Proceedings of the 2024 Winter Simulation Conference
H. Lam, E. Azar, D. Batur, S. Gao, W. Xie, S. R. Hunter, and M. D. Rossetti, eds.

A REVIEW OF TRENDS AND PRACTICES IN USING VISUAL DATA FOR CONSTRUCTION-RELATED MACHINE LEARNING MODELS

Abbas Mohammadi[1], SeyedeZahra Golazad[1], and Abbas Rashidi[1]

[1]Department of Civil and Environmental Engineering, University of Utah, Salt Lake City, Utah, USA

ABSTRACT

This paper systematically reviews image-based analysis in the construction industry, examining 136 articles through 2023. The findings reveal a marked increase in the use of machine learning (ML), deep learning (DL), and reinforcement learning (RL) models, which utilize image and video data to enhance worker safety, monitor construction progress, and improve project management. The study identifies a significant shift towards integrating real and synthetic data, enhancing model robustness. It also highlights the rising adoption of data-sharing practices, with an increase in publicly available datasets. However, the review highlights underexplored areas such as synthetic data use and advanced privacy-preserving methods. These gaps suggest opportunities for further research to leverage technology more effectively in the construction sector.

1 INTRODUCTION

Nowadays, different data types are extensively used in various sections of the construction industry, such as sustainability (Golazad et al. 2024), materials (Mohammadi and Ramezanianpour 2023), resilience (Golazad et al. 2022), automation (Cheng et al. 2017), safety (Lee et al. 2020), and more. The widespread accessibility of point-and-shoot, time-lapse, and smartphone cameras has dramatically expanded the volume of photos taken daily on construction sites. Numerous photography documentation services have recently emerged, providing stakeholders with visual records of the constructed projects (Han and Golparvar-Fard 2014). Additionally, the emergence of new aerial robotics companies is now offering frequent delivery of aerial photographs depicting as-built conditions (Yang et al. 2015).

Recent advancements in computer vision and techniques for learning from images have enabled computers to interpret images and video content autonomously. Due to the ease of image acquisition and widespread availability, these methods have garnered interest from scholars across various fields. Presently, many researchers are exploring sophisticated image-based techniques within the construction industry. These applications aim to enhance safety for construction workers, track the progress of activities, facilitate project management, and assess structural damages for structural health monitoring and rehabilitation purposes (Mostafa and Hegazy 2021).

Image-based analysis has the potential to significantly improve safety on construction sites. The complexity of construction activities, characterized by the dynamic interaction between workers, equipment, space, materials, and environmental factors, frequently puts those involved at risk of injury or even fatality. In the United States, in 2018, the construction sector accounted for 7% of all non-fatal injuries and 14% of deaths in the workplace (Statistics 2017). An estimated 80% of these incidents are linked to workers' behavior, including not using protective equipment like helmets and safety harnesses, being hit by vehicles or equipment, and maintaining unsafe postures (Li et al. 2015). Thus, effective monitoring of construction sites to constrain dangerous behavior is crucial. However, traditional monitoring methods must be revised as they rely heavily on direct human observation and manual data collection.

The image-based analysis could also improve construction project productivity management and activity progress monitoring. Half of all construction projects are reported to experience delays, and sixty percent exceed their initial budget estimates (Han et al. 2018). A key factor in these shortcomings is the ineffective monitoring and reporting of progress, contributing to poor management and decision-making (Changali et al. 2015). Utilizing image-based techniques could offer insights into the numerous activities on a construction site by capturing the progress of work, observing the behavior of workers and equipment, and assessing productivity levels. This enables project managers to identify where the construction schedule lags and make more informed, timely decisions to advance the project (Mostafa and Hegazy 2021).

The image-based analysis extends beyond the construction phase into the post-construction period. All infrastructure elements must be monitored to confirm their structural usability. Regular monitoring after the completion of construction is vital for informed decision-making and the efficient allocation of resources towards the structure's maintenance, rehabilitation, and enhancement.

Considering these observations, it becomes evident that the intersection of image-based analysis and construction offers a productive ground for innovation. As we handle the challenges of modern construction projects, the importance of technology, like advanced imaging and analysis, is undeniable. By utilizing the power of these technologies, stakeholders can gain outstanding insights into project dynamics, thereby enhancing decision-making processes, safety protocols, and operational efficiency. This study seeks to contribute to this evolving landscape by systematically reviewing recent advancements, identifying gaps in current research, and highlighting areas for future investigation. In this review, we will explore publication and data trends, the use of synthetic data, and consider methods related to storage, sharing, and privacy that were discussed in related studies. With a focus on practical applications and the potential for technological integration, the research presented aims to pave the way for safer, more efficient, and technologically enriched construction environments.

To contextualize current work within the broader scope of simulation, it is essential to highlight the intersection of image-based analysis, machine learning (ML), deep learning (DL), and reinforcement learning (RL) models with simulation methodologies. While the primary focus is on the construction industry, the advanced computational techniques and data analysis methods reviewed have broad applicability across multiple simulation domains. These include manufacturing, logistics, risk analysis, and general applications. The methodologies discussed, such as synthetic data generation and privacy-preserving techniques, align with showcasing cutting-edge research and practical applications in simulation. The current review contributes valuable insights that can enhance simulation practices and decision-making processes in various industries by bridging the gap between visual data analysis and simulation.

2 RESEARCH METHODOLOGY

This research utilized Scopus, a detailed abstract and citation resource, to locate relevant studies. Chosen for its wide-ranging journal inclusivity, superior keyword search tools, and comprehensive citation analysis features, Scopus stood out as the preferred database (Falagas et al. 2008). The research parameters included a search for specific keywords: ("Construction") AND ("Machine Learning" OR "Deep Learning" OR "Reinforcement Learning"). Executed within the Scopus environment, the search targeted titles, abstracts, and keywords of articles to identify pertinent research employing ML, DL, or RL strategies to develop models based on data related to construction. Figure 1 shows the steps for selecting the related papers.

The initial search produced 10,953 articles. Then, the study focused on those published by the end of 2023 for further examination. The top ten journals that were most pertinent to construction were identified to narrow the selection, which reduced the list to 522 articles for a more detailed review. During the next phase, a manual inspection was carried out to discard articles not directly linked to construction based on their titles. The subsequent phase entailed a thorough assessment of the remaining articles' methodologies, case studies, and abstracts to verify they satisfied three key criteria:

1. Utilization of data specifically from the field of construction engineering and management.
2. Application of ML, DL, or RL approaches for model training with construction-related data.

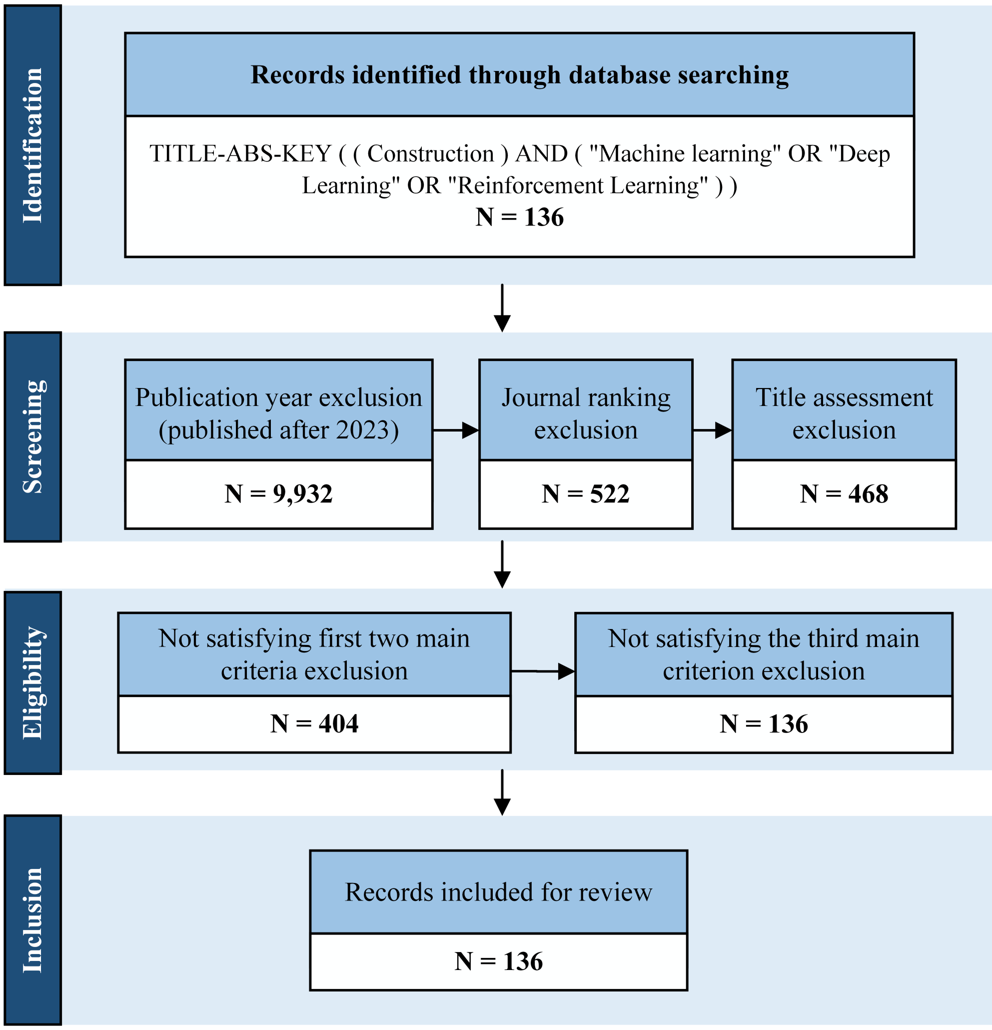

Figure 1: Review conducted systematically using the PRISMA approach.

3. Incorporation of video frames or images for model training.

This strict selection process allowed us to pinpoint articles that effectively demonstrate using ML, DL, or RL techniques within construction. After the first two criteria were applied, 404 articles remained. These were then evaluated against the third criterion, ultimately leading to the selection of 136 articles considered most relevant to the objectives of this review.

All the selected 136 papers are from the top ten journals within this field of research. These journals were selected from the initial search findings, prioritizing their Cite and SJR scores. Automation in Construction emerged as the primary contributor to this research area, accounting for 80 papers. Following closely, the Journal of Computing in Civil Engineering and the Journal of Construction Engineering and Management contributed 15 and 14 papers, respectively. Notably, the International Journal of Construction Management did not publish any papers that fulfilled the third selection criterion. The 2022 SJR and CiteScore values for these journals are detailed in Table 1.

Table 1: Overview of chosen journals, their input to the research, and their Cite Score and SJR Score for the year 2022.

Journal	No. of papers	CiteScore	SJR Score
Automation in Construction	80	16.7	2.443
Journal of Computing in Civil Engineering	15	12.1	1.349
Journal of Construction Engineering and Management	14	8	1.152
Computer-Aided Civil and Infrastructure Engineering	13	16.9	2.962
Construction Innovation	5	6	0.719
Journal of Building Engineering	4	8.3	1.232
Engineering, Construction and Architectural Management	3	7	0.927
Journal of Information Technology in Construction	1	5.6	0.594
Building and Environment	1	11.3	1.584
International Journal of Construction Management	0	7.1	0.914

3 SCIENTOMETRIC ANALYSIS

3.1 Publication Trend

Figure 2 provides a trend analysis of the frequency of articles within the construction field that have utilized image or video data to train ML, DL, and RL models. The recorded data is from 2010, which shows the emergence of such articles in selected journals, while previous years lack any entries in this field. From this starting point, engagement with these data types was minimal and infrequent, as evidenced by a single article per year for 2010, 2012, and consecutively from 2015 to 2017.

A gradual interest was observed in 2018, as indicated by an increase to four articles. This interest escalated markedly in 2019, with the frequency of articles rising to ten. The following years witnessed a more noticeable surge, with article frequencies reaching 20, 32, 34, and 31 for 2020, 2021, 2022, and 2023, respectively. The significant growth in publication numbers signifies an expanding recognition of the value that image and video data contribute to advancing the construction field through various modeling techniques. This pattern may reflect broader technological progress trends, enhanced data access, and a growing incorporation of complex analysis methods within the sector. The modest reduction in 2023 might indicate a consolidation phase following intense expansion or a potential redirection of research interests. These data underscore the progressive integration of visual data analysis in construction, which has become integral to developing intelligent models within the industry.

3.2 Raw Data Type

Figure 3 presents a compilation of raw data types from which the selected studies extracted the video frames and images. It is important to note that due to our selection criteria, which excluded papers not utilizing video or image data, our analysis is inherently focused on studies that employ these types of data. Consequently, the findings in this section reflect trends within this specific subset of literature. The dominant data type identified is "Image," with a frequency of 71, indicating that static visual information is considerably employed in the domain's analytical tasks. "Video" data follows with 41 instances, signifying the importance of temporal data in modeling dynamic environments or processes. The combined use of "Image" and "Video" data, observed in 10 articles, reflects an integrated approach to visual analytics. Furthermore, "Image" combined with "Building Information Modeling (BIM)" data is represented in two instances, suggesting an intersection of visual data with detailed construction models. Similarly, "Image" coupled with "Tabular" data and "Image" combined with "Text" data, each reported in two instances, indicate a multimodal approach where visual data is augmented with structured and textual datasets. "Sensor Data," also observed in two instances, underscores the application of quantitative metrics. Unique combinations, each reported once, such as "RGB-D Image, BIM," "Image, Point Cloud, BIM," "Image, Point Cloud," and

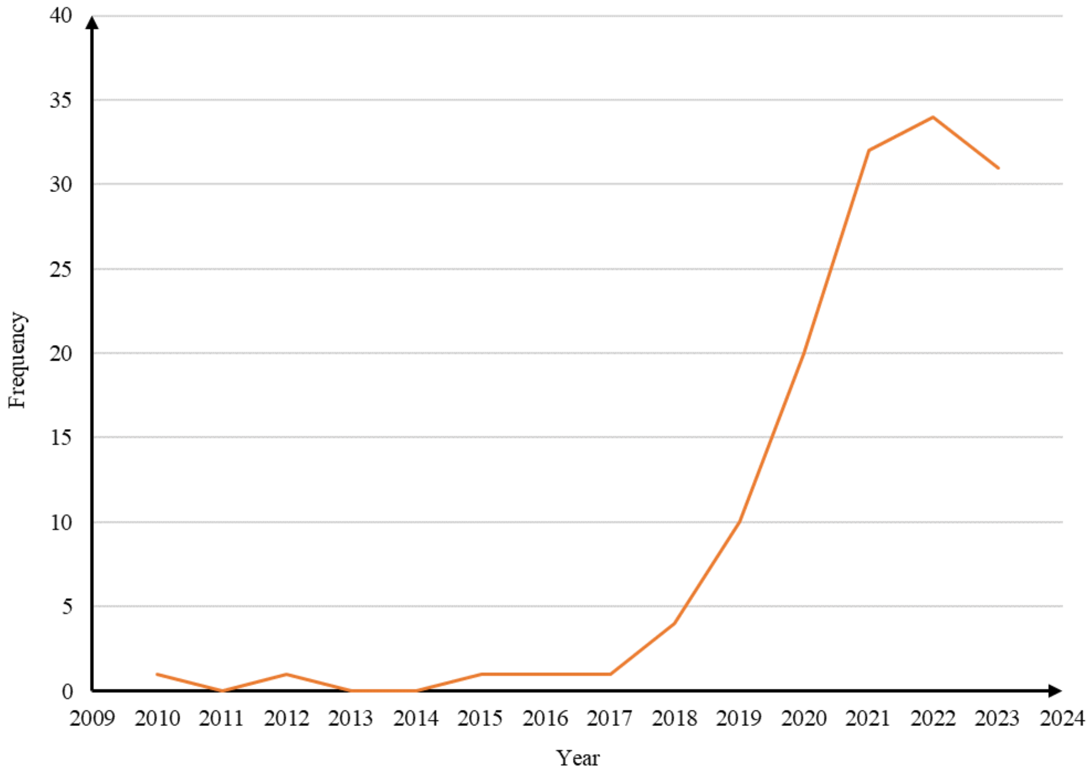

Figure 2: Yearly trends in the publication of construction field articles utilizing visual data for ML, DL, or RL models.

"RGB-D Image," highlight the incorporation of depth sensing and 3D spatial analysis into construction-related research. Lastly, singular instances of "Image Sequence" and "Tabular, Vector Graphics" data usage reflect niche applications in sequence analysis and the integration of structured data with graphical representations, respectively. This distribution of data types illustrates a diverse set of methodological preferences, and research focuses on applying ML, DL, and RL models within the construction industry.

3.3 Data Size Trend

Figure 4 enumerates the average image and video frame data size employed in articles within the construction industry for training ML, DL, and RL models. A gradual increase in data size is discernible from 2010, starting with 281 units, to 560 units in 2015, suggesting an early phase of moderate growth. A noteworthy expansion is observed in the following years, with 2017 marking an increase to 1610 units. A significant escalation in data size is apparent in 2018, with a recorded average size of over 35 thousand units, potentially reflecting advancements in data collection and processing capabilities. The subsequent year, 2019, witnessed a slight reduction to around 22 thousand units. 2020 marked a decrease to 15 thousand units, followed by an increase in 2021 to 28 thousand units, implying variable but substantial data utilization trends. The year 2022 exhibited a decrease to about ten thousand units, which could be indicative of various factors, including optimizations in data usage or changes in modeling techniques. In contrast, 2023 witnessed a remarkable surge to 67,320 units, the largest in the observed period, potentially signaling enhanced computational capabilities and the increasing complexity of models requiring more extensive training datasets. These fluctuations underscore the dynamic nature of data employment in construction-related research, highlighting the field's evolving technical demands and methodological shifts over the identified span.

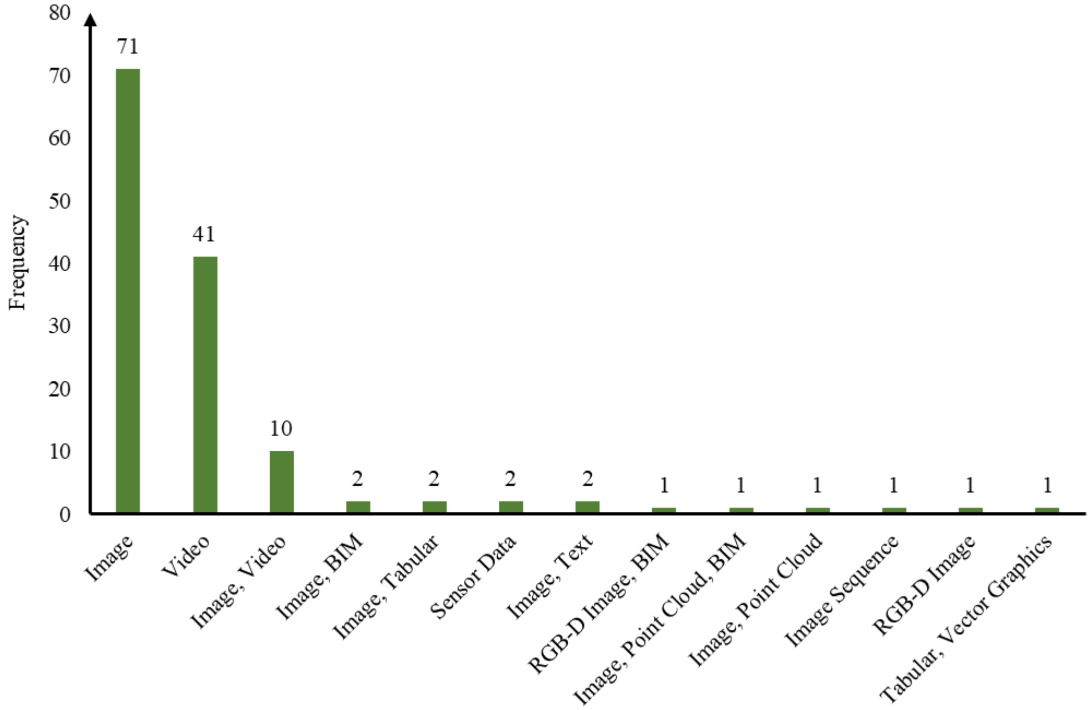

Figure 3: Distribution of raw data types in the selected publications.

3.4 Synthetic Data

Figure 5 presents the distribution of data types utilized in construction field research articles from the year 2020 onward, focusing on the deployment of real, synthetic, and a combination of both data types

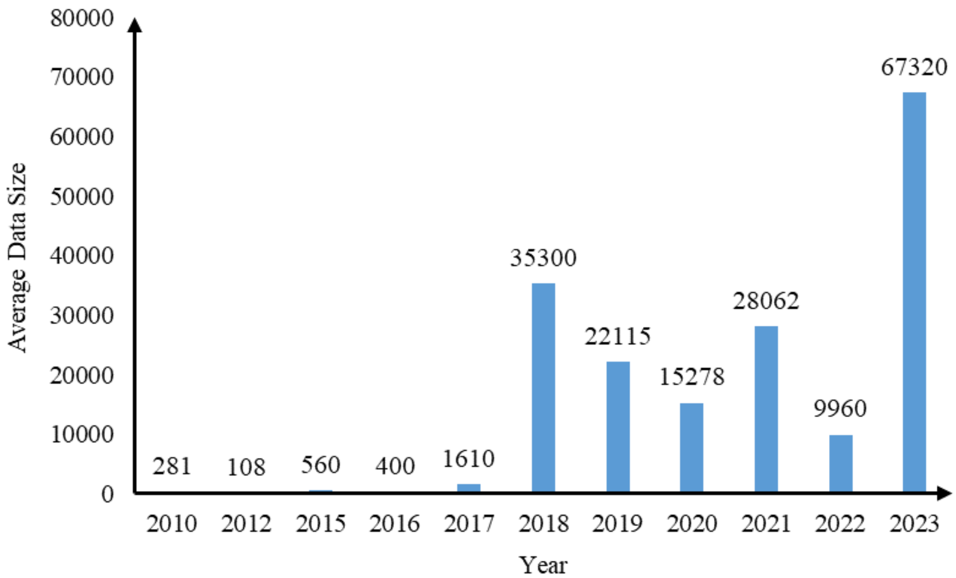

Figure 4: Average data size in construction research articles utilizing visual data for ML, DL, or RL models.

for training. Most articles, 86.0%, have utilized real data, 117 instances. This preference for real data underscores the sector's inclination toward empirical research that relies on actual on-site images or videos.

The use of both real and synthetic data is represented in 17 articles, corresponding to 12.5% of the total, suggesting an integrative approach that employs the strengths of empirical accuracy and the control provided by synthetic environments (e.g., (Zheng et al. 2020; Jeong et al. 2023)). Synthetic data alone accounts for only 1.5% of the data usage, with two instances reflecting its novel presence in the literature (e.g., (Hou et al. 2020)). This minimal reliance on synthetic data could be attributed to the complexity of accurately simulating construction environments or a current emphasis on real-world data applications. It depicts a research landscape where real data is predominant, with an emerging but still limited incorporation of synthetic data. Integrating both data types in several articles could signify a growing trend toward hybrid approaches that balance real-world context benefits and simulated scenarios' versatility. The data suggests that while real data remains the cornerstone of research in this domain, there is recognition of the value synthetic data can add to model robustness and training efficacy.

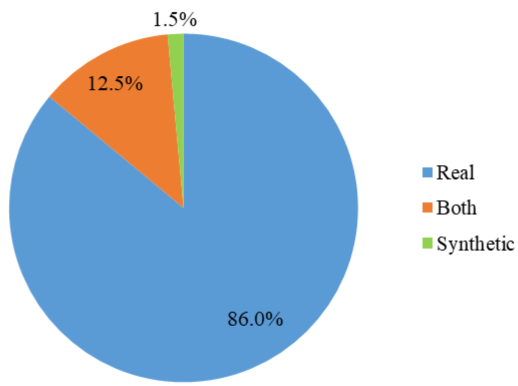

Figure 5: Proportion of construction research articles using real, synthetic, and combined visual data for ML, DL, or RL model training.

Figure 6 analyzes the frequency of studies that used synthetic data, starting from 2020, when such data application in scholarly publications was first recorded. No prior usage of synthetic data in this context and among the selected papers is documented before that year. From its start in 2020, with four entries (e.g., (Hou et al. 2020)), the application of synthetic data shows variability over the following years. The year 2021 shows a decline to three instances of synthetic data application (e.g., (Torres Calderon et al. 2021)), followed by a slight increase to five in 2022 (e.g., (Lee et al. 2022)). In 2023, there is a noticeable increase to seven instances (e.g., (Wang et al. 2023)), suggesting a renewed interest or an improvement in synthetic data generation techniques that make it more viable for research purposes. This trend may indicate a cautious yet growing exploration of synthetic data's potential in the construction field for model training. The fluctuations in frequency reflect the research community's experimental engagement with synthetic datasets, which can offer controlled conditions for model training, albeit without the full complexity and unpredictability of real-world data. The initial uptake, followed by fluctuations, could be attributed to the experimental nature of incorporating synthetic data into construction-related ML, DL, and RL research, alongside developing and refining methods to generate and utilize such data effectively.

3.5 Data Sharing

Figure 7 outlines the distribution of articles explicitly mentioning their image or video frame data's availability for public access or upon request. The analysis spans from 2019, marking the onset of data

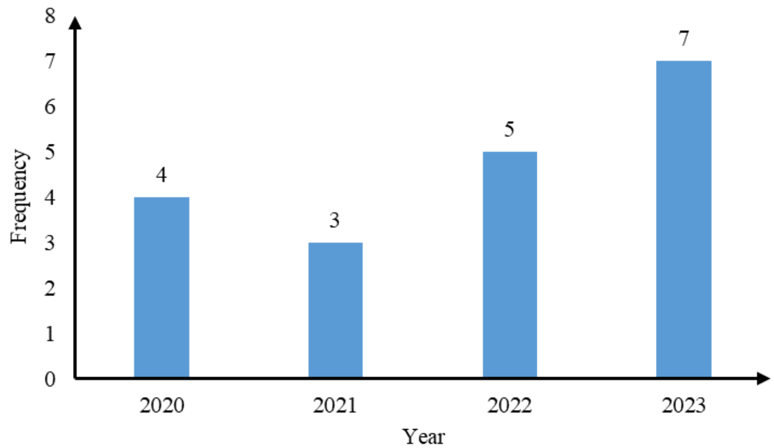

Figure 6: Frequency of using synthetic visual data in construction field research articles.

sharing within the reviewed publications, with no prior records of such practices. In 2019, a modest beginning was noted, with four articles indicating data availability (e.g., (Li et al. 2019)), signifying an initial adoption of open data practices in construction research. A noticeable decrease is observed in 2020, with only two articles mentioning accessible datasets (e.g., (Nath et al. 2020)), which could be attributed to various factors, including possible shifts in research priorities or data-sharing policies. Subsequently, in 2021, the frequency of articles with available data increased to eight, indicating a revival and potential growth in recognition of the importance of data sharing (e.g., (Shen et al. 2021)). This trend is sustained in 2022, with the number remaining steady at eight, suggesting a stabilization of data-sharing practices among researchers (e.g., (Zhang and Ge 2022)). The year 2023 shows a further increase to nine articles (e.g., (Hong et al. 2023)), culminating in 31 out of 136 papers. This progression reflects a growing commitment to open science and transparency within the construction research community, enabling replication studies and furthering advancements by allowing other researchers to build upon accessible datasets. The increase illustrates a broader trend toward democratizing data and collaborative research practices.

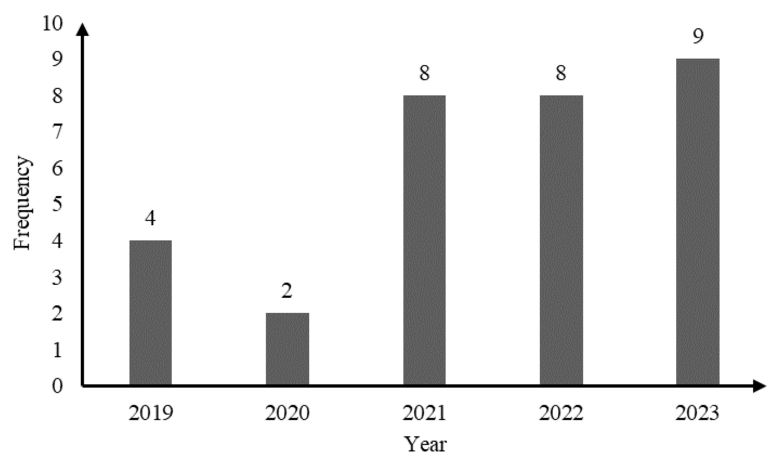

Figure 7: Frequency of articles providing publicly accessible data or availability upon request.

3.6 Data Privacy

Out of 136 papers reviewed, five papers specifically address privacy measures, signifying a developing but notable awareness of privacy in the field. One paper has taken the step of blurring human faces within datasets to ensure individual privacy (Xiao and Kang 2021), while another has extended this approach by blurring company logos (Duan et al. 2022). These measures indicate a targeted strategy to anonymize sensitive visual identifiers. Another article reports the removal of metadata, the absence of geographical information, and secured Department of Transportation (DOT) permission to further the privacy-preserving agenda (Bianchi and Hebdon 2022). This indicates a multi-layered approach to privacy, where various attributes that could lead to identifying subjects or locations are meticulously obscured or omitted. An advanced privacy-preserving technique is mentioned in one paper, utilizing federated learning coupled with homomorphic encryption (Li et al. 2021). This indicates a sophisticated approach to collaborative model training without compromising data security, suggesting a move towards more technologically advanced privacy solutions. Lastly, a focus on decentralized learning through permissioned blockchain is discussed in one paper, showcasing an innovative approach to maintaining data integrity and privacy in distributed research environments (Li et al. 2023).

These papers underscore a trend towards incorporating privacy-preserving techniques in construction field research, reflecting an approach to the ethical challenges posed by using potentially sensitive image and video data in model training.

3.7 Data Storage

Within the 136 papers reviewed, a minority of five papers specify the data storage methods utilized for their datasets. One paper mentions using cloud storage (Rahimian et al. 2020), which suggests adopting scalable, remotely accessible storage solutions. Another paper's utilization of Google Drive highlights a reliance on commercial cloud services known for user-friendliness and widespread accessibility (Ekanayake et al. 2022). This might be chosen for convenience or to facilitate collaboration. The storage of data in XML files in the PASCAL VOC format by one paper suggests an emphasis on a standardized data annotation format that facilitates data sharing and interoperability in computer vision applications (Fang et al. 2018). Lastly, GitHub, a platform typically associated with source code management, is mentioned in two papers (Bianchi and Hebdon 2022; Zhang and Ge 2022) as a means of storing data. This may reflect a trend towards open-source practices and data sharing alongside code for reproducibility.

These papers, though limited in number, display a variety of data storage methods, each with its considerations and implications for accessibility, standardization, and collaboration. The diverse storage solutions adopted point to differing priorities and potential constraints faced by researchers in the field.

4 CONCLUSION

This paper has systematically reviewed the current state of image-based analysis within the construction industry, highlighting its significant contributions to enhancing safety, monitoring progress, and facilitating project management. This study has meticulously examined relevant literature and identified key trends, methodologies, and data usage patterns that underscore the growing integration of ML, DL, and RL models in construction research. The analysis reveals a marked increase in the application of these technologies, driven by the accessibility of image and video data and the continuous advancements in computational methods.

One of the notable findings of this research is the predominant use of real data. However, a trend towards incorporating synthetic and combined data types is emerging. This shift indicates a growing recognition of synthetic data's value, especially in scenarios where real data is scarce or difficult to obtain. Moreover, the study has highlighted the importance of data sharing practices, privacy considerations, and the diverse methods employed for data storage, which contribute to the advancement of open science and ethical research methodologies in the construction domain.

Several limitations should be noted. Due to the selection criteria, which excluded papers not utilizing video or image data, the conclusions are inherently focused on studies employing these data types. This may result in an overrepresentation of findings related to visual data and potentially overlook significant contributions from studies using other data types. The review includes articles published up to the end of 2023. Although efforts were made to include recent studies, the fast-evolving nature of technology in this field means that very recent developments may still need to be fully captured. Scopus was used as the primary database for locating relevant studies. While Scopus is comprehensive, other databases such as Web of Science or Google Scholar may contain additional pertinent articles not included in this review.

Future reviews should consider including studies that utilize non-visual data types to provide a more comprehensive understanding of the field. This can help identify trends and advancements in other construction-related machine-learning research areas. Conducting longitudinal studies that track the evolution of technology and its applications over extended periods can provide deeper insights into long-term trends and impacts. Further research should explore the potential of synthetic data in construction. Developing sophisticated synthetic data generation techniques and validating their effectiveness in real-world scenarios can enhance the robustness of ML models. More research is needed on advanced privacy-preserving techniques like federated learning and blockchain. These methods can help address ethical concerns related to data privacy and security. Integrating insights from other disciplines, such as computer science, data science, and civil engineering, can foster innovative solutions and methodologies in construction-related machine learning research.

Image-based analysis in construction has shown considerable potential to transform traditional practices, making construction sites safer and more efficient. As the field continues to evolve, it is crucial for future research to address the identified gaps, explore the integration of emerging technologies, and promote a culture of openness and collaboration. By doing so, the construction industry can utilize the capabilities of image-based analysis to meet the challenges of the 21st century and beyond.

REFERENCES

Bianchi, E. and M. Hebdon. 2022. "Development of extendable open-source structural inspection datasets". *Journal of Computing in Civil Engineering* 36(6):04022039.

Changali, S., A. Mohammad, and M. van Nieuwland. 2015. "The construction productivity imperative". *McKinsey Quarterly* (June):1–10.

Cheng, C.-F., A. Rashidi, M. A. Davenport, and D. V. Anderson. 2017. "Activity analysis of construction equipment using audio signals and support vector machines". *Automation in Construction* 81:240–253.

Duan, R., H. Deng, M. Tian, Y. Deng and J. Lin. 2022. "SODA: A large-scale open site object detection dataset for deep learning in construction". *Automation in Construction* 142:104499.

Ekanayake, B., A. Ahmadian Fard Fini, J. K. W. Wong, and P. Smith. 2022. "A deep learning-based approach to facilitate the as-built state recognition of indoor construction works". *Construction Innovation*.

Falagas, M. E., E. I. Pitsouni, G. A. Malietzis, and G. Pappas. 2008. "Comparison of PubMed, Scopus, web of science, and Google scholar: strengths and weaknesses". *The FASEB journal* 22(2):338–342.

Fang, Q., H. Li, X. Luo, L. Ding, H. Luo, T. M. Rose *et al*. 2018. "Detecting non-hardhat-use by a deep learning method from far-field surveillance videos". *Automation in construction* 85:1–9.

Golazad, S., G. Heravi, and A. AminShokravi. 2022. "People's post-disaster decisions and their relations with personality traits and decision-making styles: The choice of travel mode and healthcare destination". *International Journal of Disaster Risk Reduction* 83:103395.

Golazad, S., G. Heravi, A. AminShokravi, and A. Mohammadi. 2024. "Integrating GIS, agent-based, and discrete event simulation to evaluate patient distribution policies for enhancing urban healthcare access network resilience". *Sustainable Cities and Society* 111:105559.

Han, K., J. Degol, and M. Golparvar-Fard. 2018. "Geometry- and Appearance-Based Reasoning of Construction Progress Monitoring". *Journal of Construction Engineering and Management* 144(2):04017110.

Han, K. K. and M. Golparvar-Fard. 2014. "Automated monitoring of operation-level construction progress using 4D BIM and daily site photologs". In *Construction Research Congress 2014: Construction in a Global Network*, 1033–1042.

Hong, Y., W.-C. Chern, T. V. Nguyen, H. Cai and H. Kim. 2023. "Semi-supervised domain adaptation for segmentation models on different monitoring settings". *Automation in Construction* 149:104773.

Hou, X., Y. Zeng, and J. Xue. 2020. “Detecting structural components of building engineering based on deep-learning method”. *Journal of Construction Engineering and Management* 146(2):04019097.

Jeong, I., J. Hwang, J. Kim, S. Chi, B.-G. Hwang and J. Kim. 2023. “Vision-Based Productivity Monitoring of Tower Crane Operations during Curtain Wall Installation Using a Database-Free Approach”. *Journal of Computing in Civil Engineering* 37(4):04023015.

Lee, J. G., J. Hwang, S. Chi, and J. Seo. 2022. “Synthetic image dataset development for vision-based construction equipment detection”. *Journal of Computing in Civil Engineering* 36(5):04022020.

Lee, Y.-C., M. Shariatfar, A. Rashidi, and H. W. Lee. 2020. “Evidence-driven sound detection for prenotification and identification of construction safety hazards and accidents”. *Automation in Construction* 113:103127.

Li, H., M. Lu, S.-C. Hsu, M. Gray and T. Huang. 2015. “Proactive behavior-based safety management for construction safety improvement”. *Safety science* 75:107–117.

Li, S., X. Zhao, and G. Zhou. 2019. “Automatic pixel-level multiple damage detection of concrete structure using fully convolutional network”. *Computer-Aided Civil and Infrastructure Engineering* 34(7):616–634.

Li, X., H.-l. Chi, W. Lu, F. Xue, J. Zeng and C. Z. Li. 2021. “Federated transfer learning enabled smart work packaging for preserving personal image information of construction worker”. *Automation in Construction* 128:103738.

Li, X., J. Zeng, C. Chen, H.-l. Chi and G. Q. Shen. 2023. “Smart work package learning for decentralized fatigue monitoring through facial images”. *Computer-Aided Civil and Infrastructure Engineering* 38(6):799–817.

Mohammadi, A. and A. M. Ramezanianpour. 2023. “Investigating the environmental and economic impacts of using supplementary cementitious materials (SCMs) using the life cycle approach”. *Journal of Building Engineering* 79:107934.

Mostafa, K. and T. Hegazy. 2021. “Review of image-based analysis and applications in construction”. *Automation in Construction* 122:103516.

Nath, N. D., A. H. Behzadan, and S. G. Paal. 2020. “Deep learning for site safety: Real-time detection of personal protective equipment”. *Automation in Construction* 112:103085.

Rahimian, F. P., S. Seyedzadeh, S. Oliver, S. Rodriguez and N. Dawood. 2020. “On-demand monitoring of construction projects through a game-like hybrid application of BIM and machine learning”. *Automation in Construction* 110:103012.

Shen, J., X. Xiong, Y. Li, W. He, P. Li and X. Zheng. 2021. “Detecting safety helmet wearing on construction sites with bounding-box regression and deep transfer learning”. *Computer-Aided Civil and Infrastructure Engineering* 36(2):180–196.

Statistics, U. 2017. “National Census Of Fatal Occupational Injuries In 2016”. *Estados Unidos de América. Recuperado de https://www. bls. gov/news. release/archives/cfoi_12192017. pdf*.

Torres Calderon, W., D. Roberts, and M. Golparvar-Fard. 2021. “Synthesizing pose sequences from 3D assets for vision-based activity analysis”. *Journal of Computing in Civil Engineering* 35(1):04020052.

Wang, T. H., A. Pal, J. J. Lin, and S.-H. Hsieh. 2023. “Construction Photo Localization in 3D Reality Models for Vision-Based Automated Daily Project Monitoring”. *Journal of Computing in Civil Engineering* 37(6):04023029.

Xiao, B. and S.-C. Kang. 2021. “Development of an image data set of construction machines for deep learning object detection”. *Journal of Computing in Civil Engineering* 35(2):05020005.

Yang, J., M.-W. Park, P. A. Vela, and M. Golparvar-Fard. 2015. “Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future”. *Advanced Engineering Informatics* 29(2):211–224.

Zhang, M. and S. Ge. 2022. “Vision and trajectory–based dynamic collision prewarning mechanism for tower cranes”. *Journal of Construction Engineering and Management* 148(7):04022057.

Zheng, Z., Z. Zhang, and W. Pan. 2020. “Virtual prototyping-and transfer learning-enabled module detection for modular integrated construction”. *Automation in Construction* 120:103387.

AUTHOR BIOGRAPHIES

ABBAS MOHAMMADI is a Ph.D. candidate at the University of Utah, USA. His research interests include using machine learning and deep learning techniques to address challenges in the construction industry. His current research is focused on integrating LiDAR data with machine learning algorithms to predict the retroreflectivity of road markings. His email address is u1431018@utah.edu.

SEYEDEZAHRA GOLAZAD is a Ph.D. candidate in the Civil and Environmental Engineering Department at the University of Utah. Her research focuses on the application of machine learning techniques within the field of construction engineering and management. Her e-mail address is u1423707@utah.edu.

ABBAS RASHIDI Abbas Rashidi is an Associate Professor in the Civil and Environmental Engineering Department at the University of Utah. He earned his Ph.D. in Civil Engineering from the Georgia Institute of Technology. His research interests include information and sensing technologies for construction engineering and management, audio signal processing for civil infrastructure systems, and video/image processing for 3D reconstruction of civil infrastructure systems. His email address is abbas.rashidi@utah.edu. His webpage is https://faculty.utah.edu/u6013686-Abbas_Rashidi/hm/index.hml.