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To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning

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ABSTRACT

The use of virtual reality has its roots in visual communication science but disparate mechanisms and applications set it apart from the many tools of visualization. This paper reviews the use of virtual reality (VR) environments for research and teaching in the context of three disciplines: architecture, landscape architecture and environmental planning. As opposed to other uses of virtual environments, for example, in the health sciences or engineering, simulations using virtual reality theatres or labs in the three fields we explore are used to display inaccessible realities. VR environments are typically used in these fields for planned and designed realities, not yet existent or with nonexistent components. Each field has different reasons for spatial or temporal inaccessibility to reality, prompting the need and eventually the capability to achieve various levels of accuracy in the virtual setting. We describe current VR research opportunities and challenges in each discipline and emphasize what they can gain from sharing virtual reality systems for research and education.

1. Introduction

A recent book entitled *Visual Research Methods*, edited by Margolis and Pauwels (2011), covers topics so broad that it is hard to get a sense from the book just what visual studies entail. Are they typically studies in communication? Sociological or anthropological inquiries? All types of media are covered in this book, from the rhetorical use of images to social and cultural expressions depicted in websites, video, cartography, semiotics and more. It seems that the word "visual" added on to almost every discipline in the sciences, both social and natural, would describe work being done. As an opening to this special issue on the use of virtual reality (VR) and particularly one showcasing the interdisciplinary nature of visualization, we highlight the contribution of VR to visual studies within three subfields of the more general design professions.

Unfortunately, there is little integration with respect to the contributions of visual research methods to different disciplines (Hansen & Machin, 2013; Lange, 2011; Pauwels, 2014); this spills over into the design professions so that each sub-discipline finds itself reinventing the wheel. It is our intention, therefore, in this review, to describe the use of VR for architecture, landscape architecture and environmental planning while underscoring research and educational aspects that are common to visualization tools. We look at the use of visual research methods applied for studies of VR as relevant for the design disciplines. Subsequently, we posit that the use of VR for architecture, landscape architecture and environmental planning can aid in making visual studies in these fields more interdisciplinary.

By and large, the use of VR in laboratories for professional design and research purposes facilitates access to situations that do not (yet) exist. Although lab applications are sometimes used to determine visual preferences in regards to extant views (or images) in a controlled environment, a frequent purpose is to inform about future visual change. Such anticipated changes may be either planned – such as for reuse of existing buildings in urban design (e.g., Gill, Lange, Morgan, & Romano, 2013) – or expected, such as to solicit a response from stakeholders regarding climate change (e.g., Sheppard, 2012).

For this review, we start by describing the evolution of VR within the context of visual research methods and paradigms and then look at each of the three disciplines of concern – architecture, landscape architecture and environmental planning – with reference to the type of visualization needed. We consider the meeting of these needs through the use of a "theatre" or laboratory facility. The widespread and growing existence of such facilities allows the identification of common research themes and gaps as well as challenges to the use of outcomes and products in praxis.

2. Background

Virtual reality is ultimately a type of "visualization", a technique which has experienced a recent boom in professional and academic literature. Two special issues, one published in *Environmental*

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Communication (2013; Vol 7(2)) and the other in *Landscape and Urban Planning* (forthcoming), showcase visualization. The former offers a collection of scholarly work now emerging and using various methods in the field of visual environmental communication research. The latter provides a critical view of visualization. Although visualization for environmental and urban planning has numerous dimensions and applications in the literature, there is invariably some mention of virtual reality (e.g., Ball, Capanni, & Watt, 2008; Bishop, Wherrett, & Miller, 2001; Ghadirian & Bishop, 2008; Lange, 2011; Paar, 2006; Portman, 2014).

A cursory search (conducted May 2014) for the keyword "virtual reality" in the Academic One online database yields 1677 academic papers on the topic, ranging broadly from the field of physical therapy to education, from interior car design to treatment for weight loss and more. The large volume of academic papers indicates the widespread use of VR, but fails to give an indication of what concerns us for this review: research on VR for urban design. A search for "virtual reality" in *Design Studies* (conducted June 2014) resulted in 94 papers, most related to architectural design. This second search indicates a significant volume of research related to the use of VR for design. Some of these address research being conducted on VR in laboratories and theatre-type situations. We assume that to make sense of the term that engenders such a large volume of literature requires examining the contribution of virtual reality to visualization methods.

A common thread between visualization and VR is the emphasis on the visual sense as a tool of communication. Tufte (1990) describes visualization as a medium for clarifying certain complex data that has great advantages over the written word or voice alone. The visual sense is by far the dominant component of human sensory perception (Bruce, Green, & Georgeson, 1996; Rose, 2012). Scholarly work on visualization promotes expanding the sense of the visual, incorporating all types of representation – television, film, photographs, across different fields, and including the broadest range of representations possible – from maps to photos to visual representation of data in graphs and tables (Hansen & Machin, 2013; Valiela, 2009; Ware, 2013). Although simulating reality may be the crux of the VR experience, the use of VR for design purposes leads to an expansion of this definition, based on the "real" simulation or replication, but also going beyond it.

Research on the effectiveness of various technologies as simulation tools for design is on the rise; novel virtual world platforms and technologies developed for all types of applications during the last decade – like Second Life and World of Warcraft – have drawn the attention of researchers including some from the design disciplines (e.g., Koutsabasis, Vosinakis, Malisova, & Paparounas, 2012). Frequently visual quality of these games is similar or even superior to that used in professional design disciplines and VR laboratories. However, despite VR's potential contribution to professional design and planning (Gill et al., 2013; Paar, 2006; Silvestri, Motro, Maurin, & Dresp-Langley, 2010), it is hard to find current *interdisciplinary* research aimed at improving VR techniques or helping define across disciplines, what we mean by "virtual" or even by "reality".

Over a decade ago, Simpson (2001) compiled a bibliography of virtual reality and urban simulation in the planning literature. Looking for instances in which simulation technologies have been implemented for improving urban and regional planning, the author describes urban simulator labs (such that at UCLA) designed to simulate cityscapes. Visual simulation models described developed in such labs used a combination of computer-aided design and geographic information systems (GIS). Simpson concluded that the small number of research institutions applying these technologies for research and education indicated that cross-discipline application to planning lagged behind system capabilities due to high costs. Pietsch (2000) makes a similar observation about implementation by planning authorities lagging behind research on technologies. Visualization labs are more commonplace today such that opportunities exist to reduce the lag. In any case, an applied research agenda must be clearly articulated and this includes one dedicated to cross-discipline design as distinguished from other visual communication research.

In a broad sense virtual technologies have engendered changes in how we understand the world, i.e., 'going-to' or 'visiting' websites, writing or reading of Facebook® 'walls'. These phenomena have been included in visual communications research that investigates how virtual technologies, especially those with emphasis on the visual sense, have changed our lives; for example, how multi-media representation has generated a host of virtual locations, situations, transactions, relationships, etc. (Wagner, 2011). These environments, though perhaps not originally envisioned as such, replace reality rather than replicate or simulate it. So what exactly are we referring to when we consider VR as a type of visual communication for urban design?

2.1. Virtual reality defined

A standard definition of "virtual reality" is hard to find. The Webster Collegiate Dictionary (1991) has no definition for it whatsoever.[1] A little over two decades later, we have the following definition: VR is a "computer-generated environment that, to the person experiencing it, closely resembles reality" (Collins Dictionary, 2014). Other definitions of VR emphasize the participatory aspect whereas VR is "experienced" (as opposed to "viewed") and it is synthetic or fabricated. Addressing the later point, Regenbrecht and Donath (1997) have defined VR as "the component of communication which takes place in a computer-generated synthetic space and embeds humans as an integral part of the system…". Both these points – experience and synthetic – are highlighted by Sherman and Judkins's (1992) five "i"s of VR: "intensive, interactive, immersive, illustrative and intuitive." These characteristics seem to be a good starting point for a definition. Without one or more of these characteristics there is no VR.

But how far does the fabrication or synthetic element go? Can VR be completely fabricated or at most a copy, or simulation, of reality? Debatably, virtual reality connotes a greater synthetic component than do related techniques described by the terms "mixed reality" and "augmented reality (AR)".

Mixed reality describes a continuum between digital experiences that depict the completely real world to those that are completely synthetic or fabricated; it includes both AR and VR (see Fig. 1). Augmented reality dynamically overlays virtual images on images of the real environment such that the real environment is still part of the visual display seen by the viewer (Guo, Du, Luo, Zhang, & Xu, 2008); when the viewer moves in the AR environment, information changes in response. Predating other authors on the topic, Milgram and Colquhoun (1999) distinguish between two main types of AR: one which involves the use of a head-mounted display worn by the user and another covering any situation in which the real environment is "augmented" by means of virtual (computer graphic) means. Azuma (1997) defines the three characteristics of AR as: the combining of real and virtual objects; the appearance of images interactively and in real time; and the registering (aligning) of real and virtual objects with each other. We frame VR as creating realities that do not yet exist or are largely inaccessible and therefore consisting of greater created (synthetic) parts than AR.

Both AR and VR are being explored through their integration with GIS technologies (e.g., Ball et al., 2008; Bishop et al., 2001; Guo et al., 2008), with the latter now moving from desktops to on-line

[1] The closest term in the Webster Collegiate Dictionary (1991) is perhaps "virtual image" (origin: 1859) defined as: "an image (as seen in a plane mirror) formed of virtual foci".

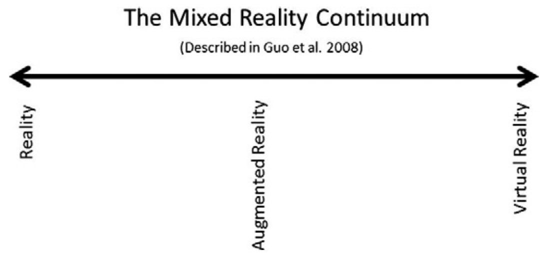

Fig. 1. The mixed reality continuum.

applications (e.g., ArcGIS on-line (AGOL)). The addition of VR to GIS technologies enables the user to move with discretion through real or modeled information displayed with a high level of spatial accuracy. The use of GIS turns the traditional *inside* interactive static man–machine mode to *outdoor* dynamic mode (Guo et al., 2008) useful for a wide-range of fields including geoscience research and education. The combination of VR and GIS facilitates exploring large regions at high resolution leading to field scale experiences with varying levels of immersion. Examples include Geowall, which is a low-cost interactive 3D stereoscopic projection system that provides 3D immersion using a single wall, Vision Dome, that creates a full 360° projection with 180° field of view, and Cave Automatic Virtual Environment (CAVE™) that projects images on multiple walls of a room-sized cube (Mitasova, Weaver, & Lyons, 2011).

For the fields of interest in this paper, and in this issue, mixed reality is a given, meaning that virtual reality is a type of mixed reality. It can include AR referred to by Milgram and Colquhoun (1999) in their second, broader definition above, involving "augmented" objects. In visual studies, the term "virtual" can refer to the complete fabrication of materials, or even situations, that adopt concepts from the structural design world, such as "walls", "sites", and chat "rooms". By contrast, for architectural, landscape and environmental planning, digital simulations of real structures, land or seascapes *are* virtual realities whether they mix in real objects or not.

3. How real must real be?

Over two decades ago, Pittman (1992) described the historical development of computer-generated scenes as going from "cartoon-like" images to "convincing and accurate representations of physically based environments". When Pittman penned his paper, the Virtual Environments Laboratory he describes at the School of Design at North Carolina State University introduced design concepts at that university with relatively new levels of accuracy. As additional labs have become established the ability to accurately represent environments has increased and the use of VR has broadened (e.g., Atwell & Gretlein, 2013; Gill et al. 2013; Lange, 2011; Mitasova et al., 2011).

As technologies improve and access becomes widespread, our expectations change as to *how* "real" virtual reality needs to be. Some applications, for example, those in the health sciences, reality needs to be extremely accurate and highly multi-sensory. Examples are the use of visualization for remote surgery (Millesi et al., 1997) or as used to treat veterans returning from overseas combat duty and suffering from post-traumatic stress disorder or brain injury (Rizzo, Reger, Gahm, Difede, & Rothbaum, 2009). Much more than the visual sense or experience is essential here. Life-threatening activities are at stake during surgeries. Similarly, an unrealistic VR system will be ineffective in therapists assessing patients' balance and coordination for determination of a treatment plan. Similarly, for determining landscape/scenic beauty values, abstract representations will be inappropriate (Daniel & Meitner, 2001), but complete accuracy may not be essential. From a practical, urban design or planning-related point-of-view, questions still need to be answered on how much abstraction is allowed (Lange, 2002).

In the past, powerful visualization tools, those that provided the end-user with the means to generate, explore, analyze and share prospective plans were uncommon, expensive and the time and resources required to generate images rendered them impractical. In a broad-based early article on the subject, Doyle, Dodge, and Smith (1998) discuss the potential of VR technologies being developed on the Web for the visualization, modeling and analysis of urban environments. To some extent, the foresight discussed in that paper rings true today – web-based mapping tools have helped make progress with respect to data visualization and, albeit it to a lesser extent, data analysis.

Information available from the Web, such as GoogleEarth and publicly available data portals, has led to the increased use of visual tools in a broad range of research (Collins, 2011; Ware, 2013). This information is often "good enough". Even so, the question of how realistic visualizations must be has been part of the research agenda for some time, especially for landscape planning (e.g., Ervin, 2001; Guo & Yang, 2013). As pointed out decades ago (Zube, Simcox, & Law, 1987), we posit that the extent of "realness" depends on the context of application. We proceed with these thoughts in mind.

This paper considers the applications of VR technologies in a limited range of landscape and urban design contexts. For the remainder of this review, we focus on immersion among highly realistic digital simulation images in a theatre or laboratory setting (as illustrated in Fig. 2). Using such systems, designers and planners can "enter" three-dimensional digital simulations (models) of planned or existing buildings, cities and landscapes. Such facilities are increasingly sought-after for research and education (D'Souza et al., 2011; de Freitas & Ruschel, 2013; Pietsch, 2000; Pittman, 1992; Simpson, 2001).

4. Virtual reality in the design fields

A recent Design News article claims in its title "There is no excuse for not designing virtually…" (Atwell & Gretlein, 2013). Yet the use of virtual reality in design will be different in specific design sub-disciplines; for example, in urban design versus industrial design. Overall, design as an academic discipline is relatively young and still evolving. The definitions of what the design discipline entails are, in and of themselves, broad, covering the manmade, i.e., the planning of the fabricated object in product design (Buchanan, 1995; Shen, Ong, & Nee, 2010) to the conceptual, i.e., the modeling of democratic and participatory processes in urban planning (Björgvinsson, Ehn, & Hillgren, 2010).

The use of action terms such as "change" and "develop" in definitions of design establishes it generatively as a process of transformation that leads to tangible outcomes (Boradkar, 2014). For the fields in which we are interested, we characterize architecture as involving significant human intervention and by contrast landscape planning as involving largely natural systems with minimal human intervention (e.g., Guo & Yang, 2013). Environmental planning takes place in both very disturbed environments (i.e., landfills) and in more natural environments (i.e., undeveloped open space). In any case, design sub-disciplines are close enough for an integrative and comparative review in regards to their use of VR. What is generally a problem for urban design applies to the application of VR in other design sub-disciplines. For example, Pietsch (2000) laments the complexity of use of VR by authorities making planning decisions: "the computing power and sophistication of the system… places virtual reality beyond the reach of local planning authorities." Similarly, for architectural applications El Araby (2002) posits that high costs and hardware needs limit VR to use in large university labs. However, a more recent article by Lange (2011) suggests that new in-field

Fig. 2. A VR laboratory for teaching and research (the VizLab, located at the Technion–Israel Institute of Technology). Three synchronized projectors display a continuous image onto a concave screen. Students interactively control the model or image, using surveillance cameras, sensors and a wireless controller (a wand) which facilitates a virtual "trip" through the projected environment.

collection of data and hand-held devices that display *in situ* simulations, offer potential solutions.

An immersive experience still requires large and expensive facilities to bring about an emotional and all-encompassing viewing response, which is usually one that diminishes over time. This means that investments must be carefully weighed. What can be done by VR that cannot be done otherwise? To this we answer that VR contributes to the creation of new designs (or design guidelines) and this is true for all three of the fields discussed here. This could be as distinct as a policy or guidance document based on an assessment of relative aesthetic values articulated through the viewing a series of scenes (for environmental planning) or a series of pre-construction renderings based on VR image analysis (for architecture) as explained below.

What follows is a brief review of the use of VR in the theatre/laboratory context for each of the respective disciplines: architecture, landscape architecture and environmental planning. We describe current VR research opportunities and challenges in each discipline and emphasize what they can gain from sharing VR systems for research and education.

5. VR in architecture

Virtual environments were originally embraced by architects for design concept presentation. In their review, Schnabel, Wang, and Kvan (2008) explain that virtual environments have empowered designers to express and explore their imagination with greater ease. de Freitas and Ruschel (2013) reviewed and grouped two hundred papers on virtual and augmented reality applied to architecture into research areas and technological development stages. They adopt a definition of VR taken from Burdea and Coiffet (2003): a technology that adds the dimensions of immersion and interactivity to three-dimensional computer generated models allowing "exploration" that is not possible with the traditional forms of representation. This fits with the characterization of VR for environmental planning and landscape architecture as a tool that enables going beyond, in some sense, existing reality.

Beyond allowing the addition of virtual entities to real-world views, VR technology enhances collaboration among members of design teams (Wang, 2007). Effective collaboration during the early design stages in architecture is a condition for effective overall design and construction (Koutsabasis et al., 2012). Dorta, Lesage, and Pérez (2011) explain that virtual design studios can compensate for the absence of collective local or remote ideation space. They describe a case in which two teams were able to co-design while they were virtually "teleported" into each other's representations. Gu, Kim, and Maher (2011) evaluate two current synchronous advancements: three-dimensional (3D) virtual worlds for remote design collaboration and tangible user interfaces. Research on 3D virtual world applications highlights changes in design behavior when designers are physically remote but virtually co-located as avatars within their design representation in the form of a 3D model. These types of applications can be used to improve both designer–designer collaboration and designer–client collaboration in architectural applications (Viet, Yeon, Hak, & Choi, 2009).

Beyond salient collaboration advantages, VR also facilitates the understanding of spatial conception; recent research in its application for architecture has focused on these advantages. Rahimian and Ibrahim (2011) addressed the identifying and designing of "problem-space" or "solution-space" using VR and Chen and Schnabel (2009) address what they call "lost space". The latter is defined as the hidden, unperceived space that can be identified for use and access through VR exploration. This is particularly apposite to the interior design realm but can apply to architecture as well (Viet et al., 2009; Ye, Campbell, Page, & Badni, 2006).

Also related to spatial conception is the testing of navigational aids and signposts for orientation within the built environment. For this type of research, the immersion capabilities of VR labs and theatres provide a controlled environment for testing hypothetical designs. Parush and Berman (2004) examined how users navigate through a 3D on-screen virtual environment. They discuss their findings in terms of the impact of navigation aids and landmarks on the acquisitions of route and survey knowledge for urban design.

Similarly, Mavridou, Hoelscher, and Kalff (2009) address the issue of three-dimensional scale of the urban environment as a missing element within the "space syntax" discourse. They conducted an experiment using VR that examined participants' performance at way-finding based on survey knowledge in four environments with the same plan configuration but among different buildings heights. This research sheds light on how geometrical and topological properties of space affect participant movement in cities and can inform architectural design decisions.

When virtual reality is immersive, designers tend to work interactively and three-dimensionally with their media; every creation is a place experienced directly through movement and interaction parallel to real world familiarity (Schnabel et al., 2008). Chen and Wang (2008) research "tangible augmented reality" that merges computer-generated learning materials and stimuli of virtual objects into real space. They discuss an empirical research framework for design and strategies for implementing such technologies to improve pedagogical effectiveness for architectural design education.

To stimulate interest and promote new users, Yan, Culp, and Graf (2010) present a framework for integrating Building Information

Modeling (BIM) used in architecture. They integrate BIM with games and a sample experiment of real-time, interactive and photorealistic walkthroughs within a virtual user model. This system allows "play" in designed environments with the capability of simulations of physical dynamics and virtual user activities. For similar purposes, VR has been used to engender interest on the part of high school students in urban design and architectural studies. An interesting finding from the VR–KiDS study described by D'Souza et al. (2011), which did just that, was the comfort exhibited by young people in using VR and their advanced capabilities compared to their teachers.

There are mutual benefits to the simultaneous development of virtual games and VR as used for the design disciplines, including architecture. Building and user simulations can benefit from the improved graphics, level modeling, and character modeling delivered through advances made in game technologies. At the same time, adoption of BIM in design and education facilitates the application of games in the design process (Yan et al., 2010). Also, game players acquire knowledge, agility and familiarity with simulations that may help them both technically and creatively (Green & Bavelier, 2003).

Even though de Freitas and Ruschel (2013) note a decrease in publications describing research on VR (and augmented reality) used for architecture, they suggest that this may denote a more precise delimitation of the topic over the period considered. Examples of the use of VR in architectural design education abound and the familiarity of young people with virtual worlds means that there is much potential for increasing the use of VR in the architectural design profession.

6. VR in landscape architecture

The widespread adoption of the use of digital simulation software in landscape planning practices has increased over time (Lange, 2011; Orland, Budthimedhee, & Uusitalo, 2001) and can be seen as a precursor to the application of VR based on 3D simulation. In fact, the start of the era of digital landscape visualizations coincides with the early period of landscape planning and design (Lange, 2011; Zube et al., 1987). Since then, landscape VR applications have contributed to advancements across the scope of the profession with implications for site planning, landscape restoration, parks and recreation planning, green infrastructure planning, residence landscape master planning and more (see Lange, 2011).

To gauge extent of use, Paar (2006) conducted a survey of the extent of 3D visualization software in landscape design in which 1044 parties responded from a sample of private landscape planning consultancies, freelance landscape architects, public planning and environmental authorities in Germany. The survey found that twenty-eight percent of private consultancies and freelance landscape architects together with 7% of those from public authorities, stated that they used 3D simulation software and recognize its positive role in landscape development.

During the last few decades digital landscape representations using VR have advanced from simplistic, static representations (e.g., Pittman, 1992) to extremely realistic visualizations, allowing exploration with real time movement experienced at multiple spatial and temporal scales (e.g., Ghadirian & Bishop, 2008). Yet from among the fields we consider in this review, landscape architecture (including landscape planning) has the least application of not-yet existent scenes. Also, it is the least distinguishable of the three with much in common with environmental planning. On the one hand, landscape architecture uses VR for large scale visual representations of existing scenic views – for example, to determine what viewers feel toward a particular landscape while roaming through it (Orland et al., 2001). In these cases, realistic representation of detail may be secondary to total effect. However, some landscape researchers are focusing on improving the micro-scale details of large-scale landscape presentation; for example, Guo and Yang (2013) are perfecting the realistic movements of grass blades in prairie landscape imaging for VR application.

The most obvious representative trait of the use of VR for landscape architecture is perhaps the integration of virtual reality and GIS (Bishop et al., 2001). For instance, a linkage between GIS-based modeling and a realistic representation landscape view allows for the demonstration of temporal changes of the landscape over a period of few decades (Ghadirian & Bishop, 2008). Such approaches promote communication between policy makers and non-experts and improve decision-making processes, particularly at the landscape scale (Orland et al., 2001). These applications, since they are future or scenario-oriented, regularly involve the portrayal of not yet existent realities.

A common and promising area of research for both landscape architecture and environmental planning involves the incorporation of stakeholder perceptions (Schofield & Cox, 2005). Ball et al. (2008) describe the use of VR for public participation GIS (PPGIS) through which planners educate stakeholders and vice versa, thus providing mutual benefits. Similarly, by conducting experiments in a VR lab, questions about landscape perceptions, preferences and user route choices as affected by landscape design can be answered (e.g., Bishop et al., 2001). Such applications are similar to those in architectural design that employ VR for way-finding and navigation (as mentioned above) because they usually require a controlled environment.

In spite of VR's ubiquity and the continuous development of VR applications for landscape architecture, several areas of concern remain. One of these is the challenge of efficient validation of virtual landscape modeling and simulation. Lange (2001) identified this gap in contemporary landscape research and attempted to determine to what degree the real visually perceived landscape can be validly reproduced by VR. Virtual landscape design should include botanically realistic vegetation, which requires detailing of plants, branches, twigs, flowers, leaves, etc. Rendering a walk-through simulation of these elements at a detailed scale requires development of sophisticated technologies, high technical abilities and a basic understanding of human perception (Honjo & Lim, 2001; Ware, 2013). The details of micro- to macro-scale images relevant to land and seascapes have been researched by perception psychologists, including the effects of visible light, optical flow and textured surfaces (e.g., Ware, 2013) yet findings have not been widely incorporated by landscape architects.

Many challenges for the use of VR for landscape architecture pointed out over a decade ago still remain: i.e., while VR tools for landscape planning are increasingly being adopted, there is a lack of research addressing what is to be gained by VR or the cautions necessary for its use (Orland et al., 2001). Moral and ethical topics related to the use of VR on the landscape scale have been addressed by Sheppard (2012); however, these have mostly been for the purpose of behavioral change and environmental protection as these relate to climate change adaption and response and therefore distinct from the needs and purposes of landscape design.

7. VR in environmental planning

Environmental planning applies the process of planning to environmental protection and problem solving. It addresses human–environment interactions at numerous levels and scales, including natural hazards, human and environmental health issues, natural resource use and management, sustainable community design and applications for decision-making based on the functions and processes of natural systems and ecosystem services (Randolph 2011). The different types of urban planning processes, including comprehensive (synoptic), incremental, participatory, adaptive, contingency and advocacy planning, can be adapted to environmental planning. While the various process types can make use of VR, certain processes are more frequently mentioned in the environmental planning literature as having incorporated VR, with participatory planning at the top of the list (Ball et al., 2008).

In the field of environmental planning, two VR applications stand out, the first for visualizing the effects of climate change (Bishop, Pettit, Sheth, & Sharma, 2013; Sheppard, 2012) and the second, for visual impact assessment (Lange, 2011; Portman, 2014; Schofield & Cox, 2005). Both these applications are well suited to VR; participants are asked to take actions, and to make behavior-related decisions, based on their virtual experience. These are usually process-oriented applications that contrast with the more outcome-oriented architectural applications. For these processes, uncertainty must be clearly articulated. Sheppard (2012), who has used VR extensively for visualizing the effects of climate change relevant to environmental planning, the '3 Ds' of visualizing are: disclosure, drama, and defensibility. The latter 'D' relates to uncertainty about outcomes arrived at through models or forecasts. Visualization of climate change effects (for example, flood levels) must be based on sound science, meaning rigorous, replicable models of effects should be "defensible" by the planners conducting the visualizations.

In research on the use of visualization techniques to assess the aesthetic impacts of proposed wind farms, Chias and Abad (2013) characterize the issues to be dealt with as threefold (1) technical – how to visualize anticipated changes in views; (2) theoretical – how to evaluate scenic beauty; and (3) administrative – how to integrate visual aspects in the planning process. For these three objectives, they call for a multidisciplinary approach to impact assessment. Interestingly, we see the increasingly importance of visualization techniques in the approval of projects, such as evidenced by the famous case of an offshore wind farm in the US (Cape Wind) for which approval hinged on the effectiveness of visual simulations (see Phadke, 2010). For such environmental planning applications, questions of "realness", or verisimilitude, have administrative importance and can even engender grave legal consequences – evidence of the need for interdisciplinary approaches for VR research and education.

Another area of concern and development within the realm of environmental planning relates to the assessment of ecosystem services (Portman, 2013). As in aesthetic impact assessment, culture services assessment within the ecosystem services (ES) approach to conservation refers to the relative values placed by viewers on scenic views. VR can be used to assess "cultural" ecosystems services[2] based on aesthetic valuation of scenery in a controlled and accessible environment. Through the awareness of anticipated changes in views (which reflect ES changes), decision-making by planners and stakeholders is improved (Tengberg et al., 2012). A barrier to the application of VR for ES assessment may be the variability in technological capabilities from one laboratory to another and the lack of standardization that hinders progress in the development of agreed-upon, transferable values. Accepted standards would render the application of experiments in numerous applications redundant. Further, standardizing aesthetic values and preferences developed through the use of VR would ease difficulties in ES assessment that arise from the high costs of such endeavors, undertaken by national governments and often subject to limited funding (Portman, 2013).

8. Bringing it all together

Based on our comparative review, we conclude that each discipline has its challenges with the regard to the use of VR and therefore research on the subject lends itself toward different emphases. For architects, despite important contributions of VR to collaboration among practitioners, immersive VR struggles with integrating the three-dimensional urban scale with smaller scales (e.g., building or interior design scale). For landscape architecture, getting beyond descriptive visualizations and incorporating multi-sensory experiences are among the most pressing challenges, as gleaned from the literature. The use of VR in environmental planning often focuses on aspects of the participatory process and therefore has numerous ethical challenges and responsibilities (for example, making sure that uncertainty is accounted for with regard to climate change scenarios). VR applications for environmental planning are distinguishable from those in architecture and landscape architecture by their emphasis on development control and decision-making for a broad range of human-environment interactions. Also, VR is applied more frequently at a larger scale (e.g., view-shed scale) for environmental and landscape planning than for architectural design.

Largely missing from the landscape and environmental planning literature is the use of "theatre" or laboratory conditions for VR. Mixed reality applications incorporating visualization laboratories appear more frequently in the professional architectural design and teaching literature than in the other two sub-disciplines. For environmental planning, with the exception of climate change issues and within the framework for environmental impact assessment, VR applications seem to be less frequently used.

For architectural design, it is difficult to distinguish between the use of the VR in a laboratory or theatre setting versus its application as a digital modeling and visualization tool used in the design studio or practice. The theatre or laboratory setting has advantages for collaboration and immersive and/or interactive designing and it is gaining ground in architectural design education. A number of design students can work together in one viewing venue for real-time interaction while viewing or experiencing the generated reality.

The participatory domain made possible in the virtual reality laboratories and its broad possibilities offer landscape and architectural design researchers and practitioners the greatest advantages. For environmental planning, the advantages of collaboration using such systems have yet to be explored and adopted on a large-scale, even though participatory planning has benefitted based on some initial research in the area of participatory GIS. Interestingly, in Pittman's (1992) early article on the use of VR in a lab setting, only landscape model examples are illustrated, even though the lab described served other disciplines, namely architecture, product design and visual urban design. Almost two decades later, we are still concerned with the possibilities of cross-fertilization between disciplines because truly integrative research agendas from which to build on are in short supply.

As a first step, we acknowledge that the use of the virtual reality expands a work flow that serves all three disciplines by providing an opportunity for planner-user interaction and for users' experience and feedback. VR advantages, including users' interaction with the design, have been added to the traditional necessary steps of the design process (Fig. 3). A similar attempt to enable a VR-designed landscape experience by web visualization systems for the public was initiated by Honjo and Lim (2001). In the VR theater the observers experience the design in a dynamic mode. This proposed flow can be applied to all three fields discussed and can provide common ground. Subsequently, the design process may take a form of cross-iteration comparison contributing to the designers', users' and stakeholders' understanding of the planning and design process.

As has been the case over the past two to three decades, the concept of "good enough" reality prevails. However, for improved reality that takes the form of more "real" VR, there is much to be learned by cross-fertilization between disciplines. Rather than "reinventing the wheel", environmental planners could learn from technological advances made by architects in this regard. After all, architectural design at the detailed scale requires the development of very specific technologies and we find these frequently the subject of literature on VR (e.g., D'Souza et al., 2011; Koutsabasis et al., 2012; Rahimian &

[2] Ecosystem services are defined as "the direct and indirect contributions of ecosystems to human well-being" (TEEB, 2010). There are four types of ecosystem services: provisioning, regulating, supporting and cultural. That last includes values of ecosystems derived from generally non-market values such as heritage, historic-meaning and aesthetics.

Ibrahim, 2011; Ye et al., 2006). Although the scale (building versus land- or sea-scape) may be different (e.g., Portman, 2014), technologies for creating realistic immersive and interactive experiences are needed in all three (see Table 1).

We posit that cross-fertilization among disciplines can be facilitated through the use of faculty-wide visualization laboratories. A symposium which served as the opening event for a new state-of-the art Virtual Reality and Visualization Laboratory ("VizLab") http://architecture.technion.ac.il/Visualization-Lab/ at the Technion (Haifa, Israel) in November 2013 engendered this type of cross-fertilization. It was centered on a lecture series entitled *"VIZWORLD-Spatial Analysis and Cognition in Architecture, Landscape, Urban Planning and Industrial Design"* and was the impetus for this special issue of CEUS. Faculty from architecture, landscape architecture and environmental planning tracks presented research projects that employ VR technologies in a laboratory setting. World-renowned experts from the three disciplines came together for the benefit of researchers, instructors and students. Our impression from the symposium is that much more interdisciplinary work revolving around research and education in VR has yet to be done. This impression came from the common questions raised, i.e., how do we create reality and how do we judge it? What are the advantages of VR and when is it worth the investment? Although each field has different reasons for spatial or temporal inaccessibility to reality, prompting the need, and the capability of various levels of accuracy in the virtual setting, there is much to learn from one another.

In conclusion, we ask whether VR in a laboratory or theatre setting leads us where 'no man has gone before'? Maybe not, but we can certainly say that it leads us where some have gone and many more will follow. Qualified use of virtual reality creates a framework for testing the overall validity of proposed planning and architectural designs, generating new alternatives and conceptualizing learning, instruction and the design process itself.

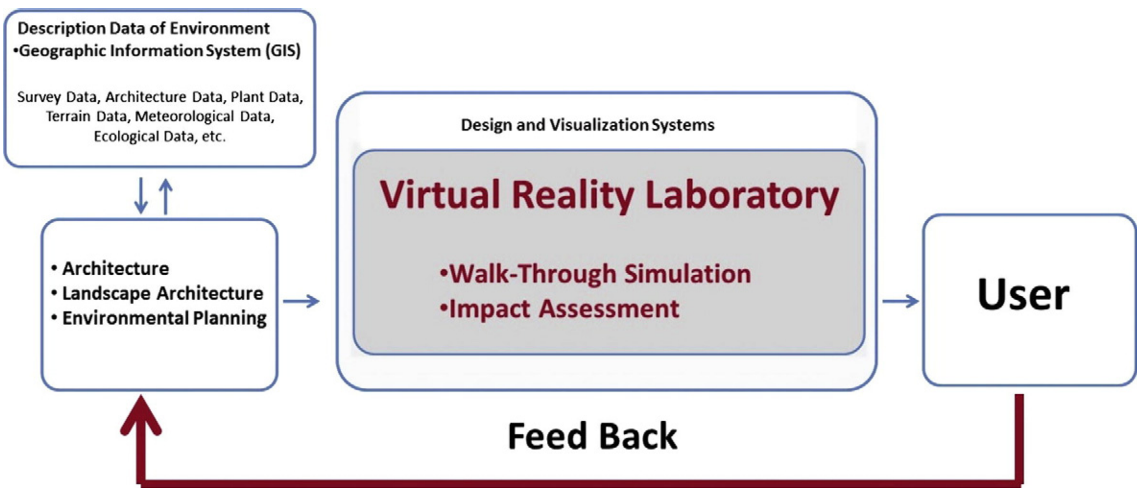

Fig. 3. For all three fields – architecture, landscape and environmental planning – the VR work process for research and educational setting will take the form of retrospective, cross-iteration comparisons through which the first stage investigates research questions and the following stage can develop design alternatives based on the extracted research results.

Table 1
Summary table for the use of VR in the three disciplines of interest in this paper and this issue.

Discipline	Main contributions	Challenges	Opportunities
Architecture	Development in praxis Discovery of 'lost' non-accessible spaces Pre-construction quality of space User behavior simulations	Closing the gap between professional and education/research use	Highly accurate data usually available Fine-scale data available Distant collaboration facilitation Navigating through virtual spaces Testing hypothetical designs Comparison between design options
Landscape architecture	Development in praxis Transitions from inside (architecture) to outdoor (landscape) Scene-series viewing for decision making Integration between GIS based modeling and realistic representations	Appropriate-scale data often lacking Models lack accuracy in details Viewing bias	Hand-held devices offer *in situ* simulations
Environmental planning	Scene-series viewing for policy making	Large-scale data lacking	Stakeholder feedback and participation Less precision needed at fine scale
Cross-disciplinary[a]	Decision-support Moving from conceptual to "concrete" Emotional/all-encompassing viewing New exploration possibilities	Research lags behind system capabilities High costs	Cost reduction through collaboration and multi-use facilities/equipment Less "reinventing-the-wheel" Cross fertilization Involving younger generations Enabling participation of lay people Involving interdisciplinary professionals

[a] Includes cross-discipline use of VR for research and education

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