DESIGN CREATIVITY:
Future Directions for Integrated Visualisation

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Abstract
The Architecture, Engineering and Construction (AEC) sectors are facing unprecedented challenges, not just with increased complexity of projects per se, but design-related integration. This requires stakeholders to radically re-think their existing business models (and thinking that underpins them), but also the technological challenges and skills required to deliver these projects. Whilst opponents will no doubt cite that this is nothing new as the sector as a whole has always had to respond to change; the counter to this is that design 'creativity' is now much more dependent on integration from day one. Given this, collaborative processes embedded in Building Information Modelling (BIM) models have been proffered as a panacea solution to embrace this change and deliver streamlined integration. The veracity of design teams' "project data" is increasingly becoming paramount - not only for the coordination of design, processes, engineering services, fabrication, construction, and maintenance; but more importantly, facilitate 'true' project integration and interchange – the actualisation of which will require firm consensus and commitment. This Special Issue envisions some of these issues, challenges and opportunities (from a future landscape perspective), by highlighting a raft of concomitant factors, which include: technological challenges, design visualisation and integration, future digital tools, new and anticipated operating environments, and training requirements needed to deliver these aspirations. A fundamental part of this Special Issue's 'call' was to capture best practice in order to demonstrate how design, visualisation and delivery processes (and technologies) affect the finished product viz: design outcome, design procedures, production methodologies and construction implementation. In this respect, the use of virtual environments are now particularly effective at supporting the design and delivery processes. In summary therefore, this Special Issue presents nine papers from leading scholars, industry and contemporaries. These papers provide an eclectic (but cognate) representation of AEC design visualisation and integration; which not only uncovers new insight and understanding of these challenges and solutions, but also provides new theoretical and practice signposts for future research.

Keywords: *Collaborative Working, Building Information Modelling, Design Visualisation, Decision Support Systems, Innovative Design Interfaces*

INTRODUCTION

Construction and engineering projects are increasingly becoming more complex, often engaging new business processes and technological solutions to meet clients' requirements. These new processes and allied technological solutions often require parallel improvements to be made, supported by appropriately skilled professionals and operatives (Arif *et al.*, 2012; Goulding *et al.*, 2014a). Building Information Modelling (BIM) has demonstrated the need for integrating collaborative design teams' "project data", to not only help coordinate the design, engineering, fabrication, construction, and maintenance of various trades, but also facilitate project integration and interchange (Goulding & Rahimian, 2012). Given this, numerous potential benefits have inspired several countries to consider the implications of implementing BIM Level 3 (Cloud) as an innovative way of further enhancing the design, management and delivery process, *ergo* aligning needs and expectations towards a fully Integrated Project Delivery approach (Goulding *et al.*, 2014b). A number of innovative approaches are starting to pervade the market, including: virtual/augmented reality, mobile and web-based platforms, laser scanning and photogrammetry technologies, 3D printing etc. Whilst these are particularly beneficial for integrating visualisation data, and promoting the maxim of sharing/integration; prototyping and testing (especially with geographically dispersed users) still has many challenges to overcome. Establishing advanced design representation futures is therefore considered essential. This Special Issue enables readers to appreciate some of these nuances, particularly to envision future foresight into future digital tools, their expected operating environments, and the training requirements needed – particularly for design professionals. This Special Issue highlights how these improved virtual delivery processes and technologies affect the designed products, including the design procedures, production approaches and subsequent implementation (construction). In doing so, it evaluates how digital design (especially in virtual environments) can support AEC design organisations to optimise project deliverables.

This Special Issue encouraged submissions on foresights, development and application of advanced digital tools within the AEC sector to highlight existing theoretical, practical and technical gaps within: design-practice, design-production, design-construction, and design-facilities management. This embraced collaboration and implementation needs of multi-disciplinary team members, including: conceptual and theoretical frameworks, technological innovation and empirical research on designed products, and their tools and processes (including organisational behaviour). Nine papers were accepted, representing world-leading scholars in the field – the findings of which present new critical debate and discourse on design visualisation and integration.

Soetanto *et al.* (2015) used questionnaire surveys, focus groups, observation of online meetings, and personal reflections to identify key success factors - leading to the development of guidance for international collaborative design projects, via the implementation of collaborative design courses in the UK and Canadian universities over three academic years. Research findings revealed the significance of the perceived risk of collaboration and a difference in preferred communication mode between architects and civil/structural engineers. This work emphasised the impact of training in the subject discipline, and that the opportunity for co-located working had helped the development of trust. This paper provides guidance for Built Environment educators wishing to implement collaboration into courses.

Yuan *et al.* (2015) reflected on the challenges and risks associated with construction labour working on or near temporary structures. It provided statistics on fatalities and capital losses for companies. This paper introduced Cyber-Physical Systems (CPS) as a viable solution for preventing potential structural hazards. Evidence from seminal literature was used to inform findings, which advocated CPS applicability in temporary structures, along with potential benefits associated with structural monitoring. A conclusion drawn was that CPS had significant potential to address safety and structural problems of temporary structures. The authors provided a scaffolding system exemplar application scenario to show how CPS worked in structural monitoring, including the requirements and system architecture.

Kim *et al.* (2015) emphasised the link between the effectiveness of visual displays and the quality of 'sense of presence' in immersive VR environments. This proffered that there was a gap in research for analysing how presence was associated (from a multi-users' quality of communication perspective) within the context of AEC. In order to address this issue, they conducted an exploratory study on social interaction, with the remit of improving the presentation and communication of complex data through immersive simulation techniques. Research findings from seminal literature emphasised the importance of embedding key concepts such as presence and immersion, as these were seen as pivotal factors that influenced communication. A Hub for Immersive Visualization and eResearch (HIVE), was introduced, supported by a conceptual framework for enabling multi-users to understand how to implement social interaction in a system efficiently – especially to determine whether a visualisation system could support communication effectively. Findings proposed additional research in the context of cognitive factors (within shared environments) and the need to validate this framework.

Maftei and Harty (2015) presented findings from a study based on the design of a new hospital using immersive Virtual Reality (VR) technologies. They used the concept of reflective practice (Schön, 1983) supported by video-based methods to analyse the ways design teams approach and employ collaborative design work using a full scale 3D immersive environment. This paper revealed some unique aspects of design work in this environment. Research findings highlight that rather than enhancing or adding to our existing understanding of design through paper based or non-immersive digital representations, that such new immersive and interactive design interfaces have the potential to challenge or 'surprise' designers as they experience immersivity in full-scale.

Shih *et al.* (2015) introduced new insight on the impact of interfaces with design cognition. They presented the results of a preliminary protocol study on the cognitive behaviour of architects, to better understand the similarities and differences using Sequential Mixed Media and Alternative Mixed Media (AMM) approaches. This work employed protocol analysis methodology and coded video recordings of participants working on different projects (based on the Function-Behaviour-Structure coding scheme). Research findings present the views of participants on their switching behaviour when transiting between different types of media; noting that despite some challenges, these switches could make it possible for designers to integrate different approaches into one design medium to facilitate design processes within AMM design environments.

Wang *et al.* (2015) focused on learning styles, advocating that changes triggered by the digital paradigm shift affected perception, and that users' experience was not always favourable. This study investigated the impact of VR technologies on the learning style preferences by studying 245 architecture and construction students over a two-year period. Results indicated that when virtual reality applications were used in teaching and learning, that learning behaviour favoured a more concrete 'experiential' mode of learning, with a preference or tendency toward the Accommodator learning style. However, whilst novel visualisation techniques were examined, a caveat of note identified that as VR becomes more deeply embedded in teaching and learning programs, studies of learning style preferences should become more representative than a single technology per se.

Park and Kim (2015) presented a case for employing automatic methods for checking design quality and compliance with building codes (as opposed to conventional manual control methods), as this was considered particularly important with increased project complexity. This work also highlighted the importance of applying semantics in the checking process, examining BIM in the context of design teams and regulatory bodies – especially useful for decision-making and evaluation with rich data and formal descriptions. A BIM-based quality checking process case study was presented to resolve building health and safety issues. Research findings suggest that BIM-based quality checking processes can be successfully employed to improve safety management.

Megahed (2015) acknowledged the progressive increase in demand for use of BIM in historic buildings; noting that BIM can present an accurate virtual model of a historic building in order to maintain the building through its entire lifecycle, including demolition. This approach, known as HBIM, represents a new paradigm within architectural heritage; the remit of which can be used for creating, conserving, documenting, and managing complete engineering drawings and information. This paper presents an overview of the HBIM concepts, including surveying and representation techniques applied to support integration – including complexity associated with built heritage resources. A theoretical framework is presented for discussion, highlighting the different aspects of historic preservation and management through a smart open platform.

Jamaludin *et al.* (2015) highlight the dynamics of daylighting within a residential college building and internal courtyard arrangement. This research was supported by various field measurements to complement computer simulations. The field measurements involved eight unoccupied student rooms, selected as samples to represent ten scenarios and orientations (viz the level of radiation and penetration of sunlight). Various visualisation and simulation techniques are presented for discussion, including: different amounts of daylight in specific room scenarios. Research findings highlight that rooms can be augmented to consume less electricity usage, particularly for lighting purposes, to enhance the comfort of indoor living space.

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