Applications of UAVs and AI in Civil Engineering: A Systematic Review of Current Uses and Future Directions in Road Construction

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Abstract

This review paper explores the combined use of unmanned aerial vehicles (UAVs) and artificial intelligence (AI), particularly focusing on the you only look once (YOLO) algorithm in construction. It explores the current use of these technologies in construction and proposes future use in road construction. Through a systematic review of recent studies, this paper highlights how these technologies are applied in various aspects of construction, such as real-time progress monitoring, pavement distress (PD) detection, and safety inspections. While UAVs and AI are proving valuable in current applications, there are still areas that require further exploration, including automated volume calculation and comprehensive inspection of roads. The findings suggest that integrating UAVs with AI can significantly enhance construction task's speed, accuracy, and automation, particularly in road projects. The integration of UAVs and AI is still an early concept in some aspects of road construction, so the paper also explores potential future applications. By exploring and addressing these gaps, this review hopes to inspire a more efficient and cost-effective future in the construction industry.

Keywords

Road Construction, YOLO, 3D Mapping, Drone technology, Aerial Road Survey.

1. Introduction

Roads are not only just physical structures, but they are important infrastructures. Roads play a critical role in economic development and social progress, contributing significantly to a country's growth by providing access to jobs, healthcare, education, and social services. Efficient and proper progress monitoring of road construction is essential to maximize its benefits. However, the current construction practices cause us to face many issues, such as delays in project completion, cost overruns, and rework due to errors caused by the workers. To overcome these challenges, it is important to introduce new methods to ensure that construction projects proceed on schedule, remain within budget, and meet quality standards.

UAVs have been used in different fields to perform various tasks for quite some time, and their number is increasing yearly. The number of drones in use worldwide is gradually increasing each year. The global drone market was 34.5 billion US dollars in 2023 and is expected to increase to 101.1 billion US dollars by 2033 (Market.us 2024). With so many drones, they could become even more valuable if combined with AI algorithms for various applications. UAVs are currently being used in various areas. For instance, in precision farming, UAVs increase the efficiency of land mapping, soil testing, pesticide application, and weed management, thus reducing resource use and increasing production (Pathak et al. 2020). In geophysical research, UAVs speed up surveys and use fewer resources, making them a promising tool for faster and more efficient studies (Aleshin et al. 2020). For logistics transportation, UAVs significantly reduce overall energy consumption and improve performance compared to traditional methods (Chu et al. 2021). In engineering geology, UAVs offer a cost-effective and quick method for acquiring detailed images and 3D models (Giordan et al. 2020). Furthermore, in the construction industry, UAVs inspect structures visually to identify potential safety hazards and monitor compliance with safety regulations (Umar 2021; Szóstak et al. 2023). Integrating UAVs with digital technologies improves project performance, management quality, and safety in the construction industry(Rachmawati and Kim 2022).

AI has attracted much attention in recent years because of its ability to increase efficiency and save time, money, and resources. AI is undoubtedly one of the most important technological advancements humans have achieved because of its vast range of applications. AI is extensively used in educational technologies, including adaptive systems, intelligent tutoring systems, and assessment tools. It is used to make the learning experience personalized and for administrative processes(Zawacki-Richter et al. 2019; He et al. 2023a). It has transformed healthcare by improving the accuracy of diagnosis, personalizing treatment plans, and enhancing patient care through deep learning and machine learning(Arabi and Zaidi 2020). It has transformed food production, manufacturing, and quality control, ensuring efficient and safe food supply chains (Sadiku et al. 2020). AI has also been helpful in the construction industry, where it is currently being used to improve traditional practices, making the construction process more time-efficient and budget-friendly. It is being used to improve construction efficiency and to reduce the number of on-site operators such as surveyors(Guo 2023). Additionally, AI, in collaboration with BIM and digital twins, is used in transforming construction engineering and management (CEM) through improved automation, risk mitigation, and digitalization(Pan and Zhang 2021).

Many AI models have been developed for object detection. These models have been pivotal in improving visual recognition and object detection tasks. Various models, such as OverFeat, R-CNN, Fast R-CNN, Faster R-CNN, SSD, RFCN, YOLO, RetinaNet, and SNIPER, have achieved considerable success in object detection. YOLO is a state-of-the-art object detection algorithm known for its speed and accuracy. This algorithm applies a single neural network to the entire image, which divides the image into regions and predicts bounding boxes and probabilities for each region simultaneously. The latest model of YOLO that has been released is the YOLOv10, and it has demonstrated superior performance and efficiency when tested on standard benchmarks like common objects in context (COCO). YOLO has been utilized in many ways in the construction industry to ensure safety and improve operational efficiency. For instance, YOLOv2 has been used for the real-time detection of construction vehicles for anti-blocking construction, significantly improving speed on construction sites (Hou et al. 2021). YOLO has also been used to detect safety violations such as not wearing helmets and smoking at construction sites (Chen et al. 2021). Beyond construction, YOLO is widely used in various fields; for instance, it is used to accurately predict the location of typhoon center and cloud evolution, improving early warning and response in coastal cities (Wang et al. 2023). Moreover, it is applied in face recognition, demonstrating its use in different domains (Sun 2023).

Most of the work done on UAVs and AI in construction is focused on its application in areas like BIM, construction management, inspection, etc. Still, little work has been done in integrating AI (YOLO) and UAVs for the progress monitoring of road projects and comprehensive inspection of roads. This systematic literature review examines the applications of UAVs and AI technology in today's construction industry and suggests areas that need further exploration.

2. Literature Review

2.1 Data Collection

The initial phase involved an extensive search for peer-reviewed articles and conference papers. Databases such as ScienceDirect, SpringerLink, and Google Scholar were used to ensure a comprehensive collection of relevant studies. The Systematic Literature Review (SLR) method was followed for this study to identify, select, and assess (Snyder 2019) the research on UAV and YOLO in construction. The reason for following this method is because it provides a thorough and organized way to gather all relevant research and also because this method helps to avoid bias and ensures that the findings are based on a solid foundation of evidence. Keywords such as ‘unmanned aerial vehicle,’ ‘construction,’ ‘road construction,’ ‘YOLO,’ ‘progress monitoring,’ ‘artificial intelligence,’ ‘object detection,’ ‘Construction Automation,” ‘Real-time Construction Monitoring,’ and ‘Road Infrastructure’ guided the search process. Initially, over 27000 records were collected from ScienceDirect, SpringerLink, and Google Scholar, whose distribution is shown in Fig.1.

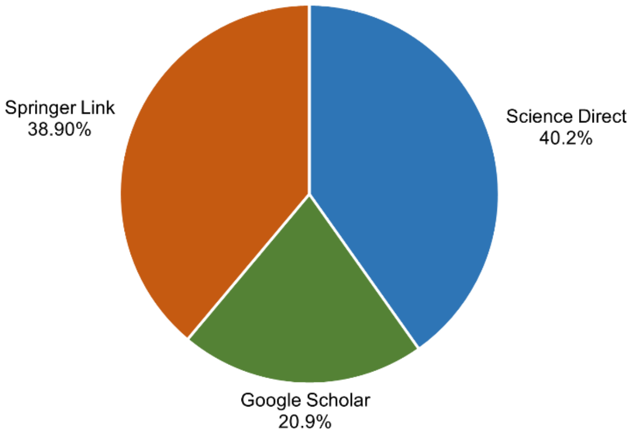

Fig.1 Proportion of Papers from Springer Link, Google Scholar and Science Direct

During the collection of records, only peer-reviewed journal publications and proceedings from conferences in the English language were considered. The data consisted of many duplicate entries, which were then removed. The time of the publication was restricted to the last four years (2020-2024), and the papers published before 2020 were removed. Based on these rules, a total of 10650 records were removed. After that, publications whose titles or descriptions focused on UAV applications in construction, AI-based monitoring, and the specific use of the YOLO algorithm in construction in these contexts were selected. The records were further narrowed by selecting publications from mid and high-tier journals. Additionally, publications published in or before 2023 with citations greater than five were selected. This criteria did not apply to papers published in 2024, so the latest research could be included. After the rigorous filtering, 115 records were left. Then, from these publications, data such as objectives, methodologies, findings, and conclusions were extracted and studied, and those publications that were not entirely relevant to our criteria were discarded. Finally, 35 records were left and used for this systematic literature review. The process can be seen in Fig.2.

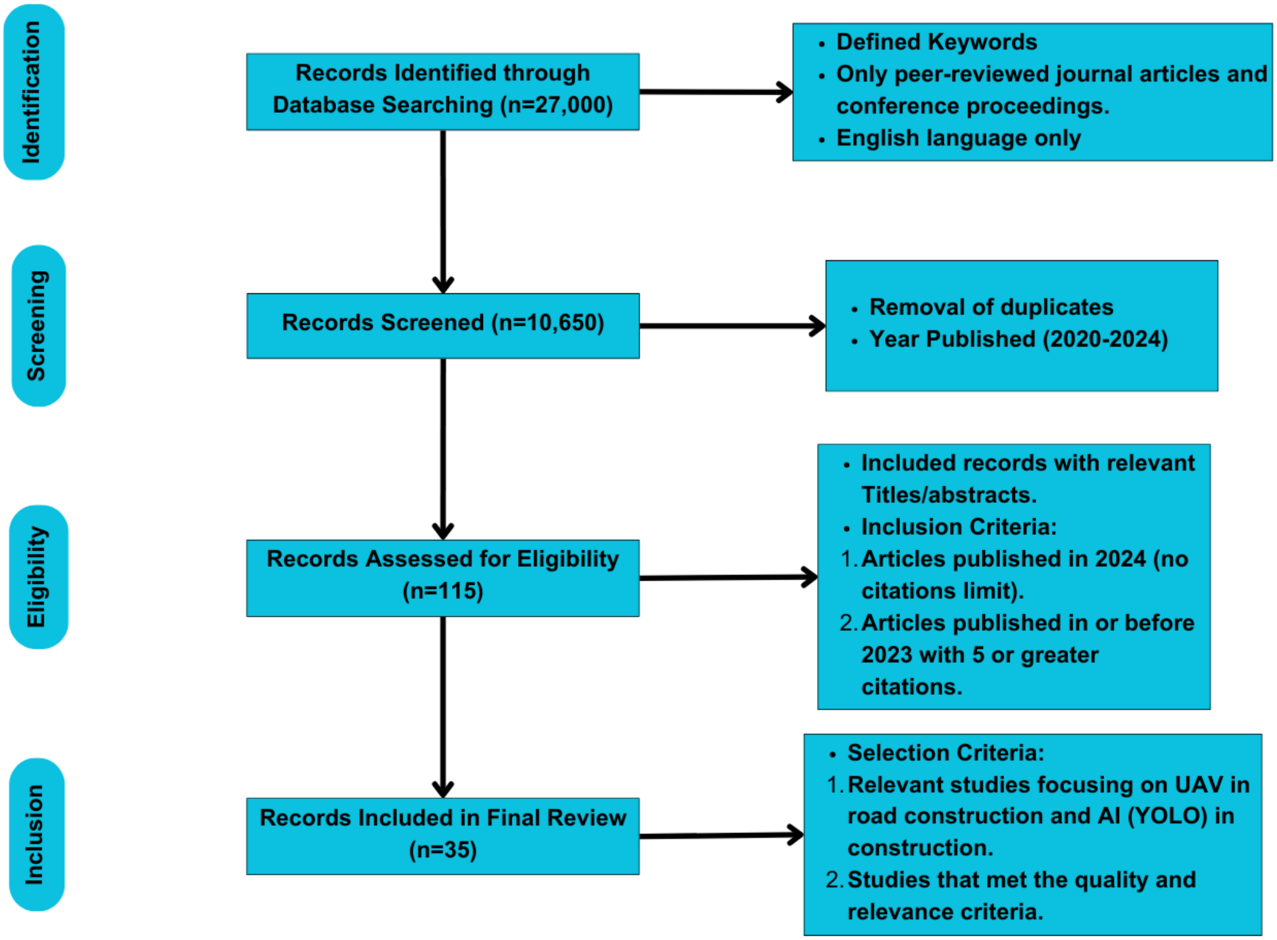

Fig.2 Literature Filtering Process

2.2 Country Analysis

The records left after the rigorous filtering consisted of publications from various countries; the countries were determined based on the country of the lead author or the funding by the country. Most of the articles included in this review paper were published in China, with 15 papers, followed by the USA, with four articles. The third in number was South Korea, with three published articles. Followed by the Netherlands, with two published papers. Finally, 11 countries had one published paper, see Fig.3.

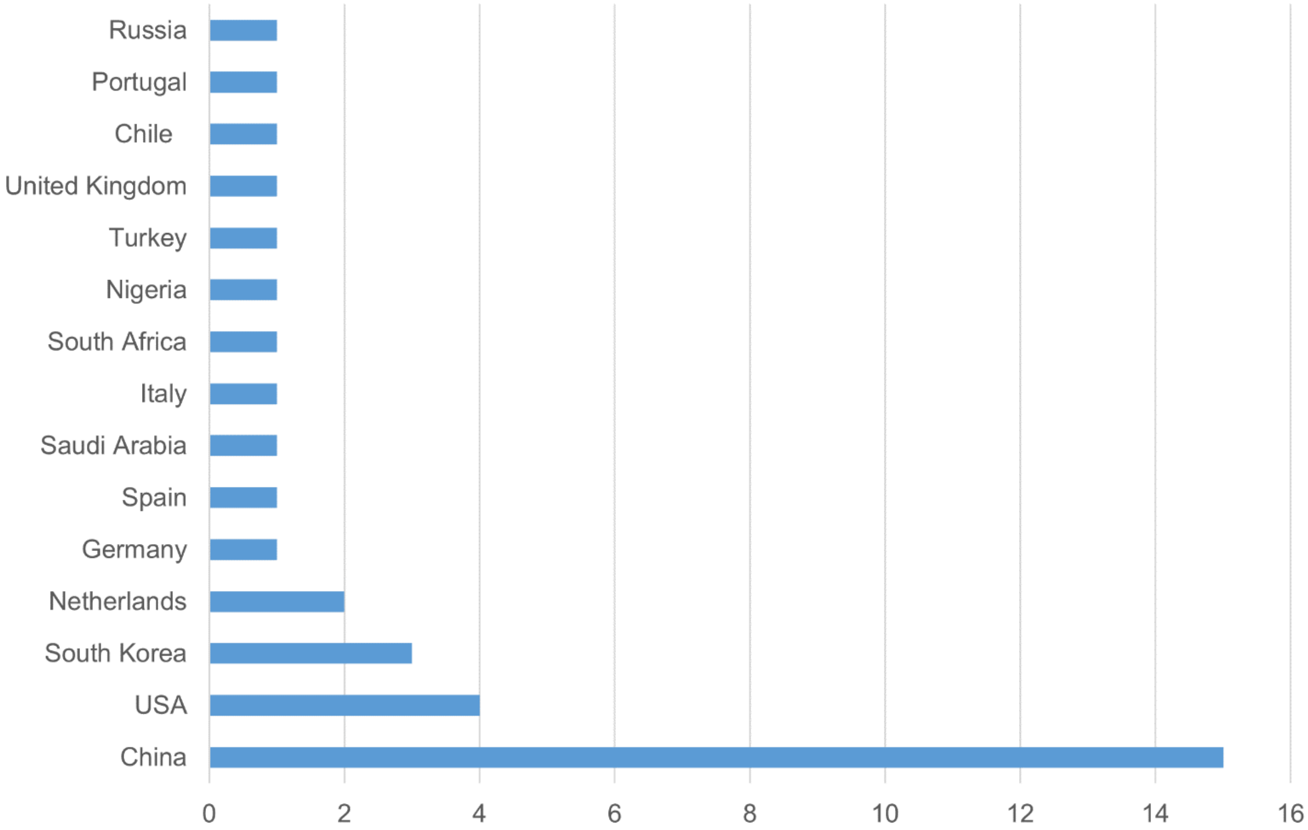

Fig.3 Country-wise Distribution of Publications

2.3 Journal Analysis

Of the 35 papers, the majority were from journals, and there were only a few conference papers. As seen in Table 1, the highest number of papers was from the journal Automation in Construction, with 12 papers, followed by the journal Sensors, with three papers. The journals buildings, and Sustainability were in third place, with two papers.

Journal	Number of Papers
Automation in Construction	12
Sensors	3
buildings	2
Sustainability	2
International Journal of Construction Management	1
Journal of Construction Engineering and Management	1
ISPRS Journal of Photogrammetry and Remote Sensing	1
aerospace	1
remote sensing	1
International Journal of Pavement Engineering	1
Computer Vision and Pattern Recognition	1
Reports on Geodesy and Geoinformatics	1
Measurement	1
2023 International Conference on Electrical, Computer, and Energy Technologies	1
Applied Sciences	1

Waste Management	1
Transportation Research Record	1
Construction and Building Materials	1
Journal of Intelligent Construction	1
Engineering Geology	1

Table 1 Journal-wise Distribution of Reviewed Papers

2.4 Keyword Co-Occurrence Analysis

Keyword co-occurrence analysis is a technique that is used to examine the relationship between keywords in academic literature by visualizing how different research topics are connected based on shared keywords (Sedighi 2016). This technique helps identify the changes and emerging trends within a field (Lozano et al. 2019). It is also used in systematic review to provide a complete overview of a research area by identifying the most relevant and frequently co-occurring concepts (Radhakrishnan et al.).

This study created a keyword analysis map using the software VOSviewer, widely used for constructing and visualizing bibliometric maps that show how research topics are connected (van Eck and Waltman 2009). In Fig.4, each node represents a keyword, and the lines show their connections. Larger nodes mean the keyword appears more often, and thicker lines show stronger connections. The largest nodes are 'unmanned aerial vehicles,' 'deep learning,' and 'YOLO,' which means these keywords have the most occurrences. The keyword unmanned aerial vehicles has the most occurrences and is linked with 'construction progress monitoring,' 'YOLO,' and 'deep learning,' suggesting UAVs are commonly used in these areas. Deep learning and YOLO have the second most occurrences and share a strong link. However, their connection to specific construction tasks like 'construction progress monitoring' and 'road construction' is notably weaker. This suggests that although these technologies are well established in general object detection and monitoring tasks, their integration into more specialized road construction activities is still in the early stages. This gap represents an opportunity for further research in the combined application of UAV and YOLO in road construction.

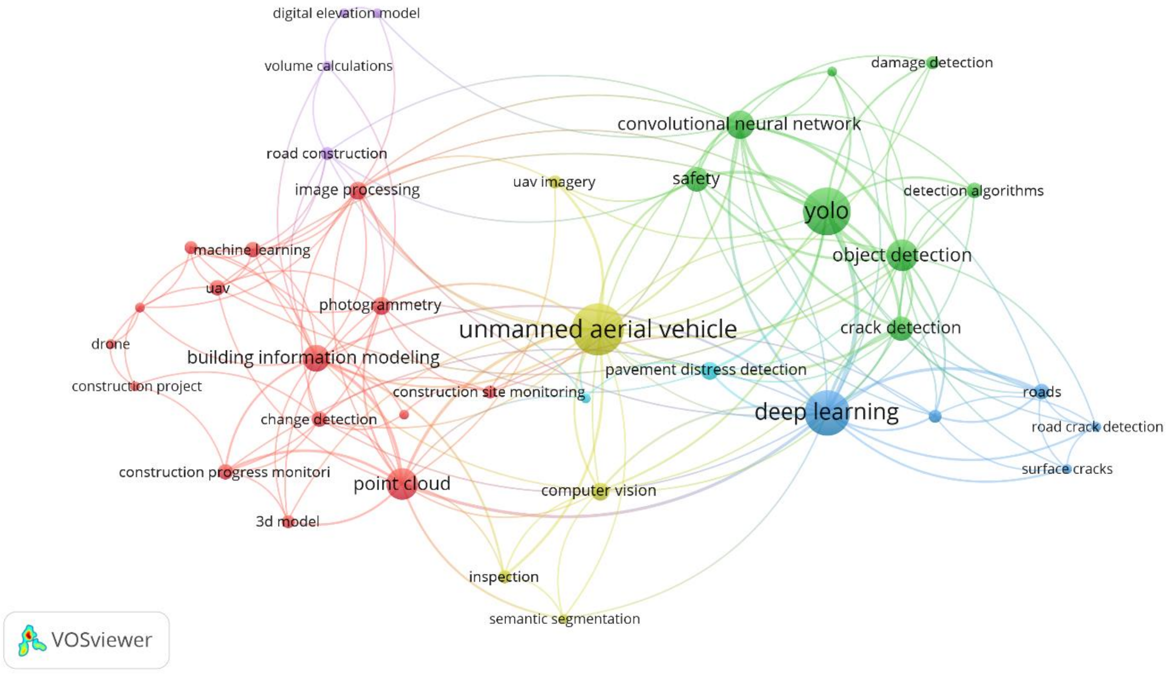

Fig.4 Keyword Co-Occurrence Analysis

3. Current Applications

Through this literature review, 5 application areas were determined, which either utilized a UAV, an AI model, or both. Fig.5 represents the distribution of papers based on application areas. These application areas comprised monitoring, safety, estimation, remote sensing, and road assessment.

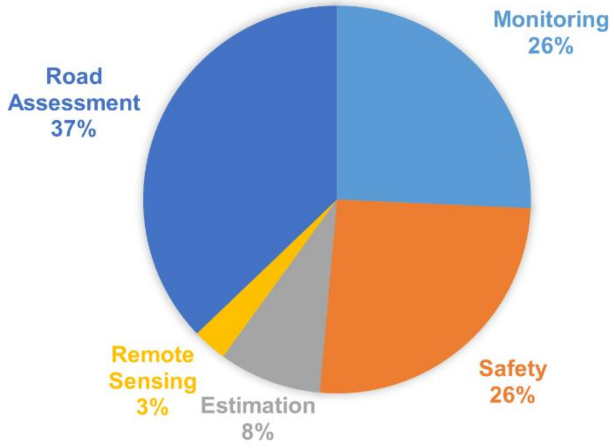

Fig.5 Application-wise Distribution of Publications

3.1 UAV Applications

This literature review identified four applications of UAVs in construction, as shown in Table 2. These applications were interpreted from articles that solely utilized UAVs without any implications for AI. The articles that proposed combining the application of UAVs and AI are discussed in the following sections. A total of 6 articles proposed the use of UAVs alone. The application areas included progress monitoring, safety, estimation, and remote sensing.

Application Area	Example	Reference
Monitoring	Monitoring road base course construction Monitoring physical progress in construction	(Lo et al. 2023; Jacob-Loyola et al. 2021)
Safety	Rapid safety monitoring and analysis	(Wu et al. 2021)
Estimation	Volume calculation of Earthwork Dump and landfill waste volume estimation	(Lee and Lee 2022; Filkin et al. 2022)
Remote Sensing	Dense thermal point cloud generation	(López et al. 2021)

Table 2 UAV Applications

3.1.1 Monitoring and Safety

Traditional methods of monitoring road projects are time-consuming, prone to errors, and laborious. UAVs help to make the process of monitoring more time and cost-efficient. The methodology in both monitoring-related articles was the same. Firstly, the trajectory of the UAV was defined for the inspection, and then the parameters that help guide the pilot to perform the inspection and acquire images were defined. Following this was the processing of the data collected during the site inspection to generate a high-resolution 3D model, followed by the integration of this 3D model with a 4D BIM model of the project or with a framework. The 4D BIM model was integrated to compare actual construction progress with the planned schedule. This was done by superimposing the point cloud on the BIM model to identify any change or delay. The integration with the framework allowed the generation of detailed and accurate progress reports and schedule comparisons to find any delays (Lo et al. 2023; Jacob-Loyola et al. 2021).

Traditionally, the safety monitoring of foundation pits is carried out through manual onsite measurements with complex equipment and relies on complicated methods. These methods are labor-intensive and time-consuming and sometimes ignore the risk of accidental collapses caused by serious local deformation. Wu et al. (2021) used UAVs for safety monitoring and analysis of the foundation fit. The safe inclination angle of the foundation pit was used as the safety-monitoring index. The methodology included data collection using UAVs and the generation of 3D models by surface fitting. The purpose of surface fitting was to make the 3D model more precise and usable. The 3D model was then used to assess the pit's structural integrity accurately and to detect any deformations that may cause safety risks. The assessment was done by analyzing local deformation distribution, providing detailed insights into the pit's stability.

3.1.2 Estimation and Remote Sensing

A study by Lee et al. (2022) proposed using a UAV to calculate earthwork volume by generating a 3D model. The 3D model was created using vertical and high-oblique images taken by the UAV at different heights. The study found that the best results were obtained when using vertical images and oblique images of 40 to 50 degrees. The highest accuracy obtained was 99.73% compared to GPS measurements, but it decreased with the increase in the height of the UAV. The study concluded that including vertical and high-oblique images results in more accurate 3D models and, hence, results in precise earthwork volume calculation. Filkin et al. (2022) utilized UAVs for a similar purpose in volume estimation. The study assessed how using different software and a specialized geodetic class UAV, or a non-specialized low-cost UAV, affected the accuracy of volume estimation for landfills and dumpsites. Both specialized geodetic and non-specialized low-cost UAVs estimated the volume with differences of about 1% compared to ground surveys when a minimum number of ground control points (GCP) were present and differences of about 5% with no GCP present. The study concluded that a geodetic-class UAV allows the creation of a highly accurate digital terrain model but does not have prominent advantages in the volume estimation of landfills and dumpsites.

López et al. (2021) proposed a methodology of fusing RGB and thermal images to generate high-density thermal point clouds with improved accuracy and processing time compared to commercial software. Initially, a basic 3D model was generated through Structure from Motion (SfM), which was then converted to a detailed point cloud using Multi-View Stereo (MVS). A key step in their technique was aligning the RGB and thermal images accurately using the Enhanced Correlation Coefficient (ECC) technique, significantly improving the accuracy and processing time.

3.2 AI Applications

This literature review identified three applications of AI in construction, as shown in Table 3. These applications were interpreted from articles that solely utilized AI without UAVs. The articles that proposed combining the application of UAVs and AI are discussed in the following sections. A total of 13 articles proposed the use of AI alone. The application areas included safety, road assessment, and progress monitoring.

Application Area	Example	Reference
Safety	Construction job site safety Hazard identification Detecting safety equipment Monitoring of dangerous areas	(Wang et al. 2021; Zeng et al. 2021; Hayat and Morgado-Dias 2022; Alateeq et al. 2023; Alvarez et al. 2023; Zhang et al. 2024a; Feng et al. 2024)
Road Assessment	PD inspection	(Ghosh and Smadi 2021; Du et al. 2021; Li et al. 2023)
Monitoring	Progress monitoring Equipment activity identification	(Slaton et al. 2020; Liu et al. 2023; Zhang et al. 2024b)

Table 3 AI Applications

3.2.1 Safety

Seven of the thirteen articles discussed using AI for safety, and all of them discussed using YOLO. The methodology of using a YOLO model is mostly the same, involving data collection (images), data processing (annotation), model training, and evaluation (Wang et al. 2021; Zeng et al. 2021; Hayat and Morgado-Dias 2022; Alateeq et al. 2023; Alvarez et al. 2023; Zhang et al. 2024a; Feng et al. 2024). Feng et al. (2024) developed a model based on YOLOv8 for construction safety management, focusing on detecting worker's personal protective equipment (PPE) and monitoring dangerous areas. The study followed an approach of transfer learning by using YOLOv8s as the pre-trained model to train the main model. Wang et al. (2021) and Alvarez et al. (2023) also developed a model for the detection of PPE, including helmets and vests, on construction sites. Wang et al. (2021) trained some YOLO models on a color, helmet, and vest (CHV) dataset and concluded that YOLOv5x had the best performance and YOLO v5s had a faster processing speed. Alvarez et al. (2023) trained a YOLOv7 model and a YOLOv5 model to compare their performance and found out that the YOLOv7 model outperformed YOLOv5.

Additionally, two more studies discussed the use of YOLO. One study developed a YOLOv5 helmet detection model to ensure construction workers' safety. The Hard Hat worker image dataset was used to train the YOLOv5, YOLOv4, and YOLOv3 models, and YOLOv5 outperformed them (Hayat and Morgado-Dias 2022). The second study developed a real-time equipment detection and localization model using YOLOv3 for detection and a grey wolf optimizer improving extreme learning machine (GWO-ELM) for localization. On the job site, surveillance video provides a real-time status to the supervisor. However, the presence of various-sized objects makes it difficult to recognize small-sized objects, which is crucial for ensuring safety on-site. The model developed by Zeng et al. (2021) allows more efficient detection and localization of multi-scale objects, improving overall safety.

On construction sites, collision accidents of construction vehicles usually occur, and they are difficult to mitigate using the traditional methods of on-site inspection and surveillance video. Zhang et al. (2024) proposed a collision risk warning model for this problem utilizing YOLOv7 for the identification and DeepSORT algorithm for the tracking of the vehicles. In another study, Alateeq et al. (2023) developed a YOLOv5 model to improve the safety of the construction site by identifying construction workers, the PPE they are wearing, and heavy equipment near them based on images and weather conditions.

3.2.2 Road Assessment

Three of the thirteen articles discussed using AI for maintenance, and all used YOLO. Pavement is an essential part of a road that functions as a protective layer and requires inspection and maintenance from time to time. One study used a YOLO model and an omni-scale network (OSNet) for PD detection. The YOLO model detected distress, which was an input for OSNet to perform feature extraction and instance-level recognition. This was then integrated with a vehicle to detect distress (Li et al. 2023). Another study utilized two deep learning algorithms, YOLOv3 and Faster-RCNN. The models were compared with manual quality assurance and quality control results, and it was determined that YOLOv3 and Faster-RCNN have potential as replacements (Ghosh and Smadi 2021). Du et al. (2021) also developed an object detection framework for PD detection. They created a large dataset of PD images and used it to train a YOLO model, which could detect PD with high accuracy.

3.2.3 Monitoring

Out of thirteen articles, three discussed using AI for progress monitoring. One study proposed using direct sparse odometry with loop closure (LDSO) to achieve rapid and high-quality 3D point clouds. This study tackled the problem of time-consuming 3D reconstruction and achieved near real-time 3D reconstruction (Liu et al. 2023). Another study developed a deep learning framework to predict construction equipment activities using accelerometers for activity tracking. The framework was developed using convolutional neural network (CNN) and long short-term memory (LSTM) layers and was applied to a roller compactor and an excavator (Slaton et al. 2020). Zhang et al. (2024) proposed a global stability optimization (GSO) – YOLO model, enhancing the YOLOv8 framework by integrating it with a global optimization module (GOM) and steady capture module (SCM). The study aimed to improve object detection accuracy in complex construction sites with issues like varying lighting conditions. The integration improved the model's detection ability and enabled it to effectively utilize information from the entire construction site.

3.3 UAV and AI Applications

This literature review identified four combined applications of UAV and AI in construction, as shown in Table 4. These applications were interpreted from articles that used both AI and UAVs. A total of 16 articles proposed the use of UAVs and AI. The application areas included monitoring, safety, maintenance, and estimation.

Application Area	Example	Reference
Monitoring	Progress monitoring by change detection Site data collection Real-time monitoring	(Asadi et al. 2020; Han et al. 2021; Huang et al. 2022; Tilon et al. 2022)
Safety	Safety inspection	(Zhu et al. 2022a)
Road Assessment	Road damage detection Road health monitoring Road Inspection	(Nguyen and Han 2020; Biçici and Zeybek 2021; Garilli et al. 2021; Nappo et al. 2021; Zhu et al. 2022b; Zhang et al. 2022; Qiu and Lau 2023; Kulkarni et al. 2023; Gao et al. 2023; He et al. 2023b)
Estimation	Volume calculation of earthwork	(Ajayi et al. 2020)

Table 4 UAVs and AI Applications

3.3.1 Monitoring

Out of sixteen articles, four proposed using AI and UAVs for construction progress monitoring. Two studies discussed change detection. One study used point clouds generated by the images taken by UAVs for semantic-aided change detection. The method consisted of two key parts: the detection of geometric changes, which are changes of occupancy in 3D space, like appearance or shapes, and the detection of semantic changes, which are difficult to detect based on occupancy changes. The detections were done using the Dempster–Shafer theory (Huang et al. 2022). Another study developed a method for automatically detecting changes in construction areas. A UAV was used to acquire images of the construction site, which were converted to orthoimages using Pix4D mapper. A trained CSN model was then used to detect changes between the images (Han et al. 2021).

Tilon et al. (2022) developed a system for real-time road infrastructure monitoring using edge and remote processing based on UAV. The system, which consisted of a UAV controller, a ground control station (GCS), and an onboard processing unit, was created to perform vehicle detection, scene segmentation, and 3D scene reconstruction. Asadi et al. (2020) tackled the problem related to traditional data collection methods. He introduced an automated data collection system using a UAV and an unmanned ground vehicle (UGV). The UGV autonomously navigated through the space using its sensors while the UAV acted as the eye for the UGV, monitoring the space that was inaccessible to the UGV, hence showing its feasibility for autonomous data collection.

3.3.2 Road Assessment

Ten of the sixteen articles discussed using UAVs and AI for maintenance-related purposes. Most of the articles focused on detecting road damage or cracks. One article developed a Multi-level Attention Block (MLAB) mechanism using UAVs and YOLOv3 for pavement damage detection (Zhang et al. 2022). Another study developed a model named ARD-Unet that performed detection pixel-by-pixel. The model was created by combining U-Net with Depth Separable Residual Block (DR-Block), Atrous Spatial Pyramid Fusion Attention Module (ASAM), and Receptive Field Block (RFB) and was effective in detecting road cracks in remote-sensing images (Gao et al. 2023). He et al. (2023) developed a road crack detection algorithm, MUENet. The MUENet algorithm was comprised of a main and auxiliary dual-path module (MADPM) to extract morphological features, uneven fusion structure with transpose and inception convolutions (TI-UFS) to explore the color of cracks, and E-SimOTA strategy to differentiate between cracks. It was determined that MUENet appeared to be effective in detecting road cracks. Qiu and Lau (2023) integrated YOLO with UAV to perform real-time crack detection in tiled sidewalks. The study compared different architectures, including YOLOv2-tiny, Darknet19-based YOLOv2, ResNet50-based YOLOv2, YOLOv3, and YOLOv4-tiny and found that ResNet50-based YOLOv2 and YOLOv4-tiny outperformed all of the architectures, in detection. Kulkarni et al. (2023) tried to replace the ground-penetrating radar with a framework to detect sub-pavement voids. The framework detected the sub-pavement voids from the infrared (IR) images taken using UAVs. The framework improved its accuracy by utilizing principal component thermography analysis and relied on the EfficientDet algorithm for automation. It was determined that the proposed framework demonstrated accuracy similar to that of the ground-penetrating radar.

Two studies worked on the detection of PD. One study by Zhu et al. (2022) used a UAV equipped with a high-resolution camera to collect PD information. The data was used to train three models: Faster R-CNN, YOLOv3, and YOLOv4, and the YOLOv3 model showed the best performance in PD detection. Another study proposed a different approach to finding distress. It followed a similar methodology of using a UAV for data collection. The images were used to create a 3D point cloud, and an algorithm was used to measure and detect the distress (Biçici and Zeybek 2021). The traditional methods of assessing road damage after landslides are laborious and time-consuming. Nappo et al. (2021) proposed a semi-automatic procedure for assessing roads after a landslide. The methodology included four steps: (1) road section selection, (2) data acquisition using UAVs and 3D point cloud reconstruction, (3) crack detection, and (4) classifying the cracks based on severity on a scale of (D0 to D3) using international roughness index (IRI). The proposed methodology effectively identified and classified road pavement damage.

Traditional maintenance and inspection methods are quite costly if the number of roads to be surveyed is larger. Nguyen and Han (2020) proposed a method that used a UAV to capture images of the road at different times. A convolutional Siamese network (CSN) was employed to extract features from the images. Subsequently, an Euclidean distance function was used to determine the distance between the extracted features. A contrastive function was then applied to increase the distance between changed features while maintaining the unchanged features unaltered. Finally, edge detection was used to determine the boundaries of the changed areas. The method was found to be highly accurate for change detection on road surfaces. Garilli et al. (2021) performed a comparison between two classification frameworks. The comparison was done between a Semi-Automatic Classification Plugin for QGIS and a CNN to determine the best alternative to traditional inspection methods. It was determined that U-Net CNN outperformed the classification plugin when tested on images taken using a UAV.

3.3.3 Safety and Estimation

Out of sixteen articles, two discussed using UAV and AI for safety and estimation. One study proposed a system based on UAVs for monitoring the road construction site. It proposed using detection and tracking algorithms for safety management. A UAV (DJI Mavic 2) was used to capture road construction videos and create a dataset. Subsequently, two deep learning algorithms, YOLOv4 and DeepSORT, were used to process the videos for automatic detection and tracking. It was determined that this approach can effectively manage safety (Zhu et al. 2022a). The other study focused on mapping and volume calculation using UAVs. A UAV (DJI Phantom 4 quadcopter) was utilized to capture images. Image processing was conducted using Pix4Dmapper, Agisoft Photoscan, and Micmac, while volume calculation was performed using a MATLAB-based system. It was determined that the approach followed in the study achieved an accuracy greater than the traditional methods (Ajayi et al. 2020).

4. Future Applications

Fig.6 represents the current application areas of UAVs and AI determined through this literature review and also depicts further areas to be explored. The literature review determined that UAVs and AI have been used considerably in construction, improving safety management and road condition assessment. The studies related to safety were concerned with PPE, site hazards, safety factors, and large equipment. They utilized UAVs, surveillance videos, YOLO, and other detection algorithms to improve safety management. Additionally, the studies related to road condition assessment were concerned with crack detection, distress detection, change detection of road surface, and road structural health monitoring. They also utilized UAVs, point clouds, YOLO, and other detection algorithms to improve road inspection. Some studies also discussed using AI and UAV for progress monitoring and volume estimation. They utilized point clouds to create 3D models to estimate volume and monitor changes or activities. These advancements show a shift in road construction towards more automated, precise, and accurate construction management practices.

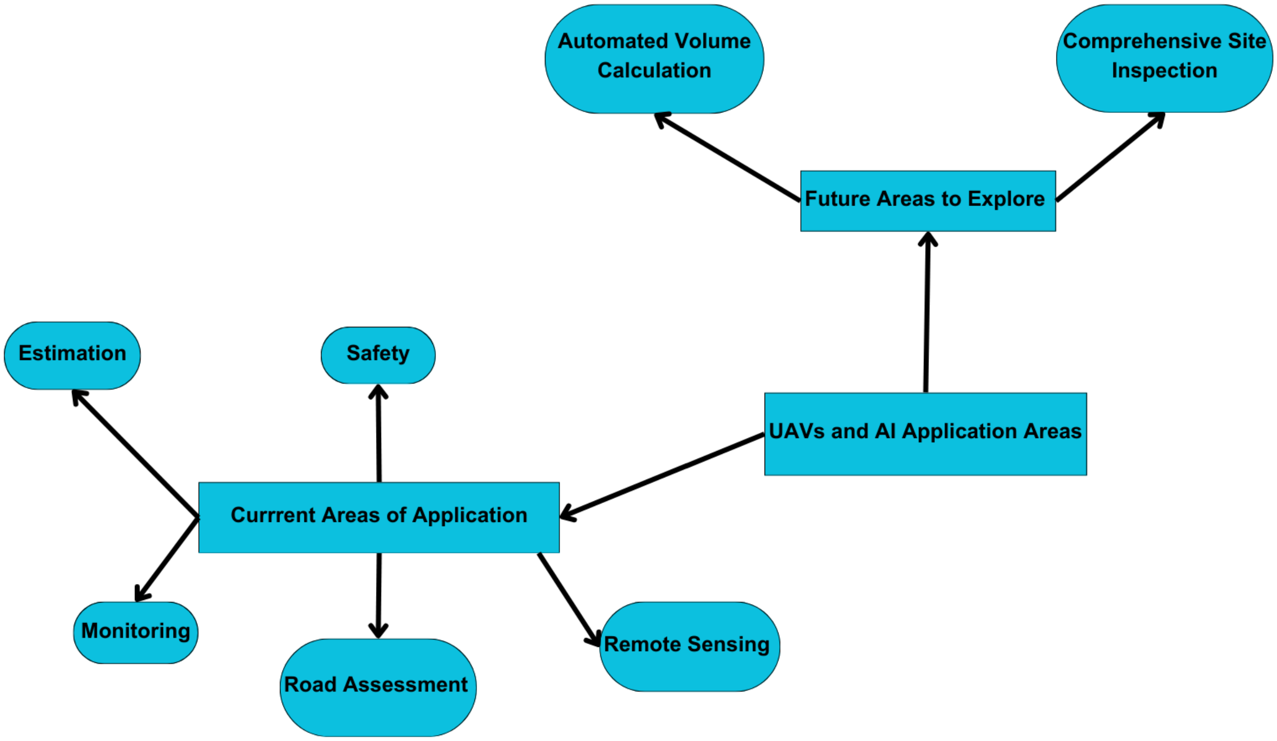

Fig.6 Current and Future Applications of UAVs and AI

However, despite these advancements, some aspects of road construction have not been explored, including automated volume calculation and comprehensive road inspection involving detecting road layers. Current methodologies use UAVs to create 3D models using point clouds for volume estimation. However, these methods still depend on manual practices. There exists an opportunity for further exploration of automation in these tasks by using AI classifiers to classify the road layer in the point cloud and estimate its volume. One approach to achieving volume automation involves using the baseline concept. In this approach, UAVs will be used to capture images before the layer is started and then capture images after completion. The first captured images will be utilized to generate a 3D model and will serve as a baseline. Subsequently, images captured after completion will be used to generate a new 3D model. A classifier will be used to classify the area of interest. Then, by analyzing the coordinates of these points in the area of interest, an algorithm could calculate the volume automatically.

Additionally, while current methodologies use YOLO for crack, PD, and road surface change detection, its potential for comprehensive road inspection remains largely unexplored. YOLO can be trained on various components of a road construction site, including layers. We need to prepare a large dataset for this unexplored area, including images of different layers and other parts of the roads from various road projects. This dataset will be used to train a YOLO model that can detect the components of the roads from the images taken using UAVs, thereby automating road inspection. Overall, using UAVs and AI in different aspects of construction will make road construction faster and more accurate.

5. Conclusion

This review paper explored the current use of UAVs and AI technologies in road construction, particularly focusing on the YOLO algorithm. Initially, we collected data of about 27000 articles from different databases. After applying strict inclusion criteria and filtering, we selected 35 papers for this review. This review focused on exploring the methodologies, applications, and potential benefits of UAVs and AI through an extensive systematic literature review. However, it also highlighted a gap in integrating these technologies in certain road construction activities. This includes road volume estimation and comprehensive road inspection, indicating future research opportunities.

The keyword analysis provided insights into the matter, highlighting that ‘unmanned aerial vehicles,’ ‘deep learning,’ and ‘YOLO’ were the most frequently occurring terms. It showed a strong connection between UAVs and AI in construction, especially in progress monitoring, road assessment, and safety applications. However, it also revealed a gap in the integration of these technologies in certain road construction activities.

After analyzing 35 articles, we determined 5 application areas: monitoring, safety, estimation, remote sensing, and road assessment. Most of the papers discussed methodologies related to road assessment (37%), followed by monitoring (26%) and safety (26%). The remaining studies discussed about estimation (8%) and remote sensing (3%). The studies related to road assessment focused on tasks such as PD detection, crack detection, and road health monitoring. The studies related to safety discussed PPE detection and real-time hazard detection. Monitoring-related studies focused on progress monitoring, change detection, and activity tracking. Estimation and remote sensing were less frequently studied but showcased the potential of UAVs for tasks like earthwork volume calculation and high-resolution 3D model generation.

Most existing studies have focused on using UAVs and AI in different aspects of construction. However, certain areas, including automated volume calculation and comprehensive site inspection that involves detecting road layers, remain underexplored. This review paper also proposed methodologies to explore these research ideas. It studied the current application areas of UAVs and AI and proposed how these technologies can be used in other aspects of road construction.

Data availability

No datasets were generated during the current study.

Abbreviations

MLAB - Multi-level Attention Block

YOLO – You Only Look Once

UAV – Unmanned Aerial Vehicle

DR-Block - Depth Separable Residual Block

ASAM - Atrous Spatial Pyramid Fusion Attention Module

RFB - Receptive Field Block

AI – Artificial Intelligence

MADPM – Main and Auxiliary Dual-Path Module

PD – Pavement Distress

IRI - International Roughness Index

IR – Infrared

CNN – Convolutional Neural Network

CSN - Convolutional Siamese Network

PPE – Personal Protective Equipment

GCS - Ground Control Station

UGV - Unmanned Ground Vehicle

LSTM - Long Short-Term Memory

COCO - Common Objects in Context

SfM - Structure from Motion

MVS - Multi-View Stereo

ECC - Enhanced Correlation Coefficient

BIM - Building Information Modeling

GCP - Ground Control Points

LDSO - Direct Sparse Odometry with Loop Closure

GSO - Global Stability Optimization

SCM - Steady Capture Module

GOM - Global Optimization Module

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- Muhammad Hammad Iqbal: Conceptualized the review article, performed the literature search and data analysis, and drafted the main manuscript.
- Naveen Bachan: Responsible for creating all figures and tables and performing some literature searches.

- Muhammad Abdullah Khan: Collaborated in data collection and literature summarization.
- Mehmood Mushtaq Subhani: Contributed to the critical content revision for clarity and depth and wrote summaries.

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