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EDITORIAL NOTES: APPLICATION OF COMPUTATIONAL /ARTIFICIAL INTELLIGENCE IN CONCRETE STRUCTURES AND MATERIALS

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Abstract — In recent years, the application of computational/artificial intelligence (CI/AI) in concrete structures and materials has gained popularity as evident in the search in the SCOPUS database using these keywords. The integration of CI/AI in concrete structures marks a significant advancement in civil engineering, offering innovative solutions across various stages of infrastructure development. From analysis and design to construction, monitoring, and maintenance, CI/AI technologies revolutionize traditional practices, enabling engineers to optimize concrete structures for enhanced performance, durability, and sustainability. Material design and optimization in concrete have also been propelled forward by CI/AI technologies. Traditional methods rely on trial-and-error, but CI/AI models analyze vast datasets to identify optimal mixtures with superior properties and resistance to environmental factors. Utilization of supplementary cementitious materials and industrial wastes introduces complexities, addressed by CI/AI's predictive capabilities for short- and long-term concrete properties. By minimizing waste and energy consumption, CI/AI-driven design fosters environmentally friendly formulations while ensuring structural integrity. Overall, CI/AI enhances prediction, optimization, and monitoring, ushering in a new era of resilient and sustainable concrete materials. These advancements also contribute to sustainable development by optimizing material usage, reducing waste, and improving energy efficiency, underscoring CI/AI's transformative potential in shaping the future of concrete structures and materials.

***Keywords*:** artificial intelligence, computational intelligence, concrete structure, concrete material, SCOPUS

1.0 INTRODUCTION

In recent years, there has been an increasing utilization of computational/artificial intelligence (CI/AI) methodologies in addressing civil engineering challenges, e.g., structural engineering [1–6], concrete materials [7–14], water distribution system [15–17], construction management [18–21], transportation [22, 23], and geotechnical engineering [24–27]. These studies showed that CI/AI is generally effective for design optimization and prediction purposes in solving various real-world engineering problems. In publications, CI/AI is occasionally referred to as machine learning or soft computing.

Figure 1 shows the trend of publication in the area of application of CI/AI in the discipline of concrete structures in the past ten years based on the SCOPUS search engine. It can be observed in Figure 1 that the trend of growth in publication is exponential, indicating the popularity of this area of research. It is anticipated that the number of publications will continue to expand in the years ahead.

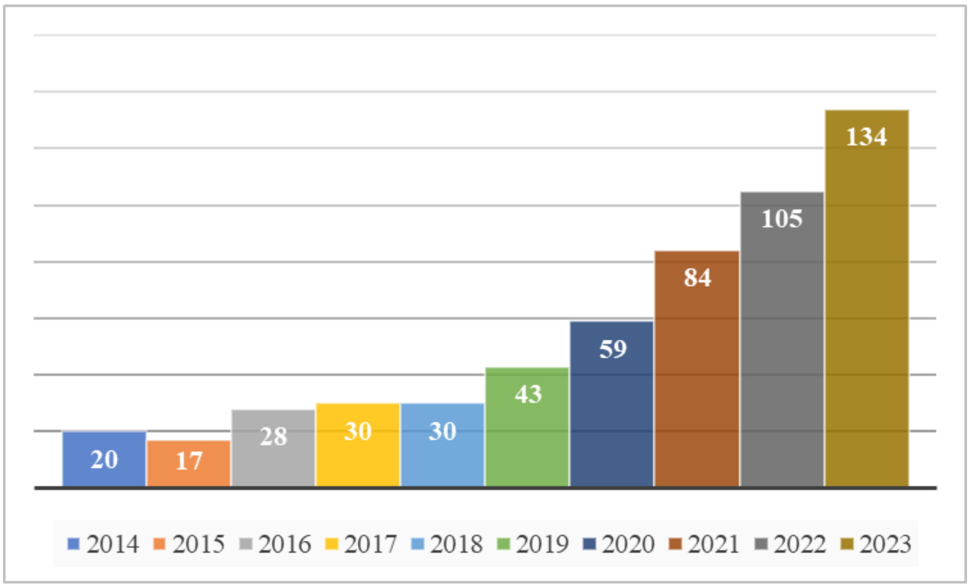

Figure 1 Number of publications based on SCOPUS search engine with keywords: “computational” OR “artificial” AND “intelligence” AND “concrete” AND “structures”

As for concrete materials, Figure 2 illustrates an exponential increase in publications within this domain over the past decade based on the SCOPUS search engine. This suggests that this field of research has experienced a surge in popularity over the last ten years and is predicted to show further growth in publication volume.

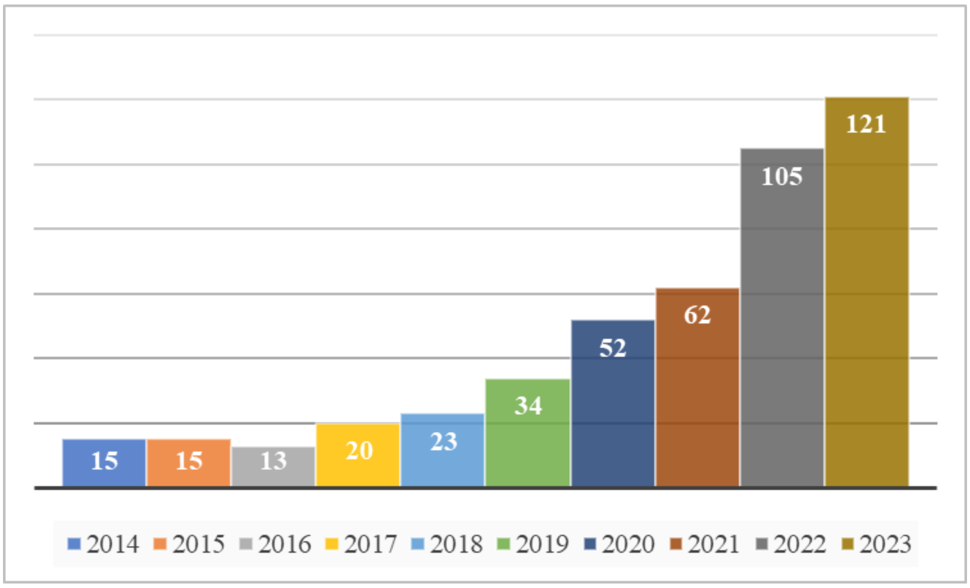

Figure 2 Number of publications based on SCOPUS search engine with keywords: “computational” OR “artificial” AND “intelligence” AND “concrete” AND “materials”

2.0 COMPUTATIONAL/ARTIFICIAL INTELLIGENCE IN CONCRETE STRUCTURES

The application of CI/AI in concrete structures represents a significant advancement in the field of civil engineering, offering innovative solutions to enhance the analysis, design, construction, monitoring, and maintenance of infrastructure. This integration of technology revolutionizes traditional practices, enabling engineers to optimize concrete structures for improved performance, durability, and sustainability.

Computational/artificial intelligence proves beneficial in structural analysis tasks, such as the prediction of tendon stress in external prestressing as demonstrated by Lau et al. [4]. The study illustrates that the CI/AI system proposed in the study can accurately predict the stress in the external tendon, which is dependent of a few parameters. In a separate study [28], chained machine learning model was used for the prediction of load capacity and ductility of steel fiber–reinforced concrete beams.

One of the primary areas where CI/AI techniques are making a profound impact is in the design phase of concrete structures. Sophisticated algorithms have the capability to process extensive datasets concerning material characteristics, structural burdens, environmental circumstances, and design limitations, thereby producing refined designs [29]. Through machine learning algorithms, CI/AI systems can learn from past design experiences and adapt to evolving project requirements, resulting in more efficient and cost-effective structural solutions. Additionally, CI/AI-driven design tools can facilitate the exploration of innovative design concepts and help engineers uncover novel approaches to address complex engineering problems.

In addition to analysis and design, CI/AI technologies are revolutionizing the construction phase of concrete structures. Autonomous construction equipment equipped with CI/AI systems can streamline construction processes, enhance productivity, and improve safety on construction sites. Robotics and automated systems powered by CI/AI algorithms can perform tasks such as concrete mixing, placement, and finishing with precision and efficiency, reducing labour costs and accelerating project timelines. Furthermore, CI/AI-driven monitoring systems can continuously assess construction quality, detect defects, and provide real-time feedback to construction crews, enabling proactive interventions to address potential issues before they escalate [30].

The integration of CI/AI technologies also offers significant advantages in the monitoring and maintenance of concrete structures throughout their service life [31]. Sensor networks embedded within concrete elements can collect data on structural performance, environmental conditions, and material degradation over time. With the incorporation of internet of things (IoT), data can be collected in real-time without the hindrance of distance and time. Computational/artificial intelligence algorithms can analyze this data to assess the health and condition of the structure in real-time, identify early signs of deterioration or damage, and predict future maintenance needs. By implementing predictive maintenance strategies based on CI/AI-driven insights, asset owners can optimize maintenance schedules, extend the service life of concrete structures, and minimize lifecycle costs [32].

Furthermore, CI/AI-powered monitoring systems can enhance the resilience of concrete infrastructure to natural and man-made hazards. By continuously monitoring structural health and performance, these systems can provide early warning of potential hazards such as seismic activity, excessive loading, or corrosion-induced deterioration. In the event of an emergency, CI/AI algorithms can facilitate rapid decision-making by providing real-time data and predictive analytics to aid emergency response and recovery efforts [33]. This proactive approach to risk management helps to enhance the safety and resilience of concrete structures, protecting lives and property in vulnerable communities.

Additionally, the application of CI/AI in concrete structures opens up new opportunities for sustainable development and environmental stewardship. By optimizing material usage, reducing construction waste, and improving energy efficiency, CI/AI-driven design and construction processes contribute to the creation of more cost-effective infrastructure [34]. Furthermore, CI/AI algorithms can optimize the operation of smart concrete systems equipped with embedded sensors and actuators, enabling adaptive responses to changing environmental conditions and user requirements. These intelligent concrete systems have the potential to revolutionize the way we design, build, and maintain infrastructure, ushering in a new era of sustainable and resilient construction practices.

3.0 COMPUTATIONAL/ARTIFICIAL INTELLIGENCE IN CONCRETE MATERIALS

One of the primary areas where CI/AI technologies have made significant strides is in material design and optimization. Traditional concrete mix designs rely on trial-and-error methods and experience-based approaches, often resulting in suboptimal outcomes. However, computational models powered by CI/AI can analyze vast datasets and simulate various material compositions, enabling engineers to identify optimal mixtures that exhibit superior mechanical properties, durability, and resistance to environmental factors [9]. By incorporating machine learning algorithms, these models can continuously learn from experimental data, refining their predictions and accelerating the development of innovative concrete formulations tailored to specific applications.

Over recent years, there has been a growing trend towards the increased utilization of supplementary cementitious materials (SCMs) in concrete mixtures, making the area of concrete materials even more complex. Furthermore, the incorpopration of waste materials as SCMs has introduced additional challenges to concrete mix design [9]. Through the application of CI/AI, it becomes feasible to predict both short-term and long-term properties of concrete [7, 8, 10–14].

Moreover, CI/AI technologies facilitate the integration of advanced materials and smart functionalities into concrete materials, paving the way for the development of next-generation infrastructure solutions. For instance, self-healing concrete, equipped with microcapsules containing healing agents activated upon crack formation, exemplifies the transformative potential of CI/AI-driven innovation in concrete materials. Machine learning algorithms analyze environmental data and structural conditions to optimize the deployment of self-healing mechanisms, ensuring timely repairs and prolonging the service life of concrete elements [14, 35].

Furthermore, CI/AI approaches offer novel solutions for addressing sustainability challenges in concrete materials and construction practices. By optimizing material usage, minimizing waste, and reducing energy consumption during production and transportation, CI/AI-driven design methodologies contribute to the development of more environmentally friendly concrete formulations. Additionally, machine learning algorithms can optimize the performance of concrete over their lifecycle, considering factors such as energy efficiency, carbon footprint, and resilience to climate change impacts. Through data-driven decision-making and predictive modeling, stakeholders can make informed choices that prioritize sustainability without compromising structural integrity or functionality.

In short, CI/AI is revolutionizing the field of concrete materials by providing innovative solutions for prediction, optimization, and monitoring of concrete properties. By leveraging vast datasets and sophisticated algorithms, CI/AI techniques can accurately forecast various concrete properties, including compressive strength, durability, and workability. These predictive models analyze factors such as material composition, curing conditions, and environmental influences to generate precise estimations, enabling engineers to optimize concrete mix designs and enhance performance. Moreover, CI/AI algorithms facilitate real-time monitoring of concrete properties during construction and service life, enabling early detection of anomalies or deterioration. By integrating CI/AI into concrete property analysis, researchers and practitioners can unlock new insights, improve efficiency, and develop more resilient and sustainable concrete materials for the future.

4.0 CONCLUSION

The application of CI/AI in concrete structures and materials has emerged as a transformative force in the field of civil engineering. By harnessing advanced algorithms and data-driven techniques, researchers and practitioners can optimize concrete mix designs, predict structural behavior, and monitor the health of concrete infrastructure with unprecedented accuracy. Computational/artificial intelligence methodologies enable engineers to simulate complex interactions within concrete materials, leading to the development of innovative formulations that exhibit enhanced mechanical properties, durability, and sustainability. Furthermore, CI/AI-driven structural analysis techniques provide valuable insights into the performance of concrete structures under various loading and environmental conditions, guiding design optimization and risk mitigation efforts. Through the integration of sensors, IoT devices, and CI/AI algorithms, stakeholders can monitor concrete structures in real time, detect defects or deterioration early, and implement proactive maintenance strategies. Overall, the application of CI/AI technologies in concrete structures and materials promises to revolutionize construction practices, paving the way for safer, more resilient, and sustainable built environments.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] Sgambi, L., Gkoumas, K., & Bontempi, F. (2012). Genetic Algorithms for the Dependability Assurance in the Design of a Long-Span Suspension Bridge. Computer-Aided Civil and Infrastructure Engineering, 27. https://doi.org/10.1111/j.1467-8667.2012.00780.x

[2] Kociecki, M., & Adeli, H. (2013). Two-phase genetic algorithm for size optimization of free-form steel space-frame roof structures. Journal of Constructional Steel Research, 90, 283–296.

[3] Roshanfar, M., Azad, A. R. G., & Forouzanfar, M. (2023). *Predicting fatigue life of shear connectors in steel-concrete composite bridges using artificial intelligence techniques*. Fatigue & Fracture of Engineering Materials & Structures.

[4] Lau, S. H., Ng, C. K., & Tay, K. M. (2015). Data-driven SIRMs-connected FIS for prediction of external tendon stress. Computers and Concrete, 15(1), 55–71.

[5] Zain, M., Keawsawasvong, S., Thongchom, C., Sereewatthanawut, I., Usman, M., & Prasittisopin, L. (2023). *Establishing efficacy of machine learning techniques for vulnerability information of tubular buildings*. Engineered Science.

[6] Meddage, D., Mohotti, D., & Wijesooriya, K. (2024). Predicting transient wind loads on tall buildings in three-dimensional spatial coordinates using machine learning. Journal of Building Engineering, 108725.

[7] Tayfur, G., Erdem, T. K., & Kırca, Ö. (2014). Strength Prediction of High-Strength Concrete by Fuzzy Logic and Artificial Neural Networks. Journal of Materials in Civil Engineering, 26(11), 11. https://doi.org/10.1061/(asce)mt.1943-5533.0000985

[8] Chiew, F. H., Chai, K. C., Ng, C. K., & Tay, K. M. (2014). A fuzzy ART-based approach for estimation of high performance concrete mix proportion. In Lecture Notes in Computer Science (p, 407–414.

[9] Chiew, F. H., Ng, C. K., Chai, K. C., & Tay, K. M. (2017). A fuzzy adaptive resonance theory-based model for mix proportion estimation of high-performance concrete. Computer-Aided Civil and Infrastructure Engineering, 32(9), 772–786.

[10] Chiew, F. H., Lau, S. H., & Ng, C. K. (2018). Monotonicity preserving SIRMs-connected fuzzy inference system for predicting HPC compressive strength. Intelligent Decision Technologies, 12(3), 293–302.

[11] Chiew, F. H., Petrus, C., Nyuin, J. D., Lau, U. H., & Ng, C. K. (2022). Prediction of HFRC compressive strength using HS-based SIRMs connected fuzzy inference system. Physics and Chemistry of the Earth, Parts A/B/C, 128(10327), 5.

[12] Liang, W., Yin, W., Zhao, Y., Tao, Q., Li, K., Zhu, Z., Zou, Z., Zeng, Y., Yuan, S., & Han, C. (2023). Mixed artificial intelligence models for compressive strength prediction and analysis of fly ash concrete. Advances in Engineering Software, 185(10353), 2.

[13] Beskopylny, A. N., Stel'makh, S. A., Shcherban, E. M., Mailyan, L. R., Meskhi, B., Razveeva, I., Kozhakin, A., Pembek, A., El'shaeva, D., Chernil'nik, A., & Beskopylny, N. (2024). Prediction of the compressive strength of vibrocentrifuged concrete using machine learning methods. Buildings, 14(2), 377.

[14] Chiadighikaobi, P. C., Hematibahar, M., Kharun, M., Stashevskaya, N. A., & Camara, K. (2024). Predicting mechanical properties of self-healing concrete with Trichoderma Reesei Fungus using machine learning. Cogent Engineering, 11(1), 1. https://doi.org/10.1080/23311916.2024.2307193

[15] Montalvo, I., Izquierdo, J., Pérez-Garc\'\ia, R., & Herrera, M. (2014). Water Distribution System Computer-Aided design by Agent Swarm Optimization. Computer-Aided Civil and Infrastructure Engineering, 29(6), 433–448.

[16] Abkenar, S. M. S., Stanley, S. D., Miller, C. J., Chase, D. V, & McElmurry, S. P. (2015). Evaluation of genetic algorithms using discrete and continuous methods for pump optimization of water distribution systems. Sustainable Computing: Informatics and Systems, 8, 18–23.

[17] Perea, R. G., Poyato, E. C., & D\'\iaz, J. R. (2024). Attention is all water need: Multistep time series irrigation water demand forecasting in irrigation disctrics. Computers and Electronics in Agriculture, 218(10872), 3.

[18] Lee, H., Yi, C., Lee, D., & Arditi, D. (2015). An advanced stochastic time-cost tradeoff analysis based on a CPM-guided genetic algorithm. Computer-Aided Civil and Infrastructure Engineering, 30(10), 824–842.

[19] Hanafi, A. G., Nawi, M. N. M., Rahim, M. K. I. A., Nifa, F. A. A., & Mohamed, O. (2022). Project managers selection in the construction industry: Towards the integration with artificial emotional intelligence and technology. Journal of Advanced Research in Applied Sciences and Engineering Technology, 29(1), 160–176.

[20] Zabala-Vargas, S., Jaimes-Quintanilla, M., & Jimenez-Barrera, M. H. (2023). Big data, data science, and artificial intelligence for project management in the architecture, engineering, and construction industry: A systematic review. Buildings, 13(12), 2944.

[21] Ji, C., Zhang, F., Huang, X., Song, Z., Hou, W., Wang, B., & Chen, G. (2023). *STAE-YOLO: Intelligent detection algorithm for risk management of construction machinery intrusion on transmission lines based on visual perception*. IET Generation Transmission & Distribution.

[22] Dong, J., Yassine, A., Armitage, A., & Hossain, M. S. (2023). Multi-agent reinforcement learning for intelligent V2G integration in future transportation systems. IEEE Transactions on Intelligent Transportation Systems, 24(12), 15974–15983.

[23] Santos, K., Firme, B., Dias, J. P., & Amado, C. (2023). Analysis of motorcycle accident injury severity and performance comparison of machine learning algorithms. Transportation Research Record, 2678(1), 736–748.

[24] Foong, L. K., & Moayedi, H. (2021). Slope stability evaluation using neural network optimized by equilibrium optimization and vortex search algorithm. Engineering with Computers, 38, 1269–1283.
[25] Bardhan, A., & Asteris, P. G. (2023). Application of hybrid ANN paradigms built with nature inspired meta-heuristics for modelling soil compaction parameters. Transportation Geotechnics, 41(10099), 5.
[26] Li, Q., & Zhu, Z. (2023). Calibration of an elastoplastic model of sand liquefaction using the swarm intelligence with a multi-objective function. Journal of Rock Mechanics and Geotechnical Engineering, 15(3), 789–802.
[27] Nagaraju, T. V, Mantena, S., Sunil, B. M., & Alisha, S. S. (2023). A review on application of soft computing techniques in geotechnical engineering. In Lecture Notes in Civil Engineering, 313–322.
[28] Shafighfard, T., Kazemi, F., Bagherzadeh, F., Mieloszyk, M., & Yoo, D. (2024). *Chained machine learning model for predicting load capacity and ductility of steel fiber-reinforced concrete beams*. Computer-Aided Civil and Infrastructure Engineering.
[29] Ojeda, J. M. P., Herrera, N., Huatangari, L. Q., & Calderón, B. a. C. (2023). Determination of steel area in reinforced concrete beams using data mining techniques. Revue D'intelligence Artificielle, 37, 4.
[30] Katam, R., Pasupuleti, V. D. K., & Kalapatapu, P. (2023). A review on structural health monitoring: past to present. Innovative Infrastructure Solutions, 8(9), 9. https://doi.org/10.1007/s41062-023-01217-3
[31] Dodampegama, S., Hou, L., Asadi, E., Zhang, K., & Setunge, S. (2024). Revolutionizing construction and demolition waste sorting: Insights from artificial intelligence and robotic applications. Resources, Conservation and Recycling, 202(10737), 5.
[32] Frangopol, D. M., & Liu, M. (2007). Maintenance and management of civil infrastructure based on condition, safety, optimization, and life-cycle cost. Structure and Infrastructure Engineering, 3(1), 29–41.
[33] Damaševi cius, R., Ba canin, N., & Misra, S. (2023). From sensors to safety: Internet of emergency services (IOES) for emergency response and disaster management. Journal of Sensor and Actuator Networks, 12(3), 41.
[34] Regona, M., Yiğitcanlar, T., Xia, B., & Li, R. Y. M. (2022). Opportunities and adoption challenges of AI in the construction industry: A PRISMA review. Journal of Open Innovation: Technology, Market, and Complexity, 8(1), 45.
[35] Lou, Y., Wang, H., Amin, M., Arifeen, S. U., Dodo, Y. A., Althoey, F., & Deifalla, A. F. (2024). Predicting the crack repair rate of self-healing concrete using soft-computing tools. Materials Today Communications, 108043.