

Assignment Report: Benefits of Machine Learning in Construction Management

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Summary research paper's:

- **Paper1: Intelligence in the Construction Industry – Present Status, Opportunities and Future Challenges**

This paper examines the application of artificial intelligence (including machine learning approaches) to construction, and what aspects of development benefit or prove counterproductive. The team conducted a comprehensive search of major databases such as Scopus, IEEE, ACM and ScienceDirect for AI applications in construction from 1960 to 2020 and classified the studies by project function: cost estimation, scheduling, safety, quality, design optimization, facility management and others. It provides management control over overruns and contingency buffers. It supports automated progress monitoring, defect detection, and safety checks while minimizing the need for manual inspections and enabling near real-time control. Machine learning-based methods are also beneficial in risk analysis. Their predictions are better than conventional methods. (Brunel University Research Archive) However, these findings also raise several limitations: much of the literature is based on small or project-specific datasets whose generalizability is limited; feature engineering and data cleaning are generally under-documented; and there are few solutions that go into the enterprise to scale. According to the authors, organizational impediments, disconnected data environments and non-consistent data schemas prevent application of ML to construction management. They recommend integration of life-cycle data, honest model evaluation and closer coordination across domain experts and data scientists (Abioye et al., 2021). (Brunel University Research Archive)

- **Paper2: Artificial Intelligence and Machine Learning Applications in the Project Lifecycle of the Construction Industry – A Comprehensive Review**

As such, this comprehensive review looks at the use of AI and machine learning to support construction project management activities through the complete project life cycle—from conceptual planning to operation and maintenance. Leveraging a rigorous search on Web of Science, Scopus, and Google Scholar, the authors conducted a literature search covering recent publications (2010–2022) and traced AI/ML applications to lifecycle stages including planning, design, procurement, construction, commissioning, and operation. (ScienceDirect) The authors state that the densest concentration of ML applications is within the planning and construction phase, specifically in schedule forecasting, cost estimation, productivity analysis, and safety/risk prediction. Supervised learning-based models trained on historic project data decrease the schedule deviation and increase the estimation accuracy

using better cost estimation, and classification models are applied to identify high-risk activities and leading indicators of incidents. In the later life cycles, ML helps predict energy use and predictive maintenance of assets, which are still new. On the whole, the review makes the assumption that it is worth noting that ML provides clear and realistic benefits: better decision-making quality, early realization of issues, minimal rework, and greater correspondence between the planned and the realized activity. The authors point out, however, that most of the evidence is small in scale or from single-organizational case studies, and very few of the studies have rigorously quantified financial returns from ML implementation. They also point out that deep learning is still underused outside of computer vision processes and there are still no governance arrangements on model validation, data ethics and change management. Additional, empirical, multidisciplinary studies are suggested to establish a direct tie-in of ML-supported workflows with schedule and cost performance measures (Datta et al., 2024). (scirp.org)

- **Paper3: Application of Deep Learning in Construction Site Management**

This research performs a scient metric and critical review of deep learning applications in construction site and project management. Combining results of 181 articles in Scopus, Web of Science and Google Scholar databases with the search results found in the literature, the authors discover 4 main application clusters: 1) automated progress monitoring, 2) automated safety warning to workers, 3) equipment management and productivity monitoring and 4) IoT/deep-learning integration for real-time onsite data. (ScienceDirect) The study presents the findings indicating that convolutional neural networks (CNNs) and related architectures are particularly powerful tools for the extraction of site image information (including in-context information from images and video) for construction activities recognition, worker and equipment counting and safety rule violation detection (i.e., helmet missing detection). These models greatly reduce the back-end labor required in visual inspections and generate deeper time series data for construction heads which may be applied to progress curves, productivity dashboards and safety reports. By automating routine monitoring, deep learning enables the engineer to concentrate on higher-level planning and decision-making, and also increases the frequency and objectivity of site feedback. Nevertheless, the authors admit limitations: the vast majority of models are trained and tested on carefully chosen data sets or tests in the style of laboratory experimentation, typically in controlled light and camera positions. Domain adaptation across sites and climates is seldom reported on, and therefore questions about robustness. Labeling large amounts of image data costs a lot, and privacy concerns of video surveillance of workers being monitored continuously has

not been completely dealt with yet. In addition, several approaches are limited to algorithm accuracy and do not look into the impact of deployment on construction management outcomes such as delay reduction or safety statistics (Elghaish et al., 2021). (Pure QUB)

- **Paper4: Deep Learning-Based Data Analytics for Safety in Construction**

The objective of this review is to review the utilization of deep-learning-based methods in analyzing site information for safety management. The researchers comprehensively explore safety research from research on deep learning and divide it into four data types (1) image/video-based analysis (e.g., computer vision to detect hazards); (2) text-based analysis (e.g., natural language analysis of incident reports); (3) non-visual sensor-based analytics (e.g. wearables, inertial sensors and location tracking); and finally, multimodality analysis using various data sources. (ScienceDirect) The main results show that vision-based models have the potential to automatically identify unsafe procedures; absence of PPE (personal protective equipment), access to hazardous conditions and discrepancies with method statements, while sensor-based models predict whether the worker is tired, whether the workers may fall or remain standing during the activities or whether they are at the appropriate position of physical stance. The paper shows that for these systems; deep learning analytics can achieve dramatically better hazard recognition rates and response times than hand-in-hand inspections and traditional rule-following methods. This, in turn, promotes proactive safety management – supervisors receive earlier warnings and can intervene before accidents occur. Simultaneously, there are some challenges that limit practical benefits, among other things: many models are trained on limited and imbalanced datasets which may result in overfitting issues, real-time inference is not always feasible on resource-constrained devices, and there is scarce evidence on how such systems are combined with current safety management flows (permits to work, toolbox talks, and safety audits). There is also the importance of standardized datasets and multisite validation as well as strategies for explaining model decisions to safety managers and to regulators (Liu et al., 2022). (ScienceDirect)

- **Paper5: Generation of Construction Scheduling through Machine Learning and BIM – A Blueprint**

This paper presents a blueprint architecture to automatically generate construction project schedules using the combination of machine learning and Building Information Modelling (BIM). The authors set up a system where IFC-based 3D BIM models from past projects are associated with their as-built schedules. Subsequently,

supervised learning models learn mappings between buildings including their elements and associated activity sequences and durations. For a newly created project, the trained models produce a draft schedule straight from its BIM model and planners are able to refine the schedule then. (MDPI) The main development benefit to construction management is to minimize the amount of time and subjectivity involved in laying out baseline project schedules. The researchers believe ML-based scheduling can foster greater consistency among projects, help “what-if” scenario analysis and enable inexperienced planners to work with known knowledge, found within historical project information. ML-generated schedules would link with resource loading, cost estimating and 4D simulations too, so making planning workflows more holistic through data-driven analysis. That said, the paper is basically conceptual and based on simulated demonstrations rather than on an industrial scale. A great deal of this needs well-structured historical BIM and scheduling data, something many organizations today do not have. The main challenges identified include data standardization, how to handle novel or unique designs, and model interpretability. The authors suggest gradual process implementation towards more repetitive types of buildings and hybrid architectures, where ML proposes schedule templates that human planners review (Al-Sinan et al., 2024).

- **Paper6: Deep-Learning-Based Automated Building Construction Progress Monitoring for Prefabricated Prefinished Volumetric Construction**

This paper presents a deep-learning-based system (WAVBCPM) for automated progress monitoring on projects that use prefabricated prefinished volumetric construction (PPVC). The proposed approach has three modules that process site images: a detection module (for example, localizing PPVC modules), the refinement module that eliminates false detections as well as occlusions, and the progress estimation module that allows for inference of system installation status as well as aggregation of findings in project-based progress metrics. Using real images taken from the sites of PPVC (prefabricated prefinished volumetric construction) construction, the system is evaluated. (MDPI) Results show that the method is even able to robustly estimate floor-level progress under visual occlusions and camera angle irregularities more effectively than baseline object-detection methods. The benefits are apparent for construction management: instead of checking visual inspections manually and depending on the reports, the site teams will also have more immediate information on the project status, resulting in more robust earned value calculation, schedule control and increased resource planning. The authors admit limitations, such as the concentration on a single construction regime (PPVC), which can limit generalization to traditional cast-in-place or hybrid projects. The

datasets are small in variety along with the geographical variations, and it does not yet link with usual project management tools. However, the work shows how you can use deep learning to analyze the raw site imagery and turn it into management information that can be leveraged (Chua & Cheah, 2024). (PubMed)

Critical Analysis:

Throughout the papers, machine learning is a recurrent approach for deriving patterns out of heterogeneous project data in the form of images, BIM models, schedules, cost ledgers, sensor streaming data which then contribute towards the prediction and indicator of improved construction management decisions. The comprehensive results conducted by Abioye et al. (2021) and Datta et al. (2024) offer robust high-level evidence, merging decades of research and showing how ML significantly enhances the accuracy of forecasting, encourages proactive risk management and facilitates automation of monitoring tasks (Brunel University Research Archive) They excel with a fairly broad covering of application types in relation to functional and lifecycle phases. The more particular reviews and case studies—on deep learning for site management and safety, or on ML-enabled scheduling and progress monitoring— provide even more technical details and specific use cases. Elghaish et al. (2021) and Liu et al. (2022) explicitly demonstrate that deep-learning vision models can detect unsafe behavior, identify workers/equipment, and achieve high accuracy in monitoring progress, decreasing the manual burden of site engineers and improving safety oversight. (Pure QUB) Al-Sinan et al. (2024) and Chua & Cheah (2024) show how ML can go beyond analytics to producing management artefacts on their own, including schedules and quantified progress metrics, where they impact planning and control directly. (MDPI) But some persistent restrictions seem to come up. First, most empirical evidence is based on simulations, curated datasets or a few projects, which limits their external validity. The practical deployment considerations of data quality, system integration, user training and change management are seldom discussed during deployment activities at the practical interface. Second, metrics tend to concentrate more on model performance (e.g., accuracy, F1-score) than on managerial output (e.g., reduction in delay, cost overrun, incident rates). This complicates measuring the real benefit for the project. Third, much of the research treats ML as a strictly technical layer and omits organizational factors as well, such as data governance, legal obligations when algorithms fail, or worker buy-in for 24/7 monitoring. Methodologically speaking, the reviewed works are best in problem framing and algorithmic experimentations, yet weaker in replicability: datasets are usually proprietary and not shared and hyperparameter selection or feature engineering steps are sometimes only briefly discussed. But the blueprint schedule paper gives explicit mention of the fact that this is a conceptual project needing to be pilot-tested in a real project, which is a methodological strength of the paper (transparency) and a methodological weakness (evidence). Overall, the literature has good support for the advantages of machine learning in construction management, yet evidence is not yet fully founded from proof-of-concept to credible and field deployed cases.

Connections:

- 1. Looking at it from a lifecycle perspective:** Abioye et al. and Datta et al. classify AI/ML applications along the construction lifecycle and find that the planning and construction stages are most mature, but that other opportunities extend into operations and maintenance. (Brunel University Research Archive)
 - 2. Focus on site monitoring:** Several articles agree that it is important to transform raw site-derived data into actionable information. Deep-learning approaches for progress monitoring and safety (Elghaish et al., Liu et al., Chua & Cheah) all use site imagery and sensors to serve their users with near-real-time feedback on what is currently taking place on-site. (Pure QUB)
 - 3. Benefits to core project controls:** Taken all together, the studies demonstrate benefits directly resulting from the traditional “iron triangle” of project management — time, cost and quality. ML-powered scheduling and progress monitoring enable time control; enhanced cost estimation and risk prediction enable cost control; and automated inspection and safety analytics ensure quality and safety performance. (MDPI)
 - 4. BIM and ML integration:** Various works implicitly or explicitly highlight BIM as a key enabler of ML in construction management, particularly in terms of connecting 3D models with schedules and progress information. Al-Sinan et al.’s blueprint is clearly based on BIM, and wider reviews observe that organized digital models facilitate the implementation of learning algorithms. (MDPI)
 - 5. Better data infrastructure needed:** Data availability and quality is recognized by all papers as vital for the delivery and impact of ML applications. If it is a series of annotations used for safety analytics, historical BIM-schedule pairs employed for automated scheduling, or integrated project databases used for lifecycle studies, a solid data infrastructure is consistently indicated as a prerequisite for providing economies of scale benefits. That’s what Brunel University Research Archive notes.
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Conflicts between the findings:

1. Perceived maturity of ML in construction management: Some works such as deep-learning safety and monitoring progress report exceptionally high detection/classification performance, presenting ML technologies as ready for implementation. Based on lifecycle reviews, on the other hand, it is acknowledged that the industry adoption stages are early, as the implementations among organizations are slow and uneven (Datta et al., 2024). (PubMed)

2. Automation vs. Decision Support: The scheduling blueprint and automated progress monitoring papers are biased in favor of substitution or over automation for traditional plans and monitoring functions. (MDPI) In contrast, broader reviews offer the view that ML primarily serves as a decision-support tool that complements, rather than replaces, human judgement in estimating, risk assessment and safety management. (Brunel University Research Archive)

3. Emphasis on technical accuracy vs. managerial impact: Whereas case-study and algorithm-focused papers frequently focus on achieving accuracy metrics and technological progress, lifecycle reviews discuss the absence of empirical evidence connecting ML adoption to visible improvement in project KPIs such as project delays, cost predictability and incident frequency. (PubMed)

4. Machine learning methods: Deep-learning-oriented research argue for an architecture based on complex neural networks as the main way to extract insights from visual and sensor data. (Pure QUB) On the other hand, mainstream AI in construction reviews argue that most practical benefits today still derive from “simpler” supervised learning approaches (e.g., gradient boosting, random forests) used with tabular project datasets, which could be easier to deploy and sustain. (Brunel University Research Archive). Generalization from one type of project to another: Progress monitoring solutions based on PPVC or one particular site geometry show that deep-learning models may work well when a variety of specific conditions exist but might not work well for high-rise cast-in-place or infrastructure projects. (ResearchGate) In contrast, lifecycle reviews tend to suggest that ML approaches can be scaled up once enough data are available, which can sometimes underestimate the domain adaptation challenges. (PubMed).

Synthesis Matrix for Literature Review:

Study	Authors	Year	Research Design	Methodology	Key Findings / Results	Limitations
Artificial Intelligence in the Construction Industry: A Review of Present Status, Opportunities and Future Challenges	Abioye et al.	2021	Systematic literature review	Extant review of AI applications in construction using SCOPUS as primary database and validating with IEEE, ACM and ScienceDirect ; six decades of publications (1960–2020) categorized by function (cost, schedule, safety, quality, etc.)	ML-based models consistently outperform traditional methods for cost and schedule prediction; computer vision and other ML tools support automated monitoring, safety analytics and facility management; AI/ML can reduce overruns, improve decision-making and enable more proactive risk management. (Brunel University Research Archive)	Evidence is fragmented across small, domain-specific studies; many datasets are proprietary and small; limited discussion of deployment at scale; organizational challenges and data governance are underexplored.

Study	Authors	Year	Research Design	Methodology	Key Findings / Results	Limitations
Artificial Intelligence and Machine Learning Applications in the Project Lifecycle of the Construction Industry: A Comprehensive Review	Datta et al.	2024	Comprehensive review with lifecycle framing	Qualitative review of AI/ML applications in construction using Heliyon's methodology: multi-database search (Google Scholar, Web of Science, Scopus); classification of studies by lifecycle stage (planning, design, construction, operation); synthesis of benefits and gaps	ML benefits are strongest in planning and construction stages (schedule forecasting, cost estimation, safety and risk analytics); opportunities exist in operation and maintenance, especially for predictive maintenance and energy optimization; provides a lifecycle-based map to guide adoption and research. (ScienceDirect)	Limited number of empirical case studies with quantified ROI; very few works link ML adoption directly to project-level KPIs; explains concepts and trends but lacks standardized metrics for comparing approaches; deep learning outside computer vision remains underused.
The Application of Deep Learning in	Elghaish et al.	2021	Scientometric and critical review	Scientometric analysis of 181 deep-learning	Identifies four main deep-learning	Relies on published research rather than field

Study	Authors	Year	Research Design	Methodology	Key Findings / Results	Limitations
Construction Site Management				publications related to construction; mapping by application area (progress monitoring, safety warnings, equipment management, IoT integration); qualitative assessment of capabilities and research gaps	application areas in construction management; shows that CNN-based models can automate activity recognition, worker/equipment detection and safety monitoring, enabling more frequent and objective site feedback; highlights potential to improve productivity and safety while reducing manual inspection workload. (ScienceDirect)	deployments; little quantitative evidence on project-level impact; dataset availability, labeling cost and privacy issues remain major obstacles; robustness to different sites and conditions is largely untested.
Deep-Learning-Based Data	Liu et al.	2022	Thematic review	Systematic review of deep-	Demonstrates that deep	Many studies use limited and imbalanced

Study	Authors	Year	Research Design	Methodology	Key Findings / Results	Limitations
Analytics for Safety in Construction				learning-based safety analytics; categorization into image/video, text, non-visual sensors and multimodal approaches; evaluation of typical network architectures, data pipelines and safety use cases	learning can enhance hazard recognition, PPE detection, unsafe posture identification and near-miss analysis across multiple data sources; supports proactive, data-driven safety management by enabling continuous monitoring and early warnings. (ScienceDirect)	datasets; few compare models across sites or organizations; challenges include real-time processing, privacy, ethical considerations and integration into existing safety management systems; lack of standardized benchmarks.
Generation of Construction Scheduling through Machine Learning and BIM: A Blueprint	Al-Sinan et al.	2024	Conceptual and experimental blueprint	Proposes architecture for linking historical BIM (IFC) models with as-built schedules; uses supervised ML models to	Shows how ML could generate draft construction schedules automatically from BIM data,	Mostly conceptual with limited real-project validation; requires extensive, high-quality historical BIM and schedule data; challenges in generalizing

Study	Authors	Year	Research Design	Methodology	Key Findings / Results	Limitations
				learn mapping from BIM features to activity sequences/durations; demonstrates concept using example datasets and scenario analyses in the buildings journal	potentially reducing planning time and capturing organizational knowledge; highlights benefit for consistency, scenario analysis and integration with 4D simulation and cost/time control tools. (MDPI)	across unique designs; not yet integrated with mainstream scheduling software; human-AI collaboration mechanisms are not fully defined.
Deep-Learning-Based Automated Building Construction Progress Monitoring for Prefabricated Prefinished Volumetric Construction	Chua & Cheah	2024	Experimental case study	Development and testing of WAVBCPM system; uses deep-learning detection, refinement and progress estimation modules applied to real PPVC site images; evaluated for accuracy and robustness compared to baseline	Achieves accurate estimation of PPVC module installation and project progress under challenging visual conditions; reduces manual effort in progress tracking and	Focused on PPVC projects; dataset drawn from limited number of sites; generalization to other construction methods not proven; integration with enterprise project management systems is not fully addressed; does not quantify financial benefits

Study	Authors	Year	Research Design	Methodology	Key Findings / Results	Limitations
				object-detection approaches	supports more reliable schedule control and resource planning; demonstrates practical benefits of deep-learning-based visual analytics in a real construction context. (PubMed)	(e.g., reduction in delay costs).

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