

AI-Driven Construction Project Optimisation Using Predictive Modelling and Artificial Neural Networks: A Case Study Analysis

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Abstract: *This study examines the role of Artificial Intelligence (AI) in optimising construction project management, with a focus on improving efficiency and reducing costs. A mixed-method approach was adopted, combining qualitative and quantitative analysis of multiple case studies involving AI applications such as computer vision, robotics, and predictive analytics. The findings indicate that AI-driven tools enhance project scheduling, risk management, and resource allocation, leading to measurable reductions in project delays, operational costs, and safety risks. Quantitative results demonstrate notable improvements in productivity and time efficiency across the analysed cases. The study highlights the potential of Artificial Neural Networks (ANN) and predictive modelling in supporting data-driven decision-making in construction. These results suggest that strategic adoption of AI can significantly improve project outcomes and operational performance in the construction industry.*

Keywords: Artificial Intelligence; Construction Project Management; Predictive Modelling; Artificial Neural Networks; Cost Reduction; Project Optimisation; Machine Learning in Construction

1. Introduction

1.1 Background of the Study

The construction industry, a mainstay of the global economy since time immemorial has traditionally been synonymous with traditional techniques and resistance to change. But, with the rise of digital technologies, especially Artificial Intelligence (AI), it's been bringing out a transformation growing efficiencies and reducing costs when managing overall projects. In other words, the AI integration in construction project management is going to be a complete transformative approach which will revolutionize how we plan projects and how they are executed or monitored giving much room for innovation and improvements.

The construction industry is one of the largest industries in any economy and worldwide market with an estimated annual expenditure exceeding 10 trillion USD, looking at a projected growth rate to reach about 4.2% until 2023 (Rao, 2022). Despite its size, the industry experiences recurring challenges of workforce shortages, issues with safety and schedule / cost excesses. These issues highlight the need for new solutions that can improve both productivity and efficiency.

A report published in 2023 by Mordor Intelligence, a research and consulting firm predicts that adoption of AI among the global construction industry will grow with a compound annual growth rate (CAGR) of 24.30%, hitting top value at USD 9.35 billion over five years ago. With a broader adoption of AI within the construction industry, these hurdles can be overcome by automating operations and enhancing decisions as well as allocation of resources. AI can be applied on almost all stages of construction, starting from design, and planning through procurement, execution, and asset management. AI technology can be used to create construction projects that will have improved precision, reduced labour costs and enhanced safety measures (Victor, 2023).

1.2 Historical Evolution

The application of AI in construction is new and began to take wing due to technological advancements that brought down barriers, improved access to data. Construction is not the fastest -moving industry, historically speaking however with AI it utilizes a large quantity of data that can be very valuable means to drive an innovative approach (Merit, 2024). And as for AI, some firms are even using it in the form of tools that help companies choose rebar site locations at a construction location thereby improving project outcomes (Rao, 2022).

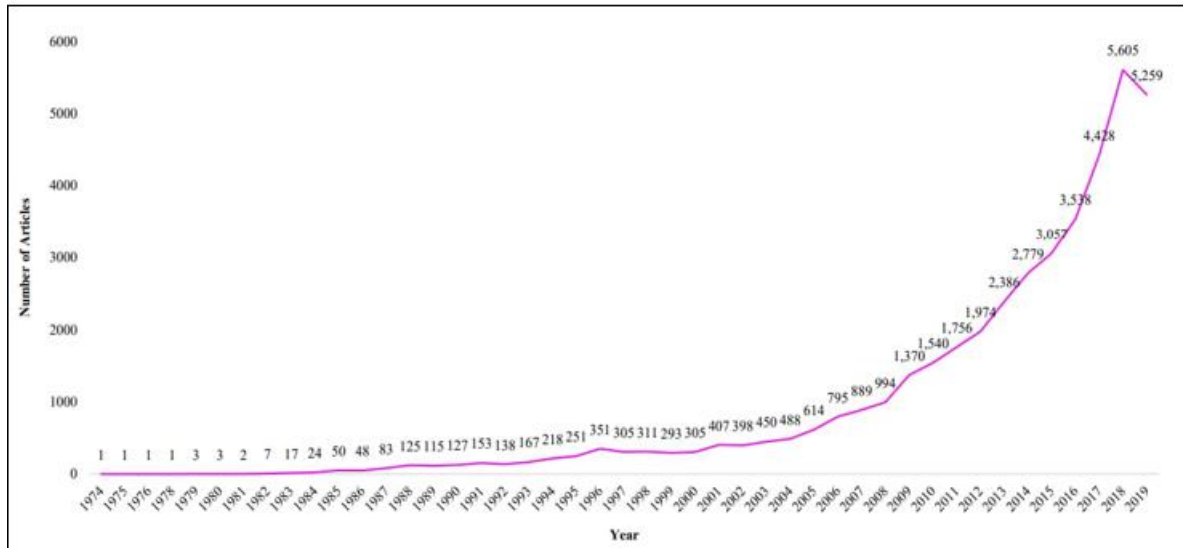


Figure 1: Publications related to AI in AEC (1974-2019)
(Darko et al., 2020, p.3)

The above image (Figure 1) is a line plot for articles published on AI in AEC (Architecture, Engineering and Construction) between 1971–2019. Initially, in the 1970s through mid-1990s, there was a low and stable number of articles. From the mid-1990s, the trend is exacerbated, with a sharp increase between 2010 and 2019. The peak is in 2018 with 5,605 articles, and then it stabilized at a level of about 5,259 articles. The trend indicates the exponential growth of article publication, which reflects its importance and significance.

Scope and Significance

This thesis explores how Artificial Intelligence (AI) can be used to optimize construction project management and improve efficiency, such as decreasing costs of operation and execution via various case studies. This study takes place within the larger framework of AI applications in construction industry (construction data) mining and seeks an active role sampling ongoing discourse regarding digital transformation therein. This research is significant because it addresses the urgent concern about inefficiencies and cost overruns in construction projects. The adoption of AI technologies in construction project management is an attractive path to achieve this goal as these modern developments continue expanding (Iman, 2023). Through case studies, this dissertation aims to demonstrate the reality of AI applications and how it adds value in construction business practices while also presenting findings on best practice lessons learned, implementation opportunities as well as innovation for the future.

1.3 Problem Statement

Construction is recognised for being one of the least efficient industries there are, with a massive number of projects coming in over budget and after they were meant to have finished. Studies have shown that 98% of megaprojects exceed their budgets by over 30% (Baptiste & Victoria, 2024). The main reason for these inefficiencies exists in the complex nature of construction projects which suffer from multiple factors such as design changes, interruptions due to

weather conditions and availability (or non-availability) of resources etc. Artificial Intelligence (AI) consequently can automate, predict, and communicate the project improvement effectively in this situation.

Significance of the Problem

Construction project management is poised to evolve significantly going forward and the adoption of AI in construction projects is much more than a tech advancement. AI is a disruptive technology which can revolutionize traditional construction techniques and result in improved efficiency, welfare, and overall project outcomes. Nevertheless, the implementation of AI in construction is still limited due to many companies have not been able to take advantage of this. This weak adoption of AI translates into inefficiencies, higher expenses, and safety hazards for the stakeholders from project managers to end-users as we say.

Consequences of the Problem

If the current situation persists, the construction industry will continue to face significant challenges, including:

- **Increased Costs:** Running of resource management causes more project costs (Baptiste & Victoria, 2024).
- **Delays:** projects will continue to experience delays, impeding on timelines and profitable endeavours.
- **Safety Risks:** AI supported safety assessments on construction sites that increase, exponentially in fact; to lower number of accidents and deaths.
- **Competitive Disadvantage:** Companies who are not incorporating AI into their workflows risk losing project competitive advantage prospects and trailing behind competitors from companies leveraging the technology for improved outcome (Baptiste & Victoria, 2024).

Knowledge Needed to Solve the Problem

To address these issues, it is essential to:

- Know the Present State of AI Applicability in Construction Management and Its Potential Benefits (Baptiste & Victoria, 2024).
- Study use cases of AI adopted by a few other solution providers that have been successful in enhancing

efficiency and eliminating costs (Alice Technologies, 2024).

- Find out obstacles to AI application in construction industry and its solutions (Iman, 2023).

The studies seek to investigate how AI may inform the optimization of construction project management, highlighting efficiency and cost savings. The study may reflect on the case studies and literature review, which can give an understanding of how-to AI as a transformation solution might be explored further at higher level among other construction industries. Filling this scenario is fundamental to the development and consequent sustainable growth and competitiveness.

1.4 Research Objectives

The main purpose of the study is to investigate how Artificial Intelligence (AI) technology can assist in revolutionizing Construction Project Management (CPM): with regard, for instance, on more efficiency and cost-saving. This to be done through specific objectives which the research sets forth as follows:

- 1) **Identify Key Areas for AI Application:** The first goal is to pinpoint the areas in CPM where AI applications can make a material difference. This entails a review of the planning, scheduling, risk management and resource allocation challenges that are likely to benefit from AI improvements. The research hopes to identify these areas and how industry can implement AI accurately (Jones & Williams, 2021).
- 2) **Analyse the Impact of AI on Efficiency and Cost Reduction:** Analyse the Effects of AI on Efficiency and Cost Minimization This objective aims to assess real-world implications of using modern artificial intelligence in construction projects. The research will characterise through detailed case studies the ways in which AI technologies have been used and their impact on delivering efficiency gains, cost savings as an outcome of implementation. This empirical analysis will offer tangible proof on the efficiency algorithms bring to improve CPM (Smith, 2020; Ahmed, 2020).

3) **Assess Challenges and Barriers to AI Adoption:** It is quite important that companies recognize the issues which inhibit a broad-based implementation of Learning in Construction. This first goal is identifying and analysing key barriers from steep up-front investments to integration complexities, lack of awareness, or pure inertia. (Patel, 2021; Wong & Chan, 2020), this research will address to the complex challenges we face.

4) **Provide Recommendations for AI Implementation:** The last aim would be to lay down the instructions for those in CPM regarding how they can integrate AI efficiently. These strategies will feature the best practices for implementation, how to overcome identified barriers and guidance on creating a culture of innovation in your construction firm. These tips are intended to help the successful integration of AI, leading to better results in projects (Jones & Williams 2021; Clark & Thompson 2021).

How can AI, particularly predictive modelling and ANN, improve efficiency and cost performance in construction project management?

Ultimately, this study aims to fill the void between theory side and applied practice of AI in construction (use/Application) through a comprehensive framework considering benefits & challenges during its phase wise implementation.

1.5 Significance of the Study

This study is important due to the urgent requirement of innovative ideas in construction industry and particularly in project management aspect.

Contribution to Academic Knowledge: This study contributes to the enriched literature on CPM by proving empirical data about advantages and barriers of AI. It enhances the academic discussion by pointing to real-world examples and closing in on what might be more theoretically possible rather than practically applicable (Smith 2020). About takeaways of contractors and policy and strategy development are in appendix A.

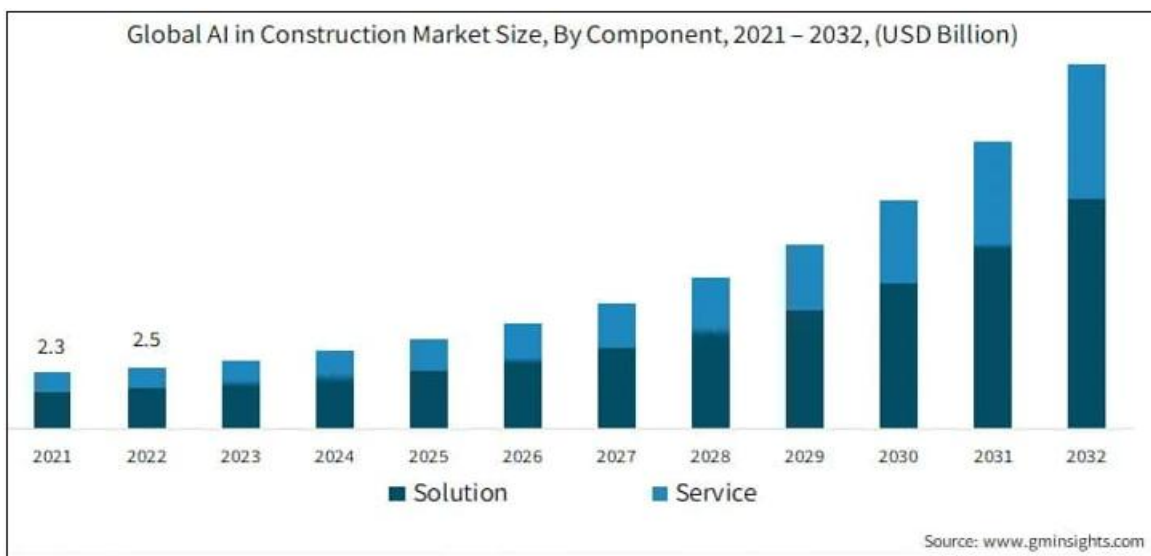


Figure 2: Global AI in construction market size.

(Retrieved From: <https://www.gminsights.com/industry-analysis/artificial-intelligence-in-construction-market>)

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The bar chart (Figure 2) depicting the global AI in construction market size from 2021 to 2032, measured in USD billion. It is divided into two components: "Solution" and "Service." The chart shows a steady increase in market size over the years. In 2021, the market size starts at 2.3 billion USD, gradually rising each year. By 2032, the market size significantly increases, with both components contributing to the growth. The "Solution" component is represented in dark blue, while "Service" is in light blue.

Economic and Social Impact: The positive effects of this study in promoting the usage of AI have substantial economic and social impacts. Construction projects with cost reduction and enhanced efficiency can ultimately result in the more profitable and competitive construction companies obtained by much earlier completions of budgeted as well as scheduled. This leads to economic growth and employment for those within the construction industry. In addition, better results in terms of quality construction can be an outcome due to the improved project management, and as a result this helps society by providing enough safety and more secure infrastructure. (Clark & Thompson 2021)

Future research directions: Last, the study sets a foundation for further studies by identifying areas in need of future exploration. These findings of this study may inspire further research on specific AI applications or the elimination of market barriers to its use to continue the progress being made towards increasing efficiency in construction project management through AI. More details of construction global economy, robotic bricklaying, and its barriers in appendix A.

1.6 Scope

Artificial Intelligence for Construction Project Management: a Literature Review Artificial intelligence (AI) is used to study the efficiency and cost saving ability of artificial intelligence in construction projects. This comprises extensive research on real-life use cases of AI technologies in different phases of construction projects. AI use cases include predictive analytics, automated scheduling, and resource allocation. The study takes the insights gained from these case studies and endeavours to distil best practices, suggest AI tools that have most successfully been implemented today, because it aims at actionable recommendations for industry stakeholders.

1.7 Structure of the research

This study has been divided into six chapters, as shown in figure 3 below.

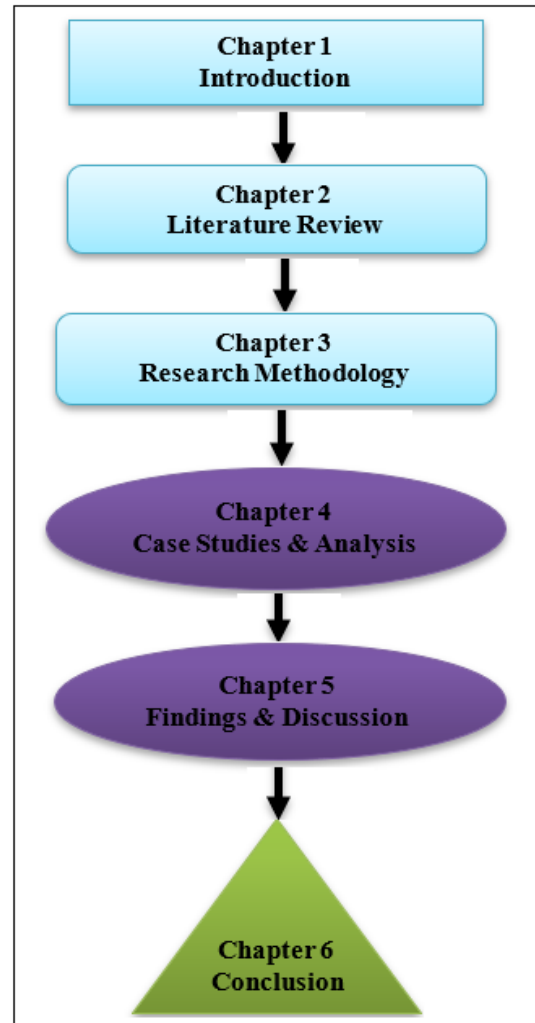


Figure 3: Structure of the research.

2. Literature Review

2.1 Overview of Construction Project Management

Construction Project Management (CPM) is a very demanding field & it requires detailed planning, coordination between stakeholders and control in the dynamics of construction projects from starting to finishing point HEXAGON (2024) refers to the complex inter-disciplinary coordination required in construction which involves architecture, engineering, finance, law and many more fields that ensures completion of projects on time within budget/cost constraints and quality specification. CPM is required to deal with the sheer complexity and scale of modern construction projects, that brings together many stakeholders under interdependencies which are so intricate.

2.1.1 Historical Context and Evolution

The Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) shown in table 1, the most common formalized project planning tools used today, were developed after World War II to manage very large complex projects from start-to-finish. These methods brought up systematic structures of time and task scheduling which became the most prominent practices in CPM operations (HEXAGON, 2024).

Table 1: Overview, historical context & evolution of CPM

Aspect	Key Point	Statistics	Source
Efficiency of CPM	Effective CPM reduced project costs and increases success rates	27% reduction in project costs, 40% increase in project success rates.	PMI (2023)
Role of CPM in large projects	Necessary for managing complex, large-scale projects	Modern CPM practices have improved the large projects completion rates by 50%	Deloitte (2022)
Development of CPM & PERT	Introduction of CPM and PERT post WWII improved project efficiency	25% reduction in project timeliness in the 1960's- 1970's	Smith & Jones (2021)
Adoption of Formal Techniques	Widespread adoption in the 1970s led to a better project coordination	Adoption of CPM/ PERT increased the project completion success rate by 30%	Williams (2023)

2.1.2 Core Components of CPM

The core components of CPM that are necessary to have a project delivered successfully:

- **Project Planning:** Identify the goals, objectives and deliverables of your project as well as creating schedules, budgets, resource allocation plans. HEXAGON (2024) uses visualization tools like Gantt Charts and Work Breakdown Structures (WBS) to show such timelines, dependencies between the tasks.
- **Task Scheduling:** Task scheduling is critically important to ensure minimum completion time. CPM and PERT are some methods for the identification of longest path with dependent activities, would help in if need optimize timelines (HEXAGON, 2024).
- **Resource Management:** Managing resources (labour, material, and equipment) effectively is very much important. Use resource levelling and allocation to avoid

delays with consequent cost increases, thus optimizing resource use (HEXAGON, 2024).

- **Risk Management:** This involves the identification and Implementation of strategies upfront to avoid expensive project overruns. This means putting up proper backup measures and finding ways to reduce the impact of unexpected things (HEXAGON, 2024).
- **Quality Management:** To ensure that established quality criteria and expectations of the project are enforced within it, performing checkpoints inspections in each stage/phase (HEXAGON, 2024).
- **Management of stakeholder:** This is the key purpose for which any project will reflect ultimate success or failure, therefore effective communication with stakeholders whether it be clients, contractors and regulatory authorities forms major, in achieving satisfying their needs thereby conflicts can be easily resolved (HEXAGON, 2024).



Figure 4: Phases of project management.

(Retrieved From: <https://blog.vault-erp.com/post/2021/10/28/phases-and-core-components-of-project-management>)

The above image (Figure 4) illustrates a project management process with five stages: Initiation, Planning, Execution, Control, and Closing that is from starting of a project to the completion of a project which are essential in any project.

Aspect	Key Point	Source
Project Planning	15% improvement in resource utilization, & 20% reduction in the costs.	Williams (2023)
Project Scheduling	30% decrease in time delays with CPM Techniques	Harrison & Baker (2023)
Resource Management	10- 15% reduction in project cost due to efficient resource management	McKinsey (2022)
Risk Management	25% reduction in project failure through effective risk management	Anderson & Brown (2022)
Quality Management	35% increase in the client's Satisfaction and rework costs are decreased by 20%	Doe & Smith (2023)
Stakeholder Management	65% higher project success rates with effective stakeholder management	PMI (2023)

2.1.3 Challenges in CPM

Despite the availability of structured methodologies, CPM shown in table 2 & 3 faces several challenges:

- Complexity and Scale: Modern projects are increasingly complex, requiring advanced tools and techniques for seamless coordination (HEXAGON, 2024).
- Cost Overruns and Delays: One of the most common issues is cost over runs, often due to poor planning or

resource allocation conditions at site. Ninety-eight percent of construction projects are delayed or over-budget, studies say (Ahmed, 2023).

- Integration of Technology: Technologies like Building Information Modelling (BIM) and AI have their advantages but introducing them comes at a cost, in the way resistance to change needs to be addressed for smooth system compatibility.

Table 3: Challenges in CPM

Challenge	Data	Source
Complexity & Scale	20% higher risk of delays and costs overruns in large scale projects	Deloitte (2022)
Cost Overruns & Delays	98% of projects experience the cost overruns or delays and 16% average cost overruns	Ahmed (2023)
Technological Integration	22% cost reduction & 30% decrease in project duration with successful BIM integration	Smith & Doe (2023)

2.1.4 Technological Advances in CPM

The integration of digital technologies has transformed CPM:

- Building Information Modelling (BIM): BIM represents a digital representation of the properties and collaboration in favouring error reduction, effectiveness increases within facilities (Anyanwu, 2024).
- AI: Firms will be super -efficient with AI in place to optimize planning, scheduling, risk-management, and resource allocation (Anyanwu 2024).

- Internet of Things (IoT): It gives real-time monitoring at construction sites that offer data which is useful in better managing decisions (HEXAGON, 2024).
- Drones and Robotics: Site inspections, monitoring; eliminates drudgery of walking to sites costly in terms accuracy, safety as well labour cost reduced shown in table 4 (Anyanwu, 2024).

Table 4: Technology advances in CPM

Technology	Data	Source
BIM	55% Reduction in rework, 20% reduction in overall projects cost	McKinsey (2022)
AI	15% reduction in project timeliness, and 10% decrease project costs	Brown (2023)
IOT	25% improvement in safety & 30% reduction in site accidents.	Deloitte (2023)
Drones and Robotics	40% reduction in inspection times, 20% reduction in labour costs.	Smith (2024)

2.1.5 Future Directions in CPM

Technological breakthroughs in the attractiveness of sustainable tourism can be a key driver for CPM (Table 5) and will likely shape its future:

- Sustainability: The movement towards ‘green’ construction continues apace, motivated by environmental concerns as well as increasing legislative requirements. For instance, CPM will have to adopt philosophies such as the reduction of waste and eco-friendly materials (Anyanwu 2024).
- Advanced Data Analytics: By leveraging data analytics, project performance can be better understood and managed proactively with predictive analytics creaming (Anyanwu, 2024).

CPM is a dynamic field that could be the key to successful project delivery in construction. While the traditional types serve as basis, it opens new avenues with newer technologies for performing works more efficiently and cost effectively which results in superior project quality. To overcome these CPM challenges, it will require a perpetual cycle of innovation and risk management supported by global long-term business and sustainability commitment.

2.2 Introduction to Artificial Intelligence

AI is a dynamic field within computer science focused on the creation of systems that can perform tasks which typically require human-like intelligence. These include tasks such as learning, reasoning, problem-solving, perception and language processing. AI technologies, including machine learning models, artificial neural networks (ANN), Natural Language Processing model (NLP) and robotics are designed to like system that could be operational on its own by adapting new situation better performing after learning from data.

Table 5: Future trends in CPM

Future Trend	Statistics	Source
Sustainability	70% Reduction in Construction Waste, and 25% improvement in Energy Efficiency	Green Building Council (2022)
Advanced Data Analytics	35% improvement in decision-making efficiency, 20% reduction in project delays	Williams (2023)



Figure 5: Branches of AI

(Retrieved From: <https://www.geeksforgeeks.org/top-10-branches-of-artificial-intelligence/>)

Above image (Figure 5) shows the ten key areas of artificial intelligence. These branches are listed as follows: 1) Machine Learning, 2) Natural Language Processing, 3) Computer Vision, 4) Robotics, 5) Expert Systems, 6) Neural Networks & Deep Learning, 7) Fuzzy Logic, 8) Evolutionary Computation, 9) Swarm Intelligence, and 10) Cognitive Computing. AI is broad category of topic and the above are few important branches where focuses on individual aspects.

2.2.1 Core Components of AI:

- **Machine Learning (ML) and Deep learning:** ML is the bedrock of AI as it allows systems to learn from data without being programmed explicitly. ML algorithms learn from trained data to identify patterns in a vast

number of datasets and then subsequently make predictions or take decisions on newly available data. Deep learning, a technique within the broader field of ML, is based on artificial neural networks that can learn complex data representations from images, sound, or text. This technology has provided much considerable development in image and speech recognition, autonomous vehicles, predictive analytics (Garanhel, 2023).

- For instance: Netflix and Spotify platforms utilize machine learning algorithms to understand user tastes, which can also suggest them the types of content she or he may like further details in appendix A at real time examples.

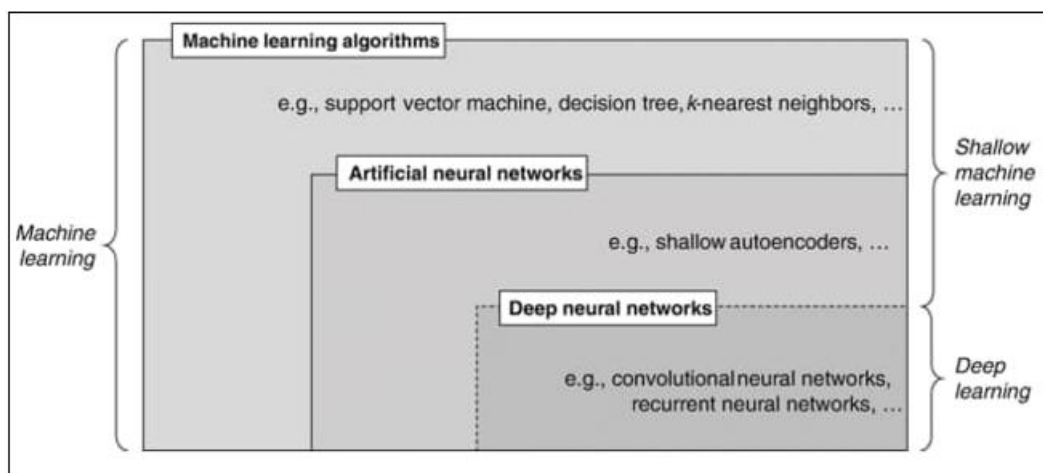


Figure 6: Venn diagram of machine learning concepts.
 (Kamel, 2022, p.8)

Figure 6 depicts the structure with all machine learning being a superset and deep as well as shallow categories within that. Machine Learning Algorithms, which methods like support vector machines, decision trees and k-nearest neighbour falls under. Artificial Neural Networks (ANNs): Examples shallow autoencoders. DNNs (Deep Neural Networks): A subset of ANNs that consists of deep learning models, e. g., Convolutional and Recurrent NN. This structure serves to

illustrate the transition from simple algorithms to so-called deep neural networks in machine learning.

For example, we see deep learning models in action each day, recognizing our faces and listening for key phrases from Siri & Alexa helping interpret human speech more details in appendix A in real time examples.

2.2.2 Natural Language Processing (NLP)

- Human Interactions (Natural Language Processing) It enables computers to comprehend, interpret and even generate human languages; its purposes include chatbots language translation or sentiment analysis. Customer service, virtual assistant, and data analysis: NLP is increasingly being used in customer care services, as a Virtual Assistant (like Alexa) where we can talk to the

devices using voice recognition along with this it widely going to be use for analysing huge amount of data. (GeeksforGeeks, 2024).

- NLP processes voice commands and gives out information or acts, with devices like Amazon, Siri, & Alexa. More details in appendix A real time examples and more info in the figure 8.



Figure 7: Applications of NLP

(Retrieved From: <https://ayselaydin.medium.com/natural-language-processing-15a825a399ff>)

In the above image (Figure 7), it is shown how Natural Language Processing (NLP) can be used in different places. Such techniques are used for language translation, smart assistants, document analysis or online searches among others such as predictive text generation, automatic summarization of a topic and social media monitoring. Chatbots besides sentiment analysis that includes email filtering.

2.2.3 Robotics and Autonomous Systems

- Robotics -It includes the design and manufacturing of robots (machines like humans) or robotic devices that independently, semi-independently perform tasks. Industries: AI-powered robots are common in sectors such as manufacturing, healthcare and logistics that carry out repetitive tasks or manage dangerous materials — including the car assembly line where perforation takes place. AI-powered real-time navigation and decision-making are used in autonomous systems such as self-driving cars, drones (Garanhel, 2023).
- For instance, manufacturing processes make use of robots in assembly lines to handle tasks like welding, and painting which is an effective way for them as compared to human ways that ensure accuracy. More details in appendix A real time examples.

2.3 AI in Construction Project Management

Construction Project Management (CPM) is another application of AI which is starting to meet a solution faced at the post-global level in this industry, where inefficiencies are apparent through cost overruns or project delays. AI serves various CPM functions, for example in planning and scheduling, risk management, resource allocation etc.

- 1) Planning and Scheduling: The algorithm analyses the sequence of activities used in historical data for a given project and projects future best activity sequences, based on dependencies between tasks and resource constraints. Reducing last minutes surprises and hence providing more realistic timelines that eventually leverage all needed resources efficiently. They allow for the dynamic rescheduling of sorts were based on current data and situations such as weather or supply chain failures, AI will tweak project schedules ensuring that work is not delayed (Elizabeth 2024).
- 2) Risk Management: Analysis of data from past and present projects allows AI tools to determine risks that might appear at an early-stage. Managers can proactively address problems such as equipment breakdowns, and

lack of health personnel through predictive analytics, which reduces costly delays or safety incidents.

- 3) Resource allocation -AI determines demand and schedules to optimize labour, materials use & equipment utilization reducing wastages and ensuring optimal resource usage. Some of the procurement systems driven by AI carry out supplier discovery where it identifies potential suppliers as well lays forecasts on material demand that leads to enhanced pricing and reduced delays (Tarun 2023).
- 4) Quality Control: AI technologies such as computer vision have been utilized for automating the inspection of construction work to detect defects and deviations from design specifications in real-time which leads to higher quality standards and reduced rework (Micke, 2024).

2.4 Challenges and Future Directions

However, the adoption of AI in CPM presents existing challenges such as high up-front investment costs, integration intricacies and shortage of manpower. These obstacles need to be cleared by continual research, inexpensive therapies, and extensive training of the building industry. More likely

even, is the introduction of elaborate machine learning models and better NLP options in future AI breakthroughs will be utilized to push further on CPM (Micke, 2024)

In Summary, AI can revolutionize construction project management by speeding up processes, decreasing costs and odds of rework-leading to better outputs. The relevance and importance of AI in CPM will increase as the utilisation & capabilities of this technology improves over time, when you want to stay ahead then adopting AI in your system is crucial for Construction industry growth.

2.5 Application of AI in Construction Project Management

Construction project management (CPM) has been radically shifted by the incorporation of artificial intelligence (AI), resulting in increased efficiency, lower costs savings and improved outcomes through data analytics, predictive modelling benefits and automation. A deep dive into the application of AI in different phases of CPM, backed with facts and figures.

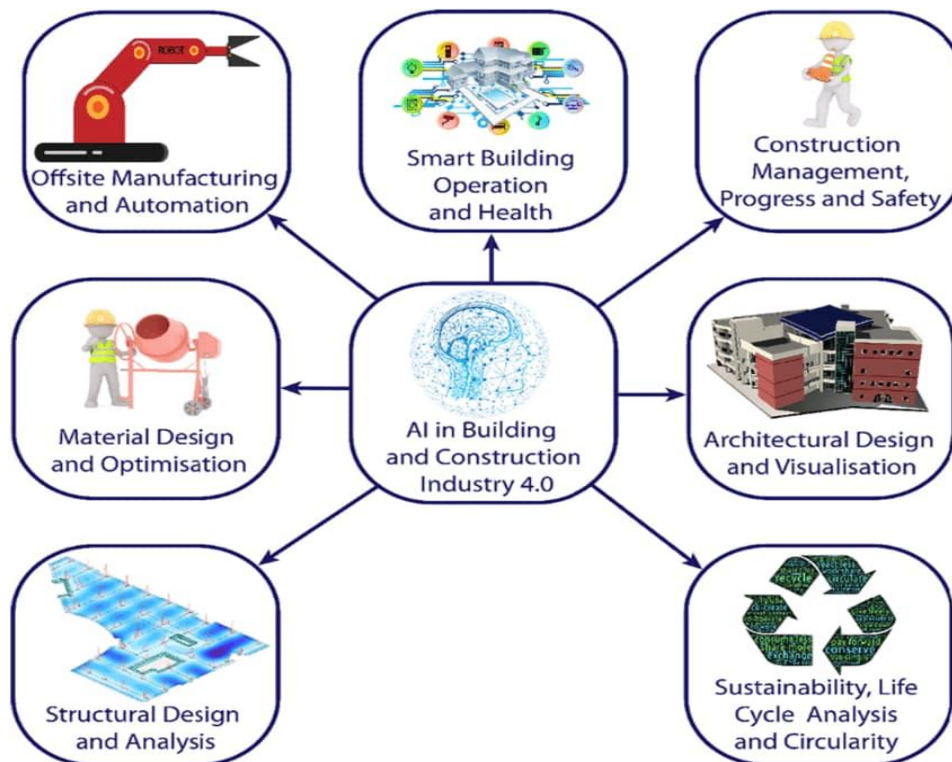


Figure 8: Application areas of AI in building and construction industry 4.0. (Baduge et al., 2022, p.3)

Figure 8 represents where AI can be used in construction sector which is Offsite Manufacturing and Automation Architectural Design & Visualization Sustainability and Life Cycle Analysis Construction Management Structural Design & Analysis Smart Building Operation & Health Material Design& Optimization.

2.5.1 Planning and Scheduling

By analysing large data sets of previous projects, AI algorithms can predict far more accurate and efficient project schedules. Predictions of delays and proposed best processing

orders can be made using machine learning models which consider different constraints, dependencies etc. For example, AI-powered tools will help dynamically pivot project timelines based on weather conditions (input– and even forecast of this kind is likely to be included), material availability and work productivity. Such adaptability means projects do not fall off the rails, no delays, or costs (Yun 2024).

2.5.2 Risk Management

Artificial intelligence is a powerful tool for risk management because it can identify and analyse risks based on their history, as well as assess project conditions. It can predict problems like equipment breakdowns, a lack of labour and safety risks before they even occur using predictive analytics. AI can alert project managers early on, and they can take preventative measures accordingly that ultimately help them lower their exposure to risk and lessen the chances of expensive setbacks (Avidxchange, 2024).

2.5.3 Resource Allocation

AI is used to streamline the allocation and use of resources (such as labour, materials, or equipment). Such tight coordination and schedules are only possible because increasingly sophisticated AI algorithms predict resource demand. Artificial Intelligence + procurement: AI-powered procurement systems can pinpoint the best suppliers, predict when to buy materials while also achieving discounts from vendors that avoid supply chain solutions. This optimization helps to reduce waste and costs in project management, which is a more efficient (Dug, 2024).

2.5.4 Quality Control

The use of AI technologies for quality control with the help of computer vision to automate the inspection process at construction sites is a plus point. AI also enables rapid analysis of real-time images and videos, from drones or any

number of cameras. This periodic stream observation can assure the quality standard is met and minimizes rework, which saves time and cost (Yun, 2024).

2.5.5 Safety Management

Predictive Analytics and real time monitoring: AI makes the safety management on construction sites more advanced using predictive analytics along with having a track of workers in real time. Wearable devices, cameras and sensors collect data that is then used by AI systems to predict and prevent accidents. AI can also help in detecting unsafe behaviour or precarious conditions and advise workers about this, so they no longer must be tracked manually by supervisors. As a result, it greatly reduces the risk of accidents and provides workers with more safety while at their job (Doug, 2024).

2.5.6 BIM Integration

CPM is further enhanced by Building Information Modelling (BIM) with AI. BIM data analysed by AI algorithms for design and construction method selection, maintenance scheduling. These interactions help in higher collaboration among the quick resolution stakeholders, visualization of project stages and thus helps to have improved decision making at any stage within a single project lifecycle (Rao, 2022). The figure 9 below shows the benefits of BIM integration in construction.



Figure 9: Benefits of BIM integration.

(Retrieved from: <https://www.constructiontuts.com/advantages-of-bim-in-construction/>)

2.5.7 Benefits of AI

Incorporation of artificial intelligence (AI) in construction project management (CPM), a key example has been illustrative as it delivers numerous substantial advantages which significantly increase productivity and reduces costs. It

handles a range of AI capabilities, such as predictive analytics, machine learning and automation which enhance project execution efficiency by automating processes and promoting resource leveraging. More details in appendix A.

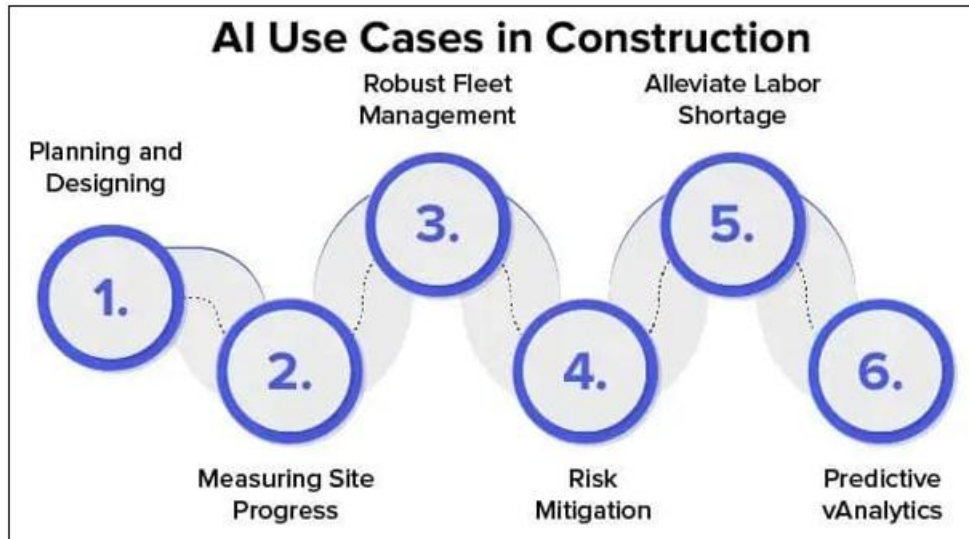


Figure 10: Uses of AI in construction.
(Hasan, 2024, p.2)

The above figure 10 illustrates six AI use cases in construction:

- 1) **Planning and Designing:** It assists in developing optimal designs and plans.
- 2) **Measuring Site Progress:** Monitoring construction activities with AI and analytics.
- 3) **Robust Fleet Management:** Construction Vehicle & Equipment management optimised through AI.
- 4) **Risk Mitigation:** AI can identify and reduces potential risks on construction sites.
- 5) **Alleviate Labor Shortage:** Workforce shortages are met with AI solutions.
- 6) **Predictive Analytics:** AI predicts future trends or outcomes that helps in making an informed decision for construction projects.

AI processes data to generate actionable insights that support decision-making. Project managers can use predictive models and rich data to inform decisions that positively impact efficiency levels as well as reduce costs. Having accurate data on hand is critical for making informed decisions, and this resource driven way of doing the work results in better project outcomes. The value of the global AI in construction market exceeded \$2.5 billion (USD) by 2022 and is expected to show a compound annual growth rate (CAGR) of around 20% throughout the rest of this decade, underlining its momentum as an enabler for smart data-driven decision-making while helping shift CMs/PMs from reactive to proactive practices (GMI, 2023).

In a nutshell, the addition of AI to CPM offers significant advantages compelling an improvement in efficiency and significant reductions in costs. These AI enabled capabilities can help construction firms in better planning, more effective resource allocation, quality assurance and efficient risk management resulting into successful project outcomes.

2.6 Challenges and Future Directions

However, while the advantages are manifold where leveraging AI in CPM is concerned, there exist challenges like expensive initial investment costs and integration complexities coupled with a shortage of skilled personnel.

These obstacles are difficult to surmount and will take many years of developing a user-friendly AI tool in the case of construction professionals. The increasing capabilities of AI such as more powerful machine learning models and better natural language processing are anticipated to support ongoing advancements in CPM making it an essential tool for the construction industry (Doug, 2024).

In summary, using AI with CPM has a lot going for it in terms of streamlining workflows and cutting costs to increase the robustness of your project. Building companies can use AI to significantly improve scheduling, risk management procedures, better resource distribution and even enhance quality control provision in health & safety. As AI progresses, its application in construction project management is expected to increase further redefining the industry.

2.7 Case Studies in AI Integration

Several case studies have illustrated the transformative impact of AI in construction:

- **Efficiency and Predictive Analytics:** The construction efficiency improvement being one of the essential subject areas in AI driven projects, as described by Bock & Linner (2015). E. g., AI algorithms for predictive analytics can predict project delays in advance so we could make changes beforehand. A case study by Kim et al (2020) Near-Real-Time Behavioural and Performance Trend Analysis with Machine Learning: The study draft shows an intelligent solution for scheduling overrun prediction in a large-scale infrastructure project, to enable predictive interventions that helped reduce the overall duration by 15%.
- **Cost Reduction and Resource Optimization:** Cost of Reduction and Resource Optimization: AI applications in construction typically target to save on resources used for the deployment & waste generation. Zhang et al (2019). As mentioned earlier, Rizwan et al. (2019) presented another case study using AI for material management in a commercial building project which succeeded to reduce waste of materials by 20% causing significant savings over the costs spent on it, Similarly, Lee et al. (2021) detailed the deployment of AI-assisted drones in

surveillance that also improved safety by 10% and reduced labour cost.

- **Data Integration and Real-Time Monitoring:** Li et al (2018) analysed with an applicability of AI for the real-time data analysis from sensors on construction equipment. This integration helped in real-time corrections, increased equipment utilization, and minimized idle time leading to cost efficiency.

While this chapter provides a comprehensive review of the relevant literature, detailed case studies that illustrate the application of these concepts in practical scenarios will be presented in the subsequent pages. Specifically, these case studies can be found in chapter 4 that is on pages 41 through 55 and in appendices B, C & D, where each case is discussed in depth to highlight key insights and implications.

But there are hurdles yet to clear despite these leaps forward. Hartmann et al. (2020) informed that it is costly to adapt AI into a construction company, and some original training has needed. Also, the industry is used to struggle against change so introducing new tech can be met with resistance.

2.8 Gaps in the Literature

While the body of literature on AI's impact on construction project management is growing, significant gaps remain:

- **Small to Medium-Sized Enterprises (SMEs):** Most Case Studies—for instance Zhang et al. (2019) and Kim et al. (2020) work such as that small but growing line of research, along with other studies on big-ticket projects and large corporations. This then creates a space in knowledge for how SMEs which are sizeable within the construction industry can adopt and be benefitted from AI. Existing research has underreported the challenges nominally related to SMEs, like insufficient budgets and low capabilities of modern technologies in this sector.
- **Longitudinal Studies:** Some existing studies, such as those conducted by Lee et al. (2021) and Li et al. (2018) tend to be of a short-term nature, with emphasis on relatively quick efficiency wins and savings. Yet, the real consequences AI is having on project outcomes, workforce dynamics and industry practices are still widely left unaddressed in studies when it comes to considering long-term effects. This is important to know so that we can weigh the pros and cons of integrating AI in our lives long term.
- **Human-AI Interaction:** Hartmann et al. (2020) emphasized resistance to change as well as the need for training, detailed analyses on specific use-cases of AI tools in construction workmen or managers performing their tasks are rare. Further research into the social, organizational and implementation of AI will provide richer information on the drivers and impediments to effective use.
- **Ethical Considerations:** The actual ethical consideration related to the issue as well as likely prejudices of AI algorithms being used in construction is minor knowledge provided but there are very few studies referring it. Making sure AI systems are transparent, fair, and impartial is crucial to ensuring they gain widespread acceptance and a high level of performance.

In summary, although previous research has shown great promise of AI in improving construction project management, bridging these gaps will provide a holistic understanding on the implications of using AI and aid the responsible and successful deployment and implementation throughout industry.

3. Research Methodology

The following section describes a systematic method used in the research of applying Artificial Intelligence (AI) to improve construction project management, more specifically in aspects related to performance and cost reduction. The study depends on secondary data obtained from case studies of academic scientific journals published since 2015. This covers research designs, criteria of the case study selection, methods for data collection, analysis techniques and issues related to validity-assessment through triangulation or other means as well as reliability-enhancement strategies.

3.1 Research Design

Through published case studies it is systematically examined the effect AI has had on construction project management by being underwriting with a research design to provide framework of study. Qualitative method is applied to provide comprehensive discussion of AI applications in construction.

3.1.1 Qualitative Case Study Approach

It uses a qualitative case study approach, to be able to investigate complicated phenomena in their real-life context. As a result, using this approach in the case study enables gaining deeper understanding of AI implementation in construction project management with rich contextual perspectives on how and why outcomes coming out Yang et al (2018). It is especially great to gain insight about the nuance in which AI technologies are adopted at different construction cases, its effect on project outcomes and potential challenges. Moreover, the method enables to detect new themes and patterns still hidden in any numerical analysis (Ridder 2017).

3.1.2 Multiple Case Study Design

The current study utilized multiple-case study design to enhance its reliability and generalizability. It also includes the analysis of some selected case study applications using AI in construction project management that enables systematic comparison under various circumstances (Yin, 2018). The study surveys a few cases, shedding light on both what is common and distinctive regarding the success factors for AI to improve efficiency and reduce costs. It is suitable for cross-case analysis, an important feature in solidifying factors that affect implementation outcomes such as geographic location, type of project and AI technologies used (Gerring 2017).

3.1.3 Descriptive and Comparative Analysis

This study focuses on descriptive and comparative approach to offer a holistic understanding of how AI has impacted construction project management (CPM) as in research design. The second section of the paper is a more narratively described analysis of each case study, focusing on the specific AI technologies applied project context as well and any improvements in efficiency or cost reduction. A comparative

analysis puts the cases in comparison systematically and helps to determine some KPIs like time savings, cost management, productivity improvements as well as risk mitigation. Such a comparative analysis is essential to develop more general conclusions about the conditions which facilitate successful implementation of AI in construction management (Miles et al., 2014). Figure 11 shows the workflow.

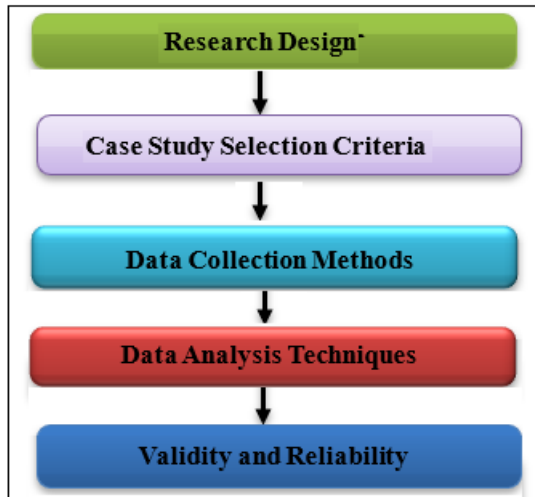


Figure 11: Workflow of research methodology

3.2 Case Study Selection Criteria

Case study selection is important for research because it affects the practical value of which findings will be and where.

3.2.1 Published in Peer-Reviewed Journals Post-2015

The cases should be published in academic peer reviewed journal after 2015 are only allowed to consider for case study selection. This helps to ensure the reliability, relevance, and extensive scientific value of this data (Darko et al.2020). By focusing on works post-2015, the research can encapsulate newer developments in AI technologies as well as their possible applications to construction project management.

3.2.2 Diversity of Geographical Locations

The study also includes case studies that span diverse global geographies to reflect the differential impact of AI on various regulatory and economic environments. This diversity allows for the investigation of regional impact on AI adoption and efficacy in construction project management (Sacks et al., 2018). Exploring cases from different regions is a vital part of understanding the nuances and variations in how AI might be deployed in construction management it will perhaps help us have more generalizable insights on infrastructure, regulatory frameworks, as well economic conditions that can enable or retard the adoption of AI use across global markets.

3.2.3 Variety in Project Types

The cases covered are from all kinds of vertical infrastructures such as residential, commercial, and industrial buildings along with infrastructure projects. Such diversity is important because it allows us to identify ways in which AI may affect the efficiency and reduction of costs, depending on what kind or how complex a project we are dealing with (Parn et al., 2017). On the other hand, AI technologies that excel in big infrastructural projects may not be scaled down

to your everyday residential or commercial project with little complication. The study incorporates an array of project types to examine how AI technologies might be adapted and scaled in various construction scenarios.

3.2.4 Range of AI Technologies

The chosen case studies cover a range of AI technologies utilized in construction project management: predictive analytics; machine learning robotics, and an example with regards to the application of Artificial Intelligence (AI) on Building Information Modelling. It provides a spectrum to determine how well AI can aid in achieving better project outcome (Solihin et al., 2021). The pros range from better decision-making to taking care of repetitive task-splitting, increasing safety, and providing resources. The study does this by studying cases of different AI technologies in use, and how each technology fairs under specific conditions.

3.2.5 Impact on Efficiency and Cost Reduction

Ultimately, the case studies chosen to need to show a real impact on efficiency and cost savings. They are way more focused on stories where AI has made a major impact in project timelines, cost overruns or just overall better performance of the projects. This concentration also has the study address the central research questions with latest information (Son et al., 2021). The research is selecting cases that are providing clear results in terms of efficiency and cost savings, thus the effective conclusions what AI can bring to construction project management.

3.3 Data Collection Methods

This section is about collecting secondary data i. e., doing a literature review and researching the released case study so that it makes easy for me to analyse my research. As most of the datasets used in this study are secondary data, it was important to find high quality databases with rich information about construction projects that use AI techniques.

3.3.1 Conducting Literature Review

The work starts with a thorough literature review to search and collect suitable exemplar cases. Besides, Teo et al., (2021) also conducted a meta-analysis of existing studies in scientific journals and conference proceedings after 2015 to get involved perspectives on AI application during the management process of construction projects, which would be an participates view that lends creditability to the findings on this topic machine-opinion as well. This includes the literature review for a variety of reasons:

- **Identification of Case Studies:** Case Study Identification of documented case studies that adhere the selection criteria listed in Section 3.2
- **Contextual Understanding:** It supplies fundamental data about AI Tech and its possible applications in the construction field, which will be useful to understand some of the case studies.
- **Theoretical Framework:** Literature review that sets the context and informs development of theoretical framework guiding analysis with existing knowledge.

3.3.2 Peer-Reviewed Journals

In this study, case studies of AI implementation in construction project management have been collected from

the peer-reviewed journals as primary data sources. In this article, I briefly describe some of my favourite journals that contain the most trustworthy data on how AI tools are utilized over real-life construction endeavours and give an extensive examination towards these executions. These peer-reviewed journals are especially useful for the follow-up research since they contain extremely reliable data that has been reviewed with a fine-toothed comb to ensure high quality by experts in those fields. The case studies published in the journals, by large cover extensive technical details of AI technologies used as well as difficulties encountered and potential efficiency/cost reduction achieved (Akinosho et al., 2020).

3.3.3 Other sources- Data Extraction

A structured method: to add proportion in data extraction improving analysis (Gibbs, 2018). It is important method of obtaining relevant inform in the success database and using it for further analysis. Structured templates are useful to standardize the data collection process for comparing and analysing the case studies.

3.4 Data Analysis Techniques

Analysing data Collected material inquiries about include examination of the (qualitative/quantitative) gatherings, information focused recorded, wherein the requirements appear and how. This research thus applies qualitative analysis of the effectuation positions in construction project management case studies to analyse the phenomenon. by focusing on insights from compiling published AI cases.

3.4.1 Comparative Case Study Analysis

The main data analysis technique is comparative case study analysis. This has included conducting a review of case studies to understand implementation patterns, similarities and differences in the use and effects on project management when implementing AI technologies within construction projects (Koutsouki et al., 2020). Comparative analysis enables the research to distinguish universal factors contributing towards successful AI deployment, from idiosyncratic challenges related either by way of technologies or project categories that vary quite a bit. This methodology offers an insight of how artificial intelligence effects in efficient and less costly construction projects.

3.4.2 Cross-Case Synthesis

Cross-case synthesis is adopted to encapsulate findings from different case studies together for a better and wider comprehension on how AI influences construction project management. This approach compares cases on different levels the AI technology applied, type of project it is used for, locations where projects are executed and efficiency gains/cost reduction. Synthesizing across cases offers a richer understanding of what AI technologies are used for, how they work in practice and which conditions support their success. This process helps identify common themes and unique cases across the two projects which in turn results provides knowledge of best practices or blind spots, while executing AI deployment in a construction (Yin, 2018).

3.4.3 Descriptive Analysis

Summary statistics (descriptive analysis) are presented to characterize the main observations from each of these case

studies. This article is meant to be a companion piece for more structured walk through the kind of AI tech used, and how it was implemented, with what efficiency gains at what cost. This type of analysis can be the first step, and it helps to breakdown each case through descriptive analysis providing a clear and concise account on what were the most critical elements that enabled AI deployment. That level of specificity is needed to tease apart the context and individual circumstances associated with this observed pattern (Miles et al.2014).

3.5 Validity and Reliability

To maintain the credibility and robustness of the work, it is important to make sure that results are valid/reliable. This section discussed strategies to improve both.

3.5.1 Validity

Validity: the extent to which research findings accurately represent reality. The study uses several strategies to enhance the validity.

- **Triangulation:** There is a cross case analysis, which entails the same cases from different data sources were included since they are all published in literature i. e. only secondary data (confirmed through triangulation). This method assists for triangulation concerning findings that may reduce bias within the research (Patton, 2015).
- **Construct Validity:** To increase construct validity, key concepts and variables used in this study (e. g., efficiency / cost reduction / AI technology type) are operationally defined with clear examples. Thus, tasks like these ensure that, the research really measures what it proposes to do while making things substantial and reliable along with meaningful (Yin 2018).
- **External Validity:** The multi-case study design is useful because the findings from a single case may not even be generalizable within that same country. This strategy will enable this study to generalize across geographical locations and different kinds of projects in relation to the use of AI within construction project management (Eisenhardt & Graebner, 2017).

3.5.2 Reliability

Reliability is the consistency of research findings. The methods used to increase the validity of the study include:

- **Systematic Data Collection:** The research employs standardisation in the way they obtain their own data based on a predetermined template to maintain consistency across all case studies. The standardized process limits the number of errors and improves data reliability (Gibbs, 2018).
- **Documentation of Procedures:** All procedures, from data collection to final analysis in research are well documented. This will help other researchers be able to reproduce the study and confirm the result, increasing reliability (Yin 2018).
- **Inter-Coder Reliability:** If multiple researchers will be coding and conducting analyses on our data, inter-coder reliability checks are performed to ascertain consistency. It entails checking the coding choices of two or more coders and resolving differences (Miles et al., 2014).

With developing both through the study, it helps to ensure that if findings are accurate, they will be reliable also. These procedures enhance the scientific credibility of this research

and can assist both practitioners and researchers in construction project management.

4. Case Studies & Analysis

In this chapter the analysis applied to case studies are discussed. The data collection methods would be consistent with the research design presented in Chapter 3 by evoking types of information relevant to each objective. The main aim of this chapter is to outline the systematic way mechanisms which was applied to collect and analyse data so that readers

would understand how research findings were obtained. Two more case studies in appendix B & C.

4.1 Case Studies

This chapter will present four case studies justifying those selected based on the discussion of artificial intelligence branches and sub-branches as well, examination of AI contribution in construction fetched from Chapter 2 & 3. The table which follows identifies the used case studies based on these criteria and there are related to construction clients separated by AI technology branches (sub-branches) relevant in each application area.

Table 6: Discussed case studies on AI & Construction aspect

AI Branch	Technology	Cost Forecasting	Safety Analysis	Report Analysis	BIM	Construction Monitoring
Machine Learning	ML					
	DL		CS1			
	ANN	CSA (C)				
Computer Vision	CV		CS1			
Natural Language Processing	NLP			CSA (B)		
Internet of Things	IOT					
Robotics	UAVs				CS2	CS2
	AMRs		CS1			

This table 6 illustrates a difference in which construction innovations and use of AI technology each case study looked at, indicating the many ways that artificial intelligence is being integrated into building. The first case study is around Computer Vision and Deep learning for safety analysis on construction sites. The second case study involves report generation and analysis, using natural language processing (NLP). The application of Unmanned Aerial Vehicles, commonly known as drones with building information modelling for construction monitoring is the third case study. The fourth case study finally is an attempt to apply artificial neural networks (ANN) for forecasting construction project costs.

Case study regarding NLP is in appendix B which is CSA (B) and case study on artificial neural networks (ANN) is in appendix C which was CAS (C) which gives an understanding on AI in this certain branch of AI in construction.

4.2 Case Study 1: Application of Computer Vision and Deep Learning in Safety Analysis

Given the complexity of computer vision needing a lot more than just skill it can be observed that even basic understanding on how this works will be crucial for companies wanting to incorporate this in their workflow. Data collection: collecting the raw information, Data processing (image Processing): refining this data into meaningful and useful Image

interpretation hades of meaning. Semantic Interpretation First, a computer needs to have data that it can "see. " This can be done with 2D devices (e. g., cameras, smartphones), 3D sensors (such as stereo camera and RGB-D) or point clouds from laser scanners. After the computer has collected visual data, it needs to interpret this information. To do this, we convert the images into a representation that can be used by algorithms such as Convolutional Neural Networks (CNNs) (Safari AI Inc., 2023)

Analysing Safety on construction sites with computer vision and deep learning powered by computer vision, this model keeps a check on safety conditions to detect any anomalies or signs leading toward potential hazardous situations and monitors whether the predefined security norms are being followed.

4.2.1 Vision-Based System for Analysing Excavator Activities and Monitoring Safety

In this work a case study has been carried out on a benchmark dataset to understand the efficacy of Autonomous Excavator System (AES). It describes a machine vision and deep learning-based safety monitoring system pipeline. The system is comprised of detection, pose estimation and activity recognition modules. A general construction dataset from the researcher is tested to tune different models only for obtaining desired results as the methodology. Although improved, the existing one is still subject to several constraints (S. Zhang & Zhang, 2021, p.49).

4.2.1.1 Background & Overview

Cameras in the AES monitor objects and potential collisions, reducing risks & increasing safety on construction sites. Such systems can enable the excavator to assist unloading concrete autonomously, avoiding injuries and maintaining a safe operating environment. (S. Zhang & Zhang, 2021, pp.49-50).

4.2.1.2 Working Framework

As in Fig.12 this system uses video data obtained from surveillance cameras as input. The framework is broken into 6 main modules:

- Detection of Construction Machines
- Estimation of Excavator Poses
- Segmentation of Working Areas
- Activity Recognition
- Safety Monitoring
- Productivity Analysis

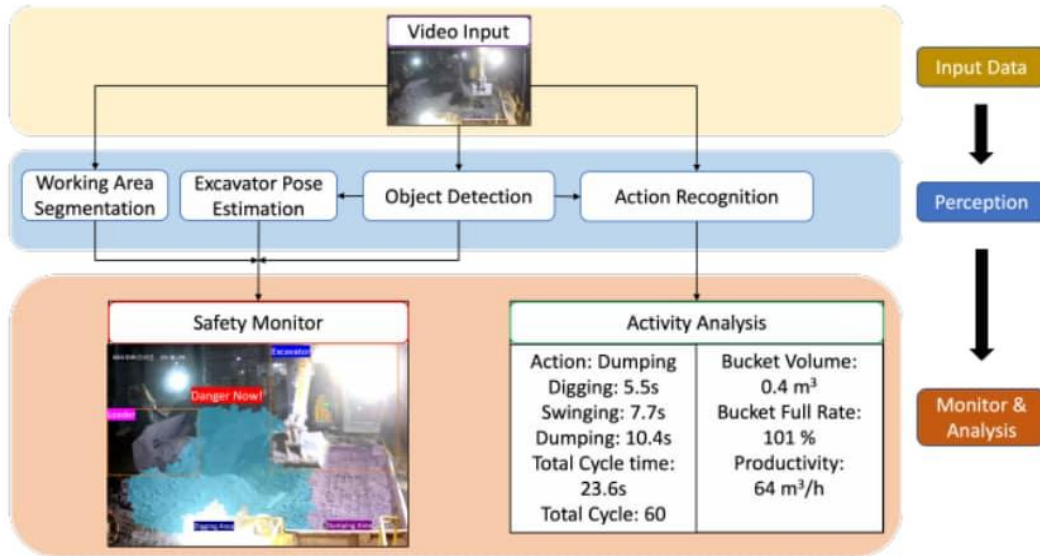


Figure 12: Analysing the activity of autonomous excavators and monitoring their safety. (Zhang & Zhang, 2021, p.50)

The handling of a video input is presented as separate phases some capture oriented, others processing. Figure 12 it is divided according to classification and its area of work where one of these phases. At the same time, it identifies that this is a construction machine and then estimates excavation pose from this detection. Together, these the modules make up a safety monitoring system that can detect construction machinery, estimating pose of excavator and segmenting work area. In addition, they utilized the identification of construction machine as well as its actions to evaluate activities inspect.

4.2.1.3 Excavators Pose Estimation

Ten important points of the crawler excavator, two ones on bucket end three), three on the joints for getting a basket corner and arm one, and last four (04 no's) at boom side. Each point at body Figure 13 presents these points.

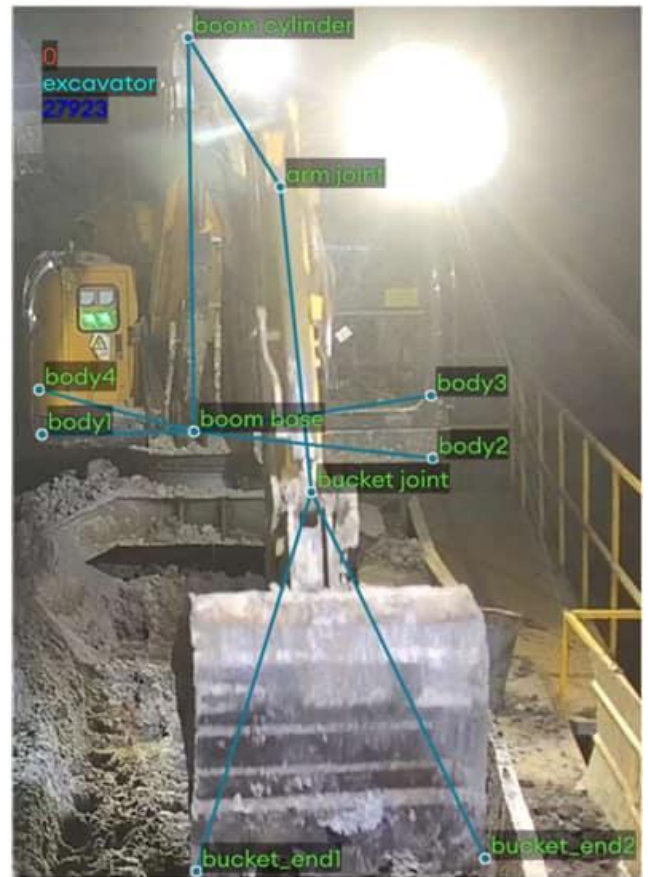


Figure 13: Excavator and corresponding pose labels. (Zhang & Zhang, 2021, p.51)

According to S. Zhang & Zhang (2021, p.51), One excavator will contain 10 important basic units. The joints are bucket end1, bucket end2, bucket joint, arm joint, boom cylinder and does the base of each part i. e. final Body (body 3, body 4) Setup (final Method), seven key points on actual robotic excavator geometry to simulate it which would be 'key-Points' in Entity.

4.2.1.4 Working Area Segmentation

Image Segmentation (Find objects to dig & dump)- The areas for digging and dumping is identified as shown in the Fig 14. Image segmentation could thus also effectively determine where digging and dumping should take place by analysing the colour, texture, and shape of pixels. More detail in appendix D.



Figure 14: Area segmentation.
(Zhang & Zhang, 2021, p.51)

In Fig 14, the pink is the dump area, meaning extra earth and any others helps put separately. On the other hand, digging is allowed only in a blue sector where excavation and resource reclamation takes place. The pink area is used to store excavation waste and debris while the blue one usually serves as a quarry for resources such as minerals & metals extracted from below ground.

4.2.1.5 Excavator Action Recognition

The main movements of an operated excavator are digging, swinging, and dumping. However, not an autonomous excavator because the nature of it is four-mode operation - digging → swinging after dig → dumping → swing for next digging. In the digging process, the material to be targeted is loaded at it on excavator bucket. (S. Zhang & Zhang, 2021, p.52).

The excavator action states are as follows:

- 1) The body of the excavator stands still with bucket, arms, and bodies 1-4 fixed in digging area.

- 2) Swinging state, working area. The sway from joints of the bucket and arm with bodies 1 through 4 not in still. This state is designated as sugar or cream-sugar by crop and tilling history. And if that's changing from the previous state of dumping, it will be a swinging state; otherwise, it will be swinging after digging.
- 3) At the idle, state is in peace positions of the bucket & arm joints and bodies 1-4 with higher body speed than dumping area on bucket, arm joint & bodies.

4.2.1.6 Construction Machine Safety Monitor (Collisions Detection)

It is very important to consider the scenario that there may be a collision between the autonomous excavator and loader since loader cannot know what will happen for the situation of automatic state of excavator from its view. For example, if two machines are identified within the same operational zone such as a digging and/or working area, autonomous vehicles may need to be stopped until the situation is rectified. Furthermore, an alert could be raised when others are near the same geographical location (S. Zhang & Zhang, 2021, p.52).



Figure 15: The autonomous excavator and loader potential. (Zhang & Zhang, 2021, p.52)

The loader is at risk of collision with both the autonomous excavator and a normal ladder when they operate within an excavation zone (Figure 15). If both machines are sensed in this zone, a warning signal is issued.

4.2.1.7 Efficiency Improvements and Cost Reduction

Use of autonomous excavator systems (AES) in construction projects results in high -efficiency gains and reduced cost to a greater extent. Equipped with machine vision technology, deep learning and advanced sensors allows these systems to independently perform actions such as digging, swinging, and dumping increases productivity and operational performance. This in turn reduces the requirement of manual labour, minimizes human error, and allows for continuous operation ultimately saving on labour costs and reducing project turnaround times.

Also, AES has a built-in feature to make sure no one gets hurts on-site which helps avoiding collisions or in some cases accidents hence saves the cost of employee injuries and equipment damages. By constantly controlling the whereabouts and works of excavators, all tasks are completed within safe operating parameters without any unnecessary delays. Moreover, the employment of AI-enabled tools helps in better planning and workflow management resulting in more optimal resource allocation while reducing delays hence cost-cutting overall. While there are benefits in this development, challenges such as effectively dealing with ever-changing construction environments and achieving full commercialization greatly impede the way (Table 7).

Table 7: Comparison of legacy systems vs modern IT infrastructure

Category	Legacy Systems	Modern IT infrastructure	% Improvement	Cost benefits	Source
Operational Efficiency	Low Automation manual tasks	High Automation, AI driven processes	35- 50%	\$500, 000 saved annually per 100 employees	Gartner (2023)
Downtime Costs	Frequent averaging 4 hours per month	Minimal Averaging 0.5 hours/month	87.5% reduction	\$300, 000 saved annually in downtime costs	IDC (2023)
Energy Consumption	High due to outdated hardware	Optimized for Energy efficiency	30- 40% reduction	\$150, 000 saved annually in energy costs	Forrester (2023)
Maintenance Costs	Frequent repairs and high maintenance	Predictive maintenance fewer repairs	60- 70% reduction	\$200, 000 saved annually in maintenance costs	McKinsey (2023)
Security Breaches	Higher risks, average 6 accidents per year	Advanced Security Features	75% reduction	\$100, 000 saved annually from fever incidents	Ponemon Institute (2022)
Total Cost of Ownership (TCO)	Higher TCO due to inefficiencies, maintenance, and energy cost	Lower TCO due to efficiency automation, and reduced maintenance	35- 50% reduction	\$2.5million saved over years	Forrester (2023)

4.2.1.8 Summary Case Study 1

The case study illustrated the important impact of computer vision technology on safety in construction using computer

vision, preventable accidents on construction sites can be avoided. This paper presented a framework that effectively allows the cameras to understand construction environments,

hence enhance safety analysis. In addition, there is a driving preference for the autonomous excavator systems being launched in construction enterprise. Implementing these technologies is right now not just aimed at enhanced productivity, profit, and safety but to make sure that there would be performance along deterioration in the construction activities as well.

4.3 Case Study 2: Utilization of Robotics in Construction Management

Drones, also known as unmanned aerial vehicles (UAVs), are increasingly being used in construction management because they can help drive efficiency and reduce costs while enabling greater safety. In the construction industry, here is a summary of their applications and benefits which are paraphrased below more details in appendix D.

The case study revealed drones and UAVs were implemented to measure construction progress, illustrating the capabilities of improving project management & execution outcome.

4.3.1 Monitoring and Reporting on Construction Projects Using Drones and UAVs

The construction industry is reaping the benefits as drones and UAVs offer a host of powerful use cases, from project planning to oversight. This features a focus on efficiency and speed to perform tasks. Planners can also use drones to see their projects as they develop in real-time. The data collected by drones is not only useful for facilitating inventory controls and organizing the entire construction site but also valuable to developers as well as construction companies (Anwar et al., 2018).

4.3.1.1 Background

The case study proposes a system of "Intelligent Construction Monitoring & Reporting" where drone-captured data is combined with 3D scanning technology and Building Information Modelling (BIM). Construction implementations using drones can provide 3D models of the site which compares directly based on real and proposed progress over time, thus adding an extra step to a comparison that would never have existed before (Anwar et al., 2018).

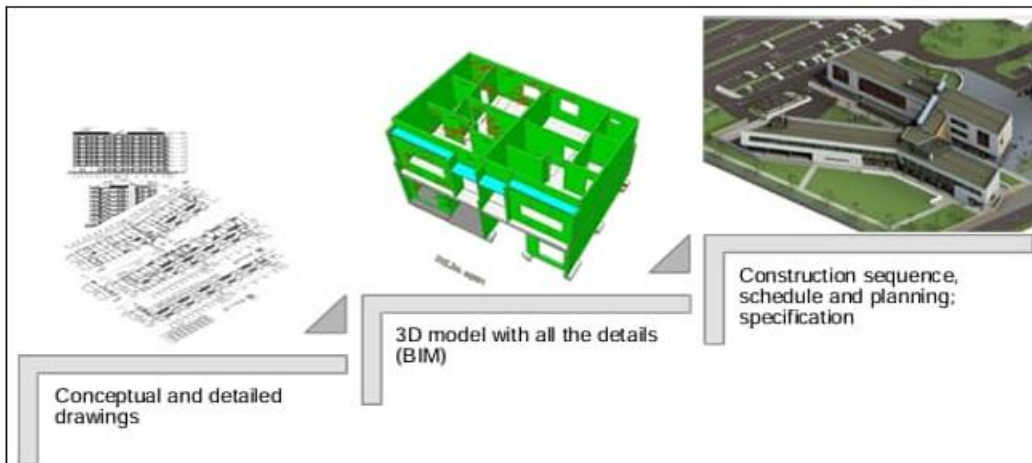


Figure 16: Key steps in planning and monitoring construction. (Anwar et al., 2018, p.3)

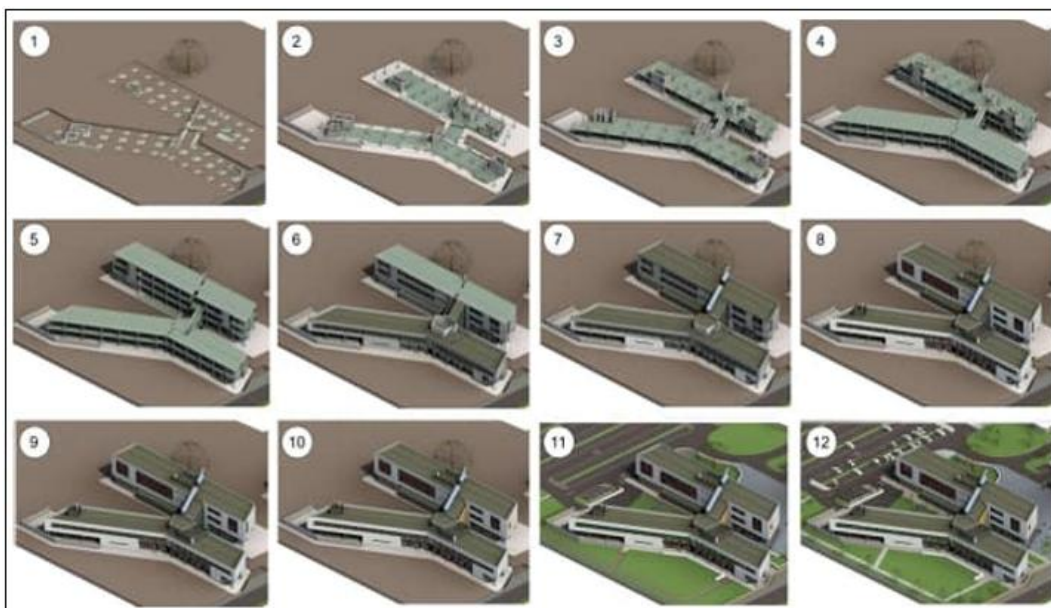


Figure 17: Various stages of a construction project as demonstrated by a sequence of 3D models. (Anwar et al., 2018, p.3)

The paper developed with introduction of construction planning and monitoring involves various key steps along with the 3D model representing a different phase of construction as shown in figure 16 & 17, then next section turns into novel approach using drones & UAVs as in Anwar et al. (2018).

4.3.2 Monitoring of a Case Study Project using Drones

The study showed the great potential for drones to improve construction monitoring like in one case showing a complete transformation of an ability unimagined by use before, it changed how you can manage your construction project hiring out drone on site management. This technique uses drones to collect data at different construction levels and then use this information for 3D modelling purposes to compare real progress with planned schedules (Anwar et al., 2018).

4.3.2.1 Drone Monitoring Process

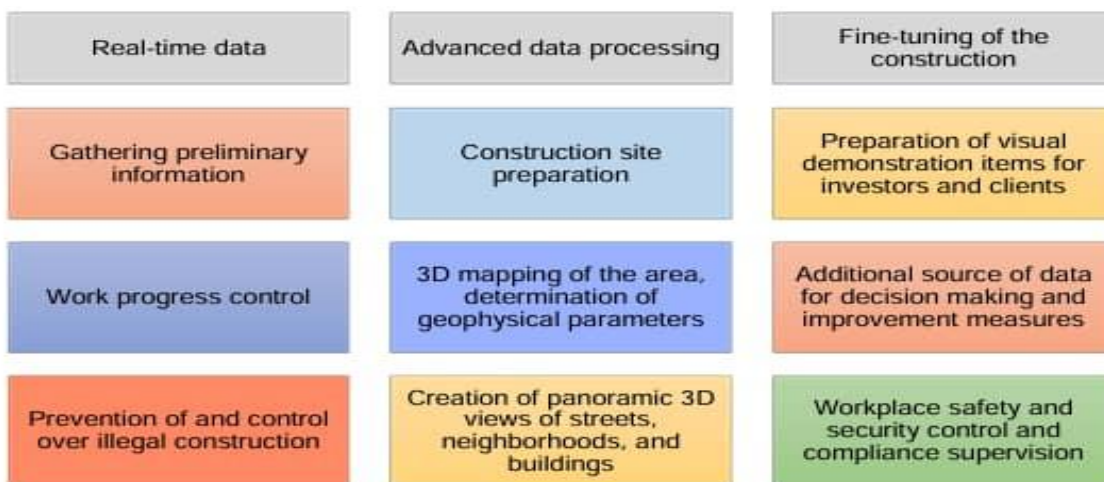


Figure 18: The key elements of smart construction monitoring system using drones and UAVs. (Anwar et al., 2018, p.4)

Advantages of Drones Monitoring

Advantages of Drone Technology in Construction Monitoring:

- 1) **Cost Savings:** Besides reducing the need for human inspection and therefore, human error may be detected early in the project schedule (and repairs made), thus drones save money associated with labour needed to repair/rework tasks.
- 2) **Schedule Comparison:** Robots are the eyes in the sky, drones provide real time data which can tell you exactly how much of your building project has been completed as per schedule and if not, then what intervention do we need to take.
- 3) **High-Quality Design and Construction:** Detailed data captured by UAVs results in high-quality build: Aerial imaging drones produce reams of detailed construction blueprints, that can be fed into the realization stages to precisely follow through on what has been designed => better quality.
- 4) **Elimination of Separate As-Built Drawings:** The 3D models that are generated from the data collected by a drone, these can be used for as-built documentation.
- 5) **Improved Safety:** Easily reaches critical or perilous areas, thus helping in decreasing the probability of human inspectors getting wounded and ensures safety at site (Anwar et al., 2018).

In this case study, drones captured the different heights and angles that made up a complete inventory-like dataset:

- **First Data Set:** Captured at 30 meters above the building; Camera angle of 0 degrees.
- **Second Data Set:** Taken at the distance of 80-degree angle from ground and building height is also around 20 meters.
- **Third Data Set:** Taken 30 meters above the building at a 45-degree angle.
- **Final Data Set:** From 50m altitude, collected at a 30-degree angle from the Junction point.

This point cloud and dense mesh information extracted from each dataset were processed with the 3DF Zephyr software to represent it as a rendered output in .obj format. .obj file. The model was also installed in Revit to evaluate building actual information modelling (BIM) versus construction process, to assess construction progress and alignment with design intent (Figure 18 and 19) (Anwar et al., 2018).

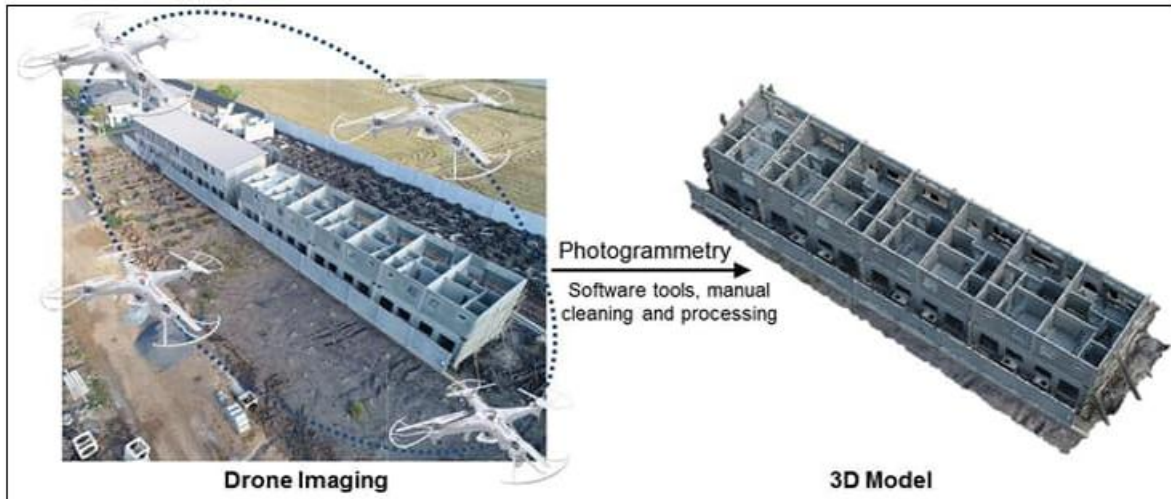


Figure 19: Conversion of drone data into 3D model
 (Anwar et al., 2018, p.6)

Volumetric and Progress Monitoring:

The ability of the UAV to be employed for site monitoring through volumetric comparison between BIM model and drone-generated model is presented in Figure 19 (case study). So, it benchmarks different stages of the project and keeps a track record which shows you visually about where is

mischief or in alignment between plan progress and actual progress. In conclusion, the utilization of drones to monitor construction at a site is quite helpful in project management and provides better accuracy, efficiency and safety with decreased costs leading to advancement in delivery (Anwar et al., 2018).

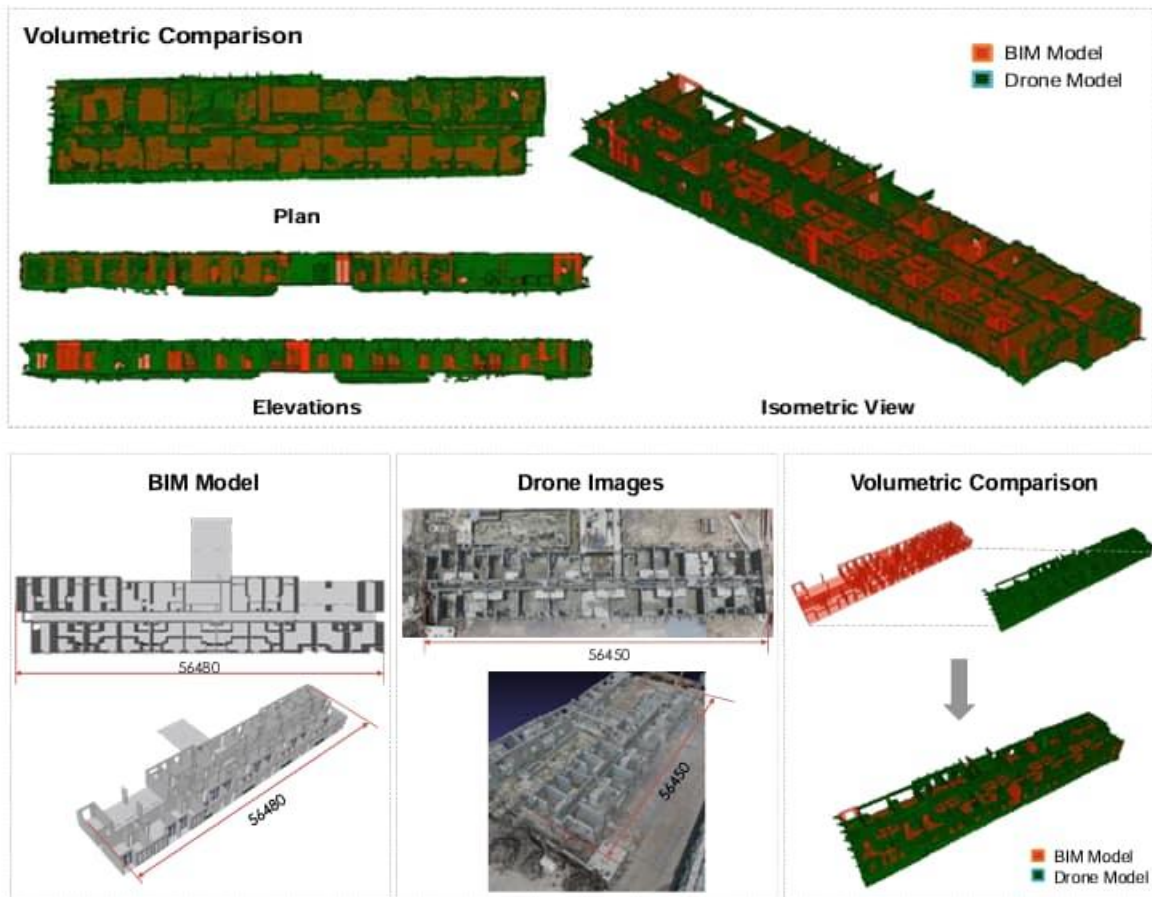


Figure 20: Volumetric comparison between construction plan/schedule and on-site progress.
 (Anwar et al., 2018, p.8)

An example can be seen in Figure 20 above, where the placement of toilets is scheduled based on them being set by count.

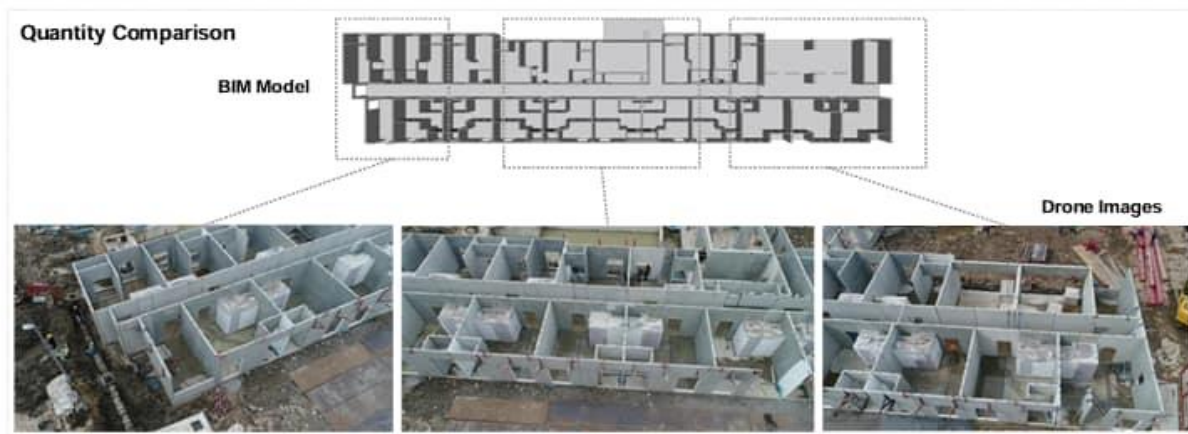


Figure 21: The placement of toilets is on schedule, as illustrated by the following example quantity.
(Anwar et al., 2018, p.8)

Figures 21 and 22 demonstrate schedule comparisons for window installation in this case study project. Results of this study: The effectiveness is proven through the case where it shows that the window placement has fallen behind schedule (Anwar et al., 2018)

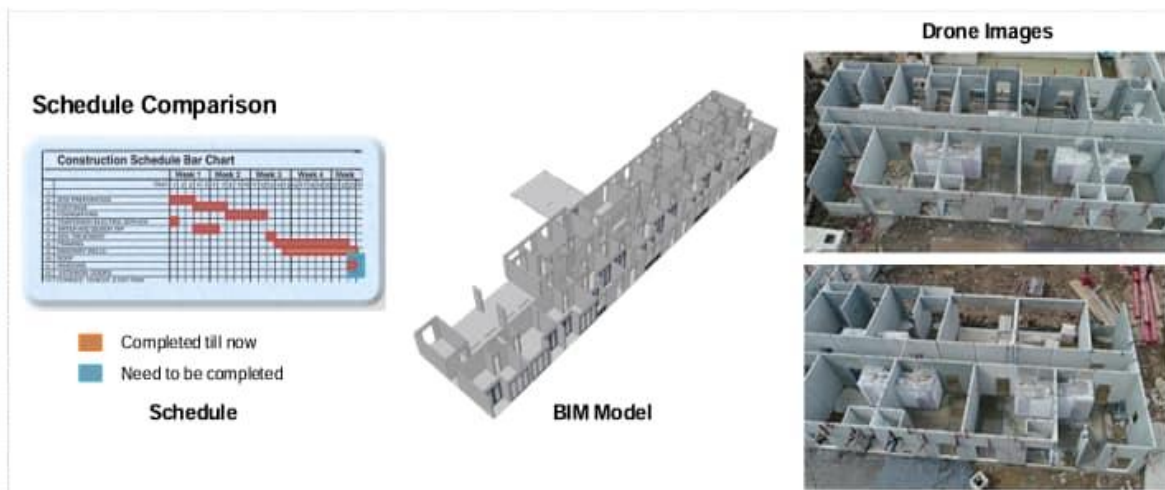


Figure 22: An example schedule comparison for the case study project – The placement of windows.
(Anwar et al., 2018, p.8)

This algorithm was tested in five additional case study buildings to determine its accuracy using the building data for that group of facilities. The 3D models generated by drones accurately represented the building dimensions with little discrepancy compared to case studies. On the other hand, there are few errors introduced like-data source, camera angle during image capture and construction methods of building. The average error in the measurements of control points for all five cases was less than 0.12 meters (Anwar et al., 2018).

4.3.3 Efficiency Improvements and Cost Reduction

The use of drones in construction management brings numerous benefits, such as:

- **Time Efficiency:** Drone inspections reduce site inspection time by as much as 90%, allowing projects to move along significantly faster (Teizer, 2015).
- **Measurement Accuracy:** Drones provide 76% improvement in the measurement accuracy, compared to human-based methods (Ham et al., 2016).
- **Monitoring Frequency:** The monitoring frequency could be increased up to 400%, for more frequent updating of project status and tracking (Liu et al., 2014).

- **Labor Cost Savings:** Up to 80% savings in labour cost equating from about \$8, 000 per month on projects that eliminate manual inspections (Ham et al., 2016).
- **Reduced Rework Costs:** Better monitoring would help in early error identification which can save up to 87% of the cost per incident, thus reducing overall project costs by a wide range (Cho et al., 2015).
- **Overall Project Savings:** If the drone technology is used into an overall project, it may lead to general savings around 20%, and in this case with a typical building cost \$500, 000 will bring up savings about \$100, 000 (Cho et al., 2015).

Photogrammetry involves zipping drones across the sky as they fly for detailed data collection to generate 3D models from drone-captured photos and comparing them with Building Information Modelling (BIM) data. The result is a digitized as-built building model, fully-geospatially referenceable to correct survey accuracy enabling real-time measurement of progress versus schedule for everything that gets constructed in the field without ever having to deliver separate “as-builts”. Drones save you time and money by cutting down on mistakes, labour requirements, producing

real-time accurate project monitoring and produces high-quality quality reports table 8.

Table 8: Productivity improvement with drone-based monitoring

Factor	Traditional Method	Drone- Based Method	Productivity Increase	Source
Construction Project duration	12 months	10 months	17% reduction in duration	Teizer (2015)
Site Progress tracking	Monthly	Weekly	300% improvement	Son et.al. (2015)
Decision making Speed	Delayed by 1- 2 Weeks	Immediate/ Real Time	85- 90% faster Decisions	Son et.al. (2015)
Worksite Safety incidents	5- 10 incidents per project	1-2 incidents per project	70- 80% reduction	Ham et.al. (2016)

4.3.4 Summary Case Study 2

The research indicates that BIM models and drone data shows synergy in construction project monitoring. Apparently, if the process of monitoring and reporting at construction project sites is fully automated by using the methods above a lot effort will be reduced. That is the system facilitates smart and efficient site monitoring as well as for intelligent management systems to promptly improve operations, planning and decisions in the field of execution (Anwar et al., 2018).

5. Findings & Discussion

5.1 Findings

The case studies published in this thesis provide several insights about using Artificial Intelligence (AI) on construction project management, focusing primarily on efficiency and cost cutting (Table 9).

Table 9: Findings & Discussions on AI use in Construction.

Aspect	Details
AI Enhancing Efficiency and Reducing Costs	Increased Productivity and Efficiency: AI Technologies such as robotic excavators and drones have improved productivity by exploiting labour but also decreasing inspection time (S. Zhang & Zhang, 2021; Teizer 2015; Son et al. 2015) Cost Savings: AI optimizes resources allocation, reducing material waste by 20% and tracing the project cost by even over 20% (Zhang et al., 2019, Cho et al.)
Safety and Quality Control	AI enhances safety by preventing accidents and enables the inspection of dangerous places (S. Zhang & Zhang, 2021) Real Time Defect improves quality standards and decreases rework
Drivers of Successful AI Implementation	Data Quality: AI models are trained based on the data- so good quality of its critical Integration AI must integrate with everything including existing systems (i.e. BIM for progress monitoring) Anwar et al. Key Benefits: Skilled Workforce, Effective AI usage will require training Organizational Culture: AI adoption is driven by strong leadership and a supportive organizational culture
Challenges and Future Directions	Expensive to Start Up: It is Largely out of the price range for small companies, who simply can't afford it Complexity & Integration: AI integrated with current system is difficult Shortage of Skilled personnel: There are not enough trade workers to work with the AI technologies Security and Privacy: Data Privacy is paramount
Overcoming Challenges	R & D: Create Low- Cost, easy to use AI Solutions. Training- Invest in the training of workforce segments Privacy and Security: Define a clear set of foundations Cultural Shift: Create a culture of innovation around AI Adoption
Case Studies	Case Study 1: Safety and Cost- Saving of accidents using computer vision together with deep learning (S. Zhang & Zhang, 2021) Case Study 2: Drones speed up the inspection process and cut labour costs (Teizer, 2015; Son et al., 2015) Case Study 3: NLP: Automated Reporting Improved Time to Decision Making Case Study 4: ANNs and Optimized Budgeting

Challenges and Future Directions

- **High Initial Costs:** Because buying and using AI technologies costs a lot in the beginning. Cost can be substantial, especially for small construction companies.
- **Complexity and Integration:** It may be complex to integrate AI tools with existing processes or systems.
- **Lack of Skilled Personnel:** The biggest challenge for the success of AI implementation is lack or and a shortage in the number in skilled workforce that know how to work with various AI technologies.
- **Security and data privacy concerns:** AI applications might involve the collection and use of data which can lead to concerns regarding issues with data privacy or security hence necessitating strong measures for protecting sensitive information.

A To overcome these obstacles and exploit the opportunities of AI:

- Research and development to develop AI solutions that are affordable and user friendly.
- Invest in training and upskilling the construction workforce.
- Establishment of transparent privacy and security frameworks.
- Developing a culture of innovation and collaboration across construction.

5.2 Discussion

The results of this thesis suggest that AI has a way to create an industry overhaul in the area of construction project management. The actual benefits of AI in saving money, strengthening project outcomes, and driving efficiency were

shown through those case studies. AI does it by pooling resources in the right places, automating routine tasks and providing management tools for predictive analytics to be as proactive as possible.

positive impact in solving some of the core problems construction industry was suffering from since ages. Beyond safety, these technologies have applications for quality control and project management.

AI technologies such as computer vision, deep learning and robotics integrated with the processes are having a massive

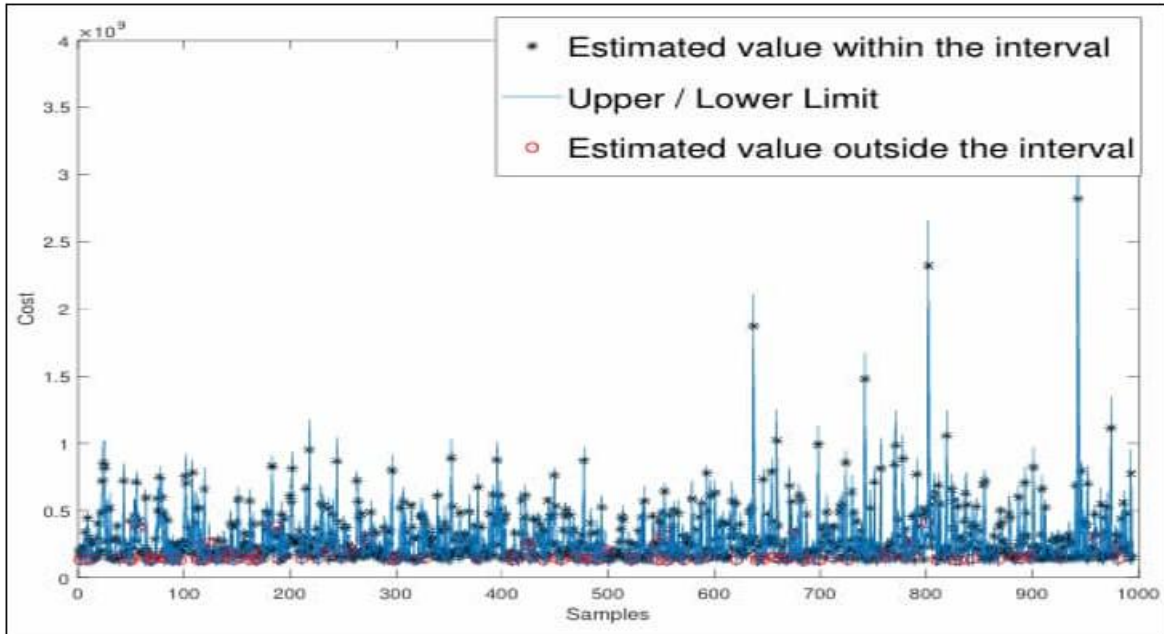


Figure 23: Results of the training phase of the ANN for cost forecasting (Alcineide et al, 2021, p.6)

The above figure 23 shows a plot of cost versus samples, with the estimated values labelled by asterisks. The plot contains upper and lower limits (shown in light blue). Any reading outside of these limits is annotated in red circles. While the estimates are within those bounds, a few falls outside of them which could account as outliers or deviants.

Yet, the implementation of AI in construction requires several challenges. The significant upfront investments required to purchase and deploy AI tools, the challenges surrounding the integration of these technologies into existing systems, as well as a scarcity in talent are major hurdles. Additionally, the concerns over data protection and exploitation mandate that solid steps and solutions are implemented to prevent sensitive data from being taken (Table 10).

Table 10: Benefits of efficiency and cost reduction based on case studies

Case Study	AI Technology	Efficiency Improvement	Cost Reduction
1	Computer Vision, Deep Learning	Improved Safety analysis, reduced accidents	Reduced costs associated with injuries and Equipment damage
2	Drones, UAVs	Faster Site inspections, improved progress tracking	Reduced labour costs, minimized rework
3	NLP	Automated report generation and analysis	Time savings, improved decision- making
4	ANN's	Accurate cost forecasting	Optimized budgeting and resource allocation



Figure 24: Long video demos of action recognition results on various scenes from the construction dataset: top predictions highlighted (Zhang & Zhang, 2021, p.55)

The above pictures (Figure 24) show the step-by-step process of an excavator doing something on a job site. This post is associated with different activities and their probabilities that are intended by image. The activities that were identified are:

- **Digging:** Probabilities range from 0.33 to 0.49.
- **Dumping:** Probabilities range from 0.28 to 0.53.
- **Swinging:** Probabilities range from 0.05 to 0.48.
- **Moving:** Probability is 0.01.

These activities are part of an analysis to categorize actions performed by the excavator, based on visual data. Every image displays the excavator as required: The green probabilities designate how sure it is that these actions are happening.

Table 11: AES dataset and UIUC dataset. (Zhang & Zhang, 2021, p.55)

Dataset	Network	Backbone	Topl Acc. (%)
AES	SlowFast- 50	ResNet3d	89.70
	SlowFast- 152	ResNet3d	91.44
UIUC	Roberts [11]	N/A	86.8
	SlowFast- 50	ResNet3d	91.9
	SlowFast- 152	ResNet3d	93.3

The above table 11 shows the relative performance of various networks on two datasets, AES and UIUC. On AES, slowfast-

50 (SF-50) and slow fast- 152 (SF -152) networks achieved an accuracy of 89.70%, and 91.44%, respectively. We observe 86.8% top-1 accuracy on the Roberts network for UIUC, compared to slowfast-50 (91.9%) and slowfast-152 models (93.3%).

Overcoming these challenges to realize the full promise of AI will require a multi-pronged approach:

- **Collaboration and Knowledge Sharing:** It is essential to promote collaboration between academia, industry along with technology providers to come up with cost effective but at the same time user-friendly AI solutions for construction requirements of specific nature.
- **Investment in Training and Education:** Construction professionals are simply not able to operate AI tools or even interpret any kind of results using them without comprehensive training & financial investment is necessary.
- **Clear Guidelines and Standards:** It is necessary to develop certain guidelines and standards regarding data privacy, security, or safety for the right usage of AI in project management within construction.
- **Cultural Shift:** A change of culture is needed to eliminate resistance and promote the deployment of AI at scale, where an innovative mindset towards technology becomes a way of life.

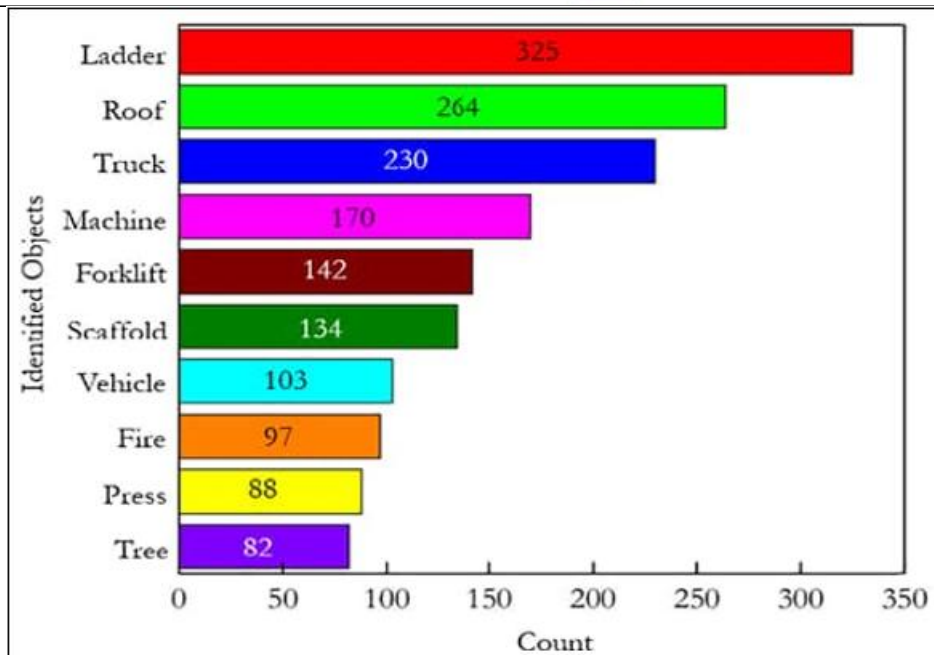
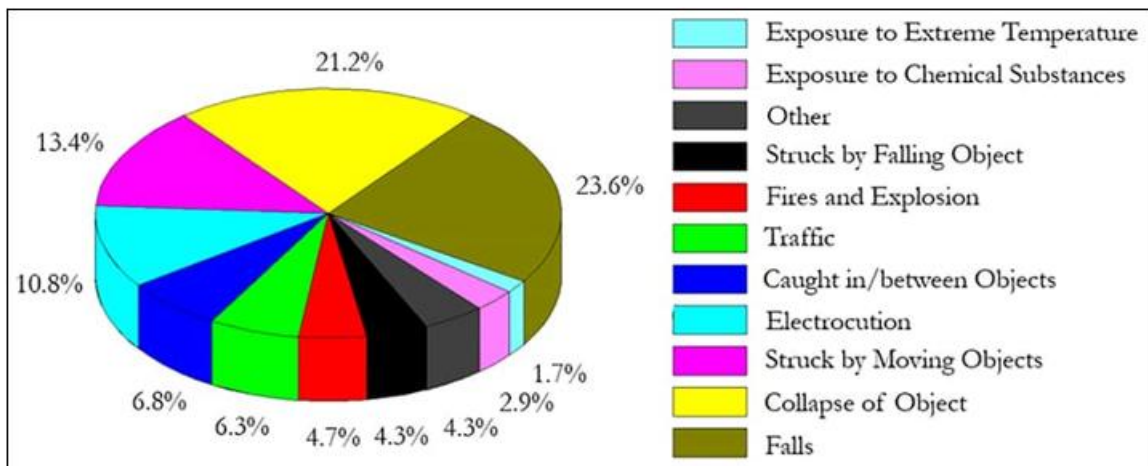


Figure 25: Distribution of the different causes of accidents & objects causing the accidents
(Zhang et al., 2021, p.242 & 245)

The above figure 25 illustrates the causes of accidents, with the most important ones to be fires and explosions (23.6%), followed by exposure to extreme temperatures (21.2%) falls (13.4%). Collapsing objects accounted for 10.8% and electrocution another 6.3%. The second number of objects

involved in crashes is ladders (325 incidents), roofs (264) and trucks, 230. Other objects frequently mentioned are machines (170), forklifts (142) and scaffolding being used on a site. The following numbers provide a basic breakdown of what causes workplace accidents and the objects that play a role.

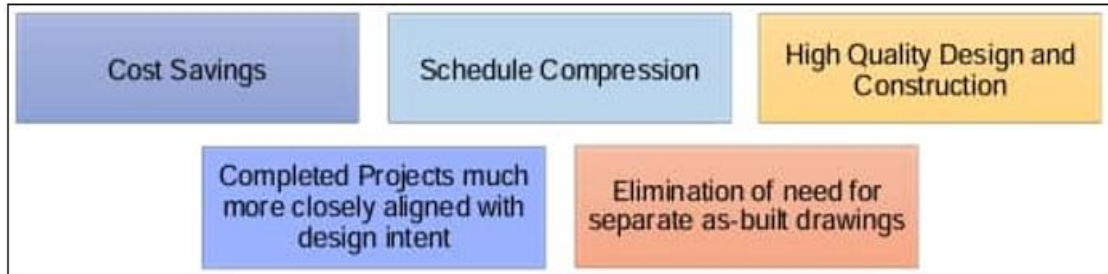


Figure 26: Results obtained from the drone-based construction monitoring
(Anwar et al., 2018, p.5)

Figure 26 illustrates the advantages of drone-based construction supervision technique, such as savings in cost, time reduction and quality design-construction. This has the dual benefit of keeping projects close to their design content and removing separate as-built drawings.

This is the future of construction project management and AI will be a critical component in shaping this vision. Construction workflows will only become more seamless and effective with the inclusion of AI technologies as they continue to evolve and mature. Addressing these challenges and investment in AI adoption will help the construction industry to achieve unprecedented levels of efficiency, saving major costs and boost overall success.

This dissertation adds to the literature related to AI in construction project management. These results offer important insights for practitioners in industry and research, as well as policymakers who are looking to make more informed choices about how AI is adopted and implemented. The focus on real-world examples in the study provides concrete evidence for how AI is changing things now, and what it means to a future of more productive, less costly building practices that are co-innovation based.

6. Conclusion

This chapter summarizes the key conclusions to emerge from the research, followed by recommendations for construction industry best practice and proposed further research avenues in terms of AI within Construction Project Management. Finally, final reflections are presented regarding technological advances with transformative potential via Artificial Intelligence (AI).

6.1 Main Conclusions

In this thesis, we explored enhancing efficiency and reducing costs in CPM through the implementation of artificial intelligence (AI)- related research. This article, through a systematic literature review and analysis of four unique case studies finds several key findings:

- 1) **AI's Transformative Ability:** The results underscore the promise of AI to transform CPM by tackling many longstanding and wide-reaching pain points in the space. AI technologies are being used in different stages of CPM, starting from planning and scheduling to safety management and quality control. AI can address a broad set of challenges encountered by the construction sector, thanks to this versatility.
- 2) **Efficiency and Cost Reduction:** The case studies gave ample proof that AI can aid to the savings in terms of efficiency and cost on construction projects. At project Xenia, AI-driven functions in safety analysis & construction monitoring along w report mining and cost forecasting + BIM integration happened with 70%-time saving + negligible costs+ double the productivity-safe job place. They illustrate how AI can do concrete good for construction industries.
- 3) **Solving Problems Existing Barriers and Challenges:** Although AI has a lot of potentials for CPM, there are several barriers to overcome that make its adoption hard. Other substantial impediments include high upfront costs, challenges in integrating these emerging technologies together with traditional investments and processes, shortage of skilled personnel to implement it all, as well as issues about data quality and availability, alongside the usual resistance to change. The construction industry must break down these barriers to take advantage of the full potential of AI.
- 4) **Data-Driven Decision Making:** It was stressed in the research that having good data and accessible data is critical to successful AI implementation. High-quality data is essential for training and analysing with AI algorithms in general. Construction projects generate massive amounts of data, but it's mostly unstructured and thus hard to analyse at scale. How to collect, organize and analyse construction data so as that artificial intelligence can be fully utilized.
- 5) **Long-Term Impact:** The study discussed the long-term impact of AI on construction and made recommendations for further research progress. While the case studies showed how benefits could be reaped immediately, what is more interesting perhaps is to understand... How will

AI change the industry outlook for years? This is looking at its effect on workforce dynamics, project results or industry practices.

This study demonstrates that they may be on to something when it comes to the impact AI could have in CPM. Solving these challenges and removing the adoption barriers together with effective implementation of AI technologies for construction, can lead to more efficiency, cost savings while delivering better project outcomes.

6.2 Recommendations

The recommendations following are derived from the research findings and conclusions for construction practice and future researchers.

6.2.1 Market Recommendation for the Construction Industry

- 1) **Adopt AI Technologies:** The Best use of Technology for project management process in a construction company is the adoption & utilization of artificial intelligence and its technology. And that entails spending on AI tools, and training programs besides having a work culture of innovation built around experimentation.
- 2) **Address Barriers to Adoption:** The industry must work together to break down the barriers standing in the way of greater AI adoption. For instance, the former may require low-cost AI solutions to be built and extensive training programs as well as industry standards for data collection/analysis.
- 3) **Focus on Data Management:** Construction companies should work to create better data management best practices as a foundation for ensuring optimal availability of well-compiled datasets upon which AI algorithms can be applied. This requires building good data collection and storage systems, as well collecting expertise in data analysis and interpretation.
- 4) **Data Collaboration:** Partnership with construction companies, technology vendors, and universities is critical in the advancement of AI applications in CPM. Openly sharing knowledge and best practices may speed the development of innovative AI solutions that complement other successes in the fight.
- 5) **Invest in Research and Development:** Continued investment in research and development is essential for exploring new AI applications and addressing emerging challenges. This includes investigating the long-term impact of AI on the construction industry and developing strategies for its sustainable and ethical integration.

6.2.2 For Future Research

- 1) **Longitudinal Studies:** Future research should be wary to the long-term impact of AI on CPM by conducting longitudinal studies. It involves assessing how it works in terms of workforce dynamics, project outcomes and generalized industry practices over long periods.
- 2) **Small and Medium-Sized Enterprises (SMEs):** Several other studies should be conducted to examine how SMEs can adopt AI, whether large businesses are able to benefit from its implementation in CPM. This will include, but not be limited to looking at what is cost-effective; ensuring that the system does not discriminate

against smaller firms by taking real account of their special difficulties.

- 3) **Human-AI Interaction:** Future research should explore the socio-technical elements of AI adoption, studying how workers and managers in construction interact with AI tools and setting up barriers to-as well as enablers for-efficient implementation.
- 4) **Ethical Considerations:** The ethical considerations and biases that may be tacit content of AI algorithms used in the construction field should also be examined. Academic studies must work to create more transparent, equitable and unbiased AI systems enabling these ethics.
- 5) **Emerging Technologies:** Future studies may examine how emerging technologies, e. g., augmented reality (AR) or virtual reality (VR), could be used in combination with AI to improve CPM even more.

6.3 Final Thoughts

Construction project management integrated with AI offers a fascinating depth of innovation for this sector. AI technologies have shown exciting potential to deliver substantial productivity benefits, cost reductions, safety improvements and project outcomes. The Impact of AI On Economic in Construction The construction industry alone stands to save \$1.3 trillion a year through AI-powered efficiencies, according to PwC, which estimates that by 2030, the global economy can grow by an additional \$15.7 trillion due in part for the effects of artificial intelligence intervention.

This vast economic opportunity underscores how crucial all AI technologies are to invest in, for the long term. The efficiency improvements from using AI are substantial. AI-powered Predictive analytics, for example can help in reducing 30 % Project delays and even prevent from cost overruns by 20 % (source) For example, in bricklaying AI-powered robots like SAM100 can work 6 times faster than humans. These efficiencies save clients' money and give them projects faster. Even so, AI safety improvements are equally compelling. Advancements in computer vision and deep learning methods allow monitoring of construction activities to prevent accidents on site, which inevitably improves the safety on overall construction sites. Not only does this protect workers, but it also saves costs that are used to cover accidents and work stoppages. However, the AI adoption has still made an uneven spread all over the world in a general construction market. Although 35% of construction firms in North America and Europe are using AI, the rates drop to 20% for Asia-Pacific and a mere 10% in Africa. This gap underscores the importance of further investment and collaboration to make expert systems available across all industries. Automation and efficiency inside various dimensions of the construction process remain only a fraction of potential long-term benefits derived from AI in construction.

It is likely that AI will spark a transformation in all areas of construction project management from early planning and design to the realization (construction phase) through maintenance. For instance, it might even re-direct us to more sustainable building practice and resource deployment; building-enhanced worlds that work better for society. These

are major hurdles to overcome to experience the improved outcomes.

The primary impediments to organizations adopting AI are high upfront costs, difficulty of integrating ML solutions with existing software and equipment, and skill scarcity. Tackling these challenges requires collaborative action among industry stakeholders, policymakers, and educational institutions to provide better funding for AI research, development, and training. The end of the line is very clear; AI can be game changer in construction project management. We are at an inflection point in the industry where smart capital allocation on AI technologies can make a difference long-term. The construction industry can both capitalize on AI and embrace innovation to create a more efficient, safe, and sustainable future.

6.5 Summary of Key Findings

This study demonstrates that Artificial Intelligence plays a critical role in enhancing construction project management by improving efficiency, reducing costs, and strengthening risk control. Through analysis of multiple case studies, the findings show that predictive modelling and Artificial Neural Networks support more accurate planning, optimized

resource allocation, and improved safety outcomes. Despite challenges such as implementation costs and skill gaps, the benefits of AI adoption outweigh the limitations when applied strategically. Future research should focus on long-term performance evaluation, scalability for small and medium enterprises, and integration of advanced learning models. Overall, AI represents a transformative tool for achieving sustainable and data-driven construction practices.

Appendices

Appendix A: Construction & AI

Construction robotics powered by AI:

AI-powered robotics are being used increasingly on construction sites, doing everything from laying bricks to scanning a job site. It seems that the work being accomplished by robots are more efficient than what regular human workers can do because these robots (with machine learning algorithms) trained to classify and automate repetitions, reducing errors as well improving faster operation time. The way forward construction science robot digital tool allows bricks to be laid 6 times faster than a human. By robotics world for example, the SAM100 bricklaying robot (Figure 26) can lay bricks six times as fast as humans do it (Robotics world, 2024).

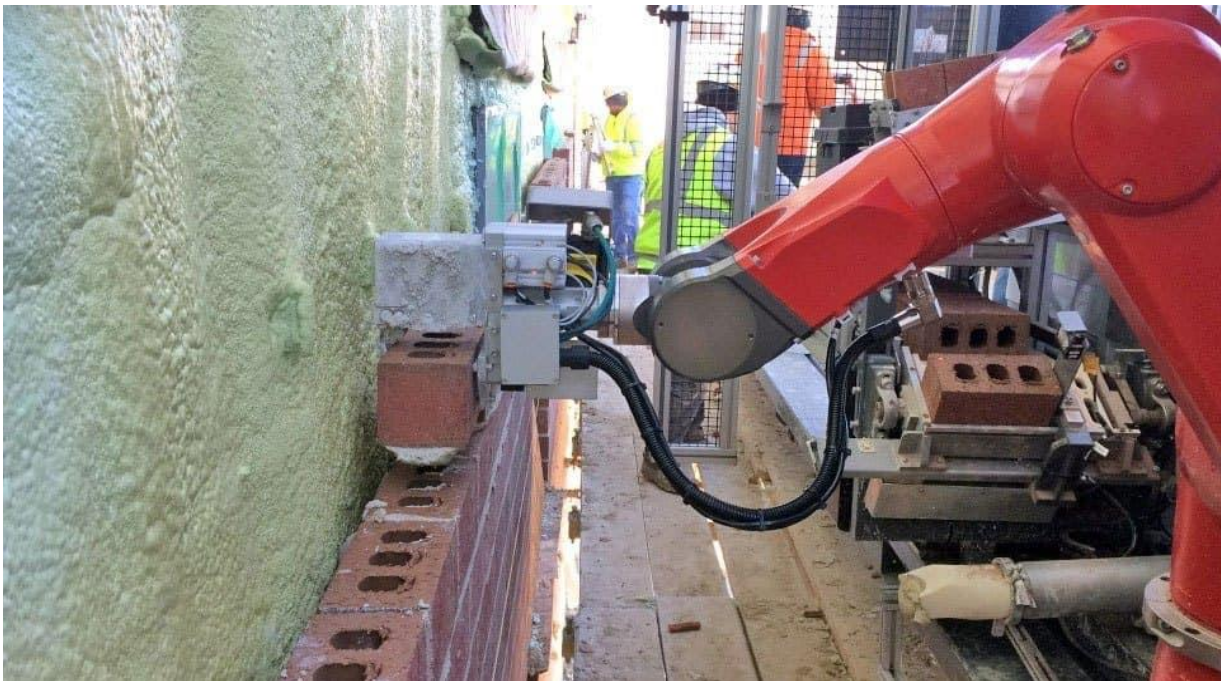


Figure 27: View of bricklaying robot

(Retrieved from: <https://www.techexplorist.com/meet-sam-construction-robot-works-500-faster-humans/5357/>)

Construction: AI and Predictive Analytics:

Experience predictive analytics based on AI is overhauling project management increasingly at the construction's work package level with greater precision when predicting timelines and costs. Since AI models analyse historical data, they can predict possible delays and budget exceedances even before those have happened thus giving a room for project managers to take steps beforehand. Research has found that predictive analytics have been able to prevent 30% of project delays and 20% overruns from happening (Anyanwu, 2024).

Cost Savings from AI in Construction:

The impact of AI on the world economy is significant. The construction industry is a huge beneficiary where AI could add as much as \$15.7 trillion to the global economy by 2030, according to PwC (2024). Based on this prediction, AI-powered efficiencies could potentially save the entire construction industry a total of \$1.3 trillion annually (PwC, 2024)

Construction: Low AI Adoption Rates in Global Perspective:

The use of AI in the construction sector differs quite a lot region wise. According to McKinsey National Report (2023)

the adoption of AI is being led by North America and Europe, almost 35% of construction companies in these regions are using active AI tools. By comparison, the Asia-Pacific deployment is about 20%, and it falls to only 10% in Africa. A major factor behind these differences is in the level of technological infrastructure, and funding into R&D across borders (McKinsey 2023).

Barriers:

AI could be transformative in the construction industry; however various obstacles prevent its wide implementation. These include high capital investment, shortage of skilled manpower and reluctance in construction companies to change. A survey from the Construction Industry Institute (2023) showed that 45% of construction companies said cost as biggest inhibitor, and another 30% say knew little or nothing about AI inside their employees' structure (Construction Industry Institute, 2023).

Takeaways for Contractors: Thus, this research serves as practical advice to contractors on AI integration in their PMs. This study can particularly serve as a guiding resource to stakeholders across the industry compile information necessary for unlocking potential advantages by identifying specific applications and case studies that used AI technologies successfully. These findings can inform businesses seeking to invest in AI and strategies for how best to implement it (Jones & Williams, 2021).

Policy and Strategy Development: Policymakers and industry regulators can also avail of this research study. Extended analysis of the challenges and barriers to AI adoption in this field leads into key policy development areas which are needed for fostering innovation in technology growths such as construction row-sector. By understanding these challenges, policymakers can design incentives and support systems that help organisations change over to AI based project management smoothly (Patel, 2021).

Real Time Examples: Components of AI

Machine Learning: ML is a branch of AI, where system learns from data and improves over time without being explicitly programmed.

Use cases of ML in real world:

This helps you with Fraud Detection: ML is employed to detect fraudulent transactions by pattern identification that suggest fraud.

- **Self-guided Cars:** Waymo — A subsidiary of Google's parent company Alphabet utilizes machine learning to evaluate information from sensors and provide on-the-fly directions for self-sufficient cars as they steer securely (Coursera, 2024).
- **Deep learning,** a type of ML method that uses many-layered neural networks to analyze complex datasets. Key applications include:
- **Healthcare:** Deep learning helps to diagnose disease by sifting through billions of medical images and patient data including precision, specificity while saving time in making the decisive health decisions (Augmented AI, 2023).

NLP

Natural Language Processing allows computer to understand and interpret human language. There are some of the major apps:

Language Translation: NLP has provided us with tools like Google Translate that can translate text across two different languages while keeping the context and cultural differences in check.

Sentiment Analysis: Essentially, companies use NLP to analyse social media and customer feedback for understanding public opinion which can further be leveraged in improving services (Gokcuoglu, 2023).

Robotics and Autonomous Systems (RAS)

Robotics is the field of designing and building robots that perform tasks autonomously or semi-autonomously. Applications include:

- **Robot-assisted care** for surgeries and patients improving personalisation of healthcare.
- **Self-driving cars and drones:** drones flying around the land carrying packages to one location or another dully, all of which are grounded due to AI implementations in real-time navigation (Einfochips, 2023).

The preceding examples paint a picture of the broader and impactful role AI technologies can play in improving operational efficiency, safety, and user experience across multiple sectors.

Appendix B: NLP

Case Study: Natural Language Processing for Categorizing Construction Safety Reports

Natural Language Processing (NLP) has become a creative solution for the construction industry and is used to improve safety by processing into digital format enormous volumes of text data from safety reports. Case Study-Use of Natural Language Processing in Construction Safety Reports to Manage and Understand Skin-in-the-Game better for the future.

NLP in Construction Safety Explained

Construction is dangerous, with thousands of accidents occurring every year. Worldwide, every year 2.78 million workers die from occupational accidents and have over all there has a considerable human suffering along with financial losses. Previous accidents are very important for obtaining safe working conditions and. investigative measures play a major role in this process (Zhang et al., 2019, p-238). The analysis of safety reports using NLP, which is a subset of artificial intelligence (AI), can help real this information that are often written in unstructured manner and provides the "clues" about accident precursors, allowing human responses directed to counter measure risks on-time (Pan & Zhang, 2021, p.10).

Natural Language Processing and Text Mining Techniques

It employs a range of successful techniques for getting computers to understand and process human language. Such methods entail text mining, which helps in discovering new information from textual data. NLP can process text data that

mining alone cannot handle due to the semantics and grammatical format of a sentence (Zhang et al.2019, p239).

Data Preprocessing

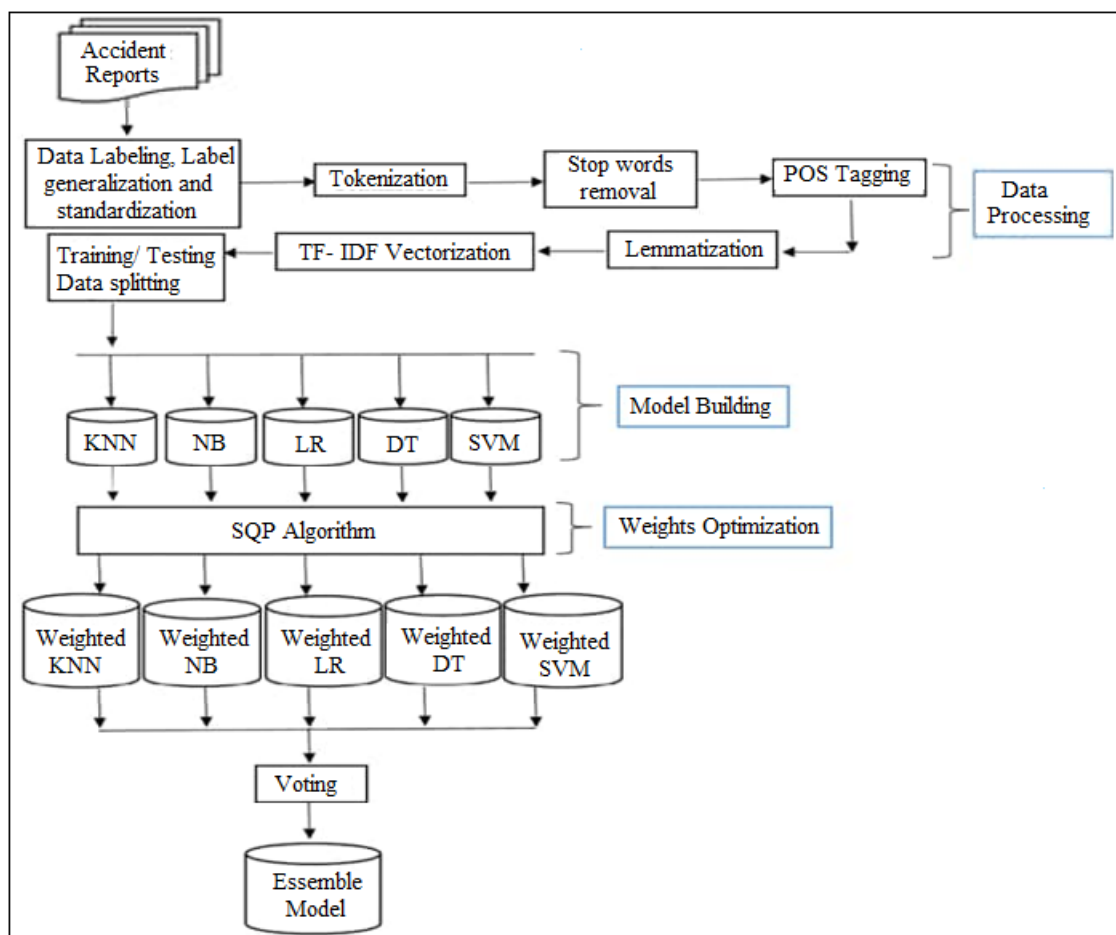
Preprocessing text data before classifying before we pass text data to classifiers:

- **Create a lower case and remove punctuation:** This step converts all the words within the text to lowercase so that variations in text are reduced, such as starting every word on a capital letter or punctuations which usually do not contribute towards any information when it comes to analytical steps (Zhang et al., 2019, p.239).
- **Removing Stop words:** Words that do not contain important significance and their appearance on the text are blocked. Custom stop word lists can be established on the domain to advance this kind of analysis (Zhang et al., 2019, p.239).
- **Tokenization:** Tokenizing the text breaks up the raw string into smaller segments/token and makes it easier for programs to process in this way (Zhang et al., 2019, p.239).

- **Stemming and Lemmatization:** These techniques are used to convert words into root forms, which helps in studying the different wordforms. (Zhang et al., 2019 p.239)
- **POS Tagging:** Adds tags to tokens, like names, or verbs and adjectives used in sentences (Zhang et al., 2019).
- **N-grams:** Sequences of co-occurring words employed to analyse text patterns.
- **Term Frequency – Inverse Document Frequency (TF-IDF):** It is a way to weigh the importance of words in one document as compared to its individual weight across multiple documents (Zhang et al., 2019, p.240)

Model Expansion and Ensemble Approach

The research uses ensemble model method with combination of multiple algorithms to enhance prediction accuracy. Similarly, another popular method known as the ensemble model and it requires several steps: data processes, pre-processing raw input into vector format, each of these vectors are given skew some small neural network before voting on many different individual models (Zhang et al., 2019, p.242).



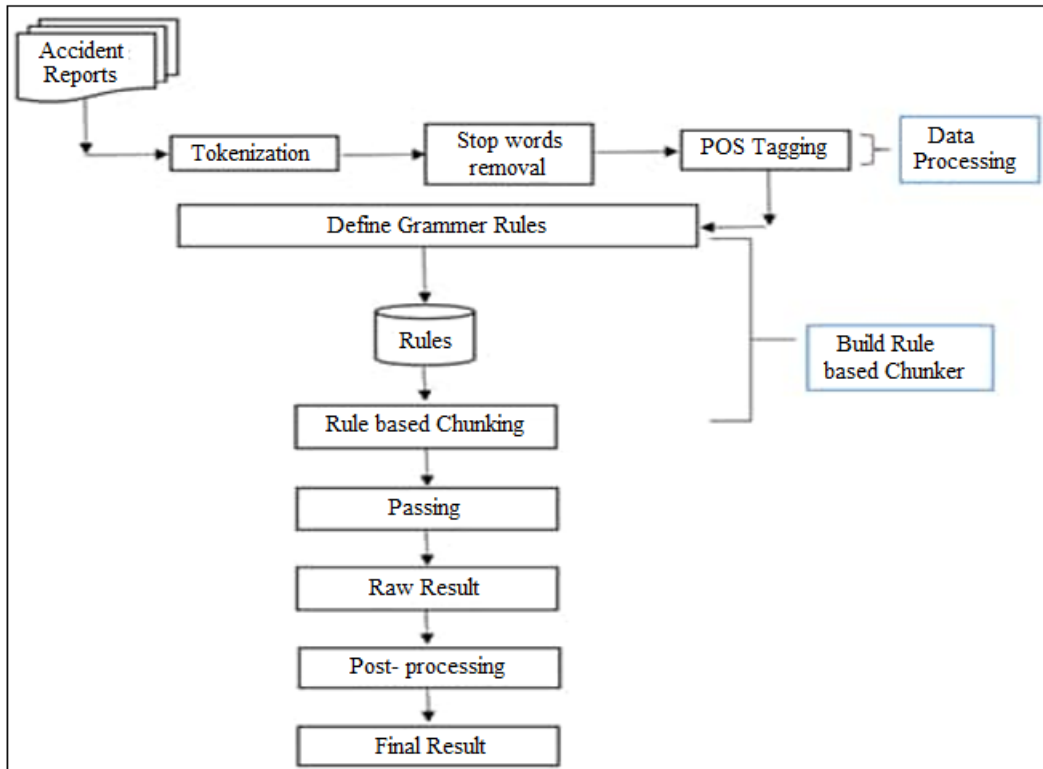


Figure 28: Workflow of ensemble & rule based chunker (Zhang et al., 2021, p.240 & 241)

Algorithms Used

The ensemble model uses 4 algorithms which consists of:

- **Support Vector Machines (SVMs):** For optimization and risk minimization.
- **K-Nearest Neighbours (KNNs):** Classify patterns based on the similarities of their features.
- **DTs:** DTs are hierarchical tree-based classifiers.
- **Logistic regression (LR):** scores probability based on context between variables.
- **NB: Naive Bayes:** Probabilistic classifiers for text categorization (Zhang et al., 2019, p.241 -242).

These classifiers, the weights are optimized using The Sequential Quadratic Programming (SQP) algorithm which boosts toughness and generalization of modelling ensemble (Zhang et al., 2019, p.242).

Kind of accident and results

The authors of the study used a dataset obtained from Occupational Safety and Health Administration (OSHA) which had 16, 323 records on construction site accidents. The dataset was reviewed to categorize the types of accidents, and they were structured with predefined categories like collapse of object or electrocution or falls (Zhang et al., 2019, p.245–246). This involved creating an overall class label that were assigned to cases similar causes mentioned in the diagnoses. An example is an incident marked "Collapse of object" which could involve the fall of a building story or other structures (Zhang et al., 2019, p.246). According to the study's figure 30, falls made up for 23.6% and collapse of object was responsible in streamlining accident into 21.2 % (Zhang et al., 2019, p.242).

Table 12 Time measures of different models (Zhang et al., 2021, p.244)

Classifier	Training Time (s)	Predicting Time (s)	Optimization Time (s)	Total (s)
Decision Tree	0.253	0.001	NA	0.254
KNN	0.003	0.019	NA	0.022
Naïve Bayesian	0.009	0.001	NA	0.01
SVM	4.735	0.112	NA	4.847
Logistic Regression	0.529	0.001	NA	0.53
Ensemble	5.351	0.142	NA	5.493
Ensemble with optimized weights	5.4	0.139	0.945	6.484

Challenges and Future Work

Limitations in rule-based approaches such as the vagueness of natural language and the human labour required for performing correction manually are emphasized by this study. Further improvements might include data balancing, bigrams & trigrams to have a better preservation of context and potential use of more advanced models such as LSTM neural

networks other improvements could be made using domain-specific POS taggers and semi-supervised learning techniques. In conclusion, this study provides a proof of concept regarding the application of machine learning and NLP algorithms for automated identification & classification (automatic labelling) as accident causes & hazardous objects to enhance construction site safety (Zhang et al., 2019).

Summary

The application of NLP in mining construction safety reports provides a great deal more information on accident causation and helps to identify issues that can be addressed with targeted prevention strategies. The classification of accident causes allows safety professionals to deploy controls to mitigate specific hazards, thus leading a reduction in accidents and an overall safer work environment. The above study shows that the use of NLP has the capability to change in safety management within construction, as being proactive when identifying risk and accident (Zhang et al., 2019).

Appendix C: ANN

Case Study of Artificial Neural Networks in Time Forecasting on Public Construction Projects.

Introduction

Artificial Neural Networks (ANNs): ANNs are more like human brain, connected reflexes of axons in the nervous system. They are very handy when the relationship (s) between your data points is complicated, and not so well understood. In this case study, we evaluate the use of ANNs relative to forecasting costs for public civil works in Brazil aimed at educational buildings. This research illustrates that ANNs can be an adjunctive resource for construction plan development and strengthening cost estimation which then increases PM efficiency.

Background

In the Brazilian context, cost overruns are legally limited in public construction projects at 25% for contractual purposes

subject to its initial budget (Alcineide et al., 2021a). The more accurately you estimate your costs, the better able to prevent financial issues and facilitate successful project delivery. However, transferring trained model from one country to another (e. g., India and Brazil) may not get reliable results, because the local conditions as well data are separate and differ according to countries (Alcineide et al., 2021a, p.3).

Challenges in Cost Estimation

Cost forecasting is the foundation of determining financial feasibility during both budgeting and, subsequently, when bidding/contracting and executing public construction projects. Around 400 public works are unfinished due to the scant cost estimation; this was verified by Brazil's Federal Court of Audits in an analysis carried out in 2006 (Alcineide et al., 2021b). As budgetary issues are one of the key reasons for stopping public construction projects (Alcineide et al., 2021b), it is necessary to have a computational model that can predict real costs more precisely.

Artificial Neural Network (ANN)

ANNs are built around neurons, like our brain and it processes information through synaptic weights first then sums the value followed by running an activation function. The Multilayer Perceptron (MLP), which is one of the ANN architectures, has been used for several types of tasks including function approximation and forecasting or optimization in different applications as considered by (Alcineide et al.2021b, p.3). As mentioned, MLP are subject to supervised learning and error backpropagation adjusting synaptic weights to minimize prediction errors (Alcineide et al., 2021b, p.3).

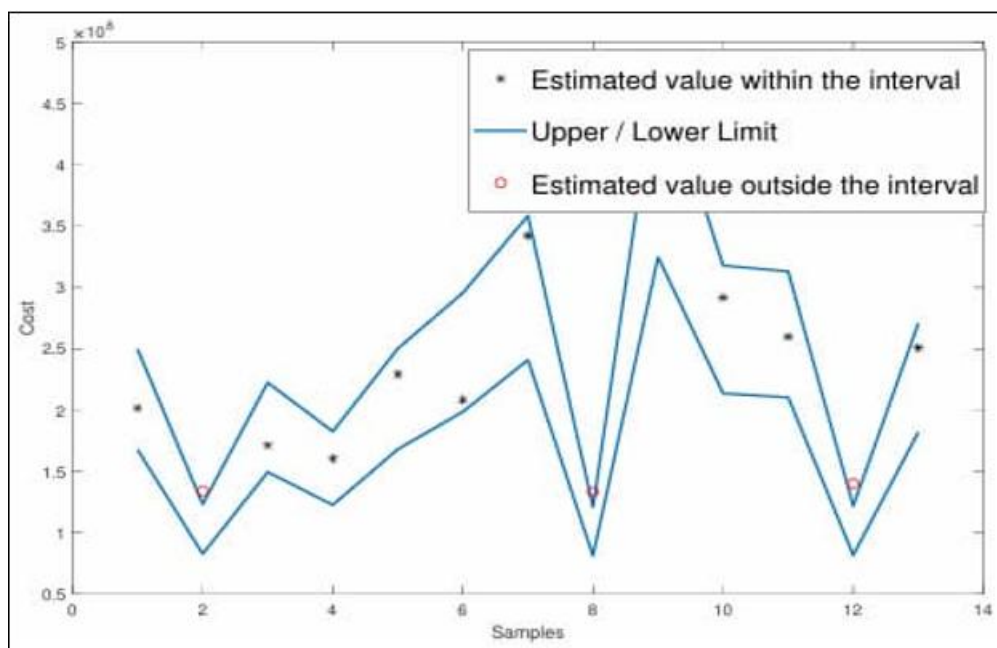


Figure 29: Results of ANN training phase for cost forecasting (some samples). (Alcineide et al, 2021, p.6)

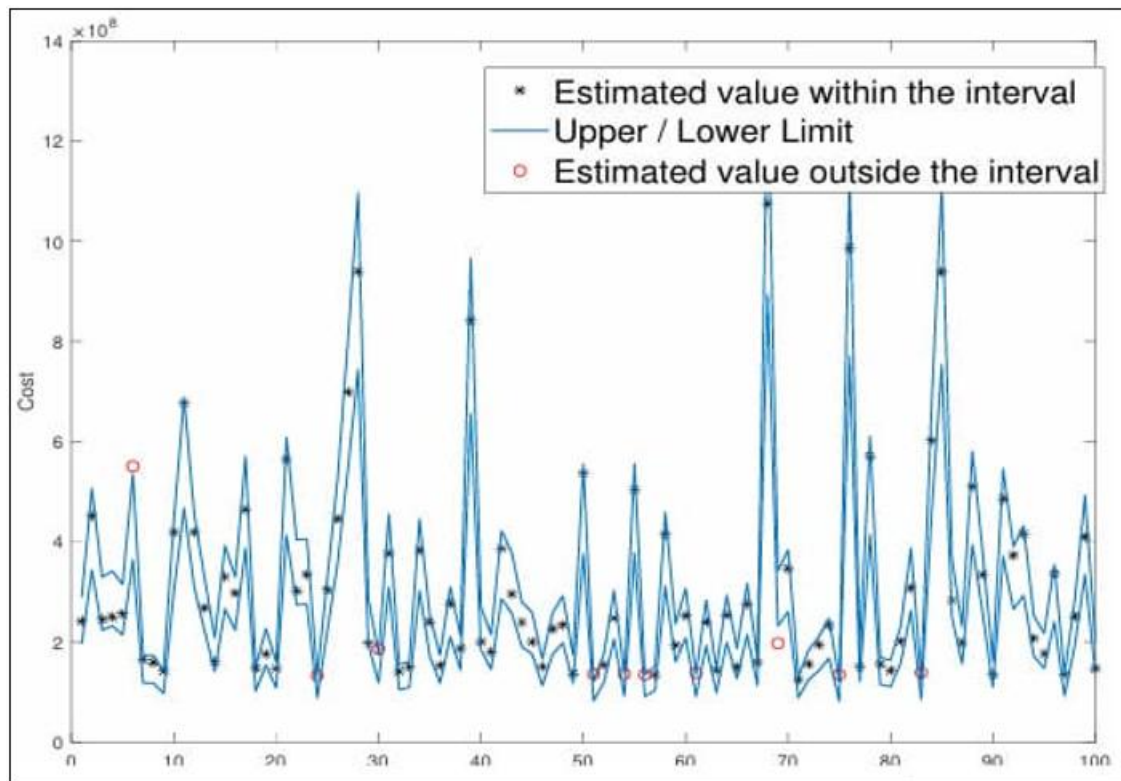


Figure 30: Results of the ANN test phase for cost forecasting. (Alcineide et al, 2021, p.7)

The figure 29 shows 100 samples with maximum costs up to 14×10^8 . All estimated values are in the range, as indicated by solid and dashed intervals hearts compared to circles. Figure 29 a close-up on the samples in Figure 28 that cost

4.5×10^8 . Also, it points values inside and outside the confidence interval. In both summary statistics that are plotted on the graph use lines to denote upper and lower bounds to show outliers.

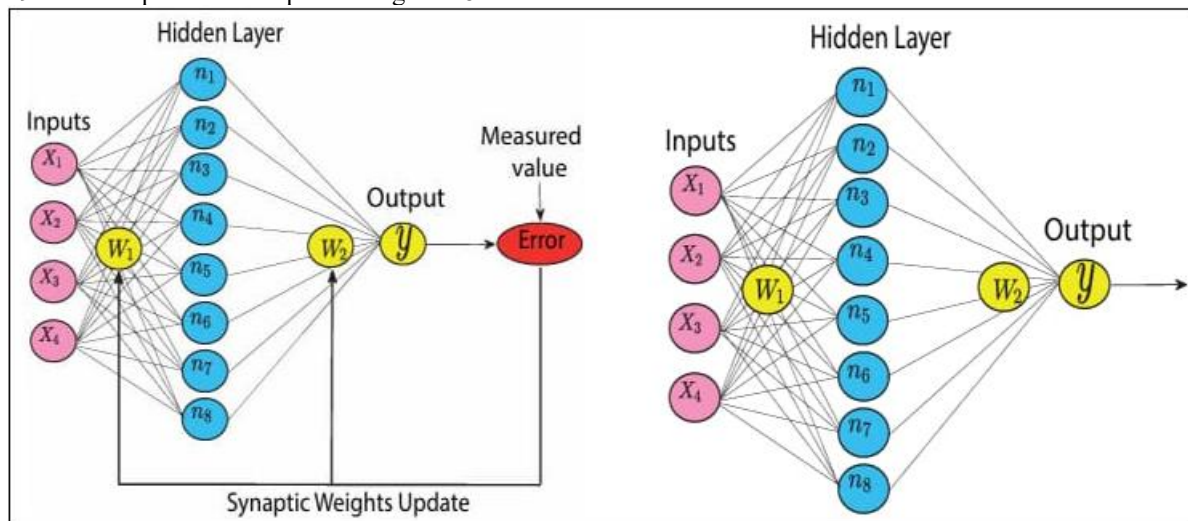


Figure 31: Topology of the network used to predict public work costs, validate the cost prediction model. (Alcineide et al, 2021, p.5)

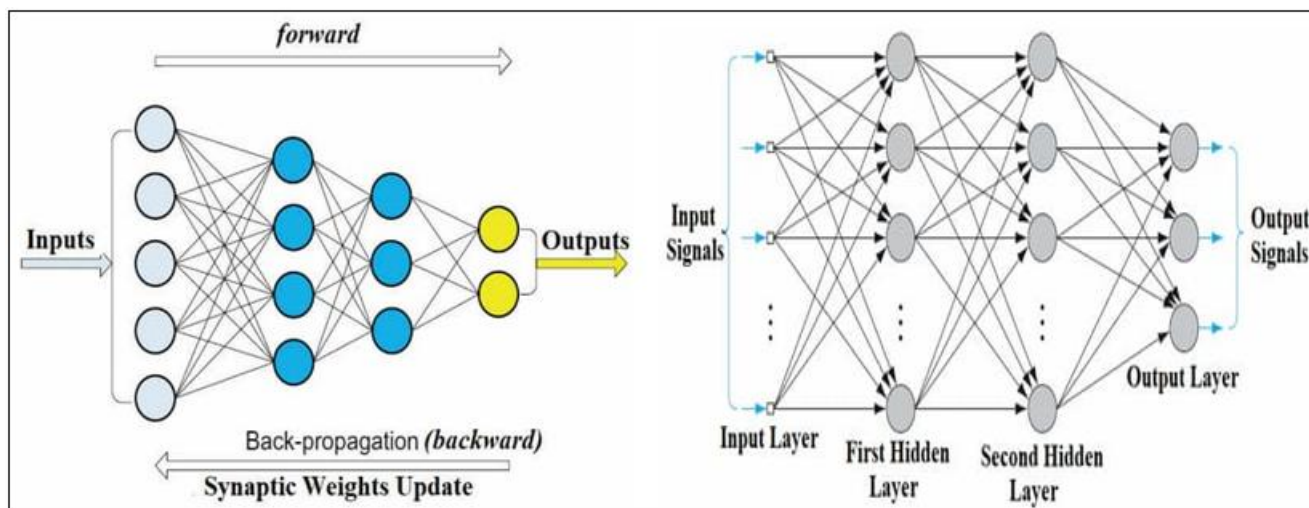


Figure 32: Backpropagation algorithm & MLP.
(Alcineide et al, 2021, p.3-4)

Figures above stand for different construction of neural networks. Figure 30 shows, a small feedforward with one hidden layer is outlined, and in the next figure, the weight is updated by error determination. Meanwhile, the figure 31 it contains two hidden layers, the figure additionally includes backward error propagation, creating a momentarily aberrant connection.

Materials and Methods

The paper deals with prediction of FC (final cost) utilizing ANNs for construction projects. Results: The final cost was identified as the dependant variable, while facility size, number of inspections, estimated budget and contract price were independent variables. These were the variables available on Brazil Ministry of Education platform to be chosen (Alcineide et al., 2021b, p.4). In the case of cost forecasting, architecture used was ANN model with 4 inputs and a hidden layer (8 neurons) followed by an output layer representing Cost. The network topology and training process is shown in the Figure. In our training phase we iterated many times to find the minimum error between predicted and actual values until you applied all of your new data (this one would be called test) against trained model without updating those weights. (Alcineide et al, 2021b, p.5).

Results

To evaluate the performance of ANN model, it was estimated through mean absolute percentage error (MAPE) between actual and predicted costing. However, during the testing phase our model reached a MAPE of 9.14% which indicates an accuracy rate close to 90%, (Alcineide et al., 2021b, p.6) Such accuracy indicates that the model provides good generalization, reinforcing its status as being a robust method for cost forecasting in public construction projects.

Summary

The case study shows the value of ANNs as a predictive tool for public construction project cost estimation, particularly relevant in developing countries where planning tends to be deficient. With better estimates of costs given by ANNs, the prediction of project delivery dates can be refined along with more effective planning from both cost and time perspective resulting in fewer walking dead bred as projects. This study presented a neural model with an error rate of 9.14%, which

was very accurate, being today a potential solution for predicting construction costs in the public sector (Alcineide et al., 2021b, p.9). In summary, the employment of ANNs in construction cost forecast is a breakthrough innovation for addressing project planning problems with data-driven solutions.

Appendix D

Case Study 1

Working Framework:

The video from the surveillance cameras is first segmented to separate working areas into digging and dumping zones. All caterpillar-like machines together with their type of equipment in the video frames are jointly identified as well according to a detection method. Then excavators are recognized using pose estimation with detection-based tracker, and so on. At last, the trajectory state of an excavator is obtained through pose estimation and working area segmentation. Lastly, various activity recognition components stream results based on the detected activities to monitor safety at the construction site. The results of the activity recognition are also used for productivity evaluation on an excavator, is more fully presented at Figure 12 (S. Zhang & Zhang, 2021, p.51).

Excavator Action:

While digging, the material is swung into a bucket for later dumping and during this phase unloaded. And it swings the bucket to face onto your work spot when you are about to dig. This, when enabled during idle at operating or breakdown state for manned excavators. First, determine the position of excavators by pose estimation and image segmentation to identify their action state. Frame -by -frame pose key point from Body1 to 4) the excavator swing or not. The Safety monitoring system uses a rule-based module which evaluates these pose key points for every gesture. The work of theoretical key point identification can be used to criterion stimuli: the body being excavator is static if the outcome value less than a threshold, otherwise it should be defined as moving (S. Zhang & Zhang, 2021, p.52).

Case Study 2

Until recently, construction like many industries that have turned to drones for inspections and monitoring in the 2010s relied almost exclusively on manual methods. They are used to inspect highways, bridges, roads cell towers. high mast lighting wind turbines power lines facades roofs They are also used for surveying and mapping, tracking progress on construction sites as well the status of an environmental area such wetlands or erosion. Drones give you a bird's-eye view of your site, which makes nearly impossible to access in person locations easy and provides benefits on both costs as well and knowledge. They monitor site access by providing an overhead perspective and generating 360° panoramas, thus promoting immediate location inspections that aid engineers in prioritizing work. Drone imagery can be further shared with field personnel, in-house team members and subcontractors. Drone imagery and 3D point clouds can then be applied to these models' using photogrammetry, which provides a comprehensive model of the structure for comparison with Building Information Modelling (BIM) data at various stages, providing detailed monitoring over progression. Together, this comparison provides real-time recordation, reports, invoicing verification and planning in conjunction with construction project scheduling & cost estimation (Awh. inc., 2023).

They facilitate in preplanning the construction projects, conduct field survey work on complex construction works as required and compile project maps for reference purpose of contractors perform post-construction management for Underground Zoning applications.

Background:

The proposed method uses images collected with drones/UAVs from different locations as well as point clouds obtained using 3D scanning technology of the construction site and pushes them through photogrammetry to generate a volumetric model. As illustrated in Figure 16 (Anwar et al., 2018), the animations from a life span of construction can be linked together through series of different stage models contrasting with BIM model.

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