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Digital Landscape Architecture Laboratory: "Landscape in Transformation – Interactive Data-Sets in Virtual Reality"

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Keywords

Virtual Reality // Simulations // Participatory Design // DataScapes // DataMapping // Data-Driven Communication and Design Strategies // Innovative Point Cloud Technology // Storytelling

ABSTRACT

Landscape architecture is currently at a major crossroad: the conventional approaches to landscape architecture cannot sufficiently support the increasing complexity of environmental and societal issues that require solutions that are both visionary and sustainable. Therefore, landscape architects must explore new design strategies that can accommodate the complex issues facing the profession today. The massive increase in scale that is often involved means that traditional tools of design cannot take proper advantage of the wealth of information at our disposal. To date, data integration into large-scale landscape architecture has been limited mainly to Geographic Information Systems (GIS) analyses for planning and evaluation or for pure data visualization. As part of the international discourse on the theme Big Data – Data Overload, the main goal of this paper is to present a strategy for combining visionary application fields of human interaction with large-scale environmental data flow in the realms of Virtual Reality (VR) and Augmented Reality (AR). The multidisciplinary research project, Landscape in Transformation, at Aalto University in Finland aims at developing an innovative platform in VR/AR to enable the designer and the future users of landscape architecture projects to actively understand and interact with the hidden layers (datasets) of the site. The perception, imagination and engagement with abstract data will open up new possibilities for revealing the relevance of datasets in relation to design.

I. Introduction

In order for the profession of landscape architecture to assert itself in multidisciplinary cooperation in an era marked by profound ecological change and progressive digitalization, a new trajectory needs to be established in design and planning. Global urban tendencies, such as urban sprawl and the rapid growth of cities, require strategies that can integrate datasets with geographical, ecological, sociological and infrastructural factors into planning and design. This exceeds the rather limited and simple integration of GIS data, used mainly for analysis, into the field of landscape architecture. New ways of computational thinking and methodologies need to be developed that can find expression not only immediately in the university setting, but also subsequently in professional practice (Hagan, 2008).

Landscape architects have to be able to handle a high level of complexity in their designs when dealing with dynamic forces, such as water, tidal activity, wind, and changes of season, and their influence on geology and vegetation over time. Therefore, landscape architects are currently challenged to generate a new computational workflow by creating multiple platforms to communicate and exchange data information (Amoroso, 2012) and design strategies. Unconventional thinking is often the first step towards innovation. Pioneering experimental computational approaches are particularly needed in the increasingly complex field of landscape architecture and urbanism.

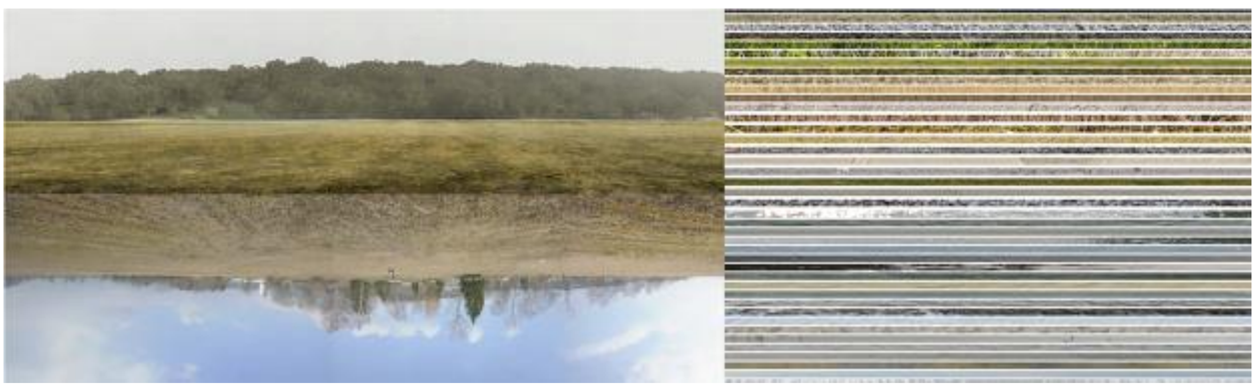

Fig. 1 Reading the complexity of landscape layers through the integration of immersive media technology and programmed methods to unveal the connections between the data sources (student project by ETH MAS LA students: Sofia Prifti and Jacqueline Frizi).

Source: Courtesy of Pia Fricker, Aalto University, Finland, Digital Landscape Architecture Studio 2017 in cooperation with ETH Zurich, Prof. Christophe Girot.

This situation has led to the development of a methodological framework and tools that will enhance the potential of landscape architecture by focussing on computational design methodologies within the realm of VR/AR (Danahy, 2012). Landscape architecture has to be strengthened as an integrative discipline deeply rooted in shaping and preserving nature through the design of sustainable environments with a site-specific character and the integration of future-oriented technology. In an era of data overload (Contin, 2012), special attention must be given to how data is handled and how specific information is chosen in order to move from mere DataMapping and DataScapes to the development of coherent and fully functional data-driven design tools (Huang, 2013).

The goal of the research platform is to close the current gap between visual representation (Amoroso et al. 2012) and the analysis of data in the design process. In order to do so, the research examines possibilities enabling a direct handling of data in the design process for perception and storytelling purposes within VR/AR (Dourish, 2001). The designer should be given the ability to influence and steer the output with direct feedback in order to achieve an iterative design process. Currently, the representation of datasets can easily be, often inadvertently, incorrectly interpreted or purposefully used to influence the design process (Klanten et al. 2012). Therefore, the exploration of immersive interaction technologies opens up a new field for interacting and reinterpreting the flow of data in order to create audio-visual interaction spaces that will open a variety of tools to help understand the changes in our living environment.

A multidisciplinary research team was founded in 2016 at Aalto University consisting of architects, landscape architects, VR artists and specialists from the fields of data-capturing and data-mining. Under the leadership of Pia Fricker, a new Chair for Computational Methodologies in Landscape Architecture and Urbanism will constitute the interface between the Departments of Architecture, Film, Television and Scenography, Media, and the Built Environment at Aalto University.

II. Tracing Virtual Reality – Cyberspace – Augmented Reality

The desire to put yourself into an immersive parallel identity goes back to the nineteenth century and the creation of the panoramic image (360-degree murals or panoramic paintings) and its representation in spatial installations. Panoramic paintings resented the first visual mass media[1] in Europe. The panorama is considered the art form of the Industrial Revolution and stilled the yearnings of the citizens for new forms of entertainment.

Up until the development of computer technology, scientists, such as Charles Wheatstone,[2] who shortened the distance to Cyperspace in 1838 through the discovery and development of stereoscopic photos and viewers. The desire to couple awareness and interaction sensors in generated spaces is represented by the drive mechanism of connected development.

Driven by the rapid developments in electromechanics and computer technology, the Sensorama Machine,[3] created by Morton Heilig in 1950, enabled the breakthrough of VR technology. Military developments and NASA both served as motors for further developments. If one considers the relevance of this technology for architecture, then the presentation by Ivan Sutherland and Bob Sproull of their first VR/AR head-mounted display, HMD (Sword of Damocles) in 1968 at MIT's Lincoln Laboratory certainly serves as a milestone. Ivan Sutherland had already described his vision[4] for the future of virtual reality in 1965 at a computer conference when he said that you shouldn't think of a computer screen as a way to display information, but rather "as a window into a virtual world that could eventually look real, sound real, move real, interact real, and feel real". This was a time of massive innovation in responsive and immersive technologies (Sutherland, 1968).

Just one year after Sutherland`s head-mounted display, the term "artificial reality" was invented by Myron Kruegere.[5] His development of computer-generated environments that responded to the people using

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[1] In 1787, the Irish artist Robert Barker applied for a patent for his 360-degree panorama image at the London Patent Office. In order to increase the illusionary effect of the image, many panoramas in the 1830s were expanded to include *faux terrain* (false ground).

[2] In 1838, Charles Wheatstone's research demonstrated that the brain processes different two-dimensional images from each eye into a single object of three dimensions. Viewing two side-by-side stereoscopic images or photos through a stereoscope gave the user a sense of depth and immersion. The later development of the popular View-Master stereoscope (patented 1939) was used for "virtual tourism". The stereoscope's design principles are being used today for the popular Google Cardboard and for the low-budget VR head-mounted displays for mobile phones. www.vrs.org.uk/virtual-reality/history.html

[3] The Sensorama Machine was invented in 1957 and patented in 1962. It is a simulator for use by one to four people that provides the illusion of reality using a 3-D motion picture with smell, stereo sound, seat vibrations, and wind in the hair to create the illusion.

4 "The Ultimate Display" paper was published in 1965 in the *Proceedings of the IFIP Congress*, pp. 506–508.

5 Myron Kruegere, a video artist, experimented with the manipulation of reality in interactive art projects. Kruegere argues that one of the computer's most unique features, its ability to respond in real-time, has yet to be fully exploited. For the past 16 years, he has been creating an interactive computer medium in which the computer perceives a participant's actions and responds in real-time with visual and auditory displays. He describes his conceptual discovery process as work in progress. VIDEOPLACE: A Report from the Artificial Reality Laboratory, *Leonardo*: Volume 18, Number 3, July 1985, pp. 145–151.

them enabled people to communicate with each other in a responsive computer-generated environment, despite being in different locations. This technology was later integrated into the field of architecture with the use of datagloves and caves, mainly invented by his Visual Programming Lab.

The term, Virtual Reality (VR), was mainly used by Jaron Lanier, founder of the Visual Programming Lab (1985), as an umbrella term for circulation purposes. Among the many VR technologies developed in his Lab, were the first commercial VR goggles.

Parallel to this, the area of Augmented Reality (AR) was further developed. In contrast to virtual reality, augmented reality presented additional information in the foreground. For the visual modality, this led to technical requirements for an essential hardening agent to use in tracking and calibration (Webster et al. 1996).

Over the last twenty years, the game industry has been the main market outlet for this technology. In 2010, Palmer Luckey designed the first prototype[6] VR goggles, Oculus Rift,[7] which came on the market in 2014 as a test version. Since then, more than 200 similar products have been developed in the area of HMD and VR goggles (mobile VR viewers). These latest tools are equipped with room-scale tracking and gesture input devices and open up many application fields within architecture and landcape architecture.

III. Tracing Big Data

Finland's current marketing effort is promoting Helsinki as the most successful open-data city in the world. This is based on a decision to publish all the available databases in the Helsinki area, which subsequently promoted rapid development in Open-Data City and Smart City projects. A critical observation of this phenomenon questions whether we will eventually no longer want to analyze or even understand the vast quantity of data available. Without the exploration of meaningful contextual questions, the data available remains unattainable and difficult to codify.

New concepts, such as smart cities, DataScapes,[8] and geodesign,[9] are products of this powerful and influential trend. In addition to the continued simplification of software products, the broad field of Big Data currently offers a wide spectrum of innovative application areas for multifaceted data to be integrated into landscape architecture (Walliss, Rahmann, 2016). In the current situation of data overload, almost everything is publicly available, including relevant landscape architecture data, such as geographical data and geographical data in combination with technical data (Oxman, 2014). A variety of geodata are available in high quality and levels of coverage through different sources in Finland, as well as throughout most of the world. Not yet recorded data can be quickly and easily gathered through the use of mobile elements, such as UAV's[10] in combination with wireless sensors or wireless sensor networks (WSN).[11]

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[6] This prototype, built on a shell of another virtual reality headset, was only capable of rotational tracking. However, it boasted a 90-degree field of vision that was previously unseen in the consumer market at the time. This initial design would later serve as a basis for later designs. Rubin, Peter. (2014). Oculus Rift. *Wired, 22*(6), 78.

[7] Oculus Rift is a virtual reality headset developed and manufactured by Oculus VR, a division of Facebook Inc., released on March 28, 2016. Oculus VR initiated a kick-start campaign in 2012 to fund the Rift's development.

[8] DataScapes have a strong relationship to formal spatial realizations of extrapolations and assumptions of the data behind them. The resulting unexpected forms go beyond the artistic representation of known geometries and create abstract seas of meaning through the mining of specific datasets. MVRDV was one of the first architecture offices to formulate the DataScape method for their design approach.

[9] In Michael Flaxman`s understanding: "Geodesign is a design and planning method which tightly couples the creation of design proposals with impact simulations informed by geographic contexts."

[10] An unmanned aerial vehicle (UAV), commonly known as a drone, is also referred to as a remotely piloted aircraft (RPA). https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle.

IMAGE: STUDIO

The question today is no longer how one obtains data, but rather which data has design-relevant significance and how this data can be understood and interpreted to generate relevant information. The handling and integration of different databases may vary extremely and from moment to moment among the different professions (Pond et al. 2012). In general, however, one can state that understanding and visualization are still at the forefront of many projects.

IV. Application Potential for the Field of Landscape Architecture

Brian Barth's article: "Virtual Reality Is Making a Leap; Will Landscape Architects Be Ready?" appeared in the December 2015 issue of *Landscape Architecture Magazine,*[12] and described the ongoing discussion of possible implementation areas of VR and AR technology in landscape architecture. Barth quotes John Danahy, founder of the Centre for Landscape Research at the University of Toronto: “VR is more than just a fun design tool, it is also a tool that can change the way the environment is perceived by both the public and the practitioners. VR technology will serve a broader social purpose to the extent that it is used “as a prosthesis for design thinking…. and to educate a group of people to think for themselves [by] teaching them a language for seeing the landscape.”

Fig. 1 In order to understand the full power of VR/AR technology, the cooperation and exchange with the game

[11] A wireless sensor network (WSN) has spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. https://en.wikipedia.org/wiki/Wireless_sensor_network.

[12] The American Society of Landscape Architects (ASLA) magazine: https://landscapearchitecturemagazine.org/2015/12/08/get-real/

industry is essential to support the creative usage of the devices. Students of the Digital Landscape Architecture Design Studio at the Dep. of Architecture are testing the VR equipment of Remedy Entertainment and the infrastructure of the UrbanMill at the Aalto Campus to communicate their design strategies.

Source: Courtesy of Pia Fricker, Aalto University, Finland

The technology is available where the innovative areas of application can coexist within the large-scale planning and design activities, however, the question remains: How can the themes of Big Data and VR/AR capture new possibilities for the profession of landscape architecture? The opportunities extend far beyond creative communication concepts (Seebohm et al., 2008) and natural and realistic images of the surroundings, they would allow spectators to investigate themes and topics in their own individual actions.

Visualizations and simulations have belonged to the communications repertoire of architecture and landscape architecture since their inception. Especially within the rapidly developing area of open-data and its integration in landscape architectural practice, it is essential to have knowledge of related areas, such as VR and AR, in order to accurately formulate the potential and be able to verify them. We are now beyond representation (Tufte, 1990; Tufte 2001); it is about narration, context and interaction.[13] The challenge lies, not in knowing the answer to the question, but in knowing the question.

VR and AR technologies allow people from all backgrounds and abilities to engage and interact with digital environments intuitively – the same way we all engage with our natural surroundings (Giannachi, 2011). It can also help us to create faster and more efficient prototyping and iterations of design variations. Within the foreseeable future, the use of VR devices and different kinds of online real-time apps will be part of daily life. As part of a participatory process, the outcomes could automatically feed back into the decision- and design processes.

IV.1 Formulation of a Theoretical Position and Instructions for Action

Researchers, for example, Jeremy W. Crampton,[14] are raising the question: “How is Big Data framing the contours of our lives today in the age of the algorithm?” Relevant positions of key figures in this domain with a strong connection to the practice of landscape architecture are summarizing the ongoing discussion. Jürgen Döllner[15] of offers this overview: “A rapidly growing collection of digital tools, systems, and applications is shaping the way we manage challenges in scientific disciplines and, to a significant degree, defines the scope of possible options and solutions we can develop. In the past few years, a general movement toward distributed, service-based IT solutions can be observed. The software architecture of geovisualization applications and systems demands efficient methods for coping with the conditions and restrictions of mobile devices, such as limited networking and computing resources."[16]

Carl Steinitz, a former member of the Harvard Laboratory for Computer Graphics[17] states: “For serious societal and environmental issues, designing for change is inevitably a collaborative endeavor, with participants from various design professions and geographic sciences, linked by technology from several locations for rapid communication and feedback, and reliant on transparent communication with the

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[13] Miro Roman, researcher at the Chair of CAAD – ETH Zurich, describes in his paper “Abstract Object in World of Data” presented at eCAADe2016, the correlation of symbolicity of information and the potential for architectural articulation.

[14] Jeremy W. Crampton, Associate Professor at the University of Kentucky, Department of Geography, works on the intersections of critical cartography, GIS and political geography.

[15] Jürgen Döllner is Professor for Computer Science at the Hasso-Plattner-Institute at the University of Potsdam, where he is Head of the Department of Computer Graphics and Visualization.

[16] Döllner, 2015, Keynote speaker at the Digital Landscape Conference (DLA) 2015 in Dessau.

[17] Carl Steinitz is an Alexander and Victoria Wiley Professor of Landscape Architecture and Planning at Harvard and Emeritus Professor of the Harvard Graduate School of Design. He is the founder of the GeoDesign methodology.

people of the site who are also direct participants.”

When one sets these theses in the context of landscape architecture, it becomes apparent where the potential, as well as the challenges, lie in the area of Big Data (Fricker, 2015). Depending on the scale and complexity of the given landscape architectural problem and its context, different databases may be relevant. The research addresses both sociological and cultural questions in relation to Big Data and the questions of how this development may be embedded in the theoretical context of information theory as well as what kind of impact can be expected from it. In the broad field of Big Data questions, the emphasis of the analysis is on parameter-based design, the correlation of data generation and integration and its possible qualitative improvement of a design.

The participatory systems developed up until now could not contribute real findings to the process and did not transmit any design-relevant interaction with the layers of a place/site/location. The goal is to translate the methodology of filmmakers and game designers as a means of further developing how to engage with environmental data and convey complex information in an intuitive way that will enable all stakeholders to participate in decision-making processes (Grau, 2003). Using the expertise of our team in the area of systems of representation, our goal is to bring different communities together in a design process that results in meaningful artifact design and storytelling.

V. Research by Design

Contemporary Virtual, Augmented and Mixed Reality interfaces (VR, AR & MR) give incredibly intuitive access to digital environments (Hale et al. 2009). Our transdisciplinary research hub created a set of tools and workflows that combine highly detailed geometrical data of a site with 3D models and point clouds of a future design, as well as site-specific environmental datasets, such as rainfall, wind or ambient noise data. The results of this first step will be combined and designed into an interactive environment and presented as part of an innovative platform for VR/AR systems, where both designers and prospective users of a landscape architecture project will be guided through these datasets with a combination of narrative tools and contemporary game mechanics (Tierney, 2007). This will allow the various participants to actively understand and interact with the hidden layers of a physical location and finally giving them a deep understanding of and connection to a specific environment. The resulting cutting-edge spatial perception space aims to open up new kinds of simulation and participatory processes in environmental design and urban development in order to shape the future and give sustainable answers to societal and environmental challenges.

Fig. 2 Storytelling with high-resolution data. Series of pointcloud animation screenshots produced by the students Elina Haapaluoma, Laura Kakkola, Nita Miinalainen and Camilla Lindroth-Vanhalla. The students were using a terrestrial scanner to generate a pointcloud, which was used to produce a 1 minute movie telling their perception of the site integrating sound.

Source: Courtesy of Pia Fricker, Aalto University, Finland, Digital Landscape Architecture Studio 2017 in cooperation with ETH Zurich, Prof. Christophe Girot - Matthias Vollmer and Johannes Rebsame, SCANVISION.

VI. Pilot Teaching Project: Entering Mixed Reality – Exploring the Island

As part of the new Professorship for Computational Methodologies in Landscape Architecture and Urbanism, the experimental VR lab at the Department of Architecture will be hosting its first teaching experiment in autumn semester 2017. The overall goal of the pilot prototype studio is to investigate the potential of integrating new technology to achieve a new reading of the Big Data topic within the field of a complex, large-scale landscape design topic.

The studio, New Approaches to Reality through Integration of Immersive VR Experiences, is geared towards Master's students or advanced students in the fields of landscape architecture, architecture, media, film and engineering. The incorporation of VR into the workflow of landscape architects, architects and designers is already standard in many offices throughout the world. Questions will be examined from a methodological, design-supportive point of view, for example:

- How can we explore this new workflow in order to re-imagine the given possibilities within mixed reality?
- How can we achieve a new way of participatory or collaborative systems by integrating VR in order to understand the complexity and potential of the future task, i.e. integrating the challenges of climate change, national and international societal challenges, etc.?
- How do these interrelated questions on datasets offer new vantage points on the landscape architectural ramifications of climate change, extending and amplifying our understanding of ideas such as resiliency, sustainability, and eco-technology.

In the experimental studio, the focus lies on entering the next level of VR and Mixed Reality, i.e. beyond a pure representation of an existing or future design. Intensive studio sessions on theoretical questions, software learning (mainly Revit and Unity) and storytelling will enable the students to formulate their personal position for integrating VR into their future career. The studio is supplemented by two intensive workshops and a lecture series with guest specialists. The use of programming will be studied in order to be able to create individualized tools on an open-source platform that are to integrate various databases, e.g. geodata and dynamic data, such as large-scale data flow and small-scale human behavior directly into the design process. This is a far cry from predefined software solutions and is already standard in parametric design.

The studio is a continuation of the Digital Landscape Architecture Studio series, which was conducted in 2015 for the first time by Pia Fricker at the Department of Architecture, Aalto University. The goal of the underlying teaching methodology is to investigate the potential of the integration of new information technology tools in the field of a complex, large-scale landscape design. The studio concentrates on achieving a new reading of landscape systems by integrating emerging tools, such as site-specific data capturing and data visualization (Cantrell, Holzmann, 2016), in combination with traditional hands-on design tools. Students are encouraged to cross disciplines and theoretical boundaries and critically analyze the dataset information as a design tool. An important component is the immediate linking of visionary technical questions and developments from the area of information technology with theoretical questions and the possibility of their practical implementation in the area of design.

In particular, the methodological approaches used in the programming module show the possibilities of programming tools that are customized to the conceptual demands of the design and therefore can be directly integrated into the planning. Research is also being conducted on workflows that thematically question the kind of data before integrating datasets in order to determine which data is relevant and how it can be integrated into the design process (Maslow, 1966).

Fig. 3 Field work of students of the Department of Architecture: Integration of sensor data (wind, noise and water qualitiy). This data was integrated through a grasshopper script into the design process and overlayed with high-resolution data from the site, generated from a point cloud.

Source: Courtesy of Pia Fricker, Aalto University, Finland, Digital Landscape Architecture Studio 2015/2016

In order to be able to define approaches to highly complex, large-scale problems, it is necessary to train people in the sensitive handling of a site. Students must learn how to understand the qualities of a place in order to subsequently be able to formulate the right questions. Without clear intent, accessible data is worthless, since no useful information can be generated from it (Fricker, 2016).

VII. Conclusion – Outlook

The research conducted by the team in the field of Smart Data out of Big Data[18] has shown the potential of using data differently throughout the whole design phase. The possibilities of VR/AR open up new intuitive ways of interacting with data streams in order to integrate them in an interactive process throughout all the phases. The contribution of this long-term visionary research platform to the field of contemporary landscape architecture, urban design, geoinformatics, and the application fields of VR and AR is very substantial and significant, as the developed workflows will close the current gap between pure data visualization and participatory and perception tools to encourage future users of a site to contribute to the process. It combines cutting-edge knowledge and new ideas and concepts, rather than a mere refinement of existing ones. The innovative team constellation opens unexplored areas of investigation and new directions for joint research.

Further interdisciplinary research projects and case studies involving international academic and professional partners will contribute to the development of a deeper methodological integration of immersive technology to enhance the academic and societal impact.

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[18] Until 2016, Pia Fricker was setting up and directing the Master of Advanced Studies Program in Landscape Design Simulation at ETH Zurich , Switzerland and has also conducted several projects in the field of data-supportive design.

References

Amoroso, N. (2012). *Digital Landscape Architecture*. UK: Thames & Hudson.

Amoroso, N., Sechter, H. (2012). 3D Geo-Design Mapping Using DataAppeal, *Peer Reviewed Proceedings Digital Landscape Architecture 2012*: Wichmann, 46–355.

Cantrell, B., Holzman, J. (2016). *Repsonsive Landscapes*. New York: Routledge.

Contin, A., Paolini, P., Salerno, R. (2013). *Innovative Technologies in Urban Mapping: Built Space and Mental Space.* Cham: Springer.

Danahy, J., (2012). *Visualizing Urban Futures*. GeoDesign Summit, Redland California

Dourish, P, (2001). *Where the Action is: The Foundations of Embodied Interaction*, MIT Press.

Fricker, P., Munkel G. (2015). Data Mapping – Explorative Big Data Visualization in Landscape Architecture, *Peer Reviewed Proceedings Digital Landscape Architecture 2015.* Zurich: Wichmann.

Fricker, P., (2016). *Extending the Limits: Using Big Data as Integrated Design Tool.*
Proceedings 2016: ASK.the.Conference “Education For Research, Research For Creativity”, University of Warswaw.

Giannachi, G, Kaye, N, 2011. *Performing ‘presence’: between the Live and the Simulated.* Manchester UP, Manchester.

Grau, O. (2003). Virtual art: from illusion to immersion. *Leonardo*, Cambridge.

Hagan, S. (2008). *Digitalia*. New York: Routledge.

Hale, C. et al. (2009). We Drew What We Imagined: Participatory Mapping, Performance, and the Arts of Landscape Making. Journal: *Current Anthropology* 50. Chicago: University of Chicago Press. 443–76.

Huang, Lin, M. & Weidong, H. (eds.). (2013). *Innovative Approaches of Data Visualization and Visual Analytics.* U.S.A: IGI Publisher,

Klanten, R.,Ehmann, S., Bourquin, S., Tissot, T. (2010). *Data flow 2: Visualizing Information in Graphic Design*. Berlin: Gestalten.

Pond, E., Schroth, O. et al. (2012). Collaborative processes and geospatial tools in support of local climate change visioning and planning. In Chrisman, N., Wachowicz, M. (Ed.), *The added value of scientific networking* (pp. 213–250). Quebec: GEOIDE Network.

Tierney, T. (2007). *Abstract space – beneath the media surface*. California U.S.A: Taylor & Francis.

Maslow, A., H. (1966). *The Psychology of Science*. USA: Maurice Bassett Publishing.

Oxman, R. (2014), *Theories of the Digital in Architecture*. London & New York: Routledge.

Seebohm, T., & Danahy, J., (2008). Towards constructive dialogue with real-time visualization and GIS. In Beesley, P. (Ed.) *Ourtopias*. Waterloo Architecture Cambridge: Riverside Architectural Press.

Sutherland, I., (1968). “A Head-Mounted, Three-Dimensional Display”, *AFIPS Proceedings of the Fall Joint Computer Conference*, Part I, pp. 757–764.

Tufte, E. (2001). *The Visual Display of Quantitative Information*. USA: Graphics Press LLC.

Tufte, E. (1990). *Envisioning Information*. Connecticut, USA: Cheshire.

Webster, A., Feiner, S., MacIntyre, B., Massie, W. and Krueger, T. (1996). Augmented reality in architectural construction, inspection and renovation. In *Proc. ASCE Third Congress on Computing in Civil Engineerin*g (pp. 913–919).

Walliss, J, Rahmann, H. (2016). *Landscape Architecture and Digital Technologies: Re-Conceptualising Design and Making.* London & New York: Routledge.