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Applications of Artificial Intelligence in Enhancing Construction Safety and Productivity

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Abstract

The construction sector is experiencing a transformation in its operations as a result of the implementation of Artificial Intelligence (AI), which has reduced the likelihood of human error, increased productivity and improved safety. This study puts together the latest research and developments in the use of AI technologies including machine learning, computer vision, robotics, and natural language processing to make construction sites safer and more productive. AI has brought about new technologies, such as very powerful ways of computing that function like the brain. It introduces real-time monitoring systems, predictive safety modeling, self-driving machines and smart scheduling tools that are changing the industry. AI is becoming more common in the construction business, although not as much as in other industries. Also, even though AI is a trendy issue in built environment research, there aren't many review studies that look at why AI isn't being used more in the construction sector. The purpose of this study is to bridge this gap by determining the advantages of AI and the steps the construction industry needs to take to implement it. The researchers and practitioners may also learn how to use AI better by reading about the problems and possible solutions that lie ahead.

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INTRODUCTION

The construction business is dangerous and unproductive by nature since it relies on physical labor and changing site conditions. The International Labor Organization (ILO) says that construction is responsible for around 20% of all workplace deaths across the world (ILO, 2021). At the same time, things like delays in schedules and cost overruns are prevalent. The use of Artificial Intelligence (AI) has become a game-changing way to solve these ongoing problems by adding automation, data analysis, and smart decision-making to construction workflows (Zhou et al., 2021). Innovations in the construction industry are essential for addressing the sustainability challenges of urban areas in a world that is swiftly urbanizing (Zhang et al., 2021). However, the construction industry has remained one of the low-innovation sectors, with limited productivity and development (Javed et al., 2018). In comparison to manufacturing, retail, and telecommunications, the construction industry is one of the least digitalized industries in the world. The construction industry's efficiency has been called into doubt as a result of the 1% annual increase in productivity over the past two decades (Young et al., 2021). The slow performance development is a result of the construction industry's fundamental rules and characteristics. The companies are commencing the investigation of artificial intelligence (AI) as a means of optimizing processes and enhancing productivity in response to this gradual performance growth (Yigitcanlar.,

2021). The benefits include the prevention of cost overruns, enhanced site safety, increased project management efficiency, and increased productivity on sites (Chien et al., 2020). The implementation of AI technologies has improved automated processes and granted a competitive edge. However, the implementation of AI on construction sites is a difficult task. The accurate data is necessary for the training of the majority of algorithms. The majority of construction companies find the process of collecting large datasets to be both time-consuming and expensive (Blanco et al., 2018). Furthermore, the implementation of AI on sites is further complicated by the non-standardized building designs and outdoor environmental conditions (Yigitcanlar., 2021). As a result, the industry is progressively integrating AI technologies into its daily operations in order to transition from a traditional hierarchy to a digital and more autonomous hierarchy. Industrialization, globalization, and digitalization have already brought about substantial transformations in the construction sector.

The industry will experience a series of significant changes over the next five years, including a product-based approach, specialization, value-chain control and supply chains, consolidation, customer centricity, investment in technology, human resources, internationalization, and sustainability (Naser., 2019). The current project-based construction processes will be replaced by a product-based approach as a result of these changes. This novel method will either digitally or through vertical integration consolidate a number of phases in the value chain. The companies will fabricate structures offsite rather than constructing them on-site (Regona et al., 2022). The procedure may bear similarities to other manufacturing processes.

The construction process is expected to become more standardized, consolidated and integrated in the future. The off-site production of structures and products resulting the system more product-based and efficient. Additionally, the degree of internationalization will be enhanced by the consolidation of the value chain (Shukla et al., 2019). Future designs will be optimized through the utilization of data and analytics regarding consumer behavior. The construction ecosystem's future will be significantly influenced by the development of AI technologies. The digitalization is necessary step in order to consolidate the value chain and transition to a more data-driven decision-making process. (Xin et al., 2022).

LITERATURE REVIEW

Recent developments in Artificial Intelligence (AI) have had a big impact on the construction industry, especially when it comes to making work safer and more productive. Many research has shown that machine learning algorithms may help forecast and stop accidents by looking at past incident data, site circumstances, and how the workers act in the environment (Zhao et al., 2019). Computer vision apps have also made it possible to find hazards in real time, to check that workers are wearing the right personal protective equipment (PPE) and keep track of workers using picture recognition and deep learning models (Kim et al., 2021). Liu et al. (2020) have also employed wearable sensors that are integrated with AI systems to monitor physiological indicators, including fatigue, heart rate and body posture. This approach has been shown to reduce the risk of injury on construction sites. AI-powered solutions have been used to improve resource allocation, automate scheduling, and make it easier to track progress with the use of drones and Building Information Modeling (BIM) integration (Golparvar Fard et al., 2015). Also, autonomous robots and equipment have been found to make dangerous or repetitive operations more efficient, which means that fewer people have to execute them and there are fewer mistakes (Bock & Linner, 2016).

Even with these improvements, researchers stress the importance of more study into how humans and AI can operate together and the creation of common frameworks for how AI may be used in construction workflows (Zhou et al., 2021).

AI Technologies in Construction

AI encompasses a broad range of technologies. The following subsections summarize the key AI components used in construction along with table 1 for its clear understanding. In addition, the substantial quantity of unstructured data on websites suggests that numerous platforms are unable to effectively analyze and operate on these datasets. The data collected and monitored across the organization and project lifecycle must be standardized in order to accomplish useful analytics. The worldwide construction sector has just lately begun to put money into the research and development of digital technology. The companies are starting to realize how these technologies may help them run their businesses better and be more productive (Regona et al., 2022). All of these good things that technologies may offer to a construction firm will assist the built environment in cities deal with safety issues, a lack of workers and costs and schedules that go over (Yun et al., 2016).

The construction industry is a developing web of hardware and software solutions that work together. Around the proven use cases, the idea of distinct "constellations" of linked solutions comes up. These show which technologies are becoming the most popular (Grover et al., 2020) Also, the technologies in the same "constellation" work well together since they make more solutions possible. Some of the most important constellations include 3D printing, modularization, robots, digital twin technologies, AI, analytics and supply chain optimization. Three of the digital twins, 3D printing, and AI and its analytics will change the way the industry works. The fourth constellation that is "supply chain optimization" is also predicted to be important in the near future. This is because optimizing the supply chain is becoming more and more important during and after the COVID-19 pandemic (Kim et al., 2015). The following are the main technologies that will have an effect on the construction sector in the near future including block chain, AI, big data analytics, the internet of things (IoT) and information communication technology (ICT) (Young et al., 2021).

Machine Learning (ML)

The robots are becoming increasingly common on building sites, and they will be quite specialized, such for painting, bricklaying, and loading. The technology will aid sites since it cuts down on the time spent on boring activities and keeps workers safe at risky building sites. The surveyors often utilize aerial drones to look at locations and gather information that lets them make 3D models of buildings. ML algorithms enable systems to learn from historical project data to predict safety risks and optimize performance. The supervised learning is commonly used for safety incident prediction while unsupervised learning helps detect anomalies in real-time data (Dong et al., 2020).

Computer Vision

In construction, computer vision may be used to find hazards, check that workers are wearing the right PPE, and recognize what workers are doing. The use of cameras and drones with image recognition algorithms makes it easier to see what's going on at a location and keep track of hazards (Kim et al., 2021). It is simpler to uncover and study dangers when you use modern technology that predicts occurrences and gives early warnings. The smart wearables may collect data for analysis and AI algorithms can

correct problems that happen on the job and come up with new methods to make things operate more smoothly. Data analytics may also assist you make judgments and organize your strategy.

Natural Language Processing (NLP)

NLP is used for automating documentation, extracting insights from safety reports and interpreting worker feedback. This helps in understanding safety trends and improving communication across teams (Fang et al., 2022).

Robotics and Automation

AI-powered robots are used for jobs that are risky or boring, such pouring concrete, laying bricks and tearing down buildings. Autonomous equipment makes projects go faster and keeps workers safer (Bock & Linner, 2016). These tools keep workers up to date on what's going on at the job site, which decreases the risk of accidents between workers and heavy gear.

Table 1.

Common AI technologies and their uses (Regina et al., 2022)

AI Technology	Applications
Machine learning	Big data and data analytics
Pattern recognition	Data and system integration
Machine learning	Robotic and automation
Automation	Mobility and wearable

Prominent Artificial Intelligence Technologies in Construction

The construction industry is increasingly implementing Artificial Intelligence (AI) technologies to enhance safety, efficiency and decision-making. Machine learning (ML), computer vision, natural language processing (NLP), and robotics are some of the most well-known AI technologies. Each one has its own set of skills that may help with building problems. ML algorithms are often used for predictive analytics, which lets us find safety hazards and project delays early on by looking at past data (Dong et al., 2020).

The computer vision which uses surveillance cameras and drones makes it possible to watch construction work in real time and automatically find dangers and make sure that safety rules are being followed (Kim et al., 2021). NLP helps make sense of unstructured data from safety reports, daily logs, and worker input. This data may then be used to improve safety management methods (Fang et al., 2022). Robotics and automation are also very important for doing jobs that are repetitive or dangerous. They make work more productive while keeping people out of dangerous places (Bock & Linner, 2016). More and more, these technologies are being used with Internet of Things (IoT) devices and Building Information Modeling (BIM) platforms to make construction sites that are smart and responsive (Zhou et al., 2021). This can be classified into three phases including planning phase, designing phase and construction phase.

Planning Phase:

Planning is an important step in the building process since it decides how well a project will go in terms of time, cost, quantity and quality. The project failure is inevitable as a consequence of inaccurate planning. Many people are involved in the planning stage, and they spend a lot of time figuring out the schedule, costs, and risks of a project. AI is very important in the early stages of a project since the cloud-based software can be utilized for more in-depth research, and what-if scenarios can

help make projects more profitable. McKinsey put out a paper that said construction companies might boost production by 50% by analyzing data in real time. This has led construction companies to put money into AI and data science (Regona et al., 2022). Figure 1 illustrate various steps that are involves in planning phase to proceed with the construction project with the help of Artificial Intelligence Technology.

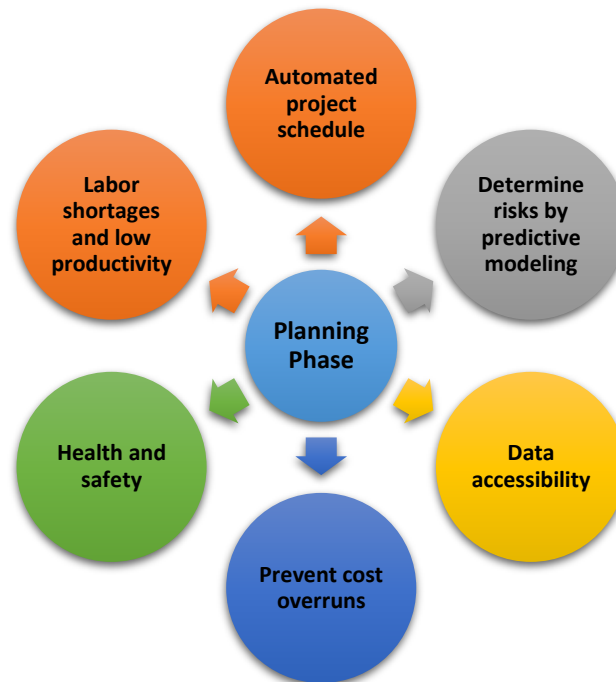


Figure 1.

**Various steps involved in planning phase of Construction project with AI
Designing Phase:**

The design phase uses a number of automated tools like the 4D AutoCAD interface to make old tasks easier. Companies are starting to switch from automated systems to AI and machine learning systems since they realize that their present platform can't handle a lot of data (Martinez et al., 2019). AI can now get data from any job site which means that companies can learn from and improve on old ways (Shukla et al., 2019). The Images, drone footage, security sensors and building information modeling (BIM) all make data that is now available during the design phase. AI can help with the project at this stage by keeping, storing and analyzing complicated design data (Eber., 2020). AI technologies will make it easier for designers to talk to one other and work together, and they will also make it easier for managers to keep track of and regulate all parts of architectural processes.

Furthermore, the integration of information and knowledge repositories can facilitate the management of a variety of initiatives with greater efficiency (Darko et al., 2020). This will make sure that everyone has access to the most recent information and can share it easily (Smith., 2019). The businesses are more likely to use these platforms now that the costs of these programs have gone down. AI tools will make it easier for people to talk to one other and work together on design tasks, and they will also make administration and control better in all areas of architecture. Adding information and knowledge repositories can also help manage different projects more effectively.

Building information modeling (BIM):

The presence of BIM is becoming increasingly apparent on construction sites. It is easy to buy and is a good approach to gather information and keep an eye on a site's growth in real time (Whyte and Hartmann, 2017). BIM has a lot of potential, and it will let companies keep track of a digital version of the physical features of construction projects. It also makes the design more flexible, which is clear throughout the building stage process and it keeps people safe on the job site by setting up a method for identifying and avoiding dangers. A study showed that contractors might use BIM 50% more than they do now. They also planned to spend a lot of money in the next few years to make their BIM programs bigger and more progressive (Ribeirinho et al., 2016). These kinds of talents will modify the risks of a project and call into question the way of doing engineering, procurement and construction.

Internet-of-things (IoT):

IoT or the Internet of Things is an important technology that lets BIM connect to real-time data. Smart Site, Site Sense, Indus.AI, and Caido are some of the biggest IoT companies on the market. These platforms turn data from every step of the construction process into useful method instructions. Also, block chain technology automatically record data in real time so that managers on site can have accurate information to share and make things safer. Combining smart homes/buildings with the Internet of Things (IoT) will make more data available and allow for more efficient operations and new business models like performance-based contracting. The companies will be able to make a virtual 3D model with IoT sensors which can make things run more smoothly and lower maintenance expenses (Li et al., 2021).

Generative design:

Most construction businesses are still looking at planning documents from different people who are working on the site. Because of this, it needs a lot of rework and appraisal which costs time and money (Ginzburg et al., 2018). Dassault systems EXALED and NETVIVES are two of the best generative design platforms. They combine data from several sources and come up with precise plans. Recent research shows that 35% of architects and engineers use generative design in their work (Wang et al., 2019). The software makes it easier to design by taking into account space needs, performance, materials and budget limits (Whyte and Hartmann, 2017). The software looks at all the various alternatives and comes up with a design option that fits all the parameters. Another kind of AI GenMEP can automatically plan how the electrical system will run through the building model (Grabowska and Saniuk, 2022). GenMEP considers the complexity of various building designs and geometries to ensure that wires do not follow the same route (Pillai and Matus, 2020). It is anticipated that the AEC industry will continue to adopt and expand generative design. It offers numerous advantages.

Visualization:

Computer-integrated construction (CIC) is another technology that is changing to include AI features. CIC and machine learning can be a potent combination because they change data and look at how it changes and the patterns in the data (Schönbeck et al., 2019). Thus, both technologies work together to make it easier to share information and lower the amount of uncertainty. This will let everyone involved in the construction project understand where it stands at all times (Kim et al., 2015).

Clash detection:

AI needs to make clash detection easier and faster throughout the design phase. BuildingSP and GenMEP are two technologies that are being worked on this task it can find clashes in real time without having to send files to other platforms (Alaka et al., 2017).

Surveying:

There are new software and technology that can help with a lot of typical surveying tasks like point arrangement and soil deformation monitoring (Yigitcanlar, et al., 2020). The utilization of information obtained during the inspection or monitoring procedure can be facilitated by a vision-based concept.

Construction Phase

The building phase of a project is where the biggest changes are happening compared to how things used to be done. Construction robots and automation improve current construction plants, equipment and task-specific specialized robots. However, cognitive machines are still in the early stages of research. KIST floor robotics, WASEDA construction robots, interior wall painting robots, mobile robots, four-leg locomotion robots and ASRERRISK robots are some of the most important robots used in construction. The use of various sensors that send information back to the site manager is an important part of running robots (Chu et al., 2010).

Construction monitoring:

Model parameters and a speeded-up robust application (SURF) are used to keep an eye on the progress of construction projects and the structural integrity of buildings. Some of these parameters include Natural frequencies, damping ratios and model form. The data analysis utilized for the SURF app may also be used to find dynamic structural traits using the Bayesian technique. Individuals have employed artificial neural networks to predict and estimate the compressive strength of concrete. This platform examines the five components of concrete, enabling organizations to assess its quality and determine if additional composite materials are necessary for enhanced durability (Regona et al., 2022).

Image processing:

The monitoring of construction structures can be achieved by collecting data from sensors that are strategically set throughout the site. RGB cameras can send data streams that record things like what workers are doing, where raw materials are, and earthworks. This is helpful since it makes things work better and cuts down on greenhouse gas emissions (Xiao et al., 2018).

Modular construction:

The offsite manufacturing automation improves industrialization by focusing on products. The procedure includes planning, designing and construction in a controlled facility away from the site. The building used a lot of different materials, sizes and systems as well as new ways of making things, digital software and modern ways of putting things together. Integrated automated production systems are the next phase in the move to more efficient offshore manufacturing (Regona et al., 2022).

Autonomous Vehicles:

A central platform can control self-driving cars and tell them where to go on a construction site to build structures. A group of airborne robots that work together to reach a certain aim is a technology. Digital twin technology capable of accurately planning and coordinating the operations of each robot can facilitate this process. (Moselhi and Alshibani, 2009).

Autonomous Excavation:

Another technique that is becoming more popular is autonomous excavation. The equipment is positioned adjacent to its operational zone, equipped with sensors and controls that enable autonomous excavation. In 2015, Komatsu, a leading equipment manufacturer specializing in data-driven and machine learning-enhanced analysis, launched its Smart Construction initiative. The analysis makes things more efficient, accurate and high-quality by getting information from dependable automated systems (Ajayi et al., 2020). INSITE is now working on technologies that will merge computer vision, deep learning and aerospace techniques to make machines smarter by figuring out where they are and how they see things in the process (Eber., 2020). These technologies will make sure that building procedures are safe, efficient and productive.

Task-specific Robots:

Task-specific robots have been employed in Japan since 2018. They can be controlled by a person who is close to the machine or by a software (Chu et al., 2010). These robots can mostly do structural work, finishing, inspection and maintenance (Hager et al., 2016). Most of the time, robots are only utilized for one part of the building process to lower the risk of failure. A smart system that automates the prefabrication process and cuts down on the requirement for on-site construction that might be affected by bad weather is another type of robotic technology being deployed (Asadi et al., 2015). Mohammadpour et al., 2018 say that it takes around six weeks to build up the roofs of jacking towers and make the work platforms. It might take another 6 to 12 weeks for automated technologies to build and weld steel frames, put in precast concrete floors, wall panels and prefabrication units. However, there still need to be people on site to watch over and control the assembly activity. Obayashi is also working on the Big Canopy system, which uses a temporary roof to protect against unexpected weather conditions. The main purpose of this temporary building is to speed up the project because of bad weather and make it safer and more productive for workers (Regona et al., 2022).

Smart wearable technologies:

The wearable technologies facilitate an environment in which safety and pertinent information are readily accessible. At a construction site, workers utilize smartwatches that receive contextually relevant information from an off-site AI module. (Oesterreich and Teuteberg, 2016).

Robotic equipment:

The significant advancements remain necessary for AI software in construction; nonetheless, it is anticipated that it will facilitate the integration of automated tools inside a 5D BIM planning environment (Dave et al., 2015). SAM100, Ekso Bionics, and Piaggio Fast Forward are the foremost robotic companies now operating in the

market. These models provide the intelligent integration of 3D CAD/CAM components with scheduling and cost data. This provides stakeholders with a means to expedite project delivery deadlines, enhance health and safety and increase profitability (Yigitcanlar et al., 2015).

VR modeling:

DAQRI and Nyfty are two firms that produce virtual reality models. AI systems are rapidly advancing, assisting engineering firms in enhancing safety and facilitating communication with subcontractors via scheduling tools. Virtual reality (VR) allows businesses to assess the constructability of their designs, identify optimal techniques considering accessibility and spatial limitations and allocate resources based on their availability (Yigitcanlar et al., 2020).

AI APPLICATIONS FOR SAFETY ENHANCEMENT

Artificial Intelligence (AI) technologies are being increasingly implemented to create proactive and data-driven safety management systems. AI enables the real-time analysis of data from various sources including surveillance cameras, sensors, and historical safety records to predict risks, detect hazards and monitor compliance with safety protocols (Zhao et al., 2019). These applications not only reduce the likelihood of accidents but also support faster decision-making and more efficient incident response.

a) Predictive Safety Models:

The AI models look at past incident reports and environmental data to guess what might happen in the future. For example, ML models have been used to predict falls and electrical injuries, which has allowed for early interventions (Zhao et al., 2019).

b) Real-Time Hazard Detection:

The real-time alerts for hazardous conditions, including proximity to heavy equipment or precarious scaffolding are generated by AI systems through the utilization of IoT sensors and computer vision (Park et al., 2021).

c) PPE Detection:

The utilization of helmets, vests and mittens can be automatically verified on-site through the use of computer vision. Safety protocols are more effectively enforced when non-compliance is immediately detected (Kim et al., 2021).

d) Fatigue and Stress Monitoring:

The integration of wearable sensors with AI models monitors physical behavior and vital signs to prevent accidents caused by overexertion and detect fatigue (Liu et al., 2020).

AI APPLICATIONS FOR PRODUCTIVITY IMPROVEMENT

Artificial Intelligence (AI) has become a significant tool for increasing efficiency in the construction sector by making project management easier, automating processes that need to be done again and over again, and making the best use of resources. Some of the applications of AI in construction to enhance the productivity improvement as mentioned in table 2.

Table 2.

Applications of AI in Construction for Productivity Improvement.

Factor	Application in Construction	References
Scheduling and Resource Optimization	AI algorithms optimize schedules and allocate resources based on real-time site conditions, improving efficiency. Reinforcement learning has shown promise in dynamic resource planning	(Zhang et al., 2022).
Autonomous Equipment	AI-driven machinery, such as excavators and bulldozers, autonomously execute repetitive tasks, minimizing errors and enhancing speed	(Bock & Linner, 2016).
Progress Monitoring	Drones and cameras powered by AI track construction progress and compare it against BIM models, enabling early detection of delays.	(Golparvar-Fard et al., 2015).
Robotics for Repetitive Tasks	Brick-laying robots, 3D printing and automated concrete systems reduce manual labor and maintain consistent output quality.	(Lim et al., 2012).

CONCLUSION

AI technologies are changing the way construction works by making it easier to monitor risks, use resources more efficiently, and automate processes that take a lot of time. As these technologies get better, they will only be widely used if the problems with implementing them are solved and they are used in an ethical way. Future research should focus on making AI systems that are strong, scalable and easy to understand for building sites that change all the time. The growing difficulty of modern construction in the pre-construction, procurement and post-construction stages is now the main reason why people are interested in digital technologies. However, AI applications for the sector are just in the embryonic stage, and there remain huge research gaps that bring digital inventions for building sites into reality. The construction sector has to narrow this gap by looking at how AI technologies are being employed in other industries. In all of these cases, the construction industry would benefit from the technological research and development work done by other industries and initiatives. This will provide the construction sector an excellent starting point in embracing AI technology. A data link between humans and technology remains absent, despite the potential and availability of deploying AI technologies in a construction project. This is clear since much of the work done on a building site requires a lot of manpower. Because of this, we need to make sure that we use the right digital tools across the whole lifetime such as sensors and smart wearable technology.

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