and maintain proper documentation. Future capabilities include quantity take-off directly from images, reducing manual effort, and enhancing site documentation. This real-time monitoring ensures transparency and accountability, facilitating timely interventions when necessary.

Construction

With labour shortages and the gradual introduction of technology on construction sites, robots trained for specific tasks are becoming more prevalent. These robots, equipped with AI for navigation and decision-making, can perform tasks like site layout plotting, bricklaying, painting, and 3D printing with high accuracy and minimal manual intervention. Robots are also used for data collection and site safety enforcement. Additionally, AI can help in the proper distribution of man and machine on sites, thereby optimising available resources and reducing the impact of labour shortages. The integration of AI-driven robotics is paving the way for safer, more efficient, and cost-effective construction practices.

Operation

AI tools can optimise operations throughout a project's lifecycle, including preventive maintenance and facilities management. For example, AI can analyse data from building systems to identify potential risks and optimise performance, helping facilities managers maintain schedules and alerting resources automatically. This proactive maintenance approach reduces downtime and extends the lifespan of building systems, leading to long-term cost savings and enhanced operational efficiency.

Site Safety

Site safety is paramount, and safety inspectors can use AI-integrated drones and cameras to monitor and enforce safety standards more effectively. These tools can detect safety gear compliance and potential hazards in real-time using computer vision, providing comprehensive site monitoring and reducing the probability of site incidents. By identifying risks before they escalate, AI contributes to create safer working environments and minimising accidents on construction sites.

AI Implementation Case Studies Globally

SCS JV leveraged AI to expedite project delivery

- **Project:** London tunnels for HS2, High speed railway lines

- **Contractor:** Skanska, Costain, and STRABAG Joint venture - SCS JV
- **Problem:** The stockpiling area for stocking the tunnel boring machine risings was limited, and the backfill was supposed to be used for backfilling also. So, the excavation to backfill rate had to be optimized to be able to maintain the stockpile within a designated area.
- **Tool used:** ALICE. It allowed the professionals to simulate four different potential scenarios to determine the optimal production rates by varying excavation rates and shifts while updating the database for work done. This enabled engineers to perform 'what-if' analysis and zero down to the most efficient answer.
- **Benefit :** Improved project delivery timelines and cost-effectiveness, allowing for more efficient sequencing. This also created an additional 3-month float as engineers were able to find the most ideal production rate.

Turner Construction turns cranes into smart devices with AI and IoT

- **Project:** Multiple
- **Contractor:** Turner Construction Company, USA
- **Problem:** On large projects, tower cranes need to be efficient to maintain the schedule and safety at the site.
- **Tools Used:** Versatile.ai, a crane-mounted device with multiple sensors to provide data insights
- **Benefit:** Crane data collection has helped Turner in identifying cycle time for various activities for a multistorey building, which helps them plan and optimize the sequence of activities and line up tasks. Turner used the crane data to experiment with multiple reinforcement installation schemes, finding an optimum solution and thereby reducing the critical path duration by 30% and using this for the next 600 vertical feet of construction project. Another improvement noticed was when hook handoff was provided to subcontractors to load/unload material. With AI-driven data insights, they were able to reduce the handoff times by 90 seconds per handoff.

Vinci aims to save 5,200 hours using AI

- **Project:** Multiple
- **Contractor:** Vinci Construction UK
- **Problem:** Site progress reporting is labour-intensive work where a staff member must take pictures, sort, organize, label, compile, and upload. This takes time and does not provide a holistic view of the site.
- **Tool Used:** Openspace a platform with hard-hat mounted 360-degree

cameras that capture images and videos of the site and sync them to the cloud. They are then stitched and labeled using AI and computer vision.

- **Benefit:** Vinci aims to save around 5200 hours in 25 sites as staff does not have to walk and take pictures. They are also able to leverage its capabilities to compare with the BIM model and monitor progress. The site is documented completely, and teams can visualize and discuss issues in a collaborative setting.

CSCEC builds first 5G intelligent construction site to combine AI, BIM, and cloud computing

- **Project:** Building C of Jingdong headquarters (Phase II)
- **Contractor:** China State Construction and Engineering Company, China
- **Problem:** Integrating various technology solutions for improved site function
- **Tools Used:** Smart Information Island, 360-degree camera monitoring, AI health analysis system, AI wearable inspection systems, AI remote collaboration systems, Smart Blueprint technology, etc.
- **Benefit:** Improves scalability and efficiency in managing multiple large projects simultaneously.

Other successful use cases around the world

Company	Use Case	Benefit	Details	Category
Balfour Beatty	AI to automate design aspects using generative design principles.	Enhances design efficiency and innovation.	Tackles complex design challenges with AI, resulting in innovative, efficient, and desirable outcomes.	Design and Engineering
Turner Construction Company	AI-based predictive analytics tool for risk management.	Identifies potential safety hazards and quality control issues, reducing risk.	Uses predictive analytics and IoT sensors to analyse images, sensor data, and safety reports to proactively manage risks and improve decision-making.	Project Management & Scheduling
Suffolk Construction	Predictive analytics and machine learning to enhance project scheduling and risk management.	Improved accuracy in project timelines and budget forecasts.	Uses AI-driven tools to pre-emptively address potential delays and budget issues, enhancing overall project efficiency.	Project Management & Scheduling

JE Dunn Construction	AI-driven platform for enhanced monitoring and management of construction sites.	Boosts productivity and enhances worker safety.	Continuous monitoring and analysis of site activities to ensure productivity and safety.	Progress Monitoring & Safety
Skanska	AI for enhanced safety monitoring through real-time data analytics and predictive modelling.	Reduces the frequency and severity of accidents.	Uses real-time data analytics to monitor safety conditions and predict potential safety issues, leading to proactive safety management.	Progress Monitoring & Safety
Vinci	AI-powered analytics for logistics management within large construction projects.	Optimises supply chain operations, reducing delays.	Uses AI to improve coordination of supplies and equipment, enhancing logistics management.	Construction
Kiewit	AI in quality control processes to automate defect detection.	Increases the accuracy and speed of quality inspections.	Uses AI to standardise quality checks across projects, ensuring consistent delivery standards.	Quality Control
Clark Construction Group	AI for materials management, tracking the usage and wastage of materials on site.	Significant cost savings and a reduction in material waste.	Integrates AI with RFID and IoT devices for precise material tracking, ensuring efficient use of resources.	Materials Management
Bechtel	AI for predictive maintenance of machinery and equipment.	Minimises downtime and prevents delays.	Implements a proactive maintenance strategy using AI to improve equipment reliability and reduce downtime.	Operations

Building a Custom Knowledge Base AI Assistant

As the construction industry has tons of documents that are unstructured and have so much information scattered in all these documents, it is sometimes difficult to make sense of or locate a data point or correlate data from multiple data sources. To address this challenge, an AI Assistant was developed for a consulting firm. This AI Assistant is capable of linking unstructured data based on context provided by users in order to generate precise responses to user inquiries. The Assistant is trained on the client’s custom knowledge base

and is provided with a BIM model based output report as an input. AI assistant is able to connect the two, analyse and determine the impact of changes made to materials and costs, providing insightful responses.

Concept

The project required reading and connecting multiple different document types containing project reports, parametric databases for various parameters, and guidelines and strategies for addressing relevant issues. The files were in CSV format and not formatted in any specific way. A conversational assistant needed to be built to answer questions about the report and perform optioneering and what-if conditions by substituting one parameter or material with another to measure the impact.

Terminology

For this project, the Retrieval Augmented Generation process was used to optimize OpenAI's Large Language Model.

Retrieval Augmented Generation

Retrieval Augmented Generation (RAG) is a process that enhances the output of a Large Language Model (LLM), such as ChatGPT, by incorporating information from an external knowledge base or custom data sources. This approach allows the model to access and utilize up-to-date and domain-specific information that extends beyond its pre-trained data, resulting in more accurate and contextually relevant responses.

Large Language Model

A Large Language Model (LLM) is an Artificial Intelligence model designed to understand and respond in human language by learning from extensive amounts of text data. These models utilize advanced machine learning techniques and natural language processing to perform such tasks. Examples of LLMs include GPT-4, Llama 3, Claude 2, Grok, and Gemini 1, each developed by different tech companies. For the current project, GPT-4 is being used.

Embedding

Embedding is a way to represent all data in sets of numbers for a computer to understand and make sense of it. Data could be images, text, etc. For this use case, OpenAI's OpenAI Embeddings was used. When these series of numbers are arranged in a particular order, they are called vector data.

Vector Database

Vector databases are specialized data storage systems designed to store high-dimensional vector data efficiently. The database indexes data for quick search and optimized querying. For this project Pinecone was used.

AI Assistant

AI Assistants are tools powered by artificial intelligence that can be assigned multiple tasks for user based on inputs. Using conversational language users can assign tasks like answering questions, finding data, calculating, adding reminders, etc. Open AI's AI Assistant was explored.

Tools

The following tools with minimal coding were used to experiment and build the solution:

1. **Bubble.io:** A No-Code web development solution that assists in creating web applications.
2. **OpenAI APIs:** OpenAI's APIs facilitated the retrieval of the GPT-4 LLM model and embeddings.
3. **GPT-4:** Open AI's latest and most powerful LLM model, which was utilized for the project.
4. **Pinecone Vector Database:** The database employed to store vector embeddings for the project.
5. **Flowise:** A No-Code application enabling users to build custom chatbots by integrating all necessary components.

Approaches

Multiple approaches were attempted to build the solution. As it was the first proof of concept project, all No-Code solutions were utilized to quickly test the idea and build a solution.

CustomGPT on ChatGPT

In this approach, the CustomGPT building capabilities of OpenAI's ChatGPT Plus were leveraged to create a Custom Chatbot. The chatbot was trained and tuned using knowledge base files, with context provided for individual files and context setting completed. The responses were highly accurate and met user satisfaction. However, this approach was discontinued because CustomGPTs cannot be called from an external application due to the absence of an API call.

Chatbot with Retrieval Augmented Generation

In this approach, the Flowise application was locally hosted, and a chatbot was built using the following workflow:

Data files were uploaded and embeddings were created using the OpenAI Embeddings API. This process breaks larger data sets like CSVs and PDFs into smaller chunks, which are then converted into a set of numbers and stored in vector databases. The data needs

to be upserted to be stored in a vector database. Once stored, context for the files must be provided to enhance the understanding of LLM models. This is then linked to the LLM model. When a user gives a prompt or a query about the knowledge base, the system retrieves information from the vector database based on the input. This is then passed to the LLM, and a response is generated. This workflow is then exported as an API.

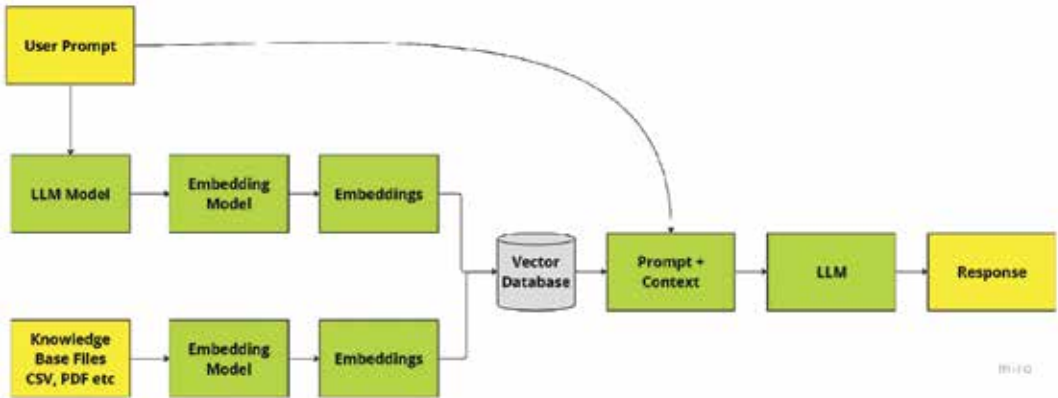


Fig 1: Typical RAG-based workflow

Bubble.io was then used to create a user interface for the application. Using API, the Flowise chatbot that was built was connected to initiate a conversation. Additionally, a database was built to retrieve and store information on the application for later viewing.

AI Assistant with Retrieval Augmented Generation

In this approach, the OpenAI Assistant API was utilized. The RAG workflow is built-in, making it a simpler approach to create an AI assistant using GPT-4 and its file search and code interpreter abilities. Files were uploaded, and context was provided to the AI Assistant. It was also tuned to search online if the information was not found in the knowledge base and further tuned to reduce hallucinations and increase factual accuracy. Once the Assistant was ready, its assistant ID was copied.



Fig 2: Create a New Assistant on Open AI Platform



Fig 3: OpenAI Assistant API workflow

The user interface was then built on Bubble.io, and all the APIs shown in the provided figures were added. A custom database was created to store all message threads for the application. Once all APIs were integrated into the user interface, the product was previewed and made live.

Result

For this use case, since there was a requirement to provide a way to replace one report with another continuously, the AI Assistant API was used in the final product. The customer observed the following advantages:

1. The Chatbot facilitates easier understanding of the generated report. Users can ask questions in their normal conversational language, and the responses are tuned to be easy to understand while maintaining a professional tone.
2. Users can perform what-if analysis by replacing materials or updating properties to see the impact of changes.
3. Using the historic project data table, users can create predictions based on the uploaded report.
4. The response is highly customized and based on proprietary data sources, making the response faster and more accurate.

Conclusion

The construction industry stands on the cusp of a transformative era with the integration of AI and advanced technologies. Embracing AI can address longstanding challenges, improve efficiencies, and drive innovation across all stages of construction. By leveraging AI, construction companies can achieve better project outcomes, enhance safety, and create more sustainable and cost-effective infrastructure.

As the industry continues to evolve, stakeholders must stay informed about technological advancements and actively pursue AI adoption. Through continuous learning, collaboration, and investment in AI, the construction industry can unlock new potentials and pave the way for a brighter, more efficient future.

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Artificial Intelligence in the Construction Industry: A Review of Applications in the Indian Public Sector

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Prologue

The construction industry across the globe faces many challenges related to time, cost, quality, safety, disputes, and the environment. Efforts being made to overcome these challenges have not been encouraging so far. However, there appears a new hope for addressing these long standing issues with Artificial Intelligence (AI) applications in construction industry. It is believed that the AI techniques could be applied to construction processes, for significant improvements in various aspects of the construction industry (CI), from planning and design to execution and maintenance. This paper explores the potential benefits that AI can unleash across various project phases, highlighting its impact on time and cost management, quality assurance, safety, dispute avoidance, and environmental sustainability.

Further, the paper presents a snapshot of implementation of AI in Indian public sector. In this respect the efforts being made by engineering organizations of the country, like the NHAI, CPWD, Indian Railways, Delhi Metro and PWD Delhi have been explored and presented.

-Editor-

Introduction

The development of infrastructure is one of the most critical elements of the overall growth of a country. Various programs for achieving social and economic goals require considerable augmentation of infrastructure. According to the World Economic Forum (2016), all economic value creation occurs within or by means of buildings or other “constructed assets”. Infrastructure growth across the globe faces many challenges related to time, cost, quality, safety, disputes, and the environment. The ill effects of construction include the depletion of natural resources, energy consumption, pollution, waste generation, and emission of harmful gases. Therefore, infrastructure projects should avoid ill effects of the construction activity to the best extent possible, while meeting the endgoals of time, cost, quality, safety, dispute avoidance, and the environment (Tripathi et al, 2022).

Efforts being made in this respect across the globe have not been encouraging so far and the challenges remain on these issues. However, there appears a new hope for addressing these longstanding issues with Artificial Intelligence (AI) applications in construction industry.

It is believed that the AI has potential to address these issues using transformative technology, with a wide range of techniques that enable machines to simulate human intelligence, including machine learning, deep learning, natural language processing, robotics, speech recognition, expert systems, and computer vision. Such techniques could be applied to construction processes, for significant improvements in various aspects of the construction industry (CI), from planning and design to execution and maintenance.

This paper explores the current state of art of AI in CI. It explores the potential benefits that AI can unleash across various project phases, highlighting its impact on time and cost management, quality assurance, safety, dispute avoidance, and environmental sustainability. Further, the paper presents a snapshot of implementation of AI in Indian public sector. In this respect the efforts being made by engineering organizations of the country, like the NHAI, CPWD, Indian Railways, Delhi Metro and PWD Delhi have been explored and presented.

Literature Review

There has been recent academic interest in the applications and potential benefits of AI in construction industry. The definition of AI has evolved throughout the time, but its foundation has always been the goal of creating machines that are capable of thinking like humans. It does this by trying to imitate human intelligence through hardware and software solutions. Studies have explored its role in optimizing design processes by way of automation and advanced simulations (Egwim et al, 2024). Other research areas have revolved around AI-powered resource management systems for optimizing material usage, equipment allocation, and labour scheduling, for better project efficiency and cost savings (Gayatri Patil, 2019). Additionally, research is underway to explore the application of AI in project scheduling, where machine learning algorithms can be used to analyse the huge historical data to flag potential delays and suggest proactive measures for real-time remedial measures, ensuring better time compliances (Abioye et al, 2021).

Thus, from the available research, it is clear that AI can help the construction industry improve decision-making, drive project success, and deliver projects on time and on budget by proactively unlocking new predictive insights from its ever-growing volume of project data. which was previously only archived for future reference (Egwim et al, 2024).

Artificial Intelligence in Construction Industry

Detailed review of literature makes it clear that the construction industry is ready to adopt AI in all its activities and enhance its performance on all parameters. In the succeeding sub-sections, it has been examined the manner in which AI has potential to impact the crucial project performance parameters like time, cost, quality, safety, sustainability, and avoidance of disputes, and integrity.

Time

Traditional methods of time estimation and scheduling may lead to wrong time estimation resulting into delays and missed deadlines. AI can be successfully deployed for improved schedule management in multiple ways.

- Identifying trends in project execution, for more accurate predictions of upcoming project timelines. It can be used to analyze humongous historical datasets to accurately calibrate project time management.
- AI can be used to analyze real-time data from construction sites to identify delays caused by weather disruptions, material shortages, or labor issues.
- By addressing these issues in advance, projects could be completed on schedule and avoid costly delays.

Cost

Completing the project within the budgetary sanctions is paramount for the successful project management. AI offers a range of tools and techniques to optimize costs throughout the project lifecycle. Some applications are as below:

- Material management system plays a significant role in optimizing the cost. AI powered tools can analyze past projects data to assess exact material needs which will minimize waste and avoid unnecessary material procurement.
- AI can be used to identify areas where automation can be employed for greater efficiency. It can optimize labour allocation by matching worker skills to specific tasks.
- During the design phase also, AI-powered simulations can be used which can detect potential design flaws and suggest rectification early in the process. Identifying the design flaws early and rectify them in the beginning itself can prevent costly rework later in the construction cycle, leading to significant cost savings.

Quality

Quality is one of the most significant factors to be ensured for project success. However, despite best efforts fool proof system for ensuring quality has not been established as yet. AI-powered quality control systems can play a transformative role in this area. The following AI powered tools and techniques can be employed at sites to ensure the desired quality.

- The sites can be equipped with image recognition and sensor technology to continuously monitor construction processes. This shall result into real-time data from the construction sites. Using the vast data so available, AI can identify deviations from project specifications and potential defects in workmanship, which shall allow for immediate corrective action.
- AI-powered quality control systems can be used to maintain a comprehensive digital record of construction progress, providing valuable documentation for future reference.

Safety

The safety of workers at construction sites becomes a major social responsibility and challenge to ensure accident-free work. AI can be a powerful tool for enhancing safety on construction sites in the following manner.

- AI-powered wearable technology can be used to monitor worker health and well-being. This can alert supervisors in respect of fatigue or heat stress to the workers.
- Safe work behaviors of workers play a crucial role in ensuring safety at work sites. AI-powered video analytics can be used to monitor workers behavior and prevent unsafe work practices.
- AI can provide real-time insights into potential hazards, which will help implementing preventative measures and create a safer work environment for the workers.

Sustainability

There are numerous beneficial impacts of construction projects. However, construction projects also have many detrimental impacts. These include natural resource depletion, environmental pollution, energy consumption, harmful gas emissions, waste generation, social disruption, and the degradation of air, water, land, and wildlife habitats. By promoting sustainable design and material selection, AI can contribute to a more environmentally responsible construction industry. Sustainable construction practices can be promoted by using AI tools in the following manner.

- AI-powered design software can be used to optimize building layouts and material selection to minimize energy consumption. These AI tools can analyze factors like solar orientation, natural ventilation patterns, and insulation requirements to design energy-efficient buildings.
- AI can be used to identify and suggest alternative building materials with lower environmental impact. For example, AI can recommend using recycled materials or local resources to reduce transportation emissions associated with traditional construction methods.

Avoidance of Dispute

Besides, other possibilities of employing AI in dispute avoidance and dispute redressal, two distinct possibilities as mentioned below can be employed in the projects to avoid disputes.

- AI-powered contract management systems can analyze construction contracts and identify potential ambiguities or inconsistencies in wording. By proactively addressing these issues before construction commences, AI can help to minimize the risk of misunderstandings and disputes later in the project.
- AI can be used to document construction progress objectively through real-time data collection and image capturing. This detailed record keeping can provide incontrovertible evidence in case of disputes over project deliverables or adherence to specifications.

Integrity

Integrity management in the construction industry is a ubiquitous challenge across countries with estimates that over 10% of the volume of the global construction market leaks through

corrupt channels. Corruption is particularly deleterious in public projects, where it results in poor project selection, inferior quality, time overruns, and wasteful expenditure of taxpayers' money (Bhagat and Jha 2023). In this regard, application of AI powered tools and techniques can play a pivotal role in ensuring the integrity of the personnel involved in the construction.

- Financial transactions can be analyzed using AI algorithms to identify suspicious patterns that might indicate fraud or theft. This will be helpful in stopping the unethical behavior and protect the project from financial irregularities.
- During background checks, vast amount of available data can be analysed using AI applications, which may help in uncovering inconsistencies that might be missed by traditional methods. This helps identify individuals who may pose a risk to project integrity.
- Using AI-powered tools worker activity on-site can be monitored. This will help in detecting violations of safety protocols or unauthorized access to restricted areas. This will promote responsible behavior by workers and discourage unsafe activity.
- Worker's performance data can be analyzed using AI tools, which will help identifying trends and potential areas for improvement. This allows for objective and unbiased evaluations, fostering a culture of accountability and ethical conduct.

Artificial Intelligence in Indian Public Sector - A Snapshot

National Highway Authority of India (NHAI)

NHAI has harnessed AI tools to enhance road safety, digital enforcement of traffic rules and prompt detection of accidents on National Highways and Expressways, through the Advanced Traffic Management System (ATMS) Standards and Specifications 2023.

The enhancements include replacing previous cameras with the newly introduced Video Incident Detection and Enforcement System (VIDES) to emphasise the digital enforcement of traffic rules. VIDES has the capability to identify 14 distinct incidents including triple riding, helmet and seatbelt violations, wrong lane or direction driving, presence of animals on the highway, and pedestrian crossings. Depending on the detected incident, VIDES will alert route patrol vehicles or ambulances, generate e-challans, relay alerts to nearby Variable Messaging Boards, or send notifications through 'Rajmargyatra' mobile app to nearby travellers, the statement added. For comprehensive coverage, these cameras are slated for installation every 10 km along National Highways, with state-of-the-art Command & Control Centres at every 100 km integrating various camera feeds. Apart from this, Vehicle Speed Detection System (VSDS) is now integrated into VIDES, optimizing use of Automatic Number Plate Recognition (ANPR) cameras. In addition, the upgraded Traffic Monitoring Camera System (TMCS), positioned every 1 km on the National Highway, are endowed with advanced capabilities like automated detection of accidents and stalled vehicles.

Strengthening collaboration with local traffic agencies, NHAI will allocate dedicated workstations in the Command & Control Centre for traffic police representatives. Provisions have been made to share camera feeds over the network to enhance real-time coordination and response.

Central Public Works Department (CPWD)

Mobile devices such as smart phones and tablets enable managers to access data and control devices from anywhere and anytime for improved communication, collaboration and enable real time decision-making. .

The Central Public Work Department (CPWD) is developing the use of a cloud-based photo documentation system to improve communication, monitoring of projects and real-time decision-making. The staff will wear a 'smart helmet' equipped with a 360-degree camera and artificial intelligence (AI) system to capture real-time images, which will be transferred and uploaded on the website through a cloud-based system automatically.

The photo will be available to all managers or officials concerned via a smart phone or tablets and enable them to collaborate and deliver decision support within the shortest possible time. The technology has been used on pilot basis at two sites — under construction AIIMS, Jammu and its maintenance division in Delhi to test its 'efficacy in effective project management.'

Railways/ Metro Railway

Railways have used Artificial Intelligence for relief in operational delays and innovations in the customer experience and service delivery.

The Delhi metro has used multiple latest Artificial intelligence amenities. Starting from the ticketing system- tokens and smart cards, the provision of vending machines allows the users to operate the machines get their tickets or tokens and recharge smart cards for their journey inside the DMRC premises. The machine learns what the user wants to do with AI assistance and make the travel easier for them. The automated systems for opening and closing of the doors of the metro and at the metro platforms are also backed by AI technology. The geo positioning of DMRC metro trains is making trips minute after minute, delays are curbed.

Public Works Department (PWD), Delhi

1. Attendance monitoring using QR scanner-based devices for housekeeping and security staff :-

One major problem faced by Public Works Department is ensuring attendance of its personnel at different locations for better service quality. Many times, it has been found that people are absent from duty during random inspections. Also, many times a single person is deputed by the contractor at two or more locations resulting in violation of labour laws as well as poor service standards. Accordingly, PWD Delhi is now working on QR scanner-based devices for tracking manpower, which is a modern approach to manage attendance and monitor personnel movements. Here is how it generally works:

- **QR Code Generation:** Each employee is assigned a unique QR code. This can be generated through software specifically designed for this purpose or integrated into existing employee identification systems.
- **QR Code Placement:** Employees can have their QR codes printed on their ID cards or on their uniforms which can be tracked using QR scanner cameras.

- **QR Code Scanning Devices:** These are stationed at various checkpoints throughout the premises. They can be fixed scanners or hand-held devices carried by security personnel.
- **Attendance Logging:** When employees enter or exit a designated area, they scan their QR code using the scanner device. The device records the timestamp and possibly the location.
- **Data Processing:** The scanned data is processed and stored in a centralized database. This data can be accessed by authorized personnel for attendance tracking, payroll processing, and other administrative purposes.
- **Integration:** QR scanner-based manpower tracking systems can then be integrated with contractor bill payments, simplifying administrative tasks, and ensuring accurate records.

Benefits of using QR scanner-based devices for tracking manpower include:

- **Accuracy:** QR codes provide a reliable and efficient way to track employee movements, reducing errors associated with manual attendance systems.
- **Efficiency:** The process is quick and easy for employees, requiring only a simple scan.
- **Security:** It helps in ensuring that only authorized personnel have access to specific areas, enhancing security protocols.
- **Data Analysis:** The data collected can be analysed to identify trends, optimize staffing levels, and improve operational efficiency.
- **Cost-effectiveness:** Compared to traditional attendance tracking methods, QR scanner-based systems can be relatively affordable to implement and maintain.

However, it is important to address potential concerns about privacy and data security when implementing such systems. Additionally, proper training and support should be provided to employees to ensure smooth adoption of the new technology.

2. GPS based tracking and repair of Potholes :-

Tracking of potholes and their repair is a tedious task on Delhi roads considering the traffic density. Recently, PWD Delhi has done away with the old school system of pothole repair and has moved to a more professional approach. In the new system, dedicated pothole repair vans have been deputed on field whose primary role is to identify potholes and fill them up. All vans are fitted with GPS based cameras for real time tracking and monitoring.

The system is a paradigm shift as we have moved from complaint-based system to preventive maintenance. Further improvements are being planned for data compilation and management.

Benefits of using GPS based Pothole repair vans:

- Live tracking of vehicle and close monitoring of process being followed by field staff
- All activities being recorded.

3 AI-based road survey vehicles :

AI-based road survey vehicles are a fascinating application of technology in transportation and infrastructure management. These vehicles are equipped with various sensors, cameras, and other data collection tools, which are powered by artificial intelligence (AI) algorithms to gather and analyse data about road conditions, traffic patterns, and infrastructure status. Some key components and features typically found in AI-based road survey vehicles :-

- **Sensors:** These vehicles are equipped with a variety of sensors such as LiDAR (Light Detection and Ranging), radar, cameras (both visible spectrum and infrared), GPS (Global Positioning System), accelerometers, gyroscopes, and more. These sensors collect data about road surface conditions, potholes, cracks, lane markings, signage, and other relevant information.
- **Data Processing Unit:** AI-based road survey vehicles have onboard computers or data processing units that use machine learning algorithms to analyse the data collected by sensors in real-time. These algorithms can detect and classify different types of road defects, identify road signs and markings, assess pavement quality, and more.
- **Navigation System:** These vehicles often utilize advanced navigation systems, including GPS and inertial navigation systems, to accurately record the vehicle's position and trajectory as it travels along roads and highways.
- **Communication Technology:** AI-based road survey vehicles may be equipped with communication technology to transmit data in real-time to centralized databases or control centres. This enables transportation authorities to access up-to-date information about road conditions and make informed decisions about maintenance and repair schedules.
- **Autonomous Operation:** Some advanced road survey vehicles are capable of autonomous operation, meaning they can navigate roads and collect data without direct human intervention. However, human supervision is often still required to ensure safety and accuracy.
- **Integration with Geographic Information Systems (GIS):** The data collected by AI-based road survey vehicles can be integrated with GIS platforms to create detailed maps of road networks, infrastructure assets, and maintenance needs. This information can help transportation agencies prioritize repairs, plan construction projects, and optimize traffic flow.

Overall, AI-based road survey vehicles play a crucial role in infrastructure management, enabling more efficient and data-driven decision-making to ensure the safety and usability of road networks.

Recently PWD, Delhi has also started utilising the technology for monitoring health of its roads. Many major Arterial roads of Delhi have now been surveyed using this technique and data is being compiled. The data generated is very useful for assessing the road health in terms of number of potholes, depression, rutting etc. and taking a decision on residual life of pavement.

Conclusion

AI presents a significant opportunity to transform the construction industry. From improved project timelines and cost management to enhanced safety and sustainability, AI offers a path for a more efficient, responsible, and future-proof construction sector. As AI technology continues to evolve and become more accessible, its adoption within the construction industry is likely to accelerate. However, construction companies need to be aware of the challenges associated with AI implementation, such as high initial costs, data security concerns, and the need for a skilled workforce. By carefully considering these challenges and developing appropriate strategies to address them, construction companies can unlock the full potential of AI to revolutionize their operations and contribute to a more efficient, sustainable, and successful construction industry.

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Artificial Intelligence Revolutionizing MEP Processes in Construction Industry

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Prologue

The integration of Artificial Intelligence technologies within the construction industry has sparked significant interest, particularly in Mechanical, Electrical, and Plumbing (MEP) systems. This paper critically examines the innovative approaches to MEP optimization facilitated by AI technologies that offer substantial improvements in efficiency, accuracy, and sustainability. Drawing on a comprehensive review of literature and industry practices, the paper evaluates various AI techniques, including machine learning, neural networks, and optimization algorithms, and their applications in MEP design, layout planning, equipment selection, monitoring, fault detection, predictive maintenance, and quality control.

The paper provides insightful analyses of different scenarios and instances to underscore the transformative impact of AI-driven optimization on improving project outcomes and enhancing sustainability in construction projects. The paper identifies challenges such as data integration and interoperability issues, workforce upskilling and the need for specialized expertise that may hinder the widespread adoption of AI in MEP and proposes strategies to address these challenges. By synthesizing empirical evidence and industry insights, this paper offers valuable guidance for stakeholders interested in implementing innovative approaches to MEP processes, reducing costs, minimizing errors, and accelerating project delivery through AI technologies.

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Introduction

MEP processes, encompassing Mechanical, Electrical, and Plumbing systems, are essential components of construction projects. These systems ensure occupant comfort, safety, and environmental sustainability within buildings. Mechanical systems regulate human safety, property safety, temperature, and air quality, while electrical systems provide power distribution and security measures. Plumbing systems manage water supply and drainage. The significance of MEP processes lies in their ability to ensure compliance with regulations, optimize energy efficiency, and integrate seamlessly with other building elements (Hossain, 2020). Proper coordination among architects, engineers, and contractors ensures the effective implementation of MEP designs, contributing to the overall functionality and longevity of the structure.

In parallel, the integration of AI is reshaping the construction industry, revolutionizing various stages of project development. AI-driven design and planning tools analyze data to optimize building designs, enhance project management, and streamline construction operations (Reddy, 2020).



**Fig. 1: Construction operations with AI technology
Robotics and autonomous machinery**

Source: AI Generated Image, <https://canva.me/ai-image-generator-en-gs>

Robotics and autonomous machinery equipped with AI technology perform tasks with precision and safety (Fig.1), while AI-based monitoring systems track progress and safety in real-time (Wang, 2014). Moreover, AI enables predictive maintenance and smart facility management, improving efficiency, safety, and sustainability throughout the building's lifecycle. The integration of AI in construction holds immense potential for cost savings, quality improvements, and innovation, propelling the industry towards a more efficient, safer, and sustainable future (Albayrak, 2021).

Emergence of AI Applications in MEP Processes

Early AI applications primarily involved basic automation in design and planning phases. For instance, AI algorithms were used to optimize HVAC system layouts for energy efficiency and occupant comfort. Similarly, AI-powered tools aided in electrical system design by optimizing power distribution and ensuring compliance with safety standards. However, these applications were limited in scope and sophistication compared to contemporary AI solutions (Reddy, 2020).

As AI technology advanced, its applications within MEP processes expanded significantly. AI-driven design tools now offer unprecedented capabilities in optimizing MEP systems for energy efficiency, sustainability, and performance. For example, advanced computational algorithms can analyze complex building data to generate optimal HVAC configurations tailored to specific usage patterns and environmental conditions. Similarly, AI-powered

electrical system design tools can optimize power distribution networks to minimize energy loss and maximize reliability.

AI is increasingly being used in plumbing system design to optimize water supply and drainage networks, reducing waste, and ensuring efficient resource utilization. Additionally, AI-driven predictive maintenance systems are revolutionizing MEP operations by forecasting equipment failures and recommending proactive maintenance strategies, thereby minimizing downtime, and extending the lifespan of building systems (Hossain, 2020).

Current Landscape

In the current landscape, AI adoption in MEP processes is at an unprecedented level, with industry leaders leveraging advanced AI technologies to enhance design, installation, and maintenance operations. AI-driven solutions enable real-time monitoring and optimization of MEP systems, leading to improved performance, energy efficiency, and occupant comfort.

AI Techniques in MEP Optimization

- **Machine Learning in MEP Optimization:**



Fig.2: Process of Machine Learning

Source: <https://www.magicad.com/whitepapers/artificial-intelligence-mep-design>

Role of Machine Learning (ML): ML algorithms analyze large datasets to identify patterns, trends, and correlations, aiding in optimizing MEP processes (Fig.2). For instance, ML can predict energy consumption patterns, identify inefficiencies, and recommend optimization strategies.

Applications: Examples include analyzing HVAC system data to optimize temperature set points, airflow distribution, and scheduling to reduce energy consumption while maintaining occupant comfort (Hoang, 2020).

- **Neural Networks for Predictive Modeling and Optimization:**

Predictive Capabilities: Neural networks excel at capturing nonlinear relationships and patterns in data, making them suitable for predictive modelling and optimization tasks in MEP processes.

Use Cases: These networks can predict equipment performance, identify potential failures, and optimize system parameters. For example, predicting electrical load profiles based

on historical data helps in accurate equipment sizing and placement, minimizing energy wastage (Hoang, 2020).

- **Optimization Algorithms for Layout Planning and Equipment Selection:**

Techniques: Algorithms like genetic algorithms, simulated annealing, and particle swarm optimization iteratively search through vast solution spaces to find optimal configurations.

Applications in MEP: These algorithms help determine optimal HVAC duct layouts, electrical conduit routes, and plumbing pipe networks, considering space constraints, energy efficiency, and cost considerations (Hoang, 2020).

Applications of AI in MEP Processes

- **AI-driven design and modeling of MEP systems:**

Design Optimization: AI leverages data-driven approaches to optimize system layouts and configurations based on building data, occupancy patterns, and environmental conditions.

Examples: AI can optimize HVAC system layouts for energy efficiency and occupant comfort, ensuring compliance with safety standards and regulations (Jung, 2019).

- **Layout planning and spatial optimization using AI algorithms:**

Spatial Efficiency: AI algorithms use techniques like genetic algorithms to find the most efficient clash free layouts and spatial configurations for MEP systems (Fig.3).



Fig. 3 : Clash Free MEP Coordinated BIM Model

Source: <https://tcadesignbuild.com/blog/f/a-guide-for-design-and-build-mep>

Practical Applications: Optimizing the placement of HVAC ducts, electrical conduits, and plumbing pipes to minimize material usage, reduce installation costs, and maximize system performance (Jung, 2019; Han, 2020).

- **Equipment selection and sizing:**

Performance and Efficiency: Machine learning algorithms analyze historical data and performance metrics to select and size equipment optimally for MEP systems.

Examples: Recommending HVAC equipment with appropriate capacity and efficiency ratings to meet building requirements while minimizing energy consumption and operational costs (Hossain, 2020).

- **Real-time monitoring and control:**

Enhanced Performance: AI-based systems integrate sensors, actuators, and IoT devices to collect and analyze data for real-time decision-making and adjustments.

Applications: Adjusting HVAC settings based on occupancy, temperature variations, and weather forecasts to optimize energy usage while maintaining comfort levels.

- **Fault detection and predictive maintenance:**

Proactive Maintenance: AI analytics detect anomalies and predict equipment failures, allowing for timely maintenance and repairs.

Examples: Analyzing HVAC system data to detect signs of malfunction or inefficiency and recommending proactive interventions (Hossain, 2020; Minaei, 2021).

- **Quality control and compliance assurance:**

Inspection Accuracy: AI-powered inspection systems use computer vision algorithms to analyze visual data, identifying defects, deviations, and non-compliance issues in MEP installations.

Benefits: Streamlining inspection processes, reducing time and labour costs, and improving accuracy and reliability (Jung, 2019).

Transformative Impact of AI on MEP Processes

- **Efficiency Improvements through AI-driven Automation:**

Streamlined Processes: Automating repetitive tasks like design optimization and layout planning reduces manual effort, accelerates project workflows, and minimizes errors.

Examples: AI-generated optimized MEP system designs ensure energy efficiency and regulatory compliance (Reddy, 2020).

- **Accuracy Enhancement in Design and Installation:**

Data-driven Insights: Advanced AI algorithms identify optimal design configurations and predict system performance, enhancing design and installation accuracy.

Continuous Monitoring: AI-powered systems enable real-time performance analysis, ensuring prompt detection and resolution of deviations or issues (Reddy, 2020).

- **Sustainability Benefits:**

Energy Efficiency: AI optimizes energy usage, minimizes waste, and maximizes resource efficiency in MEP systems.

Long-term Impact: Optimized HVAC designs reduce energy consumption, and predictive maintenance extends equipment lifespan, contributing to overall sustainability (Hossain, 2020).

- **Cost Savings and Accelerated Project Delivery:**

Reduced Costs: AI reduces design iterations, minimizes errors, and eliminates inefficiencies, leading to significant cost savings in labour and material expenses.

Timely Delivery: AI-powered monitoring systems enable real-time project tracking, allowing for proactive decision-making and timely adjustments, accelerating project delivery timelines (Hossain, 2020).

Challenges and Barriers to AI Adoption in MEP Processes

- **Data Integration Challenges across Disparate Systems:**

Challenge: MEP processes involve various systems and datasets, often stored in disparate formats and locations, making data integration challenging.

Solution: Implement data management strategies such as data standardization, interoperability protocols, and cloud-based platforms to facilitate seamless data integration across different systems and stakeholders (Becerik-Gerber, 2019).

- **Workforce Upskilling and Training Requirements:**

Challenge: Adoption of AI technologies in MEP processes requires a skilled workforce capable of understanding and utilizing advanced AI tools effectively.

Solution: Provide comprehensive training programs and continuous professional development opportunities to upskill existing workforce members in AI concepts, tools, and methodologies. Collaborate with educational institutions to incorporate AI-related curriculum into relevant training programs (Khosrowshahi, 2012).

- **Need for Specialized Expertise in AI Implementation:**

Challenge: Implementing AI solutions in MEP processes requires specialized expertise in data science, machine learning, and AI technologies, which may not be readily available within the construction industry.

Solution: Partner with AI technology providers, data scientists, and consulting firms specializing in AI implementation to access the necessary expertise and resources. Foster knowledge sharing and collaboration between AI experts and domain-specific professionals to bridge the skills gap (Khosrowshahi, 2012).

- **Regulatory and Ethical Considerations in AI Applications:**

Challenge: AI applications in MEP processes raise regulatory and ethical considerations related to data privacy, security, transparency, and bias mitigation.

Solution: Develop robust governance frameworks and compliance protocols to ensure AI applications adhere to relevant regulations and ethical guidelines. Conduct thorough risk assessments and ethical impact analyses before deploying AI solutions and prioritize transparency and accountability in AI decision-making processes (Jung, 2019).

Emerging Trends in AI and MEP Optimization

Emerging trends in AI and MEP optimization are paving the way for transformative advancements in construction projects. With the integration of AI, MEP processes are becoming more efficient, sustainable, and cost-effective. One emerging trend is the use of AI-powered digital twins, which enable comprehensive virtual simulations of MEP systems (Wang, 2014). These digital twins allow for predictive modeling and optimization of building performance, enhancing energy efficiency and occupant comfort. Furthermore, advancements in AI-driven robotics and automation are revolutionizing construction and installation processes, enabling faster, safer, and more cost-effective MEP installations (Hossain, 2020)

Potential Areas for further Research and Development

Potential areas for further research and development in AI and MEP optimization include exploring advanced AI algorithms for predictive maintenance and fault detection. By leveraging machine learning and data analytics, researchers can develop AI-driven predictive maintenance systems that accurately forecast equipment failures and recommend proactive maintenance strategies (Hossain, 2020). Additionally, there is a need for further research in AI-powered quality control and compliance assurance, particularly in the development of AI-driven inspection systems that enhance accuracy and reliability in MEP processes (Jung, 2019).

Recommendations

Recommendations for stakeholders to maximize AI benefits in construction projects include fostering collaboration and partnerships among architects, engineers, contractors, and AI technology providers. By working together, stakeholders can collectively address challenges and drive AI adoption in MEP processes (Reddy, 2020). Furthermore, stakeholders should prioritize investment in infrastructure and technology, including robust data management systems and AI tools tailored to the unique needs of MEP processes (Navarro, 2021). Continuous learning and professional development initiatives are also essential to upskill the workforce in AI technologies and ensure effective utilization of AI tools and methodologies. Finally, stakeholders should establish clear guidelines and procedures for the ethical and responsible use of AI, ensuring compliance with relevant regulations and industry standards while promoting transparency, fairness, and accountability in AI-driven decision-making processes (Reddy, 2020).

Conclusion

The integration of Artificial Intelligence (AI) into Mechanical, Electrical, and Plumbing (MEP) processes is fundamentally reshaping the construction industry, ushering in an era of unprecedented efficiency, sustainability, and innovation. Through the deployment of AI-driven design, modeling, and optimization tools, stakeholders can significantly enhance building performance, energy efficiency, and occupant comfort, all while reducing costs and environmental impact. This transformative journey has evolved gradually, from initial applications focused on system layout optimization to sophisticated AI-driven solutions that streamline design, installation, and maintenance operations (Minaei, 2021). The current landscape showcases a remarkable level of AI integration in MEP processes, with industry leaders leveraging advanced technologies to optimize performance and sustainability. Looking forward, further integration and automation driven by AI-powered digital twins and robotics are poised to revolutionize construction processes, promising even greater efficiency gains and sustainability benefits.

In this context, the imperative for stakeholders is clear: embrace AI as a catalyst for sustainable construction practices. By fostering collaboration, investing in infrastructure, and prioritizing continuous learning, stakeholders can maximize the benefits of AI in MEP processes. Through these concerted efforts, the construction industry can propel itself towards a future characterized by heightened efficiency, enhanced safety, and sustainable development, marking a significant stride towards a more efficient, safer, and environmentally responsible built environment.

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Predictive Maintenance and Managing Assets in the Construction Industry using Machine Learning and Deep Learning Techniques

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Prologue

Asset management in construction refers activities like planning, procurement, maintenance, and eventual disposal of assets. On the other hand, Predictive Maintenance refers to proactive maintenance methods use of previously recorded data from the asset management system to analyse the condition of equipment and help predict, when the maintenance activities are needed. Globally, other Industries (e.g. Manufacturing, Automobile) have started adopting AI to maintain and track the assets for making decisions and improve efficiency. The integration of ML and DL with asset management and predictive maintenance in construction represents a transformative approach towards enhancing efficiency, reliability, and sustainability in infrastructure management. This paper gives a detailed review on the integration of Artificial Intelligence using ML and DL tools for effective asset management system and electro-mechanical equipment used in the construction Industry.

-Editor-

Introduction

The maintenance of the systems is important for enhancing product efficiency and continuity. Different varieties of system maintenance exist, such as reactive, planned, proactive, and predictive. Reactive maintenance is the process of repairing assets to standard operating conditions after poor performance or breakdown is observed. The primary benefits of reactive maintenance are; lowers costs and it requires less staff to implement. Planned maintenance, sometimes referred to as scheduled maintenance, refers to any maintenance activity that is planned, documented, and scheduled. The aim of planned maintenance is to reduce downtime by having all necessary resources on hand, such as labour and parts, and a strategy to use these resources. Predictive maintenance is an approach applying advanced analytics on the obtained data from multiple sensors to predict when the system tends to fail and organize the maintenance tasks accordingly to optimize maintenance intervals, reduce malfunction time, and enhance the system's reliability. Predictive maintenance in construction engineering employs advanced technology and data analysis techniques to anticipate equipment failures and optimize maintenance schedules, thus enhancing construction project efficiency and safety.

It involves the integration of IOT sensors, machine learning algorithms, and predictive analytics to monitor the condition and performance of machinery, vehicles, and other construction assets in real-time. IOT sensors are strategically placed on equipment to collect data on various parameters such as temperature, vibration, pressure, and usage patterns. This data is then transmitted to a centralized system where machine learning algorithms analyse it to identify patterns and trends indicative of potential issues. By leveraging historical data and predictive analytics, construction engineers can forecast when equipment is likely to malfunction or require maintenance. This foresight enables them to schedule maintenance activities during planned downtime periods, minimizing disruptions to construction schedules and reducing costly unplanned downtime. Predictive maintenance also enhances construction site safety by identifying potential safety hazards associated with malfunctioning equipment before accidents occur. Additionally, it helps extend the lifespan of construction machinery by addressing issues before they escalate into major failures, reducing equipment replacement costs.

Artificial Intelligence

According to the father of artificial intelligence, John McCarthy, who coined the term "artificial intelligence" in 1956, "It is the combination of science and engineering to make intelligent devices for human welfare." Artificial intelligence (AI) technology allows computers and machines to simulate human intelligence and problem-solving tasks. The ideal characteristic of artificial intelligence is its ability to rationalize and take action to achieve a specific goal. Artificial intelligence systems work by using algorithms and data. First, a massive amount of data is collected and applied to mathematical models, or algorithms, which use the information to recognize patterns and make predictions in a process known as training. Once algorithms have been trained, they are deployed within various applications, where they continuously learn from and adapt to new data. This allows AI systems to perform complex tasks like image recognition, language processing and data analysis with greater accuracy and efficiency over time. There are 2 types of AIs used. The first one is Narrow AI: Also known as Weak AI, this system is designed to carry out one particular job. Weak AI systems include video games like personal assistants like Amazon's Alexa and Apple's Siri. Users ask the assistant a question, and it answers it for you. And the other one is General AI: This type includes strong artificial intelligence systems that carry on the tasks considered to be human-like. They tend to be more complex and complicated and can be found in applications like self-driving cars or hospital operating rooms.

Machine Learning

The primary approach to building AI systems is through machine learning (ML), where computers learn from large datasets by identifying patterns and relationships within the data. A machine learning algorithm uses statistical techniques to help it "learn" how to get progressively better at a task, without necessarily having been programmed for that certain task. It uses historical data as input to predict new output values. Machine learning consists of both supervised learning (where the expected output for the input is known thanks to labelled data sets) and unsupervised learning (where the expected outputs are unknown due to the use of unlabelled data sets).

Deep Learning

Deep learning is a subset of machine learning, which is a subset of artificial intelligence. Artificial intelligence is a general term that refers to techniques that enable computers to mimic human behaviour. Machine learning represents a set of algorithms trained on data that make all this possible. Deep learning is just a type of machine learning, inspired by the structure of the human brain. Deep learning algorithms attempt to draw similar conclusions as humans would by constantly analysing data with a given logical structure. To achieve this, deep learning uses a multi-layered structure of algorithms called neural networks. The design of the neural network is based on the structure of the human brain. Just as we use our brains to identify patterns and classify different types of information, we can teach neural networks to perform the same tasks on data. The individual layers of neural networks can also be thought of as a sort of filter that works from gross to subtle, which increases the likelihood of detecting and outputting a correct result. The human brain works similarly. Whenever we receive new information, the brain tries to compare it with known objects. The same concept is also used by deep neural networks. Neural networks enable us to perform many tasks, such as clustering, classification or regression.

Asset Management and Equipment Handling

Asset management involves the systematic and strategic handling of physical or financial assets throughout their lifecycle. This process includes acquiring, operating, maintaining, and disposing of assets in a manner that maximizes their value while minimizing costs and risks. Effective asset management aims to optimize the performance, efficiency, and longevity of assets, whether they are tangible items like buildings, equipment, or infrastructure, or intangible assets such as intellectual property or financial investments. Key components of asset management include asset tracking, risk assessment, maintenance planning, financial analysis, and compliance with regulatory requirements. By implementing robust asset management practices, organizations can enhance operational efficiency, mitigate risks, and achieve their strategic objectives while ensuring the optimal utilization of resources.

The basic operations involved in the construction of any project are excavation, digging of small or large quantities of earth and moving them to fairly long distances, placement, compacting, levelling, dozing, grading, hauling, etc. All the machines that are usually used to carry out these construction operations are referred to as construction equipment [Tsado, Theophilus Yisa et al 2014]. Construction firms are often faced with problems related to high rate of equipment failure or breakdown and accident resulting from unskilled operator's abuse. Poor training of equipment operators is often claimed as a major cause of equipment related accidents (John and Herman, 2009; Schenayder et al., 2002). Equipment plays an important role in today's construction projects which is more demanding need to be completed in stipulated time with best Quality. The cost of equipment in a project varies from 10-30 % of the total cost of project, depending upon extent of mechanization. Proper planning, selection, procurement, installation, operation, maintenance and equipment replacement policy plays important role in equipment management for successful completion of project [Sachin D. Bugged. 2019]. Asset Management is a key discipline enabling a sustainable and high-quality built environment. The physical asset is nowadays more and more integrated within the digital environment; therefore it produces a great amount of information during its life cycle. This information should be used to improve process management during the

use phase of the asset, according to a servitudes and cross disciplinary approach. Thus, leading to digital asset management which can processes and address different core areas of the discipline.

The following are the effects of lack of proper equipment maintenance:

- There is high rate of costly downtime, which decreases profitability and uptime.
- Catastrophic equipment failure is very common.
- Unscheduled equipment maintenance is at high rate, most of the repairs are made when equipment is supposed to be working, this affect production.
- Spare parts inventories are purchased at higher rate, many parts are purchased just after breakdown occurs.
- Equipment performance is not optimized; it does not operate within specifications.
- The clients are dissatisfied due to delays by the contractors because of frequent equipment failure.
- Overtime needed to make up for lost hours due to broken down or poorly performing equipment is at increased rate.
- Equipment safety is not guaranteed since site injuries are often caused by poorly performing equipment.
- The ease of operating equipment is affected.
- Quality of output is reduced because of poor equipment maintenance.
- There is low rate of quality control.
- Overall maintenance cost is increased as catastrophic failure is common.
- Equipment availability is affected.
- There is high rate of depreciation of capital investment caused by poor equipment maintenance.

Methods of Implementing AI Techniques

Machine Learning (ML) and Data Mining

Machine learning and data mining are pivotal in enhancing construction management by providing predictive analytics capabilities. These techniques involve the use of algorithms and statistical models to analyse historical and real-time data, thereby facilitating better decision-making. In construction, ML models can predict potential risks and delays by analysing past project data. For instance, supervised learning algorithms such as regression

models can forecast project timelines and costs by identifying patterns and correlations in the data.

Moreover, clustering algorithms can segment projects into categories based on similarities, which helps in identifying common factors that lead to project success or failure. Data mining, on the other hand, involves extracting useful information from large datasets, which can then be used to improve planning and resource allocation. For example, association rule mining can uncover relationships between different project variables, such as material usage and project duration, allowing managers to optimize procurement and inventory management.

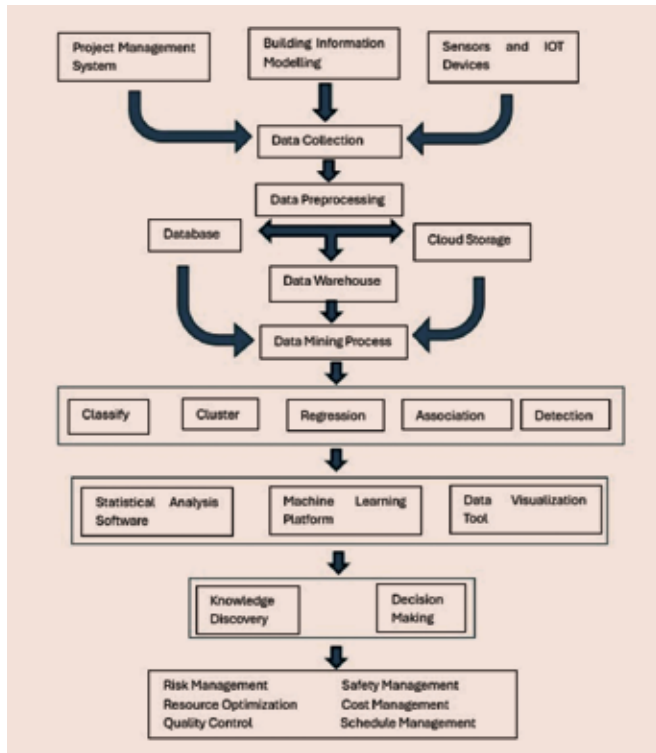


Fig. 1

Natural Language Processing (NLP)

Natural Language Processing (NLP) in construction management is primarily used to automate the analysis of textual data and improve communication processes. NLP techniques enable the extraction of relevant information from large volumes of unstructured text, such as contracts, regulatory documents, and project reports. This automation reduces the time spent on manual document review and ensures compliance with regulatory requirements.

One of the significant applications of NLP in construction is automated contract analysis. By using NLP algorithms, construction managers can quickly identify key clauses and obligations in contracts, ensuring that all parties adhere to the agreed terms. Additionally, sentiment analysis, an NLP technique, can be used to gauge stakeholder sentiments

by analysing emails and meeting notes, helping project managers to address concerns proactively.

NLP is also employed in the development of intelligent chatbots and virtual assistants that can interact with project stakeholders, providing real-time responses to queries about project status, schedules, and documentation. This improves communication efficiency and ensures that stakeholders always have access to up-to-date information.

Optimization Algorithms

Optimization algorithms are used in construction management to solve complex scheduling and resource allocation problems. These algorithms aim to find the best possible solution from a set of feasible options, considering multiple objectives such as cost, time, and resource utilization.

Genetic algorithms, for example, are used to optimize construction schedules by simulating the process of natural selection. These algorithms iteratively improve the schedule by selecting the best-performing options and combining them to produce better solutions. This approach helps in minimizing project completion times and reducing costs.

Digital Twins and Simulation

Digital twins are virtual replicas of physical assets that provide real-time data and insights into the performance of construction projects. By integrating BIM with AI-driven digital twins, construction managers can monitor and simulate various aspects of the project, from design to maintenance. Digital twins enable continuous data collection from sensors and other sources, which is then analysed to optimize performance and maintenance schedules. For example, a digital twin of a building can monitor energy consumption, predict maintenance needs, and identify areas for improvement. This real-time data allows for proactive decision-making and enhances the overall efficiency of the construction process. Simulation is another crucial aspect of digital twins. By simulating different construction scenarios, managers can visualize potential outcomes and make informed decisions. This helps in identifying and mitigating risks before they impact the project, ensuring that the construction process is smooth and efficient.

Process Mining

Process mining uses AI to analyse and improve workflows within construction projects. By examining the sequence of tasks and events, process mining tools can identify bottlenecks, inefficiencies, and deviations from planned processes. These insights help project managers optimize workflows and ensure that projects stay on schedule and within budget. AI-driven process mining can model and predict process outcomes, providing a basis for continuous improvement. For instance, it can identify delays in supply chains or inefficiencies in task execution, allowing for proactive measures to mitigate these issues. This methodology enhances transparency and control over construction processes, leading to better project outcomes. These methodologies collectively contribute to the digital transformation of the construction industry, enhancing automation, efficiency, and intelligence in project management and execution.

Information Fusion

Information fusion refers to the integration of data from multiple sources to generate comprehensive and accurate information. In the context of CEM, this can involve combining data from various sensors, project management software, and real-time monitoring tools to create a unified view of the project's status. For instance, integrating data from IoT sensors on construction equipment with project schedules can provide insights into equipment utilization and maintenance needs.

This methodology enhances decision-making by providing a more complete picture of the project's progress and potential issues. Information fusion allows for better coordination among different teams, timely identification of problems, and more informed resource allocation. This integration of diverse data sources is crucial for managing complex construction projects, where multiple variables need to be monitored and controlled simultaneously.

Real-World Applications

Predictive Maintenance at a Major Construction Firm

A leading construction company implemented an AI-based predictive maintenance system across its fleet of heavy machinery. The system used historical maintenance data and real-time sensor data to predict failures before they occurred, resulting in a 20% reduction in maintenance costs and a 15% increase in equipment uptime.

Resource Optimization in Urban Infrastructure Projects

In a large-scale urban infrastructure project, AI-driven data analytics was used to optimize the allocation of construction materials and labour. By analysing usage patterns and forecasting future needs, the project achieved a 10% reduction in material waste and a 12% improvement in labour productivity.

Risk Management in High-rise Construction

An AI-based computer vision system was deployed to monitor safety on a high-rise construction site. The system used cameras and image recognition algorithms to detect safety violations and hazards, leading to a 30% reduction in on-site accidents and a 25% improvement in compliance with safety regulations.

Challenges and Limitations

Despite the promising benefits, the integration of AI in construction asset management faces several challenges:

- **Data Quality and Availability:** AI systems require high-quality, comprehensive data to function effectively. In construction, data can be fragmented and inconsistent, posing a challenge for AI implementation.
- **Skill Gap:** The adoption of AI technologies necessitates a workforce skilled in AI and

data analytics. The current skill gap in the construction industry can hinder the effective deployment of AI solutions.

- **Cost of Implementation:** Initial investment in AI technologies and infrastructure can be high, which may be a barrier for smaller construction firms.
- **Resistance to Change:** The construction industry has traditionally been slow to adopt new technologies. Resistance to change from management and workers can impede the adoption of AI.

Conclusion

The integration of AI techniques in asset management holds significant potential to transform construction engineering. By enhancing predictive maintenance, optimizing resource allocation, improving risk management, and supporting informed decision-making, AI can lead to substantial cost savings and efficiency improvements. However, the successful implementation of AI requires overcoming challenges related to data quality, skill gaps, cost, and resistance to change. Future research should aim to address these challenges and further explore innovative AI applications in construction asset management.

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Optimization of Solar Energy Generation by Artificial Intelligence

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Prologue

The current trend in construction industry is to cater maximum electricity requirements of the building dwellers/users through solar power generation in the building itself. Owing to technical and commercial viability of the solar PV Plants, which harness the solar energy and convert it into electricity, it is usually possible to fulfil the energy demand partially if not full. Most of the buildings constructed now days are equipped with rooftop solar plants, which fulfil the electricity requirements of the building and in some of the cases generate excess power, which may be exported to the grid.

Artificial Intelligence is doing wonders in this area by providing ways and means to optimize the generation of electricity through proper designing and in subsequent maintenance operations. Artificial Intelligence is nothing but the intelligence acquired by computing machines, which analyze the data and provide the optimum solution to the issues associated with the solar energy generation. How optimization of solar energy generation is done through, AI is the subject matter of this paper along with other related issues.

-Editor-

Introduction

Apart from passive interventions in designing cool buildings and thereby reducing the energy requirements of the users by proper orientation of the building, optimizing floor to ceiling height to provide space near ceiling for lighter warm air, Stone Jalis with venturi effects, Jharokhas etc. more and more active interventions like use of energy efficient lighting and gadgets, use of sensors, placement of solar power plant on the rooftop are being adopted in buildings. The latest in this direction are Artificial Intelligence based interventions. By its sub-set called generative AI, it provides numerous options to building designers for best locating the Solar Panels on the building rooftop to achieve the maximum electricity generation without compromising the building aesthetics. Additionally, if the entire building is to be integrated with solar panels, the same can also be done with the help of generative AI. This AI technology is thus equipping the Architects/Building Planners with lots of options in short time. Just imagine how complicated and time consuming this work ought to be, when Planning and Designing team used to sit for days together to come up with few acceptable designs for ultimate selection of only one design by the building owner.

AI has thus not only resolved the issue of designing the solar panels for integration with building façade including rooftop to the best extent possible but has also improved subsequent installation, operation and maintenance of the system considerably from the

view point of safety, reliability and viability of building integrated Photovoltaics/ Rooftop Solar Systems.

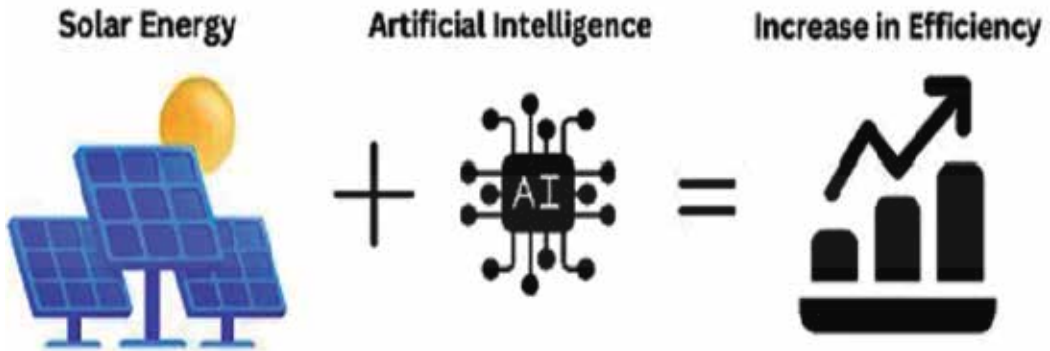


Fig.1: Solar AI Equation

Source: https://www.youtube.com/watch?v=e2LpDzH7_JU

Issues Involved in Solar Power System

Solar energy is available to human beings in abundance in the form of heat energy. There were many ways through which this energy was tapped for the beneficial use of humankind since time immemorial like drying of clothes, heating of water, cooking etc. Now with the development and advancement of technology, it has become possible to harness the solar energy for conversion into electricity through Solar Photovoltaic Panels. These panels can be either ground mounted or roof mounted on a metallic structure that provides it the required structural stability against wind pressure and the mounting surface that may be either the bare soil or the roof made either of concrete or of any other material.

These solar panels produce DC power, which is then converted into AC Power through an Inverter. This inverter supplies suitable AC power to the consumer through either interconnected transmission or Distribution Lines called Grid or directly as in the case of Rooftop solar system mounted on the roof of a building. It thus appears a very simple system for converting solar energy into electricity. However, it is not that simple as it appears from the above description. There are many issues involved at each and every step. To begin with, when it comes to the placement of these panels on either rooftop or ground top, their shape and size are important besides their power generation capability and efficiency of conversion. The mounting angle of the solar panel maximizes the power conversion as per the latitude of a place. However, it conflicts with the aesthetics as well as space utilization. Thus, technicality involved in various aspects of solar panels i.e. shadow-free area, mounting angle necessities, space requirement for maintenance between the solar panels, regular cleaning of solar panels, protection from lightning strike, earthing requirements of the whole system, location of the inverter placement for the convenience of accessibility of consumer etc. skirmishes with the architectural, structural and utilitarian requirements of the building. These issues continuously haunt a planner, designer, installer, maintenance provider and above all owner as well as user and therefore require a continuous analysis and likely solutions. Besides, weather variations as well as safety from fire and electric shock play a dominant role after installation. The reduction in power generation due to non-working of

some of the panels and other issues cropping up during operation is also a significant factor requiring continuous monitoring of the system. Sometimes the islanding effect cripples the system and needs to be tackled urgently. All this and many more issues are involved in the actual solar power production from a building. It will therefore be quite interesting to observe how AI as the foremost enabler of technological genie understands, analyses and solves these and many other issues in a unique and novel way.

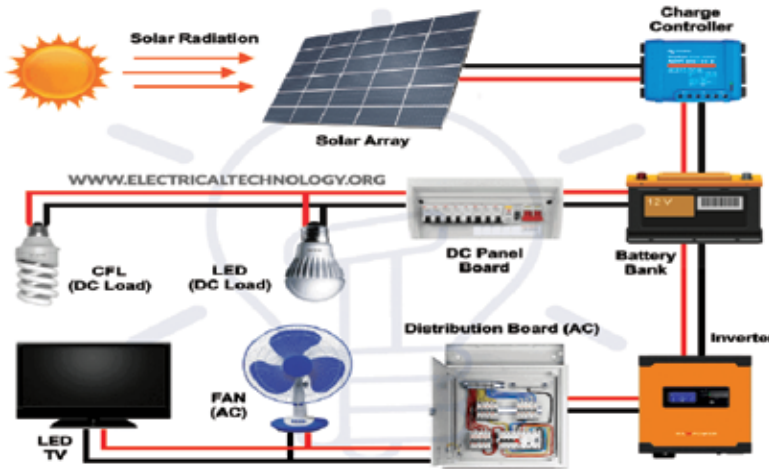


Fig. 2: Representation of solar Power System

Source-https://www.electricaltechnology.org/2020/07/design-and-installation-of-solar-pvsystem.html#google_vignette

AI Intervention in Resolving Solar Power System Issues

With the AI sweeping almost every field of human activity all the problems encountered by the solar scientists, technologists, developers, and managers will now be resolved through AI only and while doing so many more things will evolve in the field of solar energy which will be beneficial to the mankind. To elaborate this point, presently we have come across the mutual benefits of simultaneous growth of solar energy and agriculture on barren lands, which has led to the growth of another technology known by the name of Agrivoltaics, a mutually beneficial combination of solar farming with agriculture. The concept of net zero buildings and energy plus buildings which dwell upon the fulfilment or excess production of total energy requirements of the building by solar energy generation within the plot only where building is constructed, has also emerged with the development of rooftop solar power system. It will therefore be interesting to watch future developments in this field. Floating solar panels is also one area, coming up very fast, which may give solar power technology another boost.

Addressing the Challenges of Optimizing Solar Energy Generation

Uncertainty in Electricity Generation - Out of the numerous challenges faced by solar power systems, one is the uncertainty in power generation owing to unexpected changes in the weather. Based on the past data fed into the AI model, near-exact forecasting is possible now.

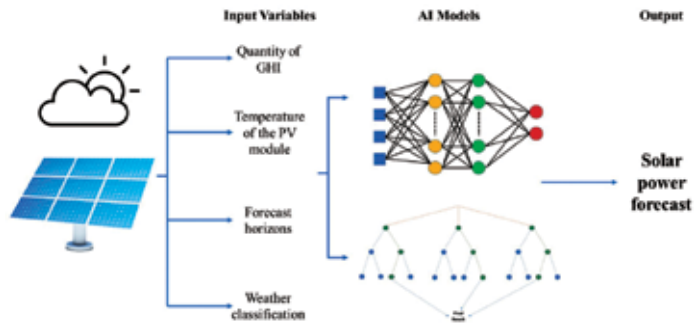


Fig.3: Schematic showing input variables into AI models for solar power forecasts

Source:<https://www.mdpi.com/1996-1073/16/24/8057>

With this and various other AI models available based on different sub sets of AI, it is possible to estimate the power generation from rooftop solar system which may help designers to provide optimum design.

Right Placement of Solar Panels - Besides, the rooftop solar Power System maximizes electricity generation, when its placement attracts maximum solar insolation. Under normal circumstances, a feasibility study is carried out to select the best possible location. But with the availability of various options suggested by AI model, optimal location can be chosen considering various factors like operational safety, maximum power generation. ease of maintenance etc. so, the variability of output can be tackled in the best possible manner. Since the amount of electricity produced by a solar panel depends on the quantum of solar radiations hitting the solar panel which in turn depends upon the alignment of the panel, time of the day, weather, clouds shadowing of the solar panel, cleanliness and many other factors; this challenge can be addressed by self-learning algorithms provided by AI. These algorithms are trained by the past weather data, cloud cover, temperature variations etc. This training gives AI the required capability to use real time weather data to predict power generation ahead.

Real Time Monitoring the Solar Plants - Traditionally, the solar power operators use a team of trained workmen to inspect solar panels manually once in a month or three months as the case may be to look for any defects. This process takes much time and is slow, expensive and not very accurate. This inspection can now be AI enabled. By using the algorithm which can detect defects of the solar panels from thermal images, more and more rooftop solar systems can be inspected with the help of images obtained from Drone. Besides speed, accuracy of inspection can also be assured.

Images collected by a drone or UAV(Unmanned Aerial Vehicle) can be processed by Machine Learning Algorithm in the cloud or control and command centre and the outcome of the faceless intervention will tell the controller which of the PV Panels has the visible signs of defect. The most common type of algorithms used here is deep learning algorithm which is a type of machine learning algorithm using neural network to understand problem solving task. Requiring large datasets of labelled images some of which are of defective panels and some are of working panels, deep learning algorithm can identify defective panels and enables AI vendor to provide the vision to identify the problem.

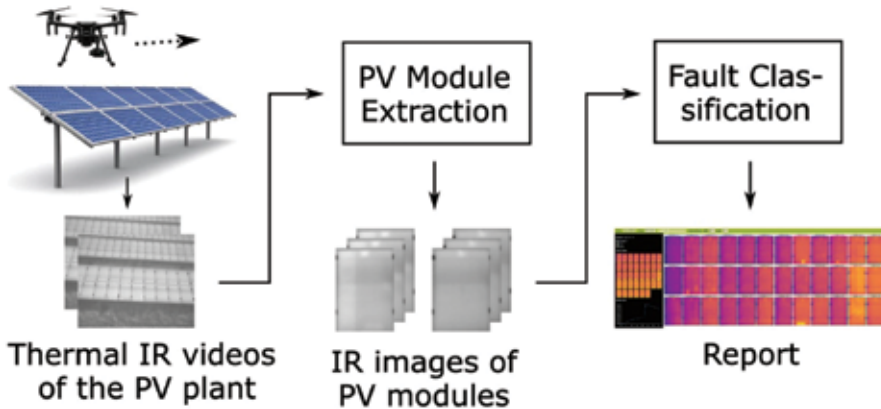


Fig.4: AI enabled Inspection of Solar Power System

Source:<https://onlinelibrary.wiley.com/doi/full/10.1002/pip.3448>

Periodical Maintenance of Solar Power Plants - Since the solar power plants stand in the open under the scorching heat of Sun to harness the best solar insolation, the exposure to open atmosphere containing UV & IR radiations, heavy rains, cool nights, heavy winds, lightning strikes may create problems in solar panels or associated components carrying the DC Power to the distribution circuit of the building premises or the grid. The corrective action requires periodic cleaning of the solar panels, replacement of solar panels or rectification of defect in any other components like Inverter, the mounting structure, cables, fuses, surge device, DC & AC distribution board etc. Even the possibility of fire through solar plant can't be ruled out. It is thus very necessary to check the system thoroughly for any defect developing or breaking out. Normally human inspection and subsequent correction by the authorized person is carried out. But with the advent of AI and Robotics, the preventive, corrective and predictive maintenance can all be done with AI enabled Robots. These robots may not be in the form of humanoid, but depending upon the application may look differently like a robotic arm, or self-moving machine.



Fig.5: Robotic Cleaning of the Solar Panels

Source-<https://reglobal.org/robotic-cleaning-of-solar-panels/>&<https://www.indiamart.com/proddetail/solar-panel-cleaning-robot-service-2853226610833.html>

AI enabled Disposal of E-waste

Substantial e-waste is generated from solar power plants after the useful life of solar panels, electrical gadgets and also due to replacements due to normal wear and tear. Normally, this e-waste is dumped at some place near to the location of its generation and then taken away to the recycling plant where metals are segregated, recovered and recycled after a substantial time, putting environment and its habitants at risk. But now with the introduction of AI powered Robots, disposal of e-waste has also become speedy. AI-powered robots and machines are equipped with sensors, cameras, and machine learning algorithms. These can identify, sort, and separate different types of waste materials with better accuracy and speedily than manually. Waste plants have the capability to engage these AI systems for sorting robots to separate trash from recyclables with more precision. They can also use AI to function as a quality control system to ascertain sorting of trash from recyclables.



Fig.6 Sequence Diagram of AI Model for Solar waste disposal

Source-<https://www.sciencedirect.com/science/article/abs/pii/S0048969723025469>

Benefits of Using AI in Solar Power Management

Some of the benefits of using AI in solar power management are:

1. Multiple Generative Designs
2. Best Model Selection
3. Optimization of the Panel Placement
4. Multiple Algorithms to deal with Different Issues
5. Fine tuning the solutions
6. Speed
7. Enhanced Human Safety

8. Organized scheduled Maintenance
9. Effective Predictive Maintenance
10. Helping solar Energy becoming more efficient, reliable and affordable

Future of AI Based Technologies

As IOT, Augmented and Virtual Realities are being added to our knowledge domain simultaneously, the future of AI appears very bright. Soon this generation will enter into a domain called Intelligent Virtual Realities where professionals will have more options to realize the potential of virtual happenings in actual world like situations.



Fig.7 : Future Venture of Solar Technology

Source-<https://oluwafemidiakhoa.medium.com/the-future-of-solar-energy-in-the-ai-era-afcc07c07d00>

Conclusion

The era of dot com is being replaced by dot ai at a much faster pace than anticipated earlier. It means to say that new history is being rewritten by various AI Tools working through the power of Machine Learning, Deep Learning, Neural Networks, Computer Vision, Natural Language Processing, Large Language Models etc. which are all the sub sets of Artificial Intelligence along with Big Data and Predictive Analytics. Though what we are encountering today is weak AI, but time is not far, when Artificial General Intelligence (AGI) will enter into fray and we will have more exposure of AI into our life. Next in line is the Artificial Super Intelligence (ASI), which so far is more hypothetical and a thing of future.

Role of Artificial Intelligence is thus revolutionary in achieving the best of everything and so also of Solar Photovoltaic system and its integration with building façade with maximum possible gain of energy. The field of AI is fast emerging every day and that day is not far when all types of construction activities including generation of renewable energy will be linked more with our thoughts than actions. But then there will be a possibility that our thoughts may collide with other opposite thoughts and may give rise to unprecedented conflict in our minds as well as in physical spaces.

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Integration of AI in AECO

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Prologue

The integration of Building Information Modeling (BIM) has significantly advanced project optimization and quality standards within the AECO (Architecture, Engineering, Construction & Operations Industry) sector. Despite these advancements, the sector still faces numerous challenges, particularly in workflow automation and data utilization. This paper explores how Artificial Intelligence (AI) can address these challenges. AI can be viewed as machines emulating Human Senses & Human Intelligence. It aims to demonstrate how AI can not only expedite decision-making processes through robust data analytics but also significantly enhance overall productivity. Through a detailed examination of specific AI tools and their applications across various stages of AECO projects, the paper highlights the current technological lag in India's AECO sector and presents a case for deeper AI integration to foster technological advancement. The anticipated benefits include streamlined operations, cost efficiency, and heightened project delivery standards, positioning AI as a crucial tool for industry advancement.

-Editor-

Introduction

Since the past 40 years, Engineering and construction (E&C) has never seen a significant revolution, in contrast to other industries, and has been hesitant to accept new technologies. As a result, productivity has remained constant or, in some circumstances, even decreased. Large projects across all asset classes often take 20% more time than expected and cost up to 80% more than expected. Since the 1990s, construction productivity has decreased in several areas. For instance, project planning is frequently done on paper and is not coordinated between the office and the site. Contracts lack incentives for innovation and risk sharing, performance monitoring is inadequate, and supply-chain procedures are still unsophisticated. Even while new digital technologies require upfront investment and have tremendous long-term advantages, the industry has not yet accepted them.

Buildings are currently responsible for 39% of global energy related carbon emissions: 28% from operational emissions, from energy needed to heat, cool and power them, and the remaining 11% from materials and construction. We are the second largest industry in the world after man manufacturing, but we are the biggest polluter. Therefore, the built

environment sector has a vital role to play in responding to the climate emergency, and addressing upfront carbon is a critical and urgent focus.

Less than 1% of revenue is spent on R&D in the construction sector, compared to 3.5 to 4.5 percent in the car and aerospace sectors. This is also true for IT expenditures, which represent less than 1% of construction revenue even though several new and useful software programs have been created for the sector.

The key is digitalization. A growing number of construction projects include digital sensor systems, intelligent machinery, mobile devices, and innovative software applications. This trend has set a pace due to the worldwide COVID-19 outbreak. Several participants in the construction industry were pushed to digitize and employ technology to increase worker safety and efficiency.

Top 3 skills of the future



Top industry skills



Survey question: What technical or digital skills do you believe your company or organization will be prioritizing when hiring over the next 3 years? Select all that apply.



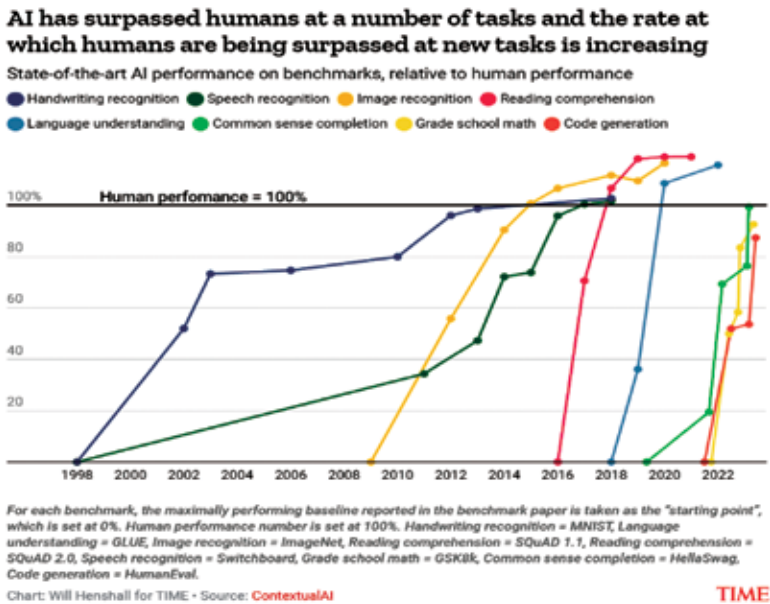
Source: 2024 STATE OF DESIGN & MAKE by AUTODESK

Stepping into the Digital Era – The question is WHY AI?

According to UN estimates by 2030, almost 60 percent of the projected 8.3 billion people will live in cities. Nearly 1,400 of the world’s cities will have half a million or more inhabitants. Cities play a crucial role in connecting people with opportunities, fostering innovation, and driving growth. However, to make cities sustainable, we need to address urban planning, infrastructure, transport, and housing. India faces one of the toughest housing challenges

but is taking an uncompromising ambitious approach in providing housing for all. Moreover, we've been hearing for a long time, ever since we were students and then working about the low productivity in our industry.

Moreover, the problems that we also have on a more local scale are whether we have BIM or not, there are project delays, thus resulting in over-budget projects. We also need to reskill every member working on the project whether directly or indirectly. And lastly, there are serious accidents on construction sites. So, there might be hope of using AI tools to help us with this.



Source: TIME by Will Henshall

AI is GOOD OR BAD?

Artificial intelligence good or bad? Like, will it take our jobs? What about our Data Safety & privacy?

Let's take a step back and talk about when the internet came along. This was, in the 90s, where we were also wondering, is the internet good or bad? And now the answer to that question is yes. Like, it can be both when you like. It depends how you use it. And that's the same answer that we can use for artificial intelligence.

The future of construction isn't just software, it's the people who use it

AI Implementation in 4 Stages of Built Environment!

(Design, Tender, Construction & Asset Management)

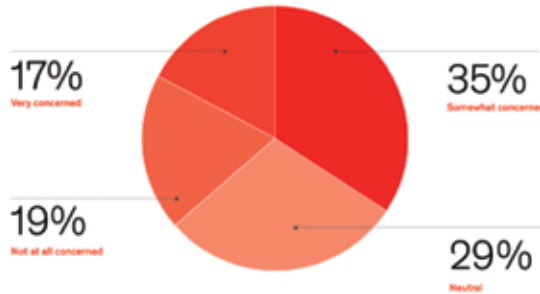
Most people want to jump straight to AI, but it often fails due to poor BIM data. Thus, we need to use these platforms to help in polishing our BIM Data. Here we will see how well

AI vs. human intelligence: Three important differences

AI		HUMAN INTELLIGENCE
May require millions or billions of samples to learn at a level exceeding average human intelligence, making humans on average more efficient learners than AI systems.	One-shot vs. multitask learning	Ability to learn new concepts and ideas from a small number of samples, sometimes from a single one. This ability is referred to as one-shot learning.
Ability to recall, recalling information as it was presented or generating a novel mashup of information that some refer to as imagination but is better described as synthetic recitation.	Imagination and recitation	Ability to form ideas, mental associations and concepts of phenomena that are not present (and/or do not exist) is considered an important element of being human.
In 2023, most artificial intelligence systems do not possess multimodal learning ability. Autonomous vehicles, however, are able to receive inputs from multiple types of sources to make navigational decisions.	Multimodal input and output	Ability to receive and quickly integrate information from all of our senses and use that perception to make decisions. The average human is able to incorporate multimodal inputs and create multimodal outputs.

Source: AI IN AEC by Stjepan Mikulic

Are you concerned about the risk that AI poses to jobs in architectural visualization and the AEC industry more broadly?



Source: Report by Architizer & Chaos

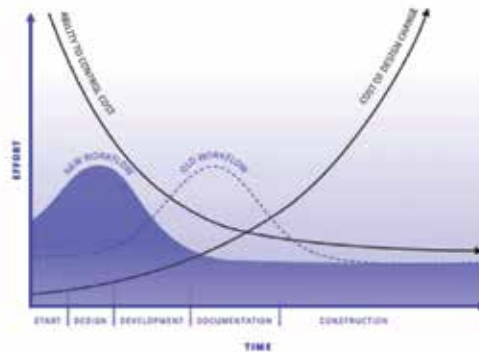
we can utilize certain AI tools in different stages of the Project. How we can benefit from the overall project delivery with the available data.

- **Data-Driven Decision-Making:** AI provides comprehensive data analysis and insights, enabling better-informed decisions at every stage of the project lifecycle.
- **Cost and Time Efficiency:** Automation and optimization reduce manual effort, streamline processes, and lead to faster project completion and lower costs.
- **Risk Management:** AI tools help in identifying, assessing, and mitigating risks throughout the project, ensuring smoother project execution.
- **Sustainability:** AI-driven optimization of designs, materials, and operations contributes to creating more sustainable and environmentally friendly buildings.
- **Enhanced Collaboration:** AI facilitates better communication and collaboration among project stakeholders by providing a unified platform for data sharing and project management. Better collaboration fuels success.

1. AI in Design Stage

- Concept Design** : AI-driven tools facilitate data-informed decision-making, enabling rapid iterations and optimized design alternatives. This enables architects to create more efficient and innovative building layouts and execute complex parametric designs. AI-Powered modelling software helps to do activities faster, & various options within a limited time along with rapid iteration & simulation, etc. thus enabling more informed decision making which helps the architects & the designers to concentrate more on creativity which is crucial rather than the engineering part of design & planning. The platforms with AR-VR capabilities provide a wide range of experience in the Design Stage enhancing the overall experience.

Planning and Early design decisions have large impacts on project outcomes



Source: AUTODESK Learning Page

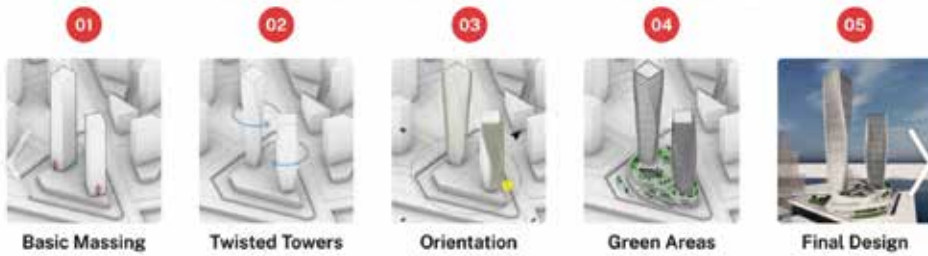
The cloud-based nature facilitates real-time collaboration across different geographic locations, allowing teams to work simultaneously on the same project, ensuring that ideas and feedback are integrated efficiently. The interoperability between the software's ensures that data flows smoothly into more detailed design phases without the need for time-consuming conversions or adjustments.

Tools like Forma of Autodesk & Rhino with grasshopper offer unparalleled capabilities in computational design. Various integrated plugins tools like Test Fit in Forma can run various iterations of Parking Units.

Forma transforms planning & early-stage design

<p>CONTEXTUAL MODELLING & DATA</p> <p>Rapid setup of BIM model with real world contextual data*</p>	<p>CONCEPTUAL DESIGN</p> <p>Create complex designs in full 3D in minutes</p>	<p>AUTOMATIONS</p> <p>Design, explore and optimize solutions with unparalleled speed and ease of use</p>	<p>ANALYSES</p> <p>Perform real time analysis to evaluate and improve designs</p>	<p>INTEROPERABILITY</p> <p>Adopt hybrid workflows with Forma- Revit sync enabling fluid connectivity downstream</p>
<p>THIRD-PARTY ECOSYSTEM Connect and extend Forma with third-party capabilities</p>				

Source: AUTODESK Learning Page – Forma



Source: ARCHDAILY – RHINO MODELLING

● **Detailed Design**

In the detailed design phase AI & various plugin tools help to perform repetitive tasks faster, better efficiency, qualitative deliverables & hence saves cost & time. It helps to auto generate annotations, tags & highlights the clashes with other disciplines that can be assigned to specific individuals.

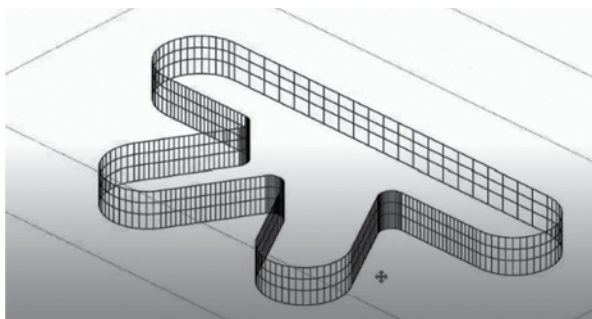
Various tools like Autodesk Revit & Bentley Systems MicroStation can automate tasks, in automation of the tasks thus reducing the timeline of the deliverables. Plugin tools like Glyph from Evolve lab for Revit automate & standardize multiple dimensioning tasks like view & sheet creation, tagging, dimensioning & sheet packaging.

Use Case of Chat GPT for Code Generation



Source: BIM PURE-Automating Revit using ChatGPT, with Alex Ritivoi

Here in the use case of AI, ChatGPT is used to produce a code to help with the designing of curved facade & mullions.



1. ChatGPT can also be used for the code generation in integration of Dynamo Scripts.

ChatGPT 4o ▾

We are making a Revit formula
 We have an arch segment
 We know the length between the segment endpoints (Width) & the arch radius (L)
 What is the formula to calculate the distance between the middle of the arch segments & the line uniting the 2 point (H) ?
 Don't forget to format for Revit family

Source: ChatGPT 4.0

2. The response received from ChatGPT

- To calculate the distance between the middle of the arch segment and the line uniting the two endpoints (H) in a Revit family formula, we can use the properties of a circular segment. Given the width (W) and the radius (R), the height (H) can be determined using the following formula:

$$H = R - \sqrt{R^2 - \left(\frac{W}{2}\right)^2}$$

Here's how you can write this formula for a Revit family:

1. Define parameters for the width (W) and radius (R) in your Revit family.
2. Create a new parameter for the height (H) and use the following formula:

$$H = R - \sqrt{R^2 - \left(\frac{W}{2}\right)^2}$$

In Revit's formula syntax, it would look like this:

```

H = R - sqrt(R^2 - (W / 2)^2)
  
```

3. The result is getting a fully completed facade following all the instructions as put inside the conditions of Revit. Thus, this is how we can use the Power of AI for our help in getting the desired output.

Good for Construction (GFC)

AI supports finalizing construction documents for the GFC Stage of Construction, integrating modifications seamlessly, and maintaining accurate revision control across all stakeholder documents. The capabilities of real-time collaboration with all the subsequent AEC models, and data insights to streamline construction workflows.

The ability to ensure that all project documentation is current and compliant with GFC standards, providing tools for document management, version control, and predictive insights that help avoid construction delays. These AI-enabled platforms enhance communication and data accessibility, significantly improving project efficiency and reducing risk.

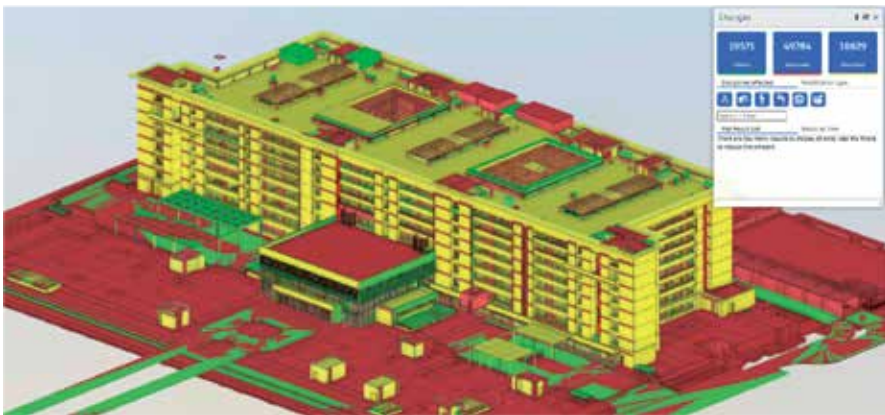
The AI enables tools to have a more data-driven approach where the abilities in the version of comparison between timelines of models, highlighting in different

submissions of sheets too thus enhancing the overall project delivery timelines with major reduction in the errors than the standard delivery approach. These tools enable seamless quantity takeoff.

Platforms like ACC Cloud, Revizto & Blue Beam are the platforms that help in validating the data for the final GFC stage. AI platform plugin for Revit like Dtoac help in reduction of timelines for producing design details. Application like Anker that allows you to create, manipulate and analyze your BIM data in cloud, supercharged by AI and automation with no loss of Data.

Use Case of ACC Cloud for a Hospital Project

The image below highlights the comparison between different versions of the Hospital Project with categorization of the number of changes along with the affected disciplines is again an example of AI.



Source: ACC Cloud: CIMS Hospital Project (SPCPL)

ACC Construction Cloud to analyze clashes between all disciplines like STR VS Revit model comparison & also analyses clashes between the STR VS Mechanical models.

2. AI in Tender Stage

Request for Proposal (RFP)

The RFP phase benefits from AI through automated document management and predictive analysis of bids. AI systems ensure comprehensive evaluation of proposals, enhancing the selection process for competitive and feasible bids.

AI-enabled platforms help analyze the tender documents, reducing the risk of missing details that could lead to exorbitant costs & affect project benefits.

Platforms that are AI enabled help us to summarize & categorize important details which are effective in the calculation of the costing & thus leading to the timely execution of the projects especially in the case of EPC projects.

Tools like Procore, which centralizes bid management, allow project managers to compare and assess proposals based on detailed analytics easily. This ensures informed decision-making by highlighting vendor strengths and weaknesses through historical data and performance metrics.

'Building Connected' specializes in the procurement process, leveraging a vast network of construction professionals and powerful AI tools to enhance the accuracy of vendor selection. It provides detailed insights into vendor reliability and project fit, thereby optimizing the RFP process and reducing the risk of project delays and cost overruns due to poor vendor performance.

Platforms like BIMDCR of Softech are the first of its kind collaborative BIM-based construction permit platform. This innovative solution for automation in Building Plan Scrutiny and approval process applies internal intelligence to read a consolidated 3D BIM model having Architectural other utility objects.

BIMDCR is an innovative 3D Building Model-based Online SINGLE WINDOW system, which enables automatic scrutiny of building proposals by reading Building Models Submitted by Applicant/Architect.

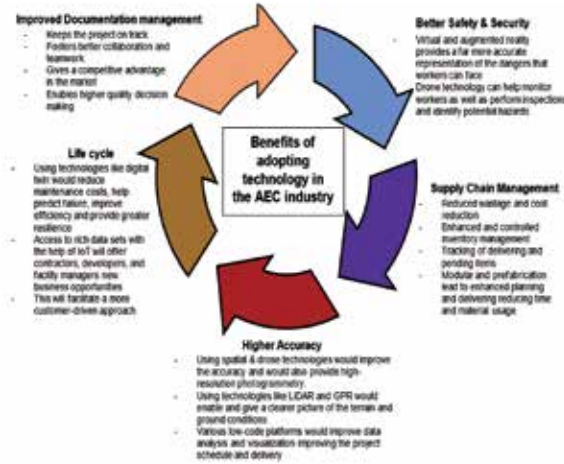


"Source: Softech BIMDCR"

3. AI in Construction Stage

During construction, AI updates as-built documentation in real-time, ensuring it reflects the actual built environment. This accuracy is crucial for compliance verification and future maintenance. AI in construction scheduling can consider task dependencies, priorities, and workforce availability. This helps to optimize schedules and reduce delays. It takes a lot of time to prepare Construction Site visit reports. The AI-enabled platforms help us in the categorization of various images also with detailed analyses. 3D Capture of the structures quickly turns detailed scans into 3D models that reflect the project's status and the physical of the project upon completion. The Prime most important thing is loss of life during construction execution thus to prevent this the AI-enabled platforms can help in analyzing & predicting any future haphazard. Platforms like Leica Geosystems for precise 3d scanning & laser measurements enable us to perform analysis in the Built-In Environment.

Inspect Mind captures site information through voice & pictures on your phone & lets their AI enable the platform to generate inspection reports by the time the representative leaves the job site, thus helping in the reduction of time to generate reports leading to more productive work.



Source: The challenge of Digitization in the AEC Industry

4. AI during Asset Management

Post-construction, AI enhances building management systems (BMS) to optimize energy consumption and manage operational efficiency through predictive maintenance. This reduces costs and extends the lifespan of building components. Smart devices like IoT with AI enable sensors to prevent & predict any maintenance requirements. These systems also give us detailed reports on the number of breakdowns, which provides evidence for the machinery's replacement.

Drone imaging technologies with machine learning capabilities capture the site condition & in the end provide detailed reports for predictive maintenance.



Bridges



Dams



Roads

Source: Qii.AI

Applications like AICON Construction help to log everything that happens on construction site. Create easy time-lapses, let the team track progress online, and start calculating site efficiency along safety prevention with alerts.

IBM TRIRIGA applies AI to optimize facility management by predicting maintenance needs and enhancing space utilization. Its comprehensive analytics help in reducing operational costs and improving the lifecycle management of buildings through intelligent resource allocation and maintenance scheduling.

Siemens Building X integrates AI in its building management systems to enhance energy efficiency and operational functionality. The technology analyzes real-time data from building sensors and systems to optimize energy usage and maintenance, promoting sustainable and cost-effective building management practices.

'Planys' technology AI enabled enterprise level digital reporting platform allows easy representation and analytics of asset maintenance and inspection data, designed specifically for usage with inspection services. Features include geo-tagging of inspection data, rich data presentation, easy navigation, data enhancement, prediction, and analysis of trends in data collected over a long duration. It allows quick analysis, accurate defect quantification, and cross-comparison of inspection data across years and much more.

Conclusion

AI significantly reduces project timelines, costs, and environmental impacts across the AECO industry, while preparing the groundwork for future technological advancements. With the Integration of AI tools, we can execute our project in a more data-driven manner, minimizing errors, increase productivity & efficiency which will also help informed decision-making.

Since AECO is the 2nd least digitized sector, let us put more effort into the integration of various AI-enabled tools for future generations to pursue this field.

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20. Plany's Technologies



Integration of AI in Design and Construction of Built Environment

Usha Batra

Former SDG, CPWD

Prologue

The construction industry, is a multifaceted discipline that encompasses the design, construction, and maintenance of built environment. From bridges & buildings to roads and water systems, civil engineers play a crucial role in shaping the built environment worldwide. Construction is a large industry and is of strategic importance at regional, national and global levels, however, it has been suffering from many problems for a long time. These problems include low productivity, low-profit margins, waste and safety concerns. Approximately 7.22% of the world's working population is employed in the construction sector. Despite its economic importance, dominating problem of this area is low labor productivity which negatively leads to waste of labor, material and financial resources. Due to low digitization in Construction Industry, it leads to in-efficient use of funds and resources, project delays, poor quality of execution, low performance indicators, risks to health and safety of workers.

Engineering and Technology are two inseparable fields. The use of artificial intelligent (AI) has increased in the field of construction engineering and management in recent years, mostly due to the potential of the technology for improving construction performance and efficiency. In India use of BIM is prevalent for design and construction of buildings and application of Artificial Intelligence Technology is seen in Bridge Construction and Maintenance, though on a smaller scale. A few case studies are discussed in the paper.

-Editor-

Introduction

Construction industry faces many problems that hinder its growth and lead to extremely low level of productivity compared to manufacturing industry as shown in Fig. 1.

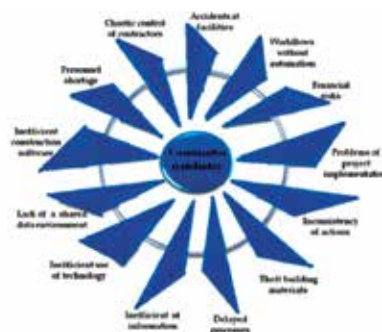


Fig. 1: Key problems of Modern Construction Industry

Source - Svetlana Ivanova

To improve building processes and level of personal safety, new technologies are constantly being introduced in construction sector. Out of all emerging technologies entering the market today, AI is a new technology that is on track to revolutionize the construction industry. One of the overall goals of Artificial Intelligence is to develop computer algorithms and these algorithms can be used to improve processes in a much faster way than a human brain could ever imagine doing.

Artificial intelligence (AI) is a computer based system capable of performing complex tasks that historically only a human could do, such as reasoning, making decisions, or solving problems. Digital assistants, GPS guidance, autonomous vehicles, and generative AI tools (like Open AI's Chat GPT) are just a few examples of AI in our daily lives. Types of AI and their uses are shown in Fig. 2

As a field of computer science, artificial intelligence encompasses (and is often mentioned together with) machine learning and deep learning. These disciplines involve the development of AI algorithms, modeled after the decision-making processes of the human brain, that can 'learn' from available data and make increasingly more accurate classifications or predictions over time.

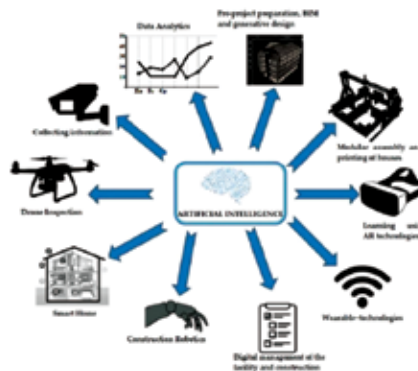


Fig. 2: Types of AI and their uses

Source - Svetlana Ivanova

Building Information Modeling (BIM) and the Internet of Things (IoT) are two digital processes and technologies that have seen growing use in the construction industry in India over the past few decades. The availability of both computer power and data has resulted in a rise in the utilization of applications of artificial intelligence more recently.

BIM

BIM is software which is useful in planning as well as construction that improves communication and collaboration between all project stakeholders, reduces errors and rework costs, increases efficiency & productivity and helps in better informed decision-making throughout the project lifecycle. BIM 360 acts as a common data environment (CDE) where all project documents, models, and information are stored in one secure location. This allows everyone involved in the project to access the latest information anytime and anywhere.

Architects and engineers use BIM software to create a 3D model of the building which includes a rich database of information about every element like walls, doors, windows, and MEP (mechanical, electrical, and plumbing) systems. This information allows for clash detection - identifying and resolving conflicts between different building components before construction even begins. BIM also helps with simulations, like analyzing energy efficiency or running daylight studies.

The BIM model becomes a central source for everyone involved in construction. It can even be used to generate accurate estimates, create detailed construction plans, visualize the sequencing of construction activities and to fabricate building components off-site, ensuring a perfect fit when they arrive on the construction site.

AI combined with BIM can automate the entire clash detection process, prioritizing them based on severity and suggesting potential solutions, thus freeing up valuable time for architects and engineers.

IoT

The IoT has automated our home / buildings to be more energy efficient. Similarly, the IoT is used at site to make them safer. We have able sensors that identify the location of workers & provide any alerts if a worker slips or falls. Field reporting software allows foreman to enter job-site activity or alerts issues like keeping important project stake holders informed in real time even if they are not on job-site.

Robotics, AI, and the Internet of Things can reduce building costs by up to 20 percent.

Role of AI and Opportunities for its Integration in Construction Industry

Artificial intelligence (AI) is having a significant impact on the construction industry, transforming how projects are designed, managed, and executed. Some of the key roles are as given in the following:

1. **Enhanced Design and Planning:** AI algorithms can analyze vast amounts of data to optimize building designs. This includes identifying patterns in past projects to suggest improvements, simulating building efficiency for sustainability, generating 3D models for better visualization and clash detection, cost and durability. By automating the design process and exploring the wide range of design alternatives evolved, one can choose the best solution more easily saving great amount of time.
2. **Risk Management and Improved Project Management:** AI-driven risk management systems can analyze project data, identify potential risks, and assess their impact on project. Accordingly, measures can be taken to mitigate risks, minimize project delays, cost overruns and safety incidents throughout the project lifecycle. One can anticipate potential risks like delays or material shortages, thus allowing proactive measures. AI can also automate tasks like scheduling and resource allocation thereby improving efficiency. AI algorithms can analyze supply chain data, optimize inventory levels, and identify opportunities for cost savings and efficiency improvements. By integrating AI into supply chain management processes, engineers can streamline procurement, reduce lead times, and improve project delivery schedules.

3. **Streamlined Construction Processes and Construction Management:** AI-powered tools can automate repetitive tasks such as data entry, document analysis, progress monitoring, identify patterns and trends, and predict potential delays or cost overruns to improve efficiency and reduce risks. Additionally, AI-powered quality control systems can use cameras and sensors to identify defects in real-time, ensuring adherence to specifications, quality of work, and perform tasks like site surveying, excavation and assembly by robotics and automation technologies.
4. **Asset Management:** AI algorithms can analyze data collected by sensors installed at infrastructure projects e.g. bridges, roads etc. to detect signs of deterioration, predict maintenance needs thereby reducing downtime, extending asset lifespan and optimizing maintenance costs.
5. **Environmental Impact Assessment:** AI can analyze environmental data to understand the potential environmental consequences of their projects and identify mitigation measures to minimize negative impacts.
6. **Increased Worker Safety:** AI can play a crucial role in enhancing safety at site. By analyzing data from wearables and sensors, AI can identify unsafe situations and alert workers or managers to potential hazards.
7. **Collaborative Design and Decision-Making:** AI-enabled collaboration platforms can facilitate communication and information sharing among project stakeholders, enabling more effective collaboration and decision-making. This empowers all stakeholders to make informed decisions and coordinate activities across distributed teams.
8. **Optimized Building Performance:** AI can analyze data from building systems to optimize energy efficiency, occupant comfort, and overall performance. This can lead to significant cost savings and create more sustainable buildings.
9. **Continuous Improvement and Learning:** AI algorithms can analyze project performance data and identify opportunities for process improvement and optimization. This empowers project stakeholders to identify best practices, lessons learned and areas for improvement to use in future projects for improvement.

Overall, AI is transforming the construction industry by improving efficiency, reducing costs, enhancing safety and promoting sustainability. As AI technology continues to evolve, even more innovative applications are expected that will reshape the future of construction industry. Thus, vast and varied opportunities exist for integrating artificial intelligence (AI) into civil engineering practice that offer potential benefits across the entire project lifecycle, from planning and design to construction and maintenance.

Implications and Challenges

1. **Ethical and Social Implications:** The adoption of AI in civil engineering raises ethical concerns related to privacy, bias, and accountability e.g. it may inadvertently perpetuate biases existing in historical data, leading to unfair outcomes.

2. **Data Privacy and Security:** AI systems rely on vast amounts of data, including sensitive information such as project plans, financial records, and personal data. Privacy and security of this data needs to be ensured to prevent unauthorized access, data breaches, and cyber-attacks.
3. **Technical Challenges:** Implementing AI in civil engineering practice requires Technical expertise in addition to investment in technology, infrastructure, software licenses and training programs.
4. **Regulatory and Legal Considerations:** The deployment of AI in civil engineering may raise regulatory and legal challenges related to liability, accountability, and compliance.
5. **Skills and Training:** Adopting AI technologies in civil engineering practice necessitates up-skilling and training the workforce to effectively use and manage these technologies.
6. **Resistance to Change:** There may be resistance to change within the civil engineering industry as engineers and stakeholders need to struggle with the implications of incorporating AI into established workflows and processes.
7. **Long-term Sustainability:** The long-term sustainability of AI in civil engineering practice depends on many factors. Engineers need to consider the lifecycle costs and environmental footprint of AI systems and weigh the trade-offs between short-term benefits and long term sustainability.

Application of AI in Maintenance, Rehabilitation, Retrofitting and Restoration

Infrastructure in harsh environments are extremely susceptible to damage. AI technology also plays a significant role in maintenance, intelligent materials, detection systems, and disaster prevention measures thus enhancing efficiency and quality.

Smart Materials The application of AI in materials science has facilitated the development of smart materials, which possess self-healing and adaptive environmental properties and thus can significantly enhance the durability and safety of bridges.

Smart materials are capable of autonomously responding to environmental changes, such as temperature, pressure, humidity, light, electricity, and magnetic fields by exhibiting corresponding functional adaptations. These responses encompass alterations in shape, hardness, coloration, among others.

Intelligent detection system based on unmanned aerial vehicles

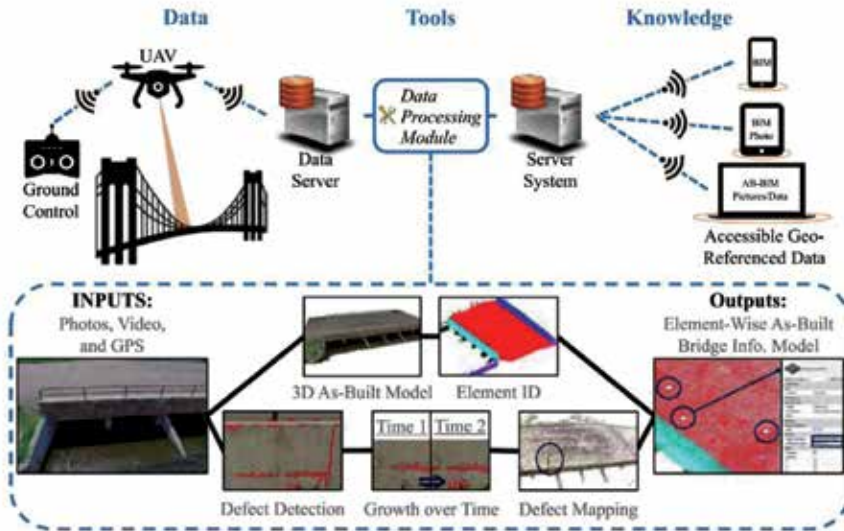


Fig. 3: Intelligent detection system based on unmanned aerial vehicles

Source - ACEGE 2023

Today, Unmanned Aerial Vehicles (UAV) plays a vital role in AI. Intelligence detection system based on UAV (Fig 3) utilizes aerial photography to collect data, which is then processed through a series of tools to create an intelligent model for each component of the deteriorated structure. Subsequently, automated damage/defect detection algorithms analyze the images to identify cracks, spalling, and scaling in concrete, providing quantitative information regarding the location, type, and severity of damage, helping efficiently to assess the structural condition of existing infrastructure.

Two case studies of the bridges are presented here highlighting the importance of AI in bridges.:

Case Studies

1. **Delaware's Indian River Inlet Bridge;** -Opened to traffic in May 2012, the cable-stayed bridge has a main span of 289m and back spans of 121m. It was constructed using a combination of cast-in-Situ and pre-cast reinforced concrete. In an effort to enhance the long-term maintenance and management of this significant infrastructure, a comprehensive structural health monitoring (SHM) system was installed on the bridge. This is the first long-span, cable-supported bridge in the U.S. which has a permanent long-term structural health monitoring system installed during initial construction. The fiber-optic SHM system has 144 sensors distributed throughout the structure. These sensors measure strain, acceleration, tilt, bearing displacement, temperature, wind speed and direction and chloride ingress at crucial locations of the bridge. The SHM system provides valuable quantitative data which can be utilized by the authorities in their management and maintenance of bridge for years to come.

2. Signature Bridge in Delhi

This cable-stayed bridge has total span of 675m, with a main span of 251m. It has four lanes of traffic in each direction. Its dramatic inclined steel pylon, with a height of 154 meters and elegant stay cable design makes it specifically attractive and imposing addition to the Wazirabad skyline.



Fig. 4: Signature Bridge, Wazirabad, Delhi

Source - Chinmoy Ghosh & others

The bridge is equipped with a sophisticated structural health monitoring system to fulfill the purpose of;-

- a. Structural health monitoring and damage detection.
- b. Monitoring of weather loading (e.g. temperature, storms)
- c. Earthquake monitoring

The system consists of total 104 sensors, using 171 data channels to measure environmental, load and structural response factors, a signal acquisition solution, including signal capture from the sensors, data processing to generate reports, and data storage as depicted in Fig.5. All components provided shall be able to sustain severe environmental conditions. The system is designed to sustain partial damage with undamaged parts remaining operational without losing real-time or stored data.

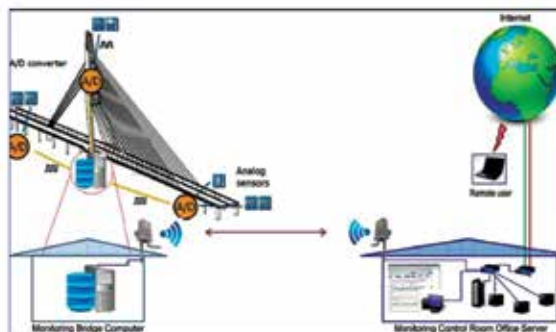


Fig.5: Data Transmission

Source - Chinmoy Ghosh & others

Hardware and software are designed and selected to ensure that they can be engineered or replaced with commonly available alternatives in future in case current supplier is unable to meet the needs.

A data file with summarized results on environmental conditions, bridge behavior and bridge performance is automatically generated and stored on the hard disc at the end of each month. The reporting period however can be adjusted to cover shorter or longer intervals as required.

Learning from case study: -Maintaining structural integrity of the Bridge for longer period of time reduces its demolition and rebuilding cost along with long-term and short-term structural maintenance costs. It also reduces need to halt profitable operations for large scale safety Inspections. Time plays an important role in comparing SHM with the traditional methods of damage detection which takes ample amount of time. Time used in rebuilding the degraded structures would also be saved by continuous monitoring of structure and providing immediate remedy or repair work at early stage only.

The quality and safety of structures will be maintained by using SHM systems as it will check quality of structure at every stage of construction and also after the construction is finished.

In India, applications of SHM are very rare in civil sector due to lack of awareness and expenses of SHM technology ,whereas onetime expense at the installation stage provides benefits like increased life span of structures, continued detection of risks without non destructive testing thus helping in improving the overall performance , life and safety of the structure.

Case Studies with Success Stories

1. Predictive Maintenance for Infrastructure Assets:

Case Study: A civil engineering firm implemented an AI-driven predictive maintenance system for monitoring the structural health of bridges. The system integrated sensor data from bridge sensors, with AI algorithms to detect signs of deterioration and predict maintenance needs.

Success Story: It enabled the civil engineering firm to proactively identify structural issues before they escalated into costly failures or safety hazards, achieving significant cost savings and improving the overall safety and reliability of the bridges under their management.

2. Generative Design for Optimized Infrastructure Designs:

Case Study: An architectural and engineering firm utilized AI-driven generative design tools to optimize the design of a new pedestrian bridge. The firm fed design parameters such as span length, load requirements, and material constraints into the generative design software, which automatically generated and evaluated thousands of design alternatives. By analyzing given alternatives, engineers identified a design that minimized material usage while meeting structural integrity and aesthetic requirements.

Success Story: It enabled optimal solution that achieved significant material savings without compromising structural performance or design aesthetics. Bridge not only met the project requirements but also gained recognition for its innovative design approach.

3. Construction Project Management and Risk Mitigation:

Case Study: A construction company implemented an AI-powered project management system to optimize construction workflows and mitigate project risks. The system analyzed historical project data, including schedules, budgets, and performance metrics, to identify potential bottlenecks, delays and cost overruns.

Success Story: The system enabled the construction company to improve project outcomes and mitigate risks by providing real-time visibility into project performance and facilitating proactive decision-making, thereby achieving higher project success rates, reducing project delays and cost overruns, besides enhancing client satisfaction.

4. Environmental Impact Assessment and Sustainable Design:

Case Study: An environmental consulting firm used AI algorithms to assess the environmental impact of a proposed infrastructure project on local ecosystems and communities.

Success Story: The AI-driven environmental impact assessment enabled the consulting firm to provide actionable insights and recommendations. By incorporating these considerations into the project planning and design process, the firm could mitigate potential environmental risks and promote sustainable development.

Thus, by leveraging AI technologies and techniques, civil engineers can optimize project outcomes, improve decision-making, and address complex challenges facing the industry.

Conclusion

- Artificial intelligence (AI) is a computer based system capable of performing complex tasks that historically only a human could do, with a goal to develop computer algorithms that can improve automatically through experience in construction.
- AI technology in civil engineering practice offers potential benefits across the entire project lifecycle- from design optimization to management of construction, assets and decision making at every stage.
- BIM software being used in India allows for clash detection - identifying and resolving conflicts between different building components before construction even begins but AI combined with BIM can automate the entire clash detection process.
- As AI systems rely on vast amounts of data, including sensitive information such as project plans, financial records, and personal data, it is challenging to ensure its unauthorized access, data breaches, and cyber-attacks.
- Application of AI in Bridge construction and maintenance helps in improving the overall

performance and life of the structure.

- Leveraging AI technologies and techniques, civil engineers can help optimize project outcomes, improve decision-making, and address complex challenges of construction industry.

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Rationalizing, Reinventing and Redefining Construction Industry Using Artificial Intelligence

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Prologue

Construction industry is known for generating employment, making valuable contribution to economy and prosperity and promoting large scale industrialization besides providing basic amenities, services, and infrastructure to the people. With rapid growth of industrialization and urbanization, role, relevance, and importance of construction sector has gained prominence. However, despite many positivity, construction is plagued with problems related to productivity, efficiency, optimum use of resources, managing manpower, cost, time, quality, safety, security, project management etc. These problems have genesis in the fact that construction sector remains largely human driven with least induction of technology. Accordingly, there is an urgent need to induct, both soft and hard, skills in the sector to make it more efficient and productive. Paper looks at the use of information technology enabled service and Artificial intelligence, as the options to make construction sector more efficient, productive, and qualitative.

-Editor-

Introduction

Making large contribution to economy, share of construction sector in Indian economy was placed at around 8.2%, and contribution made to GDP was of the order 670,778 crores (US\$ 131 billion) at factor cost in 2011–12. Estimated to register a CAGR of over 6%, construction sector is expected to reach \$1.4 trillion mark by the year 2025. Construction sector provided employment to more than 49.5 million people, next to agriculture sector in the country. Despite having large contribution to economy and prosperity, construction sector remains a laggard in adopting technology, both hard and soft including artificial intelligence, and remains inefficient and less productive. Future growth story of India, becoming a third largest economy globally (\$5 trillion), will hinge on the operational efficiency, productivity, and sustainability of the construction sector, based on adopting state of art construction technologies.

Issues and Challenges of Construction Sector

The sector is faced with numerous operational and policy level challenges that have hindered its growth and has resulted in low levels of productivity. Majority of issues and challenges facing the sector are:

- **Lack of Technology:** Construction sector remains largely human driven with least input of technology at the grass root level. Technology has been embedded in few large projects and that too by few of the reputed construction companies.

- **Unskilled manpower:** Despite being the second largest employment generator, the construction sector remains largely unskilled and manual driven.
- **Poor Project Management:** Employing large unskilled manpower, having no interface with emerging technologies has made construction sector most unprofessionally managed sector of the Indian economy.
- **Time and Cost Overruns:** Majority of construction projects in India, invariably suffer from the malaise of both cost-overrun and time overrun, adversely impacting project's economic viability.
- **Poor Quality of Construction:** In the absence of technology and soft skill, construction projects face the quality issues, which invariably increase the life-cycle cost of the project due to increased maintenance, upkeep and replacement costs.
- **Consumer of large Resources:** Studies and analysis made have revealed that buildings consume about 16% of world's fresh water withdrawal; 25% of wood harvested; 30% of raw material extracted from the planet earth; 40% of global energy consumption; 35% of world's CO2 emission; 40% of Municipal solid waste generated; 50% of Ozone depleting CFC's. Large consumption of resources and generation of waste during construction, can be largely attributed to non-availability of adequate skill, expertise, knowledge and understanding of state of art construction practices, leading to adoption of linear system of using resources.

Role of Artificial Intelligence in the Construction Sector

Artificial Intelligence refers to systems capable of performing complex tasks that historically only humans could do, such as reasoning, making decisions, or solving problems. Artificial Intelligence holds distinct advantages in terms of driving advancements and innovations in the construction industry in the field of quality, speed, safety, efficiency, accuracy, optimizing use of material resources and manpower and that the projects are carried out smarter. Few of the options which can be leveraged in the construction sector by using Artificial intelligence have been enumerated below:

- **Data Based Project Management :** Construction sector invariably suffers from the problem of lack of effective data management. Artificial intelligence holds enormous capacity to integrate the available data by pooling data from different sources on a common platform, to help project management team in rationalizing the decision making of the complex task involved in the construction projects.
- **Planning and Designing :** Artificial intelligence holds capability of decision making based on the data base. If the realistic parameters and scope of any construction project are properly defined, then Artificial intelligence can help in selecting appropriate designs out of multiple options generated by the systems.
- **Productivity :** Artificial intelligence offers enormous, opportunities to make Construction sector more productive, skilled, and operationally efficient by replacing manual work involved in the project through machine learning. Artificial intelligence can help in

defining precisely work flow of various construction components, which can be used for overcoming duplications and replications of different processes and making optimum use of available resources.

- **Managing Manpower** : In the prevailing scenario, in large sized projects, involving deployment of large manpower on regular basis, managing the manpower deployed and measuring their productivity and operational efficiency always remains a challenge. Artificial intelligence, holds enormous capacity of not only mapping the manpower deployed but also providing data related to their work output on daily basis, for effectively managing the project and manpower required. Artificial intelligence can also help in rational re-deployment of the manpower in the project based on the requirement in a particular area/activity.
- **Managing Inventories** : Being data driven, Artificial intelligence can help in managing material, including the material used / available in the store, material required immediately and over a period of time. It can help in reducing inventories, pilferage in the store and managing waste/ loss of materials from the stores. Artificial intelligence can help in defining timeline for requirement of different materials and its need at the project site, so as to tie up with the supplier in order to avoid delay in the completion of the project, due to non-availability of required materials. Use of machinery in the construction project can also be optimized through the effective use of Artificial intelligence.
- **Promoting Sustainability** : Use of energy / water can also be easily predicted, monitored, and managed through Artificial intelligence, accordingly project can be made more sustainable by optimizing the use of the energy/ water in the project. Artificial intelligence, can lower the cost of the project by promoting saving on energy and water used in project besides helping in minimizing its consumption.
- **Empowering Construction Sector** : By large scale digitization, artificial intelligence can empower the construction sector by eliminating number of prevailing issues related to cost-overrun, time-over run, delay in completing the projects and effectively monitoring and managing the project besides ensuring optimum utilization of the available manpower, machinery, and materials.
- **Making Construction Sector Technology driven** : Majority of practices in Construction sector remain onsite and manual, which are the prime reasons for the sector to be inefficient and less productive.

Making, Artificial intelligence, integral part of the construction sector, can help in introducing using Drones for monitoring and evaluation of the project; using 3D as an option for construction; using virtual reality for assessing/ evaluating the projects; using circular economy as an option of project planning, designing and using materials; making use of the state of art construction technologies; making payments; managing cost and funds; signing contract documents; preparing detailed project reports; preparing project estimates; tendering of the project; evaluating the tenders; preparing progress reports; promoting collaboration and co-ordination etc., which can go a long way in making construction sector technology driven.

Conclusion

Absence of digitization and involving large unskilled manpower makes the management of construction projects complex, cumbersome and cost and resource intensive. Considering the disasters striking humanity more frequently like pandemic Covid 19; there is realization that construction industry must be made technology led by embracing digitization to overcome the challenges posed by lack of skilled labour shortage, maintain the operational efficiency and quality of the construction sector. Induction of Artificial Intelligence, in construction sector has the ability and capacity of achieving significant process improvements, promoting cost-efficiency, reducing construction time, improving safety and helping in achieving sustainability goals.

In order to induct technology and Artificial Intelligence into the construction sector and make it a distinct reality it will be critical to; make Artificial Intelligence integral part of teaching – learning process; skilling existing manpower; promoting greater interface between IT sector and construction industry and laying down an enabling and empowering technology supportive policy framework by the government. However, it needs to be understood and appreciated that despite the fact Artificial Intelligence has opened up numerous opportunities, but also has its own limitations in applicability and operational negativities and accordingly, needs to be used with care and caution, without causing any abnormalities, distortions, and roadblocks in the efficient operation of the construction sector.

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Artificial Intelligence Transforming Construction Industry

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Prologue

Artificial intelligence is set to revolutionise the construction industry by improving efficiency, enhancing safety, and reducing costs. The paper provides a comprehensive analysis of AI's current state in the construction industry, explores potential applications and identifies obstacles that must be overcome for the technology to be widely adopted. This research offers strategic recommendations and practical insights to stakeholders in the construction sector by examining current literature and expert interviews.

-Editor-

Introduction

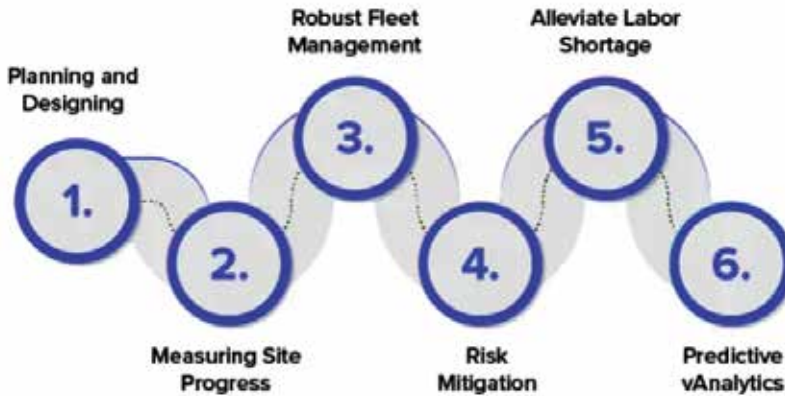
The construction industry, traditionally resistant to change, is experiencing a paradigm shift driven by Artificial Intelligence. Long burdened by cost overruns and schedule delays, construction projects are finding solace in AI's ability to optimise planning and resource allocation. This not only improves efficiency but also mitigates risks by analysing vast datasets to identify potential bottlenecks. Furthermore, AI empowers Building Information Modelling (BIM) software, allowing for clash detection between different building components and ensuring a smoother construction flow. Safety, another major concern, is addressed by AI-powered robotics that can perform hazardous tasks, minimising human exposure to danger zones. AI-powered sensors embedded in equipment and materials enable preventative maintenance, reducing downtime and unexpected equipment failures. The impact of AI extends beyond efficiency; it tackles the skilled labour shortage by automating tasks like bricklaying and welding, freeing up human workers for more specialised roles.

This integration of AI is not merely futuristic; a case study of a construction company implementing an AI-powered project management platform exemplifies the tangible benefits. This platform, analysing historical data and suggesting optimised schedules, led to a remarkable 20% reduction in project timelines and a 15% decrease in overall costs. The innovations like AI-driven construction contracts and autonomous construction vehicles poised to revolutionise the industry. AI is not a fleeting trend but a transformative force that promises to propel the construction industry toward a more efficient, safe, and sustainable future.

Status of AI in Construction

The construction industry is reaching the limits of traditional methods, shown by stagnating growth and increase in substandard works. To address these issues, the industry can

AI Use Cases in Construction



adopt automation and IoT technologies, similar to other sectors. AI built devices in built environments offer opportunities for user interaction through open interfaces, but proprietary systems can hinder widespread adoption. By integrating AI with building information data using open messaging interfaces, more stakeholders can be engaged, preventing reliance on closed systems. This approach supports innovation and effective data navigation. However, challenges include standardising data exports, ensuring secure interfaces, and managing ethical and privacy concerns. Future research should focus on these challenges to enable the effective deployment of IoT and automation in construction, leading to improved efficiency, safety, and project outcomes. Integrating AI and IoT can significantly enhance construction productivity and innovation, meeting modern infrastructure demands effectively.

Methodology

The paper utilises a mixed-methods approach, combining a systematic literature review and expert interviews. Data is collected from academic databases, industry reports and survey responses from construction professionals.

Predictive Maintenance

One notable example of successful AI implementation in predictive maintenance is showcased by a leading construction company that has integrated AI algorithms to foresee equipment failures and schedule maintenance accordingly. This approach minimises downtime and maximises the operational efficiency of construction machinery. By analysing historical data and real-time sensor inputs, the AI system predicts potential failures, allowing for timely maintenance and avoiding costly disruptions.

Safety Monitoring

AI-powered safety monitoring systems have been successfully implemented in a major construction project, significantly enhancing worker safety, and reducing the incidence of accidents. These systems utilise computer vision and real-time data analytics to identify potential hazards, ensure compliance with safety protocols, and provide immediate alerts

to workers and supervisors. This proactive approach has led to a considerable decline in workplace accidents and improved overall safety standards on the site.

Project Management

AI has been effectively utilised for project planning and management, resulting in improved project timelines and cost savings. Through advanced data analysis, machine learning, models can optimise scheduling, resource allocation, and risk management. This has allowed construction managers to make more informed decisions, anticipate potential issues, and streamline the overall project execution process.

Survey Findings

Despite the immense potential of AI, a recent report by The Indian Express (15/02/24) reveals several key roadblocks hindering its successful adoption within enterprises. The most significant challenge (30%) lies in the lack of skilled personnel. Companies struggle to find data scientists, AI engineers, and domain experts who can navigate the complexities of AI development and ensure its alignment with real-world business needs.

Compounding this issue is the absence of proper infrastructure (28%). Many enterprises lack access to cloud computing resources, specialised development tools, and model management platforms – all crucial aspects of building, deploying, and maintaining effective AI models.

Even after overcoming these initial hurdles, challenges persist. Integrating AI seamlessly into existing systems (27%) can be difficult due to legacy infrastructure incompatibility and data silos within organisations. Furthermore, scaling these models to handle larger datasets or broader applications remains a challenge.

Ethical considerations (26%) also play a significant role. Concerns about bias in decision-making and the lack of transparency in AI algorithms raise red flags. Additionally, ensuring user privacy when handling personal data in AI development is paramount.

Finally, data itself presents its own set of hurdles (25%). The time and expense required for data collection, the complexities of data cleaning and pre-processing, and the need for robust data security measures all contribute to the challenges of utilising data effectively for AI projects.

Recommendations

By overcoming challenges and implementing strategic solutions, the construction industry can embrace the transformative power of AI and build a smarter, safer, and more sustainable future. While AI offers a wealth of potential for enterprises, successfully harnessing its power requires a multi-faceted approach towards overcoming these barriers. To unlocking the transformative potential of AI, the research makes following recommendations:

- **Invest in training:** Enhance the digital skills of the construction workforce through comprehensive training programs.

- **Implement incrementally:** Begin with pilot projects to demonstrate the value of AI and build confidence before wider adoption.
- **Collaboration is key:** Foster collaboration between industry players, regulators, technology providers, and educational institutions to create a supportive AI ecosystem.
- **Address ethical concerns:** Develop guidelines to address ethical issues like data privacy and job displacement during AI implementation.

Conclusion

Artificial intelligence is on the verge of revolutionising the construction industry, but there are still hurdles to overcome. While AI has already made significant progress in areas like predictive maintenance, safety monitoring, and project management, its overall use is still limited. The high cost of adoption, especially for smaller companies, and the lack of digital skills among the workforce are major obstacles. Additionally, concerns about job losses due to automation necessitate solutions for retraining displaced workers.

Despite these challenges, the future of AI in construction is promising. By making the industry safer, more efficient, and more sustainable, AI has the potential to fundamentally change how we design, build, and maintain structures. Integrating AI with complementary technologies like BIM, IoT, and Augmented Reality (AR) will empower data-driven decision-making for smarter and more resilient built environments.

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