Augmented and virtual reality and creativity in the built environment

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Augmented and Virtual Reality and Creativity in the Built Environment

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Abstract
As part of the Creativity-Built Environment nexus, this chapter examines the potential of augmented reality (AR) and virtual reality (VR) to democratise design by making built environments and future proposals more accessible. It briefly reviews the state-of-the-art, synthesizing recent work on AR and VR in the built environment, and exploring the wider literature on how AR and VR technologies support creativity and design. It then discusses and critically reflects on frameworks and approaches for using AR and VR for creativity in the built environment and the practical challenges. There is potential for using these technologies within the built environment to understand long-term and systemic consequences, to collaborate across the diverse disciplines and to co-develop built environments with the sets of people that have interests in particular places. The chapter concludes by setting out future directions of research.

Keywords
Virtual reality, VR, augmented reality, AR, creativity

1. Introduction

With the growing interest in digital twins and data analytics to understand the long-term consequences of the interventions in the built environment, new questions arise about how to visualize future built environments and engage diverse people in shaping them. Augmented reality (AR) offers an enhanced version of the real world, overlaying digital information onto it through a transparent display or real-time video stream. Virtual reality (VR) creates a digital copy of a real or proposed world and enables an immersive experience with rich interaction. When we revised the book *Virtual Reality and the Built Environment* (Whyte and Nikolić 2018) we were interested in how AR and VR technologies are becoming used to collaboratively visualize existing built environments and show the dynamics of their operations, and to inform applications in the planning, design and construction of interventions into built environments. Since then, strong interest in these technologies has remained, with a set of reviews outlining the research and applications in construction and the built environment (Davila Delgado et al. 2020, Zhang et al. 2020, Albahbah et al. 2021). Our own recent work has sought to further explore how VR can support understanding of long-term consequences through more systematic and interdisciplinary approaches to creating sustainable built environments (Nikolić and Whyte 2021), and to take a critical lens, interested in the unintended as well as intended outcomes.

In this chapter we examine the Creativity-Built Environment nexus in relation to the potential of AR and VR to democratise design by making built environments and future proposals more accessible. We draw on a strong trajectory of recent research on the impact of AR and VR on creativity and design across a range of design domains, including industrial design (Obeid and Demirkan 2020) and construction and built environment applications (Gu and Amini Behbahani 2021, Paes et al. 2021). Interactive technologies, such as AR and VR, being independent from any professional disciplines can potentially offer a platform for the diverse sets of people to engage in a creative and collective envisioning of the desired futures. Yet, this potential of AR and VR to support a playful and creative design and inquiry often gives way to more rehearsed, reductive, and narrow applications contained with individual disciplines and with little crosspollination of knowledge and experiences.

We build on an idea of democratizing design that suggests that *"To change the industry so that it can relinquish substantial control of the design process depends on appropriating new technologies and applying them in innovative ways."* (Ewart 2018: p. 330). We make the case that there is potential for using these technologies within the built environment to understand long-term and systemic consequences, to collaborate across the diverse disciplines and to co-develop built environments with the sets of people that have interests in particular places. In section 2, we review the state-of-the-art research on AR and VR in the built environment. In section 3, we then explore AR and VR for creative visualization and playful design in the wider literature on how AR and VR technologies support creativity. In section 4 we discuss and critically reflect on frameworks and approaches for innovative ways of using AR and VR for creativity in the built environment and the practical challenges, and in section 5 we draw conclusions and set out future directions of research.

2. AR and VR and the Built Environment: State of the Art

Recent research on AR and VR in the built environment seeks to flexibly combine data-sources and to display multiple forms of dynamic or behavioural as well as static data. This is a significant advance on earlier research, which required substantial effort in preparing models that were predominantly focused on displaying the geometry.

There are many recent reviews of AR and VR in the built environment published in the last five years, which synthesize and develop insights across a wider set of individual studies. Table 1 shows examples of recent reviews. Schiavi et al. (2022) argue that this existing literature focuses on VR in the design phase, AR and VR in construction phase and AR in the FM phase.

Authors	**Focus**	**Approach**	**Main findings and directions for further research (where specified)**
Albahbah et al. (2021)	Construction project management	Review of the research on VR and AR applications	Identified applications: construction safety management (51% VR, 36% AR), visualization; communication & data acquisition; education; scheduling and project progress tracking (VR & AR) defect & quality management and facility management (AR).

Schiavi et al. (2022)	BIM data flows to AR and VR	Systematic literature review	Outlines different design review applications, and argues that existing literature focuses on VR in the design, AR and VR in construction phase and AR in the FM phase before focusing more narrowly on construction safety applications and BIM data flows.
Zhang et al. (2020)	Built environment	Review and bibliometric analysis of the research literatures	Architectural and engineering design (30%); construction project management (22%); human behavior and perception (17%); construction safety (14%); engineering education (9%) and construction equipment (8%) identified as topics. Proposed research directions: user-centered adaptive design, attention-driven virtual reality information systems, construction training systems incorporating human factors, occupant-centered facility management, and industry adoption.
Davila Delgado et al. (2020)	Industry adoption of AR and VR in construction	Review of the research; focus groups and an online questionnaire	Adoption driven by improving performance in projects; company image; company overall performance and R&D and limited by perception of immature technologies; non-technical issues (e.g. accessing knowledge and advice); special requirements for implementation; sector structure and client-contractor dynamics.
Nikolić and Whyte (2021)	Built environment and future of VR	Conceptual paper	Integrating vision of VR for promoting conversations across disciplines is challenged by the reality of VR use in the built environment that tends to be largely discipline-specific and has seen inconsistent results, with opportunities for VR use for environmental design; landscape architecture; engineering design; and operations and maintenance. Articulates how we can use these technologies to span disciplinary boundaries and integrate and make sense of diverse data to impact the designing and understanding of a more sustainable world.
Mollazadeh and Zhu (2021)	Biophilic design using virtual environments	Due to the scarcity of research this is based on a review of research that use virtual natural	Argue that virtual environments can support the study of biophilic design by including features that combine biophilic patterns, provide multimodal sensory inputs, simulate stress induction tasks, support the exposure time to observe biophilic patterns, and measure human's biological responses to the natural environment. Limitations include experience

		settings in various domains.	dimensions, user-related factors, cybersickness, navigational issues, and possible limitations of sensory input.

Table 1. Focus, approach, findings and directions for further research in selected recent reviews of AR and VR and its implementation in construction and the built environment

Such reviews are focused primarily on construction, where construction safety arises as a major application under research. Albahbah et al. (2021) describe safety management as the main application of VR and AR. Following a broader review, Schiavi et al. (2022) focuses on construction safety applications and BIM data flows; while Zhang et al. (2020) also identify safety as an area of application. As well as education (Albahbah et al., 2021; Zhang et al., 2020) other application areas identified for both AR and VR include visualization; communication and data acquisition; scheduling and project progress tracking (Albahbah et al., 2021); architectural and engineering design; human behavior and perception, construction project management and construction equipment (Zhang et al., 2020), with applications for AR including defect and quality management and facility management (Albahbah et al., 2021).

Davila Delgado et al. (2020) focus on industry adoption (using both a review and a survey), finding drivers for adoption include improving project performance, company image and performance and bolstering R&D, arguing this adoption is limited by the perception of immature technologies; non-technical issues (e.g. accessing knowledge and advice); special requirements for implementation; and by the sector structure and client-contractor dynamics.

Across these reviewed literatures, some individual studies continue to evaluate the benefits of VR in specific cases using well-established methods of user tests and individual interviews (Truong et al. 2021), emulating a style of research that has been ongoing since the first author's PhD conducted more than 20 years ago (Whyte 2000). However, there are also new strands in the research literature that relate the use of AR and VR to the changing technological landscape that is leading to greater integration across stages of delivery, and is bringing diverse stakeholders together. Areas of interest arising in these recent literatures include:

- *The increasing focus on dynamic data:* Given the phenomenal growth in the volume of data used in planning, designing, and constructing built environments, there is a renewed need to consider how built environments are visualized through such combinations of dynamic data. The recent work has a notable focus on flexibly combining data-sources and displaying multiple forms of dynamic or behavioural as well as static data. This is a significant advance from early work in VR that required substantial effort in preparing models that were predominantly focused on displaying the geometry.

- *Integrative and interdisciplinary applications:* Enabled by dynamic data streams, which raise the potential to combine diverse kinds of engineering modelling to understand tradeoffs and behaviours in visual displays, work is beginning to explore how we can use these technologies can extend beyond narrow applications in individual disciplines to span disciplinary boundaries and integrate and make sense of diverse data to impact the designing and understanding of a more sustainable world (Nikolić and Whyte 2021), for example in recent work on virtual environments and biophilic design (Mollazadeh and Zhu 2021).

- *Ethical questions:* No less important are the ethical questions raised by emerging applications. VR in the domain of entertainment has long offered a respite from a reality that is not under our control, especially in the times of the pandemics, climate change, disasters and wars. In gaming and leisure applications, VR can be a haven that is relatively under our control or in which there are few consequences of our actions. Such applications offer some guidelines for both AR and VR to be also used in ways that can explain and shape reality, and rehearse interventions into the built environments in which we live, work and play, but also suggests some of the unintended aspects and ethical questions that may need attention to implement and make use of AR and VR in creatively exploring and designing future built environments.

- *VR, AR and Construction 4.0/5.0:* Though not yet realized, there is a potential growth in machine learning to identify patterns in this data, with a suite of Industry 4.0 and 5.0 technologies and ambitions around the use of digital twins for built environments.

Such work on AR and VR in the built environment can also be informed by wider studies, and the conclusions drawn in the above reviews resonate with a general review of extended reality (including AR and VR), which identifies design as a major application, alongside remote collaboration and training, and notes the lack of consistent hardware and software and relatively low uptake (Vasarainen et al. 2021).

3. AR and VR in Creativity and Design

There is a strong trajectory of recent research on the impact of AR and VR on creativity and design across a range of design domains, including industrial design (Obeid and Demirkan 2020) and construction and built environment applications (Gu and Amini Behbahani 2021, Paes et al. 2021). While such work focuses both on virtual reality as a medium with intuitive interfaces to enable creativity; and as a means to study creativity (Yang et al. 2018, Chen et al. 2022, Wang et al. 2022), we will focus on the former in this section. These ‘VR enabling creativity’ studies highlight and explore topics such as the pervasive use of immersive and non-immersive VR in design studios (Obeid and Demirkan 2020), with recent studies in this area are summarised in Table 2.

Authors	**Focus**	**Approach**	**Main findings and directions for further research (where specified)**
Paes et al. (2021)	Comparison of users spatial perception of virtual model (of a building) using different VR systems.	Controlled experiment using survey questionnaires	Immersive systems are found to improve 3D perception and provide more immersive experience (controlling for individual factors and order effects). The authors expect this to benefit collaborative

			design review and increase productivity.
Obeid and Demirkan (2020)	Immersive and non-immersive VR in design studios	Experiment with first-year basic design students, half in immersive VR, half not immersive	Immersive systems are found to facilitate design process creativity more than the non-immersive ones, with a positive strong correlation between motivations and creative flow a weak correlation between spatial ability and flow.
Lee et al. (2021)	Cognitive action and creativity in design	Study of fashion designers, experimentally comparing immersive VR and 2D digital design	Immersive VR design tool "activated physical and perceptual action in design cognition and enhanced flexible cognitive action amongst different cognitive action levels compared to the 2D digital design"
Fillingim et al. (2021)	Physical walking versus movement only in VR	undergraduate industrial design studio used to study design	Some differences found in mood, interventions, and peak performance, but no statistically different results
Graessler and Taplick (2019)	Supporting design guidelines and VR functionalities	Experiment, with industrial design students using the 'Sensory stimulation technique'	Suitability is task related, with users designing in the virtual environment highly rating functions for inserting objects and sketching, but for idea generation preferring functions to change environments and load object configurations.

Table 2. Focus, approach, findings and directions for further research in selected recent experimental studies of AR and VR and its implementation in creativity and design

While there are far fewer literature reviews and synthetic papers in this area, significant advances are made across this work. The papers in Table 2 are illustrative of the experiments in the recent literature that explore the link between the use of specific VR configurations and the creative thinking and design work. Studies typically indicate that technologies such as immersive VR can support complex and creative activities through increased motivation, attention, and flow state. Paes et al. (2021) find that immersive systems improve 3D perception and provide more immersive experience and argue this benefits collaborative design review and increase productivity. Obeid and Demirkan (2020) find immersive systems facilitate design process creativity more than the non-immersive ones. Lee et al. (2021) find and immersive VR design tool enables flexible cognitive action and activates physical and perceptual action. Graessler and Taplick (2019) find that users designing in the virtual environment highly rate functions for inserting objects and sketching, but for idea generation preferring functions to change environments and load object configurations. As well as the above work that compares immersive and non-immersive VR configurations, there are also several studies that start to explore the creative impacts of specific aspects of VR, including interaction, physical movement and sensory stimulation (e.g. Lee et al. 2019). Areas of interest arising in recent literatures include:

- *Novel forms of interaction:* VR and AR offer ways to extend experiences beyond the real world and immerse users in new ways for viewing and interacting with data. Types of interactions that do not have their real world analogue, alongside the immersive and imaginative characteristics of VR (Gavish et al. 2015) have also been recognized as important aspects that can support creativity (Thornhill-Miller and Dupont 2016, Graessler and Taplick 2019).

- *Engaging diverse people in the conversation:* There is substantial innovation in the interfaces used creatively (Heller 2018), with significant experimentation in design conceptualization and in design review, where the questions arise about how to visualize and engage diverse people in the conversation about what future built environments should be like. Maftei and Harty (2021) indicate how participants use of VR in design review alters their understanding of design, indicating features of proposed features that have not been appreciated in other media.

- *The role of VR for creative decision making or for legitimating narratives:* Pickersgill (2021) provides a more critical voice, surfacing difference between the promised capability of VR and needs in the design process, arguing that a less-recognized aspect of the VR experience is in creating legitimating narratives for a design proposition. These differences between VR and the real world are also highlighted in work on sustainability, with a recent paper noting that: *"Although immersive technology has evolved significantly, its fidelity to the natural setting is still low, and a real experience in nature should be favored over its virtual equivalent."* (Fauville et al. 2020).

- *Rapidity of content generation:* One aspect in the new tools that enables increased use for creative decision making is the ability to rapidly create content. Early applications of VR focused on aspects such as the 'walkthrough', enabling clients and end-users to navigate models and experience the interior of a building before it was built. Such applications required models to be built, with added lighting when possible, but the VR user would move through a relatively static environment, which took substantial time to build and given the computing performance requirements was often located in a research facility or office. More recent work has enabled engineers to generate models more rapidly, while more portable visualization equipment allowed VR applications to move from academic facilities into construction offices (Nikolic et al. 2019).

- *Potential to show alternatives:* The implementation of AR and VR is growing in the built environment disciplines, although the extents of their use remain conservative and focused on representing intended "reality" during the design. The readability of the technology can thus be a double-edged sword, bringing challenges as well as opportunities to understand long-term and systemic consequences, with possible misunderstandings or misrepresentations, and a danger of becoming locked-in to envisioning one future too quickly. Yet, the focus of AR and VR applications in the built environment has undoubtedly been on presenting ever more "real" information, a pursuit that may not always yield desirable outcomes or at times can be even misleading (Whyte and Nikolić, 2018). Here there is real potential for creative solutions that share multiple options and stimulate broader consideration of futures.

- *Scaling up and down and recognizing the partial nature of representations:* As all representations of futures are inherently partial, the questions about how such representations rather than seducing, can instead engage citizens in visualizing and realizing preferred futures, become pertinent. Previous research pointed to the importance of representations having some level of abstraction in order to focus design inquiry onto topics of concern (Whyte and Nikolić 2018). Shared view points and viewing perspectives in visualization are also important, where participants may find it hard to collaborate creatively if, for example, some users view a model from above while others experience it at eye-level within the environment (Leigh et al. 1996). Examples such as these, raise questions about how to scale up and down, either through the buildings, neighbourhoods and cities within which people live, work and play, or through the infrastructure systems that support these localities, such as the transport, water and energy networks.

We observe that the developments in software libraries, VR plugins, as well as growth in computing power and consumer price-point for related equipment, all have enabled substantial recent experimentation in the creative use of VR in the design of the built environment, with results not only published in research journals, but also showcased by practitioners on social media. While the studies above focus on VR for design, examples from the technology and gaming industry offer rapid developments in interactive platforms with often playful approaches to user interaction. For example, Google's Daydream Labs has been experimenting with creating whimsical tools for use out of their typical contexts, such as a virtual drum kit that used HTC Vive controllers as drumsticks (Doronichev 2016) and observed that people are good at discovering new ways of interacting with virtual objects. Other more recent examples include AR sandboxes as a dynamic educational tool and an interface for learning about geoengineering, with recent research having developed an extendable Open AR sandbox (Wellmann et al. 2022). These examples illustrate how AR and VR can be powerful and engaging platforms that encourage users to interact with information in novel ways.

4. Discussion

While the research we review provides exciting examples of AR and VR use for creative work, the potential of interactive technologies for informing future changes in the built environment remains unrealized, limited by professional and institutional ways of working. We see the potential for using these technologies within the built environment, particularly to understand long-term and systemic consequences, to collaborate across the diverse disciplines and to co-develop built environments with the sets of people that have interests in particular places.

There are frameworks and approaches for using AR and VR for creativity in the built environment suggested in the above literatures, yet we see many of these as inadequate to support a playful and creative design inquiry with a focus on more rehearsed, reductive, and narrow applications contained with individual disciplines and with little crosspollination of knowledge and experiences. The combination of data-sources in the virtual environment is enabling designers and other professionals to have access to multiple forms of engineering data from across disciplines, and to use this creatively. We see a broader set creative opportunities for AR and VR use across domains (Nikolić and Whyte 2021):

- *environmental design*, e.g. for behavioral change, dynamic growth/change visualization, and resource use simulations;
- *landscape architecture* e.g. for dynamic site change simulation and scene visualization over time;
- *architecture* e.g. for design development, evaluation, design reviews, and design marketing;
- *engineering design* e.g. for design testing and review, (dis)assembly, operations training;
- *construction* for sequencing, e.g. clashes, site logistics, equipment operations, and site access; and
- *operations and maintenance* e.g. for design reviews and operations training.

AR has the obvious advantage of situating the user in the real world, where the future of places can be imagined. However there are also significant creative uses of VR. For example, the development of online games that teach inhabitants about resources, consumption or planning suggests ways VR can be developed into dynamic and interactive environments where users can see consequences of their actions and decisions. Two ongoing research projects include co-developing an approach to the modelling and visualization of water and housing to support collaborative planning applications (Ricco Carranza et al. 2022), and linking of diverse forms of data to support collaborative construction, through a construction production control room (Soman et al. 2022). Both projects focus on supporting collaborative visualization and for that reason use large screen displays to enable the collective sensemaking leading to better decisions in the real world.

Challenges for AR and VR are associated not only with current technology development but also with human-centric issues. Users' engagement through participation, such as in design processes, is one of the key open challenges (Victorelli et al. 2020). Improving user participation is required in both the data use (in terms of better understanding) and production (in terms of quality improvement) cycles (Locoro 2015). VR and AR allow access to data in a smooth and natural way based on both tangible and verbal interaction to convey knowledge to the end user and to ensure actionable insights that improves decision making (Olshannikova et al. 2015). Thus, AR and VR systems can demonstrably support collaboration through improved communication and access to information for all the stakeholders, regardless of their technical background. At the same time, these technologies still tend to be largely viewed as off-the-shelf, pre-defined and thus monolithic, often not examined through the lens of their distinct attributes that form an array of configurations from augmented reality to virtual reality, (non)stereoscopic, (non)immersive, as well as from single-user head-mounted displays (HMD) to multi-user large projection-based systems. As a result, applications of VR often reveal the tension between the potency of the medium to support users in visualizing information and the elusiveness of VR solutions to consistently realize the above said benefits.

5. Conclusions

With the growing interest in digital twins and data analytics to understand the long-term consequences of the interventions in the built environment, new questions arise about how to visualize and engage diverse people in shaping future built environments.

Though current applications remain conservative, developments in other fields suggest the potential to use AR and VR in a personal way, in the playfulness of the designers own process, and also in broader processes of collaborating across the diverse disciplines and to co-develop built environments with the sets of people that have interests in particular places. Take aways are the need to consider:

1. The opportunities of increasing focus on dynamic data;
2. The potential of integrative and interdisciplinary applications;
3. The emerging ethical questions;
4. The role of VR and AR and a construction industry 4.0/5.0;
5. How diverse people are engaged in the conversation;
6. The role of VR for creative decision making rather than legitimating narratives;
7. The new creative opportunities of rapidity of content generation;
8. The new creative opportunities to show and consider alternatives; and
9. The challenges of scaling up and scaling down and showing uncertainties in data.

There is hence a call to action to apply AR and VR technologies in innovative ways to democratise design by making built environments and future proposals more readable. At the start of the chapter we drew on Ewart (2018) to describe how this is required to relinquish control in ways that make design more participatory. This is important because, though there are studies that offer exciting examples of AR and VR use for creative work, unconstrained by professional and institutional ways of working, practical applications continue to lag in realizing the potential of interactive technologies for informing future changes in the built environment.

There are a number of future directions in examining the reciprocal relations between creativity and built environment. These include extending work on the way the adoption of VR and AR systems for data interaction changes cognitive processes in visualization, analysis and participatory activities warrants. While VR and AR offer powerful and novel ways to engage allied built environment disciplines in shared conversations, their use remain largely confined within individual disciplines, bound by discipline-specific tools. For interdisciplinary practice, integrating increasingly diverse data sets not only requires overcoming issues of interoperability, but understanding salient content and technology features for the intended users to evaluate longer term consequences of relevant decisions. This would also allow for an exploration of methodologies to measure the performance of VR/AR systems in a more consistent manner.

AR and VR in many ways can offer users experiences that enrich, expand and surpass those of the real world. Yet, in built environment practice, fewer studies have focused on the nature of VR interaction beyond the basic capabilities of navigating and walking through a space (Nikolić and Whyte, 2021). Abilities to experience an environment in novel ways, such as to teleport, fly, jump between various viewpoints, change the appearance of the environment and build scenarios that transcend time and space is what makes AR and VR compelling technologies, and yet, remain largely unexplored in practical applications.

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