Journal of Hunan University

(Natural Sciences)

Vol. 51 No. 11

November 2024

Available online at

http://jonuns.com/index.php/journal/index

Open Access Article https://doi.org/10.55463/issn.1674-2974.51.11.5

A Study of AI Applications in the Mexican Architecture, Engineering and Construction Industry: Opportunities and Challenges

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Article History:

Received: September 20, 2024
Revised: October 18, 2024
Accepted: October 26, 2024
Published: November 30, 2024

Abstract: Artificial intelligence (AI) has emerged as a revolutionary force that radically transforms the technological landscape and opens up a multitude of possibilities across various sectors. The architecture, engineering, and construction (AEC) industry is no exception, and fully capitalizes on the potential of AI. This technology is being crucially integrated into its processes, not only to improve operational efficiency and reduce costs but also as a driving force behind innovations that redefine building and infrastructure design and construction. The incorporation of AI into the AEC industry can lead to significant improvements in planning, design, resource management, and maintenance, thereby increasing productivity and promoting sustainability. Moreover, AI can optimize the use of materials, predict potential failures, and enhance safety at construction sites, resulting in safer and more efficient projects. However, the integration of AI is not without challenges and risks, which must be managed responsibly and prudently. These challenges include issues related to AI ethics, safety, reliability, transparency, inclusion, regulation, and long-term sustainability. This article aims to explore the various applications of AI in the AEC industry, highlighting both the opportunities it offers for innovation and efficiency, and the challenges inherent in its integration into everyday processes. By unraveling the impact of AI, we seek to not only understand its current role but also project its future influence in creating more innovative and sustainable built environments. Through a detailed analysis, we aim to shed light on how AI can transform the industry and contribute to more efficient ecological development, ensuring that technology is used ethically and responsibly for the benefit of all.

Keywords: artificial intelligence; architecture; engineering and construction; machine learning; building information modeling

墨西哥建筑、工程和建筑行业人工智能应用研究：机遇与挑战

摘要：人工智能 (AI) 已经成为一股革命性力量，它彻底改变了技术格局，为各个领域开辟了众多可能性。建筑、工程和施工 (AEC) 行业也不例外，它充分利用了人工智能的潜力。这项技术正被关键地整合到其流程中，不仅可以提高运营效率和降低成本，而且还可以成为重新定义建筑和基础设施设计和施工的创新背后的驱动力。将人工智能融入 AEC 行业可以显著改善规划、设计、资源管理和维护，从而提高生产力并促进可持续性。此外，人工智能可以优化材料的使用，预测潜在故障，并提高施工现场的安全性，从而实现更安全、更高效的项目。然而，人工智能的整合并非没有挑战和风险，必须负责任和谨慎地管理。这些挑战包括与人工智能道德、安全性、可靠性、透明度、包容性、监管和长期可持续性相关的问题。本文旨在探讨人工智能在 AEC 行业的各种应用，重点介绍人工智能为创新和效率提供的机会，以及将其融入日常流程所固有的挑战。通过揭示人工智能的影响，我们不仅希望了解其当前的作用，而且还希望预测其在创造更具创新性和可持续性的建筑环境中的未来影响。通过详细的分析，我们旨在阐明人工智能如何改变行业并促进更高效的生态发展，确保以合乎道德和负责任的方式使用技术，造福所有人。

关键词： 人工智能; 建筑; 工程和施工; 机器学习; 建筑信息模型

1. Introduction

Artificial intelligence (AI) has driven a significant shift in society, as reflected in the strategic vision of business leaders worldwide. According to a study conducted by Deloitte (an international professional services network), which surveyed approximately 2600 global business leaders, 94% believe AI will be crucial for business success in the next five years. This consensus underscores the growing competition in adopting AI-based technologies, where companies not only improve their efficiency and reduce costs, but also generate new market opportunities and foster innovation in their products, contributing significantly to increasing revenues. The broad acceptance of AI among business leaders, as the above study indicates, clearly indicates its relevance to the immediate future of business. This global trend highlights the importance of identifying and exposing specific applications of AI in critical sectors such as architecture, engineering, and construction [1].

Mexico’s construction industry faces several challenges that have hindered its growth. Resistance to digitalization in the industry complicates collaboration between organizations and their remarkable development. Organizational factors influence the adoption of these technologies, such as satisfaction with proprietary systems and the existence of Information Technology infrastructure [2].

The adoption of collaborative technologies has become essential for optimizing and streamlining processes that are redundant, tedious, and monotonous, making times more efficient and productive [3]. However, as highlighted in [4], AI is an invaluable tool capable of significantly minimizing the time spent on repetitive tasks by efficiently handling large volumes of data (Big Data) and optimizing work procedures. Other challenges are encountered in increasing participation in the design and planning processes, which results in slowness and higher costs associated with decision-making. This is because involving more stakeholders in the process can lead to longer and more complex discussions, which can delay project completion [5]. According to [6], AI can examine a wide range of design-related factors to identify the most efficient and eco-friendly options, in addition to the Building Information Modeling (BIM) tool, which offers an environment in which these design solutions can be visualized and managed. Similarly, integrating Deep Learning, an advanced branch of AI, further expands the analytical and predictive capabilities of the industry. As argued in [7], deep learning has been implemented to overcome challenges in the construction sector, such as structural monitoring, workplace safety, building occupancy simulation, and energy consumption estimation.

Overall, AI is optimizing efficiency and expanding creative capabilities. However, the rapid advancement of this technology presents significant challenges. Ethical dilemmas emerge when considering the autonomy of technology and moral implications of its use. The need to address the risks inherent in technological development is recognized to avoid negative consequences [8]. Porcelli [9] raised the importance of developing updated legislation that aligns with technological progress to effectively manage AI to ensure that regulations safeguard the interests of the population and encourage technological advancement that is ethical and responsible.

The main objective of this research is to examine multiple applications of AI in the AIC industry. Additionally, it highlights the strengths of innovation and efficiency. We consider the weaknesses that their incorporation into daily processes in the industry entails. It also highlights technological developments and innovations that are transforming the way projects are designed and built. Automation of design tasks, automatic generation of BIM models, quality control and automated inspection, risk and conflict prediction, among others.

2. Methodology

2.1. Word Map of Evidence-Based Learning Strategies

This research adopted an inductive and qualitative analytical approach to understand the phenomenon studied intensely. Through a detailed descriptive analysis, we sought to capture the essence and particularities of the reported literature, thus allowing a richer and more contextualized interpretation of the results (Figure 1).

To select literature, a three-stage process consisting of search, selection, and snowball sampling was conducted.

A detailed review of scientific literature on AI applications in the AEC industry was conducted. Scopus was used as the main database for the literature review. In the first stage, searches were conducted exclusively in English, the dominant language in science and technology, and these databases mostly contain articles in this language.

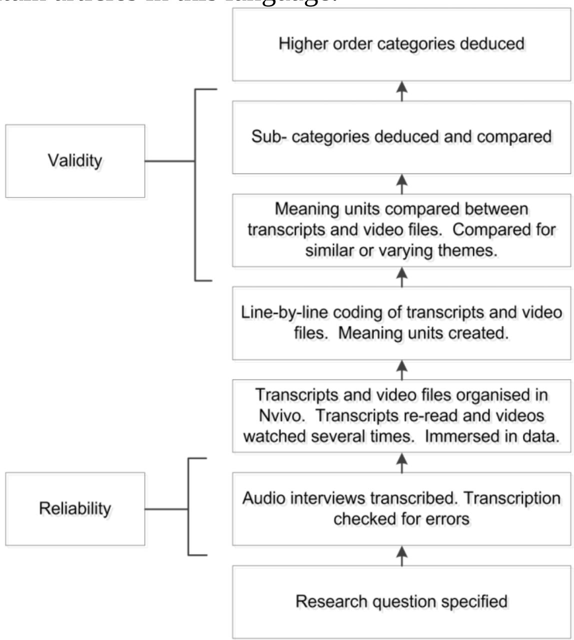

Figure 1. Word map of evidence-based learning strategies [7]

The article search strategy consisted of compound keywords such as “artificial intelligence” AND “architecture industry” OR “construction industry.” The search was performed in the “subject” category, which included searching for keywords in the title, abstract, and keywords of the articles. This search yielded 1,023 documents, which were filtered by language: English, document type: article, and publication date: 2014-2024, resulting in 307 articles that were sorted according to relevance. Articles were selected by reading the first 100 titles; thus, an initial sample of 50 articles with titles most closely related to the theme was selected.

In the second stage, the abstracts of this initial sample were read, discarding those that were not completely related to the theme or that addressed other topics but were from the same AEC branch, resulting in a second sample of 42 articles. In the third stage, according to these 42 articles, a “snowball sampling” strategy was applied, which consisted of an initial selection of articles that met the research criteria. New relevant works have been identified and added through the references of these articles, forming a growing chain of references [10]. Using this strategy, seven articles were identified, to which the same selection criteria were applied, resulting in five selected articles.

Upon completing these three stages, the search was completed and a final sample of 47 articles was consolidated, as shown in Table 1. After identifying and selecting relevant references, qualitative analysis was conducted using an inductive method. This process allowed for a detailed description, identification of the authors' key conclusions, and reporting on the applications of AI in the AEC industry.

2.2. Descriptive Analysis of the Articles Reviewed

Following the parameters established for the choice, and after carrying out the three stages of the search, forty-seven articles were selected, where some of their most relevant characteristics were highlighted, including the title, year of publication, focus, and theme.

2.2.1. Years of Publication

The years of publication of the selected articles cover the last ten years since it was considered a significant period that allows the analysis of trends and advances in the subject studied. Showing the results through a graph, an upward trend was observed in the number of articles published from 2014 to 2022, the peak year of publications with 17 articles, followed by a drastic decrease in publications for the year 2024 (Figure 2).

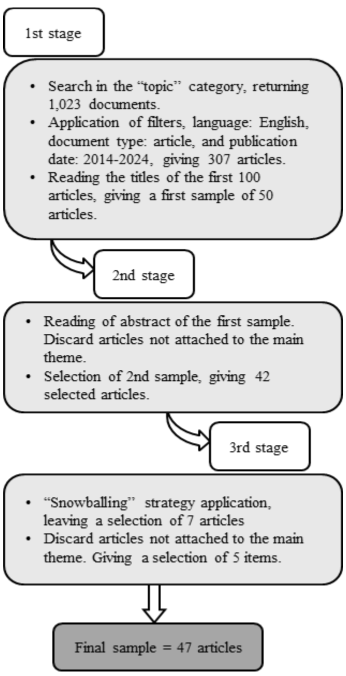

Figure 2. Process selection (the authors' elaboration)

2.2.2. Methodological Approach

Each article addressed a set of procedures and techniques for its conception. Nine qualitative articles were obtained, followed by 14 quantitative articles. The majority of articles (49%) used the mixed approach, representing a total of twenty-two articles.

2.2.3. Theme

Continuing the analysis, the main topics addressed in the articles were identified. The topics that led the list were Implementation Strategies (14 articles, 31%), prediction (13 articles, 29%), and Challenges and Solutions (eight articles, 18%). More participation is required in the following topics: risk and safety assessment, estimates and costs, challenges and solutions, and generative design.

Based on the analysis of the abstracts of the selected samples, five general main themes with specific subthemes were identified (Table 1).

Table 1. Themes. (The authors' elaboration)

Theme	Subthematic	Authors
Integration of AI in Project Management	Strategies and determining factors in the implementation of AI	[2], [11]-[15], [27]
	Challenges and opportunities in AI implementation	[2], [16]-[21]
Monitoring and Evaluation with AI	Real-Time Monitoring and Risk Assessment	[23]-[25]
	Workplace safety training	[26]
	Prediction and Quality Control	[28]-[32]
Innovation and Generative Design	Generative Design and Building Information Modeling	[33]-[37]
	Applications of Industry 4.0 and Circular Economy	[38]-[39]
Costs and Productivity	Cost Estimation and Control	[40]-[43]
	Productivity and Work Optimization	[44]-[45]
Sustainable construction	Sustainable Supply Chain	[46]-[47]
	Energy efficiency of buildings	[48]-[49]
Future perspectives		[4], [22]

3. Implementation

The first group identified in this literature review relates to the integration of AI into project management in the architecture and construction industry. Articles addressing this topic explain strategies for implementing AI in the sector.

In the growing technological transformation within the industry, various AI implementation strategies have been addressed to redefine processes, increase efficiency, and overcome traditional industry challenges. These strategies also provide determining factors for the adoption of this technology.

Some authors have proposed implementation strategies using technologies, such as BIM, DT, and ML. As reported in [27], BIM models, in conjunction with models developed using digital twins (DTs), are essential for implementing AI tools. This can help investors and innovators assess the soundness of startup technology and business strategies. The use of methods that encompass the Lean Construction methodology (LC) was suggested in [11], such as BIM (Building Information Modeling), LPS (Last Planner System), VM (Value Management), and Just-in-Time, as AI implementation strategies within the industry. In addition to the employment of Machine Learning (ML) techniques, Artificial Neural Networks (ANN) and Support Vector Machines (SVM) have been proven to have positive effects on project management processes within the AIC industry. The most recent strategies were discussed in [12], who proposed a strategy focused on fine-tuning Large Language Models (LLMs), which consists of training an existing LLM with its data to improve its performance in specific tasks, provide domain knowledge, and improve the fairness and reliability of the results.

4. Results

Some authors proposed that AI implementation strategies should depend on user perceptions [2], [13]. Understanding public perception helps to understand how the public perceives AI and its applications in construction, which guides the adoption and development of AI-related policies. According to [13], strategies should be guided by the perceived ease of use, utility for continuous use, and technological satisfaction. In addition, organizations must establish customized strategies according to their size, which must consider internal factors, such as organizational competence and perception of technology. Large corporations have the advantage of implementing large-scale capital and providing human resources for technological innovation. In addition to agreeing with these ideas, it was highlighted in [14] that these organizations have more opportunities to develop customized technology more efficiently, positively impacting perceived ease of use. They also propose strategies such as investment in capital and education, and the capacity for technological innovation.

External variables must also be considered. Technological attributes, personal competence, organizational competence, and social influence are determinants of AI acceptance [13]. Five essential formative constructs for the successful adoption of AI in health and safety management systems in the AIC industry were identified in [15]: knowledge, operation, management, integration, reliability, and adaptability. Considering these factors, methodology selection is crucial for achieving more accurate results.

Exploring the challenges and opportunities in AI implementation is critical for navigating today’s complex technological landscape and unlocking the transformative potential of this technology in the industry.

According to the analysis, several authors agree that the biggest challenge when implementing this technology within the AIC industry is the fragmented nature of the industry itself. As argued in [16], the fragmented construction industry makes it challenging to implement innovative technologies uniformly. According to [17], this fragmentation resulted in data acquisition and retention issues and hindered focused and cohesive research and development.

The need for personnel with academic knowledge and professional education was highlighted in [18] to improve the accuracy of AI R+D models and processes. It requires human intervention, from data acquisition to quality assessment. Moreover, according to [19], many professionals have yet to receive training in AI or take courses at universities, and most companies do not offer AI training.

The adoption of AI in the AIC industry is still being determined, particularly in organizations in developing countries, mainly because the benefits of AI are yet to be seen in these nations [20]. In addition, implementing this technology comes with physical challenges, such as injuries due to interactions with automated machinery or AI systems, accidents caused by software errors, or failures in automated decision-making. Moreover, sociopolitical challenges range from job displacement due to automation to ethical issues related to AI decision-making in construction projects. It also highlights the impact on data privacy and security as well as the legal and financial implications of implementing AI technologies [21].

Despite all the challenges already mentioned, there is awareness that AI is a valuable tool for risk analysis and can add value to daily work [19]. Integrating AI into the industry can improve efficiency, timeliness, operational effectiveness, and process quality. In addition, AI is helpful in planning and improving the accuracy of projects by forecasting events, risks, and costs. It also makes work more efficient, reducing the time spent on repetitive tasks and optimizing processes by analyzing big data [2], [16].

According to [16], integrating IoT, AI, and Cloud Technologies (Fog Computing) provides an opportunity to obtain significant benefits in terms of reliability, performance, availability, automation, data security, and energy efficiency. Processing and merging data on devices close to a construction site improves the network quality of service, reduces network traffic, and improves data privacy and security.

4.1.1. Impact and Prospects of AI

The study of AI applications in the AIC industry in recent years has generated significant impacts on the industry itself and on humanity, and has also provided future perspectives.

AI has affected the development of genetic algorithms, neural networks, and knowledge-based systems. With the increase in data generated during the construction lifecycle, AI can leverage these data to improve construction processes, offering the potential for more accurate predictions, as with Deep Learning [4], [22].

Some of the prospects of AI in the industry focus on the continued reinforcement and development of BIM, IoT, quantum computing, augmented reality, cybersecurity, blockchain, ubiquitous computing, context-aware systems, human-machine interfaces, and embedded systems. In addition, it is anticipated that growing support for the construction industry will motivate more publications on intelligent systems, as this industry requires further research [4].

Monitoring and evaluation in construction with AI is a fundamental pillar for the evolution of the AIC industry, as it provides significant advantages that help foresee, predict, or avoid situations that affect process compliance.

It was proposed in [23] to implement edge computing technology that allows data processing close to the source, which is a crucial aspect for real-time monitoring. Similarly, Kumar [24] stated that designing and developing a robust architecture of Artificial Intelligence of Things (AIoT) nodes/devices that communicate and extract real-time data from various parameters allows construction companies to proactively address potential hazards and improve safety measures. The extracted data were analyzed using an AI model to obtain meaningful information regarding the current condition and risk assessment. Thus, any danger to humans or assets can be prevented, and the efficiency of the work environment can be improved through specific and noticeable metrics.

Moreover, one of the most recent technological advances has been addressed in [25], who reported the design of an algorithm model using AI and BIM to identify damage to bridge structures using neural networks, where a significant improvement in the accuracy of damage recognition was observed using an improved neural network algorithm compared to a classical one; the average error of the classic was 0.77%, while the average error of the improved model was 0.56%.

Safety in the industry is a significant factor, as workers can put their lives at risk if they do not perform their tasks correctly. The use of low-cost chatbots was proposed in [26] as an experimental tool for designing construction safety awareness and training, targeting novice and less-experienced workers on-site. This approach represents a significant advance in construction safety training, offering an accessible and adaptable alternative that could be particularly useful for training workers with various levels of on-site experience.

5. Discussion

The introduction of AI into this industry has caused remarkable transformation, optimizing processes, and increasing efficiency in various areas. AI applications include technologies such as Building Information Modeling (BIM), digital twins (DT), and machine learning (ML). These technologies have revolutionized project management, cost estimation, and quality control. In addition, AI-based generative design is improving the planning and construction of sustainable urban spaces, enabling the creation of predictive models that optimize the labor productivity and energy efficiency of buildings.

The strengths of AI in the AIC industry are vast. AI facilitates emission reduction, improves resource management through sustainable construction, and enables better coordination in the supply chain and real-time monitoring, resulting in a faster response to problems. However, AI adoption also faces significant weaknesses, such as resistance to digitalization, the need for advanced training, and the management of large volumes of data. Furthermore, the involvement of multiple stakeholders can slow decision making and increase costs.

To overcome the challenges of the industry, future research should focus on overcoming them and discovering innovative applications, with an emphasis on strategic adoption that considers technological and organizational aspects. Ethics and regulations are critical to ensuring technological progress, which is ethical and beneficial to society. The synergy between AI and emerging technologies, such as cloud computing and the Internet of Things (IoT), opens avenues for innovation and sustainable efficiency in the AIC industry. Altogether, AI is redefining the industry, driving a more sustainable and efficient future, with research continuing to promise transformations that will benefit industry and human well-being globally.

6. Conclusion

Based on this study, several key aspects should be considered to promote the effective adoption of AI in this industry. Some possible recommendations are as follows.

1) Training and continuing education: Implementation of training programs for architecture, engineering, and construction professionals so that they can acquire the necessary skills to use AI technologies.

2) Investment in Technological Infrastructure: Increase investment in technological infrastructure that allows the implementation of AI solutions at all project levels.

3) Collaboration between Sectors: Promote collaboration between the academic, government and private sectors to develop and implement innovative AI-based solutions.

4) Policies and Regulations: Develop policies and regulations that support the adoption of AI and ensure its ethical and responsible use.

5) Promotion of Research and Development: Encourage research and development of new AI applications specific to the AIC industry in Mexico.

These recommendations seek to maximize opportunities and mitigate the challenges presented by the adoption of AI in this industry, thus promoting innovation and efficiency in projects.

Analyzing the literature on AI applications in architecture, engineering, and construction (AEC) in Mexico would provide valuable insights into the adoption, challenges, and potential impact of AI technologies in these sectors within the country. The following are some potential results that may be found:

1) The literature may reveal the current status of AI adoption in the AEC industry in Mexico. This could include information on which sectors (architecture, engineering, or construction) lead to AI integration, the types of AI technologies adopted, and the scale of implementation (e.g., large firms vs. small and medium-sized enterprises).

2) This review identifies specific AI applications in Mexico’s architecture, engineering, and construction practices. This includes generative design, predictive analytics for project planning and scheduling, virtual reality (VR) and augmented reality (AR) for design visualization and client presentations, and AI-driven robotics for construction tasks.

3) It would likely outline AI’s benefits of AI in the AEC industry in Mexico. These include increased efficiency in project delivery, cost savings through optimized resource utilization, improved safety at construction sites, enhanced design capabilities, and better decision-making through data-driven insights.

4) The literature review highlights the challenges and barriers hindering the widespread adoption of AI in Mexico’s AEC sector. These could range from data quality and availability issues to concerns about job displacement due to automation, cultural resistance to technology adoption, regulatory hurdles, and the need for specialized skills among professionals.

5) Case Studies: This review might feature case studies or examples of successful AI implementations in architecture, engineering, and construction projects in Mexico. These real-world examples, with their practical applications and tangible results, would provide valuable lessons learned and insights into best practices for leveraging AI technologies effectively, fostering a sense of engagement and connection with the material.

6) Policy Implications: Finally, the literature review discusses the policy implications of AI adoption in Mexico’s AEC industry. This might include recommendations for policymakers to support innovation and technology adoption but also to foster collaboration between industry stakeholders and academia. This emphasis on collaboration underscores the value and importance of the audience’s expertise and involvement in the research process, making them feel valued and integral to it.

By synthesizing these results, stakeholders in the AEC industry, including practitioners, policymakers, and researchers, can gain a comprehensive understanding of the current landscape of AI applications in architecture, engineering, and construction in Mexico. This understanding can pave the way for exciting opportunities for further research, investment, and collaboration, fostering a sense of optimism and anticipation of potential innovation and growth that AI adoption can bring to the industry.

Declarations

Author Contributions

Conceptualization, C.E.F.-J. and J.A.A.-C.; methodology, C.E.F.-J. and J.A.A.-C.; formal analysis, T.A.-S.; investigation, C.E.F.-J., J.A.A.-C., T.A.-S. and M.T.S.-A.; resources, T.A.-S.; data curation, M.T.S.-A.; writing—original draft preparation, all authors contributed equally; writing—review and editing, C.E.F.-J.; visualization, M.T.S.-A.; funding acquisition, J.A.A.-C. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are openly available in Scopus.

Funding

Instituto Politécnico Nacional

Acknowledgements

We are grateful for the facilities granted to carry out this work to the National Council of Humanities, Sciences and Technology (CONAHCYT), Instituto Politécnico Nacional through the Research and Postgraduate Secretariat with the SIP 20241946 project. Furthermore, to the Interdisciplinary Unit of Engineering and Social and Administrative Sciences and Center for Research and Development of Digital Technology. Likewise, the “Programa de estimulos al desempeño de la investigacion” (EDI), “Programa de estimulos al desempeño docente” (EDD), and “Comision de Operación y promoción de actividades academicas” (COFAA).

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

References

[1] ARQUITECTURA SINGULAR. Inteligencia Artificial (IA) aplicada a la arquitectura. Ventajas y beneficios, 2024, https://arquitecturasingular.es/inteligencia-artificial-ia-aplicada-a-la-arquitectura-ventajas-y-beneficios/

[2] REGONA M., YIGITCANLAR T., XIA B., & LI Y R. Y. M. Opportunities and Adoption Challenges of AI in the Construction Industry: A PRISMA Review. *Journal of Open Innovation: Technology, Market, and Complexity*, 2022, 8(1): 45, https://doi.org/10.3390/joitmc8010045.

[3] NIKAS A., POULYMENAKOU A., & KRIARIS Y P. Investigating antecedents and drivers affecting the adoption of collaboration technologies in the construction industry. *Automation in Construction*, 2007, 16(5): 632-641, https://doi.org/10.1016/j.autcon.2006.10.003.

[4] ABIOYE S. O., OYEDELE L. O., AKANBI L., AJAYI A., DAVILA DELGADO J. M., BILAL M., AKINADE O. O., & AHMED A. Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges. *Journal of Building Engineering*, 2021, 44: 103299, https://doi.org/10.1016/j.jobe.2021.103299.

[5] ACOSTA D. Arquitectura y construcción sostenibles: Conceptos, Problemas Y Estrategias. *Dearq*, 2009, 1(4): 14-23, https://doi.org/10.18389/dearq4.2009.02.

[6] PAN Y., & ZHANG L. Integrating BIM and AI for Smart Construction Management: Current Status and Future Directions. *Archives of Computational Methods in Engineering*, 2023, 30(2): 1081-1110, https://doi.org/10.1007/s11831-022-09830-8.

[7] AKINOSHO T. D., OYEDELE L. O., BILAL M., AJAYI A. O., DELGADO M. D., AKINADE O. O., & AHMED A. A. Deep learning in the construction industry: A review of present status and future innovations. *Journal of Building Engineering*, 2020, 32: 101827, https://doi.org/10.1016/j.jobe.2020.101827.

[8] GONZÁLEZ-ARENCIBIA M., & MARTÍNEZ-CARDERO D. Dilemas éticos en el escenario de la inteligencia artificial. *Economía y Sociedad*, 2020, 25(57): 1-18, https://doi.org/10.15359/eys.25-57.5.

[9] PORCELLI A. M. La inteligencia artificial y la robótica: sus dilemas sociales, éticos y jurídicos. *Derecho global. Estudios sobre derecho y justicia*, 2020, 6(16): 49-105, https://doi.org/10.32870/dgedj.v6i16.286.

[10] GONZÁLEZ O. Aproximación a los distintos tipos de muestreo no probabilístico que existen. *Revista Cubana de Medicina General Integral*, 2021, 37(3): e1442.

[11] VELEZMORO-ABANTO L., CUBA-LAGOS R., TAICO-VALVERDE B., IPARRAGUIRRE-VILLANUEVA O., & CABANILLAS-CARBONELL M. Lean Construction Strategies Supported by Artificial Intelligence Techniques for Construction Project Management—A Review, *International Journal of Online and Biomedical Engineering*, 2024, 20(3): 99-114, https://doi.org/10.3991/ijoe.v20i03.46769.

[12] GHIMIRE P., KIM K., & ACHARYA M. Opportunities and Challenges of Generative AI in Construction Industry: Focusing on Adoption of Text-Based Models. *Buildings*, 2024, 14(1): 1, https://doi.org/10.3390/buildings14010220.

[13] NA S., HEO S., CHOI W., HAN S., & KIM C. Firm Size and Artificial Intelligence (AI)-Based Technology Adoption: The Role of Corporate Size in South Korean Construction Companies. *Buildings*, 2023, 13(4): 4, https://doi.org/10.3390/buildings13041066.

[14] NA S., HEO S., HAN S., SHIN Y., & ROH Y. Acceptance Model of Artificial Intelligence (AI)-Based Technologies in Construction Firms: Applying the Technology Acceptance Model (TAM) in Combination with the Technology–Organisation–Environment (TOE) Framework. *Buildings*, 2022, 12(2): 2, https://doi.org/10.3390/buildings12020090.

[15] WAQAR A., ANDRI, QURESHI A. H., ALMUJIBAH H. R., TANJUNG L. E., & UTAMI C. Evaluation of success factors of utilizing AI in digital transformation of health and safety management systems in modern construction projects. *Ain Shams Engineering Journal*, 2023, 14(11): 102551, https://doi.org/10.1016/j.asej.2023.102551.

[16] ŠTEFANIČ M. & STANKOVSKI V. A review of technologies and applications for smart construction, *Proceedings of the Institution of Civil Engineers - Civil Engineering*, 2018, 172: 1-23, https://doi.org/10.1680/jcien.17.00050.

[17] PRABHAKAR V., BELARMIN XAVIER C. S., & ABUBEKER K. M. A Review on Challenges and Solutions in the Implementation of Ai, IoT and Blockchain in Construction Industry. *Materials Today: Proceedings*, 2023, in press, https://doi.org/10.1016/j.matpr.2023.03.535.

[18] HEO S., HAN S., SHIN Y., & NA S. Challenges of Data Refining Process during the Artificial Intelligence Development Projects in the Architecture, Engineering and Construction Industry. *Applied Sciences*, 2021, 11(22): 22, https://doi.org/10.3390/app112210919.

[19] BASAIF A. A., ALASHWAL A. M., MOHD-RAHIM F. A., KARIM S. B. A., & LOO S.-C. Technology awareness of artificial intelligence (Ai) application for risk analysis in construction projects. *Malaysian Construction Research Journal*, 2020, 9(1 Special issue): 182-195.

[20] TJEBANE M. M., MUSONDA I., & OKORO C.

Organisational Factors of Artificial Intelligence Adoption in the South African Construction Industry. *Frontiers in Built Environment*, 2022, 8: 823998, https://doi.org/10.3389/fbuil.2022.823998.

[21] PILLAI V. S., & MATUS K. J. M. Towards a responsible integration of artificial intelligence technology in the construction sector. *Science and Public Policy*, 2020, 47(5): 689-704, https://doi.org/10.1093/scipol/scaa073.

[22] IRANI Z., & KAMAL M. M. Intelligent Systems Research in the Construction Industry. *Expert Systems with Applications*, 2014, 41(4, Part 1): 934-950, https://doi.org/10.1016/j.eswa.2013.06.061.

[23] YUE Q., MU S., ZHANG L., WANG Z., ZHANG Z., ZHANG X., WANG Y., & MIAO Z. Assisting Smart Construction with Reliable Edge Computing Technology. *Frontiers in Energy Research*, 2022, 10: 900298, https://doi.org/10.3389/fenrg.2022.900298.

[24] KUMAR G. S. A., ROY A., & SINGH R. A Comprehensive Approach to Real-time Site Monitoring and Risk Assessment in Construction Settings using Internet of Things and Artificial Intelligence. *International Journal of Electrical and Electronics Engineering*, 2023, 10(8): 112-126, https://doi.org/10.14445/23488379/IJEEE-V10I8P111.

[25] YANG H., & XIA M. Advancing Bridge Construction Monitoring: AI-Based Building Information Modeling for Intelligent Structural Damage Recognition. *Applied Artificial Intelligence*, 2023, 37(1): 2224995, https://doi.org/10.1080/08839514.2023.2224995.

[26] ZHU H., HWANG B.-G., NGO J., & TAN J. P. S. Applications of Smart Technologies in Construction Project Management. *Journal of Construction Engineering and Management*, 2022, 148(4), https://doi.org/10.1061/(ASCE)CO.1943-7862.0002260.

[27] SACKS R., GIROLAMI M., & BRILAKIS I. Building Information Modelling, Artificial Intelligence and Construction Tech. *Developments in the Built Environment*, 2020, 4: 100011. https://doi.org/101016/j.dibe.2020.100011.

[28] BESKOPYLNY A.N., STEL’MAKH S.A., SHCHERBAN’ E.M., MAILYAN L.R., MESKHI B., RAZVEEVA I., CHERNIL’NIK A., & BESKOPYLNY N. Concrete Strength Prediction Using Machine Learning Methods CatBoost, k-Nearest Neighbors, Support Vector Regression. *Applied Sciences*. 2022; 12(21): 10864. https://doi.org/10.3390/app122110864

[29] ARSIWALA A., ELGHAISH F., & ZOHER M. Digital twin with Machine learning for predictive monitoring of CO2 equivalent from existing buildings. Energy and Buildings, 2023, 284: 112851. https://doi.org/10.1016/j.enbuild.2023.112851.

[30] YANG J., JIA L., GUO Z., SHEN Y, LI X., MOU Z., YU K., & LIN J. C.-W. Prediction and control of water quality in Recirculating Aquaculture System based on hybrid neural network. *Engineering Applications of Artificial Intelligence*, 2023, 121: 106002, https://doi.org/10.1016/j.engappai.2023.106002.

[31] WANG S., PENG H., & LIANG S. Prediction of estuarine water quality using interpretable machine learning approach. *Journal of Hydrology*, 2022, 605: 127320, https://doi.org/10.1016/j.jhydrol.2021.127320.

[32] PHAM H.A., & SÖFFKER D. Modified Model-Free Adaptive Predictive Control Applied to Vibration Reduction of Mechanical Flexible Systems. *Proceedings of the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 2020, 83914, V002T02A025. American Society of Mechanical Engineers. https://doi.org/10.1115/DETC2020-22033

[33] BLOCH T., and SACKS R. Comparing machine learning and rule-based inferencing for semantic enrichment of BIM models. *Automation in Construction*, 2018, 91: 256–272.

[34] BLOCH T., and SACKS R. Clustering Information Types for Semantic Enrichment of Building Information Models to Support Automated Code Compliance Checking. Journal of Computing in Civil Engineering, 2020, 34: 04020040. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000922.

[35] LOCATELLI M., SEGHEZZI E., PELLEGRINI L., TAGLIABUE L.C., & DI GIUDA G.M. Exploring Natural Language Processing in Construction and Integration with Building Information Modeling: A Scientometric Analysis. *Buildings*, 2021, 11(12): 583. https://doi.org/10.3390/buildings11120583

[36] OSCAR L.H., CERQUEIRA L.C., CUNHA P.H., and QUALHARINI E.L. Generative design in civil construction: a case study in Brazil. *Frontiers in Built Environment*, 2023, 9: 1150767. https://doi.org/10.3389/fbuil.2023.1150767

[37] YIGITCANLAR T., DESOUZA K.C., BUTLER L., & ROOZKHOSH F. Contributions and Risks of Artificial Intelligence (AI) in Building Smarter Cities: Insights from a Systematic Review of the Literature. *Energies*, 2020, 13(6): 1473. https://doi.org/10.3390/en13061473

[38] TURNER C., OYEKAN J., STERGIOULAS L., & GRIFFIN D. Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities. *IEEE Transactions on Industrial Informatics*, 2021, 17: 746-756. https://doi.org/10.1109/TII.2020.3002197.

[39] ELGHAISH F., MATARNEH S., EDWARDS D., POUR RAHIMIAN F., EL-GOHARY H., & EJOHWOMU O. Applications of Industry 4.0 digital technologies towards a construction circular economy: gap analysis and conceptual framework. *Construction Innovation*, 2022, 22: 647-670. https://doi.org/10.1108/CI-03-2022-0062.

[40] OWOLABI S., ODUNLADE O., & AMOSUN O. Corporate social responsibility and earnings per share of oil and gas companies in Nigeria. *International Journal of Accounting, Finance and Risk Management*, 2022, 7(2): 56. https://doi.org/10.11648/j.ijafrm.20220702.14

[41] XIE W., DENG B., YIN Y., LV X. and DENG Z. Critical factors influencing cost overrun in construction projects: A fuzzy synthetic evaluation. *Buildings*, 2022, 12(11): 2028.

[42] ELHEGAZY H., ZHANG J., AMOUDI O., ZAKI J., YAHIA M., EID M., & MAHDI I. An Exploratory Study on the Impact of the Construction Industry on Climate Change. *Journal of Industrial Integration and Management*, 2022, 09(02). https://doi.org/10.1142/S2424862222500282.

[43] WANG B., YUAN J., & GHAFOOR K. Research on Construction Cost Estimation Based on Artificial Intelligence Technology. *Scalable Computing: Practice and Experience*, 2021, 22(2): 93-104. https://doi.org/10.12694/scpe.v22i2.1868.

[44] HANAFI M.H., ZHEN M. O., & RAZAK A.A. Contractors’ Perspective on the Main Factors Influencing

On-Site Labour Productivity: A Focus on Malaysian Infrastructure Projects. *International Journal of Sustainable Construction Engineering and Technology*, 2021, 12(1): 68-78. https://doi.org/10.30880/ijscet.2021.12.01.007.
[45] EBRAHIMI S., FAYEK A.R., & SUMATI V. Hybrid Artificial Intelligence HFS-RF-PSO Model for Construction Labor Productivity Prediction and Optimization. *Algorithms*, 2021, 14(7): 214. https://doi.org/10.3390/a14070214
[46] JANG J., AHN S., CHA S.H., CHO K., KOO, & KIM T.W. Toward productivity in future construction: mapping knowledge and finding insights for achieving successful offsite construction projects. *Journal of Computational Design and Engineering*, 2021, 8(1): 1–14, https://doi.org/10.1093/jcde/qwaa071
[47] LIU T., CHEN L., YANG M., SANDANAYAKE M., MIAO P., SHI Y., & YAP P.-S. Sustainability Considerations of Green Buildings: A Detailed Overview on Current Advancements and Future Considerations. *Sustainability*, 2022, 14(21):14393. https://doi.org/10.3390/su142114393
[48] ADEL M., CHENG Z., & ZHEN L. Integration of Building Information Modeling (BIM) and Virtual Design and Construction (VDC) with Stick-Built Construction to Implement Digital Construction: A Canadian General Contractor's Perspective. *Buildings*, 2022, 12: 1337. https://doi.org/10.3390/buildings12091337.
[49] KHAIRULZAMAN H. A., & USMAN F. Automation in Civil Engineering Design in Assessing Building Energy Efficiency. *International Journal of Engineering & Technology*, 2018, 7(4.35): 722-727. https://doi.org/10.14419/ijet.v7i4.35.23096

参考文:

[1]独特的架构。人工智能（AI）应用于建筑。优点和好处，2024，https://arquitecturasingular.es/inteligencia-artificial-ia-aplicada-a-la-arquitectura-ventajas-y-beneficios/
[2] REGONA M.、YIGITCANLAR T.、XIA B. 和 LI Y R. Y. M. 建筑行业人工智能的机遇和采用挑战：PRISMA 评论。开放创新杂志：技术、市场和复杂性，2022，8(1)：45，https://doi.org/10.3390/joitmc8010045。
[3] NIKAS A.、POULYMENAKOU A. 和 KRIARIS Y P. 调查影响建筑行业采用协作技术的先决条件和驱动因素。建筑自动化，2007，16(5): 632-641，https://doi.org/10.1016/j.autcon.2006.10.003。
[4] ABIOYE S. O.、OYEDELE L. O.、AKANBI L.、AJAYI A.、DAVILA DELGADO J. M.、BILAL M.、AKINADE O. O. 和 AHMED A. 人工智能建筑业：现状、机遇和未来挑战的回顾。建筑工程杂志，2021 年，44：103299，https://doi.org/10.1016/j.jobe.2021.103299。
[5] ACOSTA D. 可持续建筑和施工：概念、问题和策略。亲爱的，2009，1(4)：14-23，https://doi.org/10.18389/dearq4.2009.02。
[6] PAN Y.，和 ZHANG L. 集成 BIM 和 AI 实现智能施工管理：现状和未来方向。工程计算方法档案，2023，30(2)：1081-1110，https://doi.org/10.1007/s11831-022-09830-8。
[7] AKINOSHO T. D.、OYEDELE L. O.、BILAL M.、AJAYI A. O.、DELGADO M. D.、AKINADE O. O. 和 AHMED A. A. 建筑行业的深度学习：现状和未来创新回顾。建筑工程杂志，2020，32：101827，https://doi.org/10.1016/j.jobe.2020.101827。
[8] GONZÁLEZ-ARENCIBIA M., 和 MARTÍNEZ-CARDERO D. 人工智能的困境。经济与社会，2020，25(57)：1-18，https://doi.org/10.15359/eys.25-57.5。
[9] PORCELLI A. M. 人工智能和机器人：社会困境、法律和司法。全球德雷乔。正义研究，2020，6(16)：49-105，https://doi.org/10.32870/dgedj.v6i16.286。
[10] GONZÁLEZ O. 不同类型的豁免非概率抽样的方法。古巴综合医学杂志，2021，37(3): e1442。
[11] VELEZMORO-ABANTO L.、CUBA-LAGOS R.、TAICO-VALVERDE B.、IPARRAGUIRRE-VILLANUEVA O. 和 CABANILLAS-CARBONELL M. Lean人工智能技术支持下的建筑项目管理建设策略—评论，国际在线和生物医学工程杂志，2024，20(3): 99-114，https://doi.org/10.3991/ijoe.v20i03.46769。
[12] GHIMIRE P.、KIM K. 和 ACHARYA M. 生成式人工智能在建筑行业面临的机遇与挑战：重点关注基于文本的模型的采用。 建筑, 2024, 14(1): 1, https://doi.org/10.3390/buildings14010220。
[13] NA S.、HEO S.、CHOI W.、HAN S. 和 KIM C. 企业规模和人工基于智能 (AI) 的技术采用：企业规模在韩国建筑公司中的作用。建筑，2023，13(4)：4，https://doi.org/10.3390/buildings13041066。
[14] NA S.， HEO S.、HAN S.、SHIN Y. 和 ROH Y. 建筑公司对人工智能 (AI) 技术的接受模型：将技术接受模型 (TAM) 与技术-组织-环境 (TOE) 相结合应用） 框架。

建筑，2022，12(2)：2，https://doi.org/10.3390/buildings12020090。

[15] WAQAR A.、ANDRI、QURESHI A. H.、ALMUJIBAH H. R.、TANJUNG L. E. 和 UTAMI C. 成功因素评估利用人工智能实现现代建筑项目健康与安全管理系统数字化转型。 艾因夏姆斯工程杂志, 2023， 14(11)：102551，https://doi.org/10.1016/j.asej.2023.102551。

[16] ŠTEFANIČ M. 和 STANKOVSKI V. 智能建筑技术和应用综述, 英国土木工程师学会会刊 - 土木工程，2018，172：1-23，https://doi.org/10.1680/jcien .17.00050。

[17] PRABHAKAR V.、BELARMIN XAVIER C. S. 和 ABUBEKER K. M. 建筑行业实施人工智能、物联网和区块链的挑战与解决方案评论。当今材料：论文集, 2023，正在印刷中，https://doi.org/10.1016/j.matpr.2023.03.535

[18] HEO S.、HAN S.、SHIN Y. 和 NA S. 建筑、工程和建筑行业人工智能开发项目中数据提炼过程的挑战。应用科学, 2021，11(22)：22 ，https://doi.org/10.3390/app112210919。

[19] BASAIF A. A.、ALASHWAL A. M.、MOHD-RAHIM F. A.、KARIM S. B. A. 和 LOO S.-C. 对人工智能(Ai) 在风险分析中的应用的技术认识建筑项目。马来西亚建筑研究杂志, 2020，9（1特刊）：182-195。

[20] TJEBANE M. M.、MUSONDA I. 和 OKORO C. 南非建筑业采用人工智能的组织因素。《建筑环境前沿》, 2022， 8：823998，https://doi.org/10.3389/fbuil.2022.823998。

[21] PILLAI V. S. 和 MATUS K. J. M. 朝着负责任地将人工智能技术融入建筑行业迈进。《科学与公共政策》, 2020，47(5)：689-704，https://doi.org/10.1093/scipol/scaa073。

[22] IRANI Z. 和 KAMAL M. M. 建筑行业的智能系统研究。专家系统与应用, 2014，41(4，第 1 部分)：934-950，https://doi.org/10.1016/j.eswa.2013.06.061。

[23] YUE Q.、MU S.、ZHANG L.、WANG Z.、ZHANG Z.、ZHANG X.、WANG Y. 和 MIAO Z. 使用可靠的边缘计算技术协助智能施工。能源研究前沿, 2022，10：900298，https://doi.org/10.3389/fenrg.2022.900298。

[24] KUMAR G. S. A.、ROY A. 和 SINGH R. 使用物联网和人工智能在施工环境中进行实时现场监控和风险评估的综合方法。国际电气电子工程杂志, 2023，10(8)：112-126，https://doi.org/10.14445/23488379/IJEEE-V10I8P111。

[25] YANG H.，和 XIA M. 推进桥梁施工监测：基于人工智能的建筑信息模型用于智能结构损伤识别。应用人工智能, 2023，37(1)：2224995，https://doi.org/10.1080/08839514.2023.2224995。

[26] ZHU H.、HWANG B.-G.、NGO J.、和 TAN J. P. S. 智能技术在建筑项目管理中的应用。《建筑工程与管理杂志》, 2022，148(4)，https://doi.org/10.1061/(ASCE)CO.1943-7862.0002260。

[27] SACKS R.、GIROLAMI M. 和 BRILAKIS I. 建筑信息模型、人工智能和建筑技术。建筑环境发展, 2020，4：100011。https://doi.org/101016/j.dibe.2020.100011。

[28] BESKOPYLNY A.N.、STEL’MAKH S.A.、SHCHERBAN’ E.M.、MAILYAN L.R.、MESKHI B.、RAZVEEVA I.、CHERNIL’NIK A. 和 BESKOPYLNY N. 使用机器学习方法 CatBoost、k-最近邻、支持向量回归预测混凝土强度。应用科学。2022, 12(21)： 10864。https://doi.org/10.3390/app122110864

[29] ARSIWALA A.、ELGHAISH F. 和 ZOHER M. 使用机器学习的数字孪生对现有建筑物的二氧化碳当量进行预测性监测。能源与建筑, 2023，284：112851。https://doi.org/10.1016/j.enbuild.2023.112851。

[30] YANG J.、JIA L.、GUO Z.、SHEN Y、LI X.、MOU Z.、YU K. 和 LIN J. C.-W. 基于混合神经网络的循环水养殖系统水质预测与控制。人工智能工程应用, 2023，121：106002，https://doi.org/10.1016/j.engappai.2023.106002

[31] WANG S.、PENG H. 和 LIANG S. 使用可解释机器学习方法预测河口水质。《水文学杂志》, 2022，605：127320，https://doi.org/10.1016/j.jhydrol.2021.127320。

[32] PHAM H.A. 和 SÖFFKER D. 改进的无模型自适应预测控制应用于机械柔性系统的减振。国际设计工程技术会议论文集和计算机与工程信息

会议论文集，2020，83914，V002T02A025。美国机械工程师学会。https://doi.org/10.1115/DETC2020-22033

[33] BLOCH T. 和 SACKS R. 比较机器学习和基于规则的推理以丰富 BIM 模型的语义。建筑自动化，2018，91：256-272。

[34] BLOCH T. 和 SACKS R. 聚类信息类型以丰富建筑信息模型的语义，从而支持自动代码合规性检查。《土木工程计算杂志》，2020，34：04020040。https://doi.org/10.1061/(ASCE)CP.1943-5487.0000922。

[35] LOCATELLI M.、SEGHEZZI E.、PELLEGRINI L.、TAGLIABUE L.C. 和 DI GIUDA G.M. 探索建筑中的自然语言处理及其与建筑信息模型的集成：科学计量分析。建筑，2021，11(12)：583。https://doi.org/10.3390/buildings11120583

[36] OSCAR L.H.、CERQUEIRA L.C.、CUNHA P.H. 和 QUALHARINI E.L. 土木工程中的生成设计：巴西案例研究。建筑环境前沿，2023，9：1150767。https://doi.org/10.3389/fbuil.2023.1150767

[37] YIGITCANLAR T.、DESOUZA K.C.、BUTLER L. 和 ROOZKHOSH F. 人工智能 (AI) 在建设智慧城市中的贡献和风险：从文献系统回顾中获得的见解。能源，2020，13(6)：1473。https://doi.org/10.3390/en13061473

[38] TURNER C.、OYEKAN J.、STERGIOULAS L. 和 GRIFFIN D. 在施工现场利用工业 4.0：挑战与机遇。IEEE 工业信息学学报，2021，17：746-756。https://doi.org/10.1109/TII.2020.3002197。

[39] ELGHAISH F.、MATARNEH S.、EDWARDS D.、POUR RAHIMIAN F.、EL-GOHARY H. 和 EJOHWOMU O. 工业 4.0 数字技术在建筑循环经济中的应用：差距分析和概念框架。建筑创新，2022，22：647-670。https://doi.org/10.1108/CI-03-2022-0062。

[40] OWOLABI S.、ODUNLADE O. 和 AMOSUN O. 尼日利亚石油和天然气公司的企业社会责任和每股收益。国际会计、金融与风险管理杂志，2022，7(2): 56。https://doi.org/10.11648/j.ijafrm.20220702.14

[41] XIE W., DENG B., YIN Y., LV X. 和 DENG Z. 影响建筑项目成本超支的关键因素：模糊综合评价。建筑，2022，12(11)：2028。

[42] ELHEGAZY H., ZHANG J., AMOUDI O., ZAKI J., YAHIA M., EID M., 和 MAHDI I. 建筑业对气候变化影响的探索性研究。工业一体化与管理杂志，2022，09(02)。https://doi.org/10.1142/S2424862222500282。

[43] WANG B., YUAN J., 和 GHAFOOR K. 基于人工智能技术的工程造价估算研究。可扩展计算：实践与经验，2021，22(2): 93-104。https://doi.org/10.12694/scpe.v22i2.1868。

[44] HANAFI M.H., ZHEN M. O., 和 RAZAK A.A. 承包商对影响现场劳动生产率的主要因素的看法：以马来西亚基础设施项目为重点。国际可持续建筑工程与技术杂志，2021，12(1): 68-78。https://doi.org/10.30880/ijscet.2021.12.01.007。

[45] EBRAHIMI S.、FAYEK A.R. 和 SUMATI V. 用于建筑劳动生产率预测和优化的混合人工智能 HFS-RF-PSO 模型。算法，2021，14(7)：214。https://doi.org/10.3390/a14070214

[46] JANG J.、AHN S.、CHA S.H.、CHO K.、KOO 和 KIM T.W. 迈向未来建筑的生产力：绘制知识图谱并寻找实现成功场外施工项目的见解。计算设计与工程杂志，2021，8(1)：1–14，https://doi.org/10.1093/jcde/qwaa071

[47] LIU T.、CHEN L.、YANG M.、SANDANAYAKE M.、MIAO P.、SHI Y. 和 YAP P.-S. 绿色建筑的可持续性考虑：当前进展和未来考虑的详细概述。可持续性，2022，14(21)：14393。https://doi.org/10.3390/su142114393

[48] ADEL M.、CHENG Z. 和 ZHEN L.将建筑信息模型 (BIM) 和虚拟设计和施工 (VDC) 与木结构建筑相结合以实现数字化施工：加拿大总承包商的视角。建筑，2022，12：1337。https://doi.org/10.3390/buildings12091337。

[49] KHAIRULZAMAN H. A.，和 USMAN F. 土木工程设计自动化在建筑能效评估中的应用。国际工程与技术杂志，2018，7(4.35)：722-727。https://doi.org/10.14419/ijet.v7i4.35.23096