Guest editorial: Embracing the future construction project lifecycle: education and training for construction 4.0

The construction industry is modernising and focussing on ensuring that its architecture, engineering and construction (AEC) workforce has the skills they need under the 4th Industrial Revolution (IR4.0) (Rahimian *et al.*, 2021). The digitalisation of the construction industry is accelerating the development of multiple new tools to support workforce capacity and capability development in the built environment, including all phases of the building project lifecycle, from design and planning to construction and facility management stages (Goulding and Rahimian, 2012; Hajirasouli *et al.*, 2023; Lee *et al.*, 2022). There is a critical need to revolutionise workforce capability to improve the construction industry's quality and productivity (Goulding and Rahimian, 2019) and take advantage of the possibilities of IR4.0 (Elghaish *et al.*, 2022). The development of technological capability and human resource capacity must be specific to the needs of the built environment. Thus, construction 4.0 emerges as a concept to drive improvement of the overall quality of the workforce in the building sector, involving professional, technical, vocational and educational training, working skills, safety competency and organising competent labour in the AEC sector.

Innovative vocational education based on emerging technologies in construction 4.0 can provide initial skilling and help workers retrain as jobs and industries evolve, including in response to economic and technological change. Prior studies posit having a new advanced construction knowledge transfer framework, such as gaming or a simulated extended reality environment, with a combination of interactive visualisation, audio cues and performance feedback mechanisms in a virtual workspace to demonstrate a process of modern methods of construction to practitioners (Rashidi *et al.*, 2012). Therefore, developing mixed reality scenarios will facilitate the proper training and education by the design and management team to fulfil the social, environmental and economic requirements for the design and management of intelligent buildings (Rashidi and Ibrahim, 2017). A recent study has demonstrated that spatial understanding, spatiotemporal conflicts, project collaboration between stakeholders, training and education and safety management are aspects of construction planning that could significantly improve from the adoption of innovative technologies such as 4D building information modelling (BIM) (Getuli *et al.*, 2021) in virtual reality (VR) environment (Rashidi *et al.*, 2023).

However, the future of construction is bright, with unprecedented opportunities for growth and improvement. In this regard, the role of policymakers and educational leaders is equally important. Additionally, accreditation bodies must update their standards to reflect the competencies required in the modern construction landscape. Employers play a vital role in this ecosystem by providing access to training resources and embracing a culture of innovation and adaptability within organisations to provide lifelong learning for the construction workforce. Last but not least, by engaging with real-world projects and utilising cutting-edge technologies, practitioners can bridge the gap between theoretical knowledge and practical application to build a resilient, skilled and forward-thinking construction industry capable of shaping the built environment of the future.

Smart and Sustainable Built Environment
Vol. 13 No. 4, 2024
pp. 757-762

2046-6099
DOI 10.1108/SASBE-07-2024-407

As a reflection on these, this *Smart and Sustainable Built Environment (SASBE)* special issue brought together 12 papers on education and training for construction 4.0. This issue will define realistic (and desirable) immersive and advanced technologies for further design and development/evaluation of appropriate skill training platforms to reinforce hands-on workforce training in building construction. It will increase human capability and capacity development towards a more efficient building industry.

Dadzoe *et al.* (2024) argue that engaging various actors within the construction value chain is critical to promoting the uptake and usage of green buildings. The authors state that despite its global acceptance, green building construction is still in the early stages in Ghana. Most studies in sub-Saharan Africa indicate that a lack of knowledge hinders its development. However, more studies are needed to assess stakeholders' knowledge levels in this context. Using a structured questionnaire, Dadzoe *et al.* (2024) compare the level of knowledge of green building construction between construction professionals and demand-side operators. The findings of this study reveal that construction professionals were more aware of green building construction than demand-side operators. It was further identified that only a few of these stakeholders had hands-on experience, as most gained awareness through research studies. Based on the study's findings, it was revealed that the concept of green building construction is more abstract to stakeholders than practical, despite their positive attitude towards its adoption.

In their paper, Kordestani Ghalenoei *et al.* (2024) explain that the development of prefabrication into full-scale offsite manufacturing processes in the construction industry is paradigm-shifting. BIM is increasingly becoming the primary method of communication and integration in construction projects to facilitate the flow of information. The authors argue that although BIM and offsite construction (OSC) research has been conducted, integrating these concepts remains ambiguous and complex and needs more documentation and structure, especially in New Zealand. Hence, in this study, they investigate OSC and BIM integration challenges by conducting a systematic literature review and semi-structured expert interviews. This paper presents a robust framework for integrating OSC and BIM, identifying integration challenges and proposing strategies for overcoming them.

Mostafavi *et al.* (2024) present a novel framework based on deep learning models to assess the energy and environmental performance of a given building space layout, facilitating the decision-making process at the early design stage. Their proposed framework helps upskill the design professionals involved with the AEC sector by engaging artificial intelligence in human–computer interactions. In this study, Mostafavi *et al.* (2024) suggest using an image-based deep learning model called pix2pix to predict overall daylight, energy and ventilation performance in residential building layouts. This method was evaluated by applying it to 300 sample apartment units in Tehran, Iran. Four pix2pix models were trained to predict illuminance, spatial daylight autonomy (sDA), primary energy intensity and ventilation maps, with the simulation results considered ground truth.

In another study, Gunarathna *et al.* (2024) explain that project-based learning effectively transfers academic knowledge and skills into real-world situations. However, its effectiveness has yet to be thoroughly investigated, with a focus on the students' narrative. In this study, Gunarathna *et al.* (2024) aim to assess the student experience and perspective on implementing project-based learning in master's programmes through research and doctoral programmes to develop proactive skills. The authors evaluate the self-reflection of 10 postgraduate students and their supervisors in developing a software tool for solar-photovoltaics-integrated building envelope design, management and related education. The findings reveal that the students significantly enhanced their subject knowledge through industry collaboration, self-learning, peer learning, problem-solving and teamwork. Gunarathna *et al.* (2024) have noticed improved decision-making and leadership skills, risk identification, planning and time management by dividing the project into student-led tasks.

Parameswaran and Ranadewa (2024) highlight that the construction industry faces challenges in implementing lean practices due to a lack of knowledge. To address this issue, Parameswaran and Ranadewa (2024) use interpretive and qualitative approaches across three selected cases. This study proposes an integrated lean learning framework based on the learning-to-learn sand cone model. The proposed framework opens several research areas on lean learning in the construction industry. Fifty-two sub-activities for nine lean learners at each stage of the lean learning process are identified. According to this study, critical practices for improving lean learning included maintaining records, providing performance updates to senior management and creating and distributing manuals for staff at all levels.

In another study, Feng *et al.* (2024) highlight that site excavation, one of the most dangerous and challenging activities in construction, requires proper training to mitigate hazards. VR has been practical for safety training in various industries but is underutilised for construction excavation safety training. In their study, Feng *et al.* (2024) introduce an immersive VR training system for safety and hazard identification for excavation. A controlled experiment compared the proposed VR training system with a health and safety manual. The authors reveal that after training, immediate test scores showed that VR training significantly improved practical performance, knowledge acquisition and self-efficacy. Furthermore, the results indicate that trainees retained knowledge four weeks after the training; VR training performed better than health and safety manuals regarding knowledge retention.

Özener (2024) explores using context-based learning in teaching BIM within the AEC industry. In this study, Özener (2024) examines doctoral-level case studies by focussing on students' actions and perspectives in simulated real-world BIM processes. Özener (2024) uses experiential learning methods such as role-play and problem-based learning to provide a deep understanding of strategic and functional BIM implementation. The findings indicate that industry-focused simulations enhance students' appreciation of BIM's value and help develop essential competencies. The study proposes a flexible and replicable BIM learning framework to equip students with the necessary skills and strategic vision for innovative practices in the modern AEC industry. This framework includes adaptable simulative settings, evaluation rubrics and instructional methods that can be applied to similar educational initiatives.

Abbasnejad *et al.* (2024) analyse the transition to online teaching in educational institutions during the COVID-19 pandemic. The authors specifically address the challenges and strategies relevant to construction management courses. This study conducts a systematic literature review and autoethnography to identify key strategies and lessons learnt in online education during the pandemic, focussing on construction management. Their analysis highlights significant barriers to online learning, including technological and infrastructure challenges, required online teaching skills, mental health and wellbeing issues, inconsistent course delivery, student engagement difficulties and specific course requirements. Abbasnejad *et al.* (2024) offer recommendations for educational institutions and software vendors to improve online course delivery, such as developing guidelines, incorporating online teaching training, applying agile and resilience teaching methods, providing mental health support and continuously enhancing course features for the online environment.

Manoharan *et al.* (2024) address the productivity challenges in the construction industry, attributing them to inadequate labour supervision and training. This study aims to assess the capabilities of construction supervisors to implement essential work practices to improve productivity. A new training programme for construction supervisors has been developed, involving 64 participants assessed on 64 competency elements across 12 units. Marking guides with varying standards are created through expert consultation and a literature review. The findings highlight the competencies required for adequate supervision, culminating in a generalised guideline for supervisory skills.

Siriwardhana and Moehler (2024) emphasise the urgent need for skills development amongst construction stakeholders to successfully implement construction 4.0, addressing the need for comprehensive analysis in this domain. Utilising a science mapping approach, Siriwardhana and Moehler (2024) identify gaps and propose future directions. A three-step holistic review, including a bibliometric review, scientometric analysis and qualitative discussion, was conducted on 57 articles from three databases. The findings of this study highlight a significant need for more policies, frameworks and strategies for skills development within the context of construction 4.0. Identified research gaps include skills shortages in certain countries, frameworks and roadmaps for effective implementation and a need for more readiness assessments from professional, company and industry perspectives.

Victar *et al.* (2024) investigate how quantity surveyors (QSs) can adapt to the evolving demands of the construction industry, particularly in achieving a circular built environment (CBE) by reducing waste and embracing sustainable practices. Through qualitative research involving expert interviews using the Delphi technique, the study identifies the critical roles and competencies of QSs during the design and building material sourcing stages. These functions and skills are categorised according to the circular 3R principles (reduce, reuse, recycle) essential for implementing CBE. Findings highlight the importance of traditional QS roles like cost control and planning alongside newer competencies such as BIM management and economic analysis. The findings of this study highlight the need for QSs to enhance their skills to align with the principles of CBE, filling a gap in existing literature and offering insights for practice and future research in sustainable construction.

Almatari *et al.* (2024) explore the challenges stakeholders encounter in Malaysia's construction industry concerning adopting IR 4.0 technologies. Despite the sector's significance in Malaysia's economic growth, it has been slow to embrace technological advancements compared to its global counterparts. Through a quantitative survey involving 183 practitioners, Almatari *et al.* (2024) identify key barriers to implementing IR 4.0 technologies, such as high costs, reluctance to adopt new technologies, lack of standards, legal uncertainties and complexity. The findings emphasise the need to address cost and regulatory concerns whilst fostering industry-wide education and government involvement in training to support skill development for IR 4.0.

Ali Rashidi
Department of Engineering, La Trobe University, Melbourne, Australia
Mina Najafi
School of Computing, Engineering and Digital Technologies, Teesside University, Middlesbrough, UK
Mehrdad Arashpour
Department of Civil Engineering, Monash University, Melbourne, Australia
Robert Moehler
Department of Infrastructure Engineering, University of Melbourne, Melbourne, Australia
Yu Bai
Department of Civil Engineering, Monash University, Melbourne, Australia, and
Farzad Rahimian
School of Computing, Engineering and Digital Technologies, Teesside University, Middlesbrough, UK

References

Abbasnejad, B., Soltani, S. and Wong, P. (2024), "A systematic review of online learning and teaching strategies during the COVID-19 pandemic: implications for the construction management sector", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 934-959, doi: 10.1108/SASBE-08-2022-0174.

Almatari, H.A.Q., Chan, M. and Masrom, M.A.N. (2024), "Factors inhibiting the adoption of industrial revolution 4.0 in Malaysian construction industry", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 1041-1065, doi: 10.1108/SASBE-10-2022-0232.

Dadzoe, F., Addy, M., Duah, D.Y.A. and Adesi, M. (2024), "Towards a circular economy: a knowledge-attitude gap between demand and supply-side operators on green building construction in Ghana", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 763-779, doi: 10.1108/SASBE-03-2022-0048.

Elghaish, F., Matarneh, S.T., Edwards, D.J., Rahimian, F.P., El-Gohary, H. and Ejohwomu, O. (2022), "Applications of Industry 4.0 digital technologies towards a construction circular economy: gap analysis and conceptual framework", *Construction Innovation*, Vol. 22 No. 3, pp. 647-670, doi: 10.1108/CI-03-2022-0062.

Feng, Z., Lovreglio, R., Yiu, T.W., Acosta, D.M., Sun, B. and Li, N. (2024), "Immersive virtual reality training for excavation safety and hazard identification", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 883-907, doi: 10.1108/SASBE-10-2022-0235.

Getuli, V., Capone, P., Bruttini, A. and Rahimian, F.P. (2021), "On-demand generation of as-built infrastructure information models for mechanised Tunnelling from TBM data: a computational design approach", *Automation in Construction*, Vol. 121, 103434, doi: 10.1016/j.autcon.2020.103434.

Goulding, J.S. and Rahimian, F.P. (2012), "Industry preparedness: advanced learning paradigms for exploitation", *Construction Innovation and Process Improvement*, pp. 409-433, doi: 10.1002/9781118280294.ch18.

Goulding, J.S. and Rahimian, F.P. (2019), *Offsite Production and Manufacturing for Innovative Construction: People, Process and Technology*, Routledge, ISBN: 1351376896.

Gunarathna, C., Yang, R., Wijeratne Mudiyanselage, P., Amarasinghe, G., Samarasinghalage, T., Weerasinghe, R.P.N., Zhao, H., Zhang, C., Liu, C., Wang, K. and Dev Sureshkumar Jayakumari, S. (2024), "Project-based learning for proactive skills development of postgraduate students in solar energy building design digitalisation", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 828-855, doi: 10.1108/SASBE-08-2022-0173.

Hajirasouli, A., Banihashemi, S., Sanders, P. and Rahimian, F. (2023), "BIM-enabled virtual reality (VR)-based pedagogical framework in architectural design studios", *Smart and Sustainable Built Environment*, ahead-of-print(ahead-of-print), doi: 10.1108/SASBE-07-2022-0149.

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D. and Sutrisna, M. (2024), "Challenges of offsite construction and BIM implementation: providing a framework for integration in New Zealand", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 780-808, doi: 10.1108/SASBE-07-2022-0139.

Lee, Y.S., Rashidi, A., Talei, A., Arashpour, M. and Pour Rahimian, F. (2022), "Integration of deep learning and extended reality technologies in construction engineering and management: a mixed review method", *Construction Innovation*, Vol. 22 No. 3, pp. 671-701, doi: 10.1108/CI-04-2022-0075.

Manoharan, K., Dissanayake, P., Pathirana, C., Deegahawature, D. and Silva, R. (2024), "A systematic evaluation on the competencies of construction supervisors in productivity and performance improvement practices – Sri Lankan perspective", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 960-988, doi: 10.1108/SASBE-11-2022-0242.

Mostafavi, F., Tahsildoost, M., Zomorodian, Z.S. and Shahrestani, S.S. (2024), "An interactive assessment framework for residential space layouts using pix2pix predictive model at the early-stage building design", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 809-827, doi: 10.1108/SASBE-07-2022-0152.

Özener, O.Ö. (2024), "Context-based learning for BIM: simulative role-playing games for strategic business implementations", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 908-933, doi: 10.1108/SASBE-08-2022-0184.

Parameswaran, A. and Ranadewa, K.A.T.O. (2024), "Learning-to-learn sand cone model integrated lean learning framework for construction industry", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 856-882, doi: 10.1108/SASBE-10-2022-0234.

Rahimian, F.P., Goulding, J.S., Abrishami, S., Seyedzadeh, S. and Elghaish, F. (2021), "Industry 4.0 solutions for building design and construction: a paradigm of new opportunities".

Rashidi, A. and Ibrahim, R. (2017), "Industrialized construction chronology: the disputes and success factors for a resilient construction industry in Malaysia", *The Open Construction and Building Technology Journal*, Vol. 11 No. 1, pp. 286-300, doi: 10.2174/1874836801711010286.

Rashidi, A., Ibrahim, R., Said, N.B.S. and Othman, M.S. (2012), "Computer-aided theoretical model for low tech laborers capability training in industrialized construction industry", *Proceedings of the 14st International Conference on Computing in Civil and Building Engineering*, Moscow, Russia.

Rashidi, A., Yong, W.Y., Maxwell, D. and Fang, Y. (2023), "Construction planning through 4D BIM-based virtual reality for light steel framing building projects", *Smart and Sustainable Built Environment*, Vol. 12 No. 5, pp. 1153-1173, doi: 10.1108/SASBE-06-2022-0127.

Siriwardhana, S. and Moehler, R. (2024), "Mastering the skills of Construction 4.0: a review of the literature using science mapping", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 989-1014, doi: 10.1108/SASBE-03-2023-0045.

Victar, H.C., Perera, B.A.K.S., Palihakkara, A.D. and Dewagod, K.G. (2024), "Roles and competencies of quantity surveyors in achieving a circular built environment: an investigation according to 3R principles", *Smart and Sustainable Built Environment*, Vol. 13 No. 4, pp. 1015-1040, doi: 10.1108/SASBE-10-2022-0231.