Guest editorial: Construction 4.0: methodologies, technologies and skills

1. Introduction

The built environment is experiencing a digital transformation of technologies, processes and policies, helping professionals to make quicker and more informed decisions based on reliable data. To answer these changes, new and innovative skills are required for professionals who want to successfully operate in Construction 4.0 on a global scale (Bolpagni *et al.*, 2022b). On the one side, it is essential to understand how to capture, create, manage, check and store data effectively using advanced concepts and techniques. In addition, hard skills should be supported by soft ones to establish effective interpersonal relationships and embrace a human-centric approach. Figure 1 presents the key elements that contribute to an effective implementation of Construction 4.0, which can be structured in three high-level clusters (Bolpagni *et al.*, 2022a; Sawhney *et al.*, 2020; Casini, 2021): technologies, concepts/methodologies and soft skills.

This editorial refers to the Special Issue "Construction 4.0: methodologies, technologies and skills" which aims to give a broader perspective of Construction 4.0, aggregating the most advanced knowledge/competences on technologies and methodologies with the required non-technical aspects related to soft-skills and education (Dixit *et al.*, 2017; Statsenko *et al.*, 2023).

2. An overview of published papers

A total of 17 papers have been accepted for publication in the context of the Special Issue after a comprehensive and strict review process, and their respective contributions are detailed as follows:

- Parisi, F., Sangiorgio, V., Parisi, N., Mangini, A., Fanti, M. and Adam, J. (2023), "A new concept for large additive manufacturing in construction: tower crane-based 3D printing controlled by deep reinforcement learning", doi: 10.1108/CI-10-2022-0278.
- Rampini, L. and Re Cecconi, F. (2023), "Synthetic images generation for semantic understanding in facility management", doi: 10.1108/CI-09-2022-0232.
- Garip, S.B., Güzelci, O.Z., Garip, E. and Kocabay, S. (2023), "A genetic algorithm-based design model to provide reduced risk areas for housing interiors", doi: 10.1108/CI-12-2022-0334.
- Singh, A., Kumar, V., Mittal, A. and Verma, P. (2023), "Identifying critical challenges to lean construction adoption", doi: 10.1108/CI-09-2022-0229.
- Likita, A.J., Jelodar, M.B., Vishnupriya, V. and Rotimi, J.O.B. (2023), "Lean and BIM integration benefits construction management practices in New Zealand", doi: 10.1108/CI-06-2022-0136.

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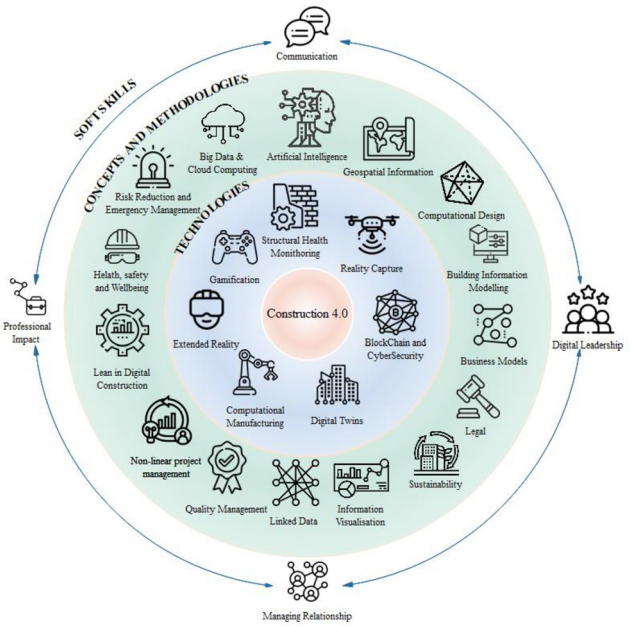

Figure 1.
Construction 4.0 high-level clusters

Source: Adapted from Bolpagni *et al.* (2022a)

- Jowett, B., Edwards, D.J. and Kassem, M. (2023), "Field BIM and mobile BIM technologies: a requirements taxonomy and its interactions with construction management functions", doi: 10.1108/CI-07-2022-0160.
- Saif, W. and Alshibani, A. (2023), "A close-range photogrammetric model for tracking and performance-based forecasting earthmoving operations", doi: 10.1108/CI-12-2022-0323.
- Matoseiro Dinis, F., Rodrigues, R. and Poças Martins, J. (2023), "Development and validation of natural user interfaces for semantic enrichment of BIM models using open formats", doi: 10.1108/CI-12-2022-0348.
- Lisco, M. and Aulin, R. (2023), "Taxonomy supporting design strategies for reuse of building parts in timber-based construction", doi: 10.1108/CI-11-2022-0293.
- Mahamedi, E., Wonders, M., Gerami Seresht, N., Woo, W.L. and Kassem, M. (2023), "A reinforcing transfer learning approach to predict buildings energy performance", doi: 10.1108/CI-12-2022-0333.
- Zani, A., Speroni, A., Mainini, A.G., Zinzi, M., Caldas, L. and Poli, T. (2023), "Customized shading solutions for complex building façades: the potential of an innovative cement-textile composite material through a performance-based generative design", doi: 10.1108/CI-01-2023-0014.
- Yu, J., Zhong, H. and Bolpagni, M. (2023), "Integrating blockchain with building information modelling (BIM): a systematic review based on a sociotechnical system perspective", doi: 10.1108/CI-04-2023-0082.
- Philip, B. and Al-Jassmi, H. (2023), "Time-series forecasting of road distress parameters using dynamic Bayesian belief networks", doi: 10.1108/CI-09-2022-0233.

- Gledson, B., Zulu, S.L., Saad, A.M. and Ponton, H. (2023), "Digital leadership framework to support firm-level digital transformations for Construction 4.0", doi: 10.1108/CI-12-2022-0328.
- Doukari, O., Kassem, M., Scoditti, E., Aguejdad, R. and Greenwood, D. (2023), "A BIM based tool for evaluating building renovation strategies: the case of three demonstration sites in different European countries", doi: 10.1108/CI-12-2022-0314.
- Faraji, A., Homayoon Arya, S., Ghasemi, E., Rashidi, M., Perera, S., Tam, V. and Rahnamayiezekavat, P. (2023), "A conceptual framework of decentralized blockchain integrated system based on building information modeling to steering digital administration of disputes in the IPD contracts", doi: 10.1108/CI-01-2023-0008.
- Sati, A. and Al-Tabtabai, H. (2023), "A paradigm shift toward the application of blockchain in enhancing quality information management", doi: 10.1108/CI-05-2023-0099.

The Special Issue brings an international overview on Construction 4.0 from 16 countries: Australia, China, France, India, Iran, Italy, Kuwait, New Zealand, Portugal, Saudi Arabia, Sweden, Taiwan, Turkey, the UK, United Arab Emirates and the USA. Published papers covered various topics related to topics supporting Construction 4.0 implementation presented before, including:

- *Methodologies for the built environment*: Building information modelling (2, 5, 6, 8, 12, 15, 16), computational design (2, 3, 11, 15), artificial intelligence (AI) and machine learning (ML) (1, 2, 10), big data (7), data analytics (7, 13, 15, 16), lean construction (LC) (4, 5), advanced project management (16), sustainability (9, 10, 11), circular building economy (9), risk management (3) and legal prospective (1).
- *Technologies for the built environment*: Reality capture (photogrammetry, laser scanning and drones) (7), computational construction and manufacturing (1, 11), bio-inspired materials (11), smart contracts (16), blockchain and cybersecurity (12, 16).
- *Soft skills for the built environment*: Digital leadership (14) and digital communication (14).

Contribution 1 proposes the conceptualization of a tower crane (TC)-based 3D printing controlled by AI as the first step towards a large 3D printing development for multi-story buildings. The research is composed of three main steps: firstly, the TC-based 3D printing concept is defined by proposing an aero-pendulum extruder stabilized by propellers to control the trajectory during the extrusion process; secondly, an AI-based system is defined to control both the crane and the extruder toolpath by exploiting deep reinforcement learning control approach; thirdly, the proposed framework is validated by simulating the dynamical system and analysing its performance. The authors concluded that the TC-based 3D printer can be effectively used for additive manufacturing in the construction industry.

Contribution 2 presents a conceptual model for creating synthetic images to increase the performance in training object detection models for facility management, particularly for digital twins' data enrichment. The proposed method uses existing 3D open-source information models to produce a photorealistic representation of indoor spaces enriched with facility-related objects. The virtual environment creates several images by changing lighting conditions, camera poses or material. Moreover, the created images are automatically labelled and ready to be used for model training.

Contribution 3 aims to present a novel genetic algorithm-based design model (GABDM) to provide reduced-risk areas in housing interior spaces during earthquakes. The GABDM uses the genetic algorithm as a base method, enhanced by the nondominated sorting genetic

algorithm II and the Wallacei X evolutionary optimization engine. GABDM is tested with two samples of housing interiors designed by the authors based on the literature related to earthquake risk in interiors. The results show the ability of the proposed method to generate adequate furniture layouts considering the particularities of the seismic risks.

Contribution 4 aims to identify and evaluate potential obstacles to implement LC in the Indian construction industry. Several indicators were recognized as major obstacles following an exhaustive assessment of the literature and a multicriteria decision analysis based on the analytic hierarchy process (AHP) of information obtained from surveys directed to several practitioners in the AEC industry. The results of this AHP model suggest that "Managerial" and "Inadequate resources" categories have the highest levels of influence, while "Inadequate knowledge" and "Just in time" categories have the lowest levels of influence.

Contribution 5 aims to identify lean and BIM integration benefits in construction industry, particularly in New Zealand. A systematic literature review and case studies were used to identify various benefits of integrating lean and BIM in the construction industry. Lean and BIM benefits identified in the study were documented such as benefits over the traditional approach, critically increased efficiency and visualization, better building process, better building performance, mitigating risk and reduce cost. Also, several factors were identified as major benefits such as improved onsite collaboration, better coordination, improve onsite communication, increase productivity, mitigating risk, reducing waste and reduced cost. The study showed integrating lean and BIM in construction management practice will help reduce several challenges which affect expected goals and customer anticipation.

Contribution 6 aims to develop a taxonomy of requirements for mobile BIM technologies (MBT), clarify the related terms and concepts and identify the interactions between MBT features and the construction management functions on sites. The MBT requirements taxonomy included requirements relating to both project and organization. Project requirements addressed MBT functionalities for sites and information management, while organization requirements focused on the integration of MBT solutions with the enterprise from information technology, legal and security perspectives. A detailed matrix showing the interactions between five key MBT features, and seven construction management functions were also developed.

Contribution 7 aims to present a highly accessible and affordable tracking model for earthmoving operations. The proposed methodology involves four main processes:

(1) acquiring onsite terrestrial images;

(2) processing the images into 3D-scaled cloud data;

(3) extracting volumetric measurements and crew productivity estimations from multiple point clouds using Delaunay triangulation; and

(4) conducting earned value/schedule analysis and forecasting the remaining work.

For validation, the tracking model was compared with an observation-based tracking approach for a backfilling site. It was also used for tracking a coarse base aggregate inventory for a road construction project. The presented model has proved to be a practical and accurate tracking approach that algorithmically estimates and forecasts all performance parameters from the captured data.

Contribution 8 aims to acknowledge the need for increasing supportive technologies enabling the use of BIM, attending to available human resources, their requirements and their tasks. A complete case study is described, including the development process centred on design science research methodology followed by the usability assessment procedure validated by construction projects facility management operational staff. Results show that participants could interact with BIM using OpenBIM processes and file formats naturally.

Contribution 9 proposes a taxonomy to define the relationships between various concepts and practices grounded on two relevant strategies for reuse, particularly the design for disassembly (DfD) and the design for adaptability (DfA). The taxonomy aims to build a vocabulary of definitions in DfD and DfA to support other researchers and practitioners working in the field.

Contribution 10 proposes a novel data-driven approach for predicting the energy performance of buildings that can address the scarcity of quality data and consider the dynamic nature of building systems. The work proposes a reinforcing ML approach based on transfer learning (TL) to address these challenges. The proposed approach dynamically incorporates the data captured by the building management systems into the model to improve its accuracy. The results showed that the proposed approach could improve the accuracy of the energy performance prediction compared to the conventional TL (non-reinforcing) approach by approximately 20%.

Contribution 11 aims to investigate the comfort-related performances of an innovative solar shading solution based on a new composite patented material consisting of a cement-based matrix coupled with a stretchable three-dimensional textile. Initially, the optical material properties were characterized to calibrate radiance-based simulations. Advanced simulation models were then implemented in a multi-objective genetic optimization algorithm to improve the shading geometries, and their performance was assessed and compared with traditional external louvres and overhangs. The system demonstrates the potential of increasing useful daylight illuminance by 35% with a reduced glare of up to 70%–80% while providing better uniformity and connection with the outdoors because of a topological optimization of the shape and position of the openings.

Contribution 12 analyses the current state of research on the integration of blockchain and BIM in the construction industry as a means of identifying gaps between the existing paradigm and practical applications for determining future research directions and improving the industry. The result of a systematic review shows that blockchain has the potential to address security, traceability and transparency and complement the system by integrating supporting applications; otherwise, significant gaps still exist between these potentials and widespread industry adoption. Current limitations and further research needs are identified, including designing fully integrated prototypes, empirical research to identify operational processes, testing and analysing operational-level models or applications and developing and applying a technology acceptance model for the integration paradigm.

Contribution 13 proposes the use of dynamic Bayesian belief networks (BBN) for the development of time-series prediction models to probabilistically forecast road distress parameters. Four dynamic BBN models are developed to represent rutting, deflection, cracking and IRI, using pavement data collected from 32 major road sections in the United Arab Emirates between 2013 and 2019. The four developed performance prediction models achieved an overall precision and reliability rate of over 80%.

Contribution 14 explores what digital leadership in construction firms is, why it is necessary and what considerations it involves. It provides a digital leadership considerations framework to aid organizational digital transformations. Eleven purposively selected expert practitioners, including construction business leaders and company digital champions, were surveyed using in-depth semi-structured interviews. Relevant insights were obtained related to how construction leaders can embed the skills to drive such transformation in their firms, what the essential digital skills for construction businesses now are in Construction 4.0 and how leaders can attempt to evaluate the value of digital technology for their business practices.

Contribution 15 describes the development of an automated process, based on BIM and principal component analysis method, for overcoming building renovation challenges. The process involves the assessment and simulation of renovation scenarios in terms of duration, cost, effort needed and disruptive potential. The proposed process was tested in three case studies of multi-residence apartment buildings, located on Greece, France and Denmark, comprising different construction components and systems in which different renovation strategies were evaluated. The developed tool was able to model and simulate the different renovation scenarios and help to design renovation interventions based on selected key performance indicators.

Contribution 16 aims to develop alternative dispute resolution (ADR) strategies for integrated project delivery contracts based on a conceptual blockchain-based dispute management (BDM) model. Model validation was performed based on interviews with experts and demonstrated that the BDM model has better function in terms of time and cost for ADR process when the project is facing serious and considerable number of disputes. The relation between blockchain and BIM was crucial to enhance the ability of the proposed model for administrating dispute resolution processes.

Contribution 17 proposes a framework using blockchain technology (Hyperledger fabric) to create a transparent and decentralized environment between the parties in Kuwait's AECO sector. A digitalized informative checklist denominated smart construction inspection checklist (SCIC) has been initiated to enhance the poor information recorded between the parties. The framework has provided a transparent, immutable, traceable and decentralized environment in which all parties are involved in transactions. In addition, the integration of the SCIC in the blockchain environment provided an advantage in which all the necessary criteria of inspection will be stated, checked by the consultant, and validated by the client to approve the transaction. Preliminary testing has been conducted to support the proposed framework.

3. Final remarks

The Guest Editors are satisfied with the conclusive outcomes of the published papers in this special issue, anticipating their utility for researchers, professionals as well as policy makers engaged in diverse thematic aspects of methodologies, technologies and skills for the built environment. The Guest Editors extend their appreciation to all authors and reviewers for their crucial contributions and for the dissemination of scientific findings. Finally, gratitude is extended to the Editorial Board of the *Construction Innovation Journal* for their patience, support and exceptional contributions.

Marzia Bolpagni
Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne, UK
Diogo Ribeiro
Polytechnic Institute of Porto, School of Engineering, Porto, Portugal, and
Rui Gavina
Europe Foundation Digital Built Environment Institute (DBEI), Delft, Netherlands

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