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SPECIAL ISSUE EDITORIAL: CONSTRUCTION 4.0: ESTABLISHED AND EMERGING DIGITAL TECHNOLOGIES WITHIN THE CONSTRUCTION INDUSTRY

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Despite its significant impact on industrial employment (i.e. over 6.6% contribution) and representation of 9.8% of the UK's Gross Domestic Product (Rhodes, 2019), the AEC industry has been continuously criticised due to its fragmentation for over five decades that resulted in several major industry reports. The knowledge gap between design and construction has been identified by many studies as a major reason for this discontinuity (Abrishami *et al.*, 2014; Fruchter *et al.*, 2016; Goulding and Pour Rahimian, 2019; Goulding *et al.*, 2015; Pour Rahimian *et al.*, 2019; Pour Rahimian *et al.*, 2008; Rahimian *et al.*, 2011).

Meanwhile, the wider world (including the built environment) is experiencing a kind of paradigm shift due to the emergence of the industry 4.0 revolution. Recent technological and other process-based advances and innovative technologies in the built environment mentioned above have a key role to play in this process. As widely reported in the popular and scientific media, the nine pillars supporting Industry 4.0 are 1) The Internet of Things, 2) Big Data, 3) Augmented Reality, 4) Advanced Visualisation, VR and Simulation, 5) Additive Manufacturing, 6) System Integration, 7) Cloud Computing, 8) Autonomous Systems, and 9) Cybersecurity.

In the case of the built environment sector, these nine pillars can be said to be underpinned by BIM, widely regarded as the tool of choice to address key issues as industry fragmentation, value-driven solutions, decision making, client engagement, and design/process flow to name but a few. Therefore, it could be argued that Construction 4.0 has ten pillars which include the nine Industry 4.0 pillars and BIM. Exemplars from other industries such as automotive, aerospace and oil and gas currently demonstrate the power and application of these technologies. However, the built environment has only just started to recognise terms such as "golden key" and "golden thread" as part of BIM processes and workflows. Construction 4.0 offers a portfolio of potential solutions to bridge the knowledge and information gaps between design, construction and operations (Gomez-Trujillo and Gonzalez-Perez, 2021; Newman *et al.*, 2020; Sawhney *et al.*, 2020).

This has led to the emergence of a series of cutting edge technologies in the AEC realm, including but not limited to virtual reality-based collaboration technologies (Pour Rahimian *et al.*, 2019), artificial intelligence-based optimisation (Pilechiha *et al.*, 2020), data-driven decision support (Seyedzadeh *et al.*, 2019), smart data modelling (Seyedzadeh *et al.*, 2020), blockchain and distributed ledger technologies (Alizadehsalehi and Yitmen, 2021; Brandín and Abrishami, 2021; Elghaish *et al.*, 2020; Wong *et al.*, 2020), and computer vision and graphics (Moshtaghian *et al.*, 2020; Pour Rahimian *et al.*, 2020). Where for example, these advancements are now able to assist decision-making in predicting the cost and performance of optimal design proposals (Elghaish and Abrishami, 2020).

Distributed ledger technologies complement these advancements by introducing consensus-based decision-making, removing the social identity and bad faith communications at the heart of many disruptive conflicts in a collaborative project (Jaffar et al., 2011). Advancements in cryptography and read-only data management optimisation are paving the way for fully-fledged distributed ledger technologies for digital twinning and asset lifecycle management (Alizadehsalehi and Yitmen, 2021; Ogunseiju *et al.*, 2021b). Previous research has demonstrated real-time centralised solutions for OpenBIM. Research has begun to demonstrate the feasibility of decentralising these OpenBIM systems (Oliver et al., 2020). Collectively, these developments are forcing a paradigm shift in design from asynchronous to real-time data exchanges, which are impervious to repudiation, ultimately improving inter-organisational perceptions of social presence (Oliver, 2019) and imbuing confidence in the design shift expected of OpenBIM.

As a reflection on the issues discussed above, this special issue of ITCON brought together ten papers on Construction 4.0 related topics. These papers are drawn from papers presented at the 20th International Conference on Construction Applications of Virtual Reality (CONVR 2021) held at Teesside University, Middlesbrough TS1 3JN, the UK, in October 2020. CONVR is one of the world-leading conferences in the areas of Virtual Reality, augmented reality and building information modelling. Each year, more than 100 participants from all around the globe meet to discuss and exchange the latest developments and applications of virtual technologies in the architectural, engineering, construction and operation industry (AECO). The conference is also known for having a unique blend of participants from both academia and industry. The overarching theme for CONVR2020 was "Enabling the development and implementation of Digital Twins."

Tallgren et al. (2021) mapped collaborative planning and scheduling methods and traditional 4D scheduling using process modelling. This mapping is followed by implementing the 4D collaborative planning and scheduling method in the virtual project planning system with support for a multi-user interactive VR environment. Pidgeon and Dawood (2021) presented a systematic review of academic and industrial literature to define a common meaning of collaborative BIM through the development of syntax to support a hypothetical infrastructure project utilising academic and industry BIM experts. This was followed by bringing to the front the inefficiencies in their current form and defining how the fundamental parts of BIM are assigned and then prioritised qualitatively and quantitively to enhance information clarity (goals and objective achievement) and inconsistency reduction towards better ways of implementation.

Reyes-Veras *et al.* (2021) argued that the adoption of Big Data in the construction industry had been identified as a possible solution to the demand of the current needs of projects, but the integration of this technology has proven to be a challenge, especially in industries such as construction that are not technological driven. They aimed to explore the challenges faced by the adoption of BD in the Dominican Republic construction industry. Al-Sehrawy et al. (2021) affirm that the knowledge created under Digital Twin real-world implementation comprises the 'know-how' and genuine practical experience upon undertaking various Digital Twin pilot projects, case studies, and proof-of-concept initiatives which the Digital Twin research and practices can further develop and mature. They conclude with an overview of the implications of Digital Twin Uses Classification System along with recommendations on how it can be further validated and improved.

Inspired by opportunities offered by mixed reality, Ogunseiju *et al.* (2021a) presented the development and evaluation of a holographic learning environment that can afford learners an experiential opportunity to acquire competencies for implementing sensing systems on construction projects. To develop the content of the learning environment, they surveyed construction industry practitioners and instructors, and explored construction industry case studies on the applications of sensing technologies. Shojaei *et al.* (2021) investigated a pilot experiment where a combination of 360, 180 3D, and flat videos was incorporated as an educational instrument in delivering construction management content. Their results showed a positive perception toward using immersive videos in construction education. As a result, they concluded that the prospect of incorporating immersive videos to enhance construction management education is promising.

Khanna *et al.* (2021) investigated the feasibility of implementing IPD approach and applying its principles. They assessed the maturity of delivery techniques, and the potential benefits and limitations of using IPD for infrastructure projects in developing countries, using India as a case study. They recommended that the regulatory bodies must establish governing standards and frameworks, amend regulations to accept IPD concepts, and upskill the workforce through training and knowledge transfer for its successful adoption. Dalui *et al.* (2021) aimed to identify the advantages and limitations in the implementation of the Building Information Modelling (BIM) and Integrated Project Delivery (IPD) in the UK consulting sector. They recommended that schools take steps to improve career advice and guidance for students in relation to construction, specifically increasing awareness of the opportunities available related to BIM and working professionals to increase awareness of and employment in BIM through training and apprentices as appropriately.

Gonsalves *et al.* (2021) presented the assessment of a commercially available passive wearable robot, BackX, designed for reducing low back disorder amongst rebar workers. The study evaluated the exoskeleton in terms of task performance and physiological conditions. Outcome measures such as completion time were employed to evaluate the effect of the exoskeleton on task performance, while activations of Erector Spinae and Latissimus Dorsi muscles, and perceived discomfort across body parts were employed to assess the physiological effects of the exoskeleton. Chowdhury *et al.* (2021) asserted that the views of web-based tool users in terms of functionality, potency and usability of the various platforms are often neglected. They anticipate that if web-based collaboration is to be further enhanced, the views of users must be known. The study explored Financeonline's top six tools CoCostruct, PlanGrid, Autodesk BIM 360, Procore, e-builder and Aconex. The results of their study highlighted that while 70% of user reviews of web-based collaborative tools are positive, there remains much room for improvement.

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