Guest editorial

Construction 4.0 and circular economy

The construction industry continues to play a significant role in providing platforms for societal development and sustenance through the development of social and economic infrastructure. The global population is currently growing at an annual rate of 1% (Ramakrishna, 2020) and this poses a source of concern for the construction industry given its reliance on the Earth's renewable and non-renewable resources. The unsustainable production patterns associated with the construction industry's bid to provide adequate infrastructure stock for society has earned the industry a reputation of undermining society's sustainability goals. These unsustainable production and consumption patterns have been traced to the linear nature of the infrastructure and construction project delivery business models replete in the industry (Kibert, 2016). To change this reputation, scholars have advocated for the holistic adoption and implementation of green and/or sustainable business models (Abuzeinab *et al.*, 2016) and construction practices (Kibert, 2016) at the firm and project levels of the industry. The adoption and implementation of circular economy (CE) in the construction industry has been identified as a means of promoting a veritable transition towards ameliorating the incidence of anthropogenic activities replete within the industry thereby giving rise to entrenchment of sustainable construction practice (Hossain *et al.*, 2020).

The adoption of the Fourth Industrial Revolution (4IR) technologies in economic sectors such as apparel and footwear, retail and resale, transportation, finance, etc. have contributed to successful CE performance. This is particularly the case for example, with the operationalization of the 4R and 9R frameworks (Kirchherr, *et al.*, 2017; Potting *et al.*, 2017). The efficiency of 4IR technologies in driving this transition has been acknowledged in relevant literature especially as it pertains to the operationalization of the 4R and 9R frameworks (Nascimento *et al.*, 2019).

Furthermore, the coronavirus disease 2019 (COVID-19) pandemic along with its impacts on construction industry resilience has led to the resurgence of the clamour for improved adoption of these innovative and disruptive technologies in supporting improved productivity and sustainability performance within the industry in the unfolding environment, often described as the new normal. Scholars have advocated for players in various economic sectors to leverage on the opportunities availed by the resetting of the global economy because of the COVID-19 shock to drive the incorporation of the CE concept along inherent value chains in these sectors (Sarkis, *et al.*, 2020; Klemes *et al.*, 2020; Wuyts *et al.*, 2020). In the construction industry, similar contributions have been made. For instance, the recently published white paper by the Institution of Civil Engineers (ICE) entitled: "*COVID-19 and the new normal for infrastructure systems -next steps*", advocates amongst other things, significant investment in digitalization towards achieving about 72% of the sustainable development goals indicators which are connected with infrastructure delivery (ICE, 2020).

Although the construction industry is witnessing the gradual adoption of these technologies, not a lot of attention has been paid to proactively applying these technologies to boost CE performance of industry processes and its products, i.e. built assets including buildings and highways, hence ultimately the collective built environment. This is the gap which contributions to this Special Issue (SI) have sought to bridge.

The papers in this SI focussed on the operationalization of the CE concept in the construction industry and the role of 4IR technologies in facilitating this endeavour. Although the utility of 4IR technologies in promoting product and process circularity in sectors such as telecommunication, transportation and logistics, etc. has been explored, their

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deployment towards enabling circularity of product and process in the construction industry remains underreported. As such, this SI solicited high-level contributions from academics and practitioners which provide answers to the question: how can 4IR technologies boost improved circular economy performance in the construction industry and of its products, i.e. built assets in our built environment?

Publications in this SI explored the opportunities associated with the adoption and implementation of 4IR technologies, and the impact thereof on the degree of product and process circularity as well as waste management efficiencies in the AEC + BE sector. These publications are presented according to the specific objectives of the SI. Whilst three (1–3) papers contributed to the first strategic objective (*To unearth, consolidate and disseminate knowledge on the circular economy (CE) concept as well as the nexus between the concept and sustainability/sustainable development as it applies to the AEC + BE sector as well as cities development*), five papers (4–8) reflected the expectations of the second specific objective (*To draw together, analyse and disseminate information regarding examples of best practice, as well as identify critical success factors (CSFs) and failure factors affecting the adoption and implementation of 4IR technologies in boosting CE performance of products and processes in the AEC + BE sector*).

Considering the pivotal influence exerted by cities on the achievement of sustainable development ethos in contemporary society (Newman and Jennings, 2008), it becomes imperative that any move to engender improved levels of circularity in society must be premised on the concept of circular cities. But relevant literature detailing how this transition from conventional cities to circular cities remains limited. Furthermore, the lack of robust case studies detailing circular city transitions is observed. The first paper in this SI; *Circular cities: the case of Singapore by Carrière, Rodríguez, Pey, Pomponi and Ramakrishna*, seeks to contribute towards filling these identified gaps. In this paper, the authors describe processes associated with the transitioning of the conventional cities to a circular city status using the present circular city transition happening within the context of the Singapore city-state as an exemplar. They rely on a systematic literature review focussing on circular economy and cities in examining the current efforts towards circular cities development. Since Singapore has already begun its journey towards circularity, this article examines its current efforts and offers recommendations in the design and implementation of CE policies that are invaluable not just for Singapore but also for high-density and rapidly expanding cities around the world that require a new development pathway to emulate.

The CE concept has largely been associated with minimization, reduction, recovery and reuse of physical (solid) waste in various economic sectors (Iacovidou *et al.*, 2017). Similarly, this is the case with the construction industry where advocacies for the adoption of CE evolved around the notion of physical waste management (Mahpour, 2018). In the second paper; *A systems thinking approach for incremental reduction of non-physical waste, by Omotayo, Olanipekun, Obi and Boateng,* the authors posit the need to extend extant knowledge concerning the CE and waste nexus within the construction industry domain to cater to the incidence of non-physical waste within construction project delivery systems. Using a Nigerian construction industry exemplar, the article identified instances of non-physical waste like the incremental reduction of activities related to purchasing orders and material deliveries. Furthermore, adopting a systems thinking approach, the paper highlighted measures for gradual reduction of such classes of waste in construction activities being managed by small- and medium-scale construction companies during the execution phase of a building project. This approach culminated in the development of an all-inclusive casual loop model for engendering cost reduction through the minimization of non-physical waste in construction projects.

A common ontology concerning the definition of CE and its implementation models remains elusive (Corvellec, *et al.*, 2020; Kirchherr *et al.*, 2017). This poses a challenge to the development of a widely accepted best-practice guide on the operationalization of CE in the contemporary society and in the future. Amongst other things, it can be argued that the sudden emergence of the COVID-19 pandemic has exposed society's high levels of unpreparedness in driving forward its sustainability initiatives in the face of such adversity. This incidence has reiterated the need for futureproofing different pro-sustainability initiatives like CE against similar happenings in future. But it appears that research into such facets is presently limited. In the third paper in this section; *The future of the circular economy and the circular economy of the future by Rodríguez, Pomponi, Webster and D'Amico,* the authors acknowledge the lack of research seeking to develop pathways through which CE can be better prepared to face any future eventualities which may affect its performance. The articles sought to provide answers to questions like: What if the future is different from what the CE expects? To address this shortcoming, this paper relies on systematic literature review – bibliometric review and snowballing technique – in proposing futures studies (FS) as a complementary discipline due to its potential to offer exactly what CE lacks: methods to explore alternative futures. The study highlights a systemic failure within CE, which is to consider the future as unknowable. It provides an understanding of where the synergy between CE and FS situates; recommendations on where to start and, introduces some FS methods that could be used by CE in the built environment context. According to the study, the inclusion of FS will allow a stronger focus on approaching possible futures to be integrated overtly into existing work, research, and action within the CE community.

The tranche of papers to be presented in this section contribute towards the actualization of the second specific objective of this SI. Whereas papers 4 and 5 focus on the issue of acceptance of 4IR technologies and CE solutions, the last three papers showcase instances where these technologies have been deployed to improve CE performance.

In the fourth paper titled: *Appraisal of stakeholders' willingness to adopt construction 4.0 technologies for construction projects, Osunsanmi, Aigbavboa, Oke and Liphadzi* examined the willingness of construction professionals towards adopting construction 4.0 technologies within the context of construction projects situated in South Africa. The study acknowledged the inherent capabilities of 4IR technologies for improving the design, management, operations and decision-making of construction projects thereby impacting on CE performance. The study observed that although the stakeholders indicated willingness to adopt 4IR technologies on their projects, such deployment was evidently hindered by the cost of the technologies, nature of the construction industry, poor understanding of modern technologies and lack of government support.

In the fifth paper, *Bottle house: utilising appreciative inquiry to develop a user acceptance model; Adefila, Abuzeinab, Whitehead and Oyinlola* identify the challenges associated with designing circular solution housing without a robust understanding of interrelated factors, which ensure sustainability and user acceptance. Utilising an appreciative inquiry theoretical construct, the authors proceed to develop a novel model for improving user acceptance circular solutions to housing design. The emergent model blended circular solution dimensions with user-acceptance concerns offering a guide that considers essential features that are both user-friendly and pragmatic, such as utility, technological innovation and functionality as well as their intersectionality. It is expected that the model will contribute to developing socially accepted circular solutions taking into consideration local context factors.

In the sixth paper, *Adoption of smart technologies and circular economy performance of buildings*; Windapo and Moghayedi explore the impact of smart technologies on the CE performance of buildings in terms of energy and water consumption, their marginal cost and the management decision time and quality, for building management companies. In this exploratory study, the authors rely on information from case studies of building situated in Cape Town, South Africa. The results of the research suggest that the implementation of smart technologies to create intelligent infrastructure is beneficial to the CE performance of buildings and the time taken for management decisions, particularly as it lowers the cost of utilities and decreases the time required for management decisions.

In the seventh paper, *A systematic review of BIM usage for life cycle impact assessment*; *Crippa, de Araujo, Bem, Ugaya and Scheer*, reviewed and compared the utility of different methods for conducting the life cycle assessments (LCAs) of buildings using Building Information Models (BIM). The study stemmed from the proposition that the integration of BIM–LCA models possess the potential to contribute immensely to the reducing time spent in the conduct of environmental analysis whilst engendering an improvement in the reliability of such analysis. The authors adopt a systematic literature review, selecting articles which highlighted instances of whole-LCA, and others featuring BIM deployment for analysing the carbon footprint, embodied CO_2 and/or energy consumption of buildings across their life cycle. The study establishes that the proper application of LCA method to evaluate the environmental impacts of the project can be hindered due to lack of information in the database about the materials or due to failures in the interoperability between BIM software and the LCA tool.

In the last paper, *An artefact for improving the delivery of building energy retrofit project in South Africa; Okorafor, Emuze, Das, Awuzie, Haupt* detail the development of an artefact for improving the delivery of energy retrofit projects therein to improve on CE performance of existing buildings. The study focusses on the South African context. The findings enabled an identification of the elements of a building energy retrofit (BER) project such as project initiation, building assessment, detailed energy survey, technical analysis and implementation plans of energy measures, monitoring and verification, and; challenges and enablers associated with successful BER projects. This information was subsequently utilized in the development and validation of an artefact for delivering successful BER projects. Summarily, a set of guidelines comprising seven stages for managing successful BERPs was elucidated.

In summary, the papers in this SI have contributed, individually and collectively, towards extending the discourse on the nexus between the construction 4.0 technologies and improved CE performance in the construction industry thereby contributing to the achievement truly sustainable construction industry. The guest editors are grateful to the authors and the reviewers of the papers in this SI as their inputs contributed to the quality of the papers. Finally, we would like to thank *Built Environment Project and Asset Management* (*BEPAM*) for facilitating and supporting this SI.

Seeram Ramakrishna
Circular Economy Task Force, National University of Singapore, Singapore, Singapore

Alfred Ngowi
Civil Engineering, Central University of Technology, Bloemfontein, South Africa, and

Bankole Osita Awuzie
Department of the Built Environment, Central University of Technology, Bloemfontein, South Africa

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