Virtual Environments as a Technological Interface between Built Heritage and the Sustainable Development of the City

Georgios Artopoulos

Science and Technology in Archaeology Research Centre, The Cyprus Institute, Cyprus

Panayiotis Charalambous

Computation-based Science and Technology Research Center, The Cyprus Institute, Cyprus

ABSTRACT

This article proposes a methodology for the cross-disciplinary study and analysis of complex urban realities, such as the historic city of Nicosia, Cyprus, the last divided capital of Europe, with the use of advanced digital tools for the creation and development of real-time virtual environments for research and collaboration that explore the capacity of analysing data of users' behaviour in space. This research envisions contributing a fresh understanding of cultural and functional pressures in Nicosia's contested urban environment through the analysis of observational data. The objective of this research is development of a digital platform, which through immersion, interactive design and crowd simulation will enable the evaluation of alternative planning scenarios and design interventions in the context of the management plan of built heritage in open public spaces that used to be popular within the urban fabric of European cities but are now forgotten or in limbo due to political, economic, or social pressures.

Keywords: Virtual reality and augmented reality; ICT; Heritage documentation and management; Interactive environments; Spatially distributed narratives; Crowd simulation; Crowd analysis.

INTRODUCTION

This article presents research that combines spatially distributed narrative structures, immersive technologies and participatory design aspects with urban modelling and computational simulations, as well as digital documentation and reconstruction techniques, for the development of a new inclusive practice of re-activating historic urban sites that have been neglected. The main objective of this research is to capture and visualise the historic palimpsest of urban environments in Mediterranean cities such as Nicosia and at the same time to engage users and local communities in the creative aspects of these patrimonies' management.

This effort is built on a simulated immersive environment that offers opportunities to users for interaction with new media in order for them to explore the transformation of heritage sites through the years – from their construction to present day – in consent with the bodily experience of sojourning in surrounding areas of the city. Through the operation of digital interaction booths, planned to be installed on site and at the premises of the research organisations participating in this effort (Figure 2[8]), the presented virtual environment will serve as a testing platform for the Municipality, the stakeholders, researchers and professionals working in the field to simulate possible site management, and the associated urban design, strategies prior to their implementation.

HISTORICAL AND SPATIAL CONTEXT

This research considers that heritage involves all types of culturally embedded commons of an urban environment, including squares, parks, sidewalks and riverbanks, buildings and monuments, and all these spatial constructions that can be used to influence positively the social cohesion of neighbourhoods. Built heritage could be promoted in such a way that, instead of provoking tensions and division between groups, it would offer spaces of inclusion, interesting everyday experiences and provide a sense of belonging to socially excluded communities. Historic public spaces can offer these capacities, along with opportunities for learning and social interaction. When this happens then public spaces succeed in becoming essential part of the everyday life of a city - i.e., part of the network of its communal amenities and common resources. By doing so, built heritage and public spaces contribute to the well-being and quality of life of the citizens.

The Eastern Mediterranean preserves significant examples of cities whose continuous history can be traced all the way back to Prehistory and Antiquity. In particular, the capital of Cyprus, Nicosia, is considered amongst the most contested urban environments having historically layered pasts and perplexing present-day realities in Europe. Between 2013 and 2014 the part of the moat outside the Paphos gate was excavated in an effort led by the Cyprus Department of Antiquities and the Municipality of Nicosia not only to preserve the history of the area and the medieval fortifications but also to develop and reactivate the neighbourhood. This was an area forgotten and abandoned during the last couple of decades due to the gradual movement of the commercial and cultural activities away from the old city centre to other parts of Nicosia.

Figure 1. [top] Panoramic view of the Paphos gate archaeological site, a patrimony of the city that the presented research attempts to re-use and manage for the re-activation of the neighbourhood (photograph); [middle] aerial view of the area of the Paphos gate archaeological site with the surrounding sidewalks and roads (view of the 3D

model of Nicosia); [bottom] eye level point of view of the Paphos gate as approached from the old city in the virtual environment.

The rehabilitation of the historic site of the Paphos gate is directed by the Cyprus Department of Antiquities, with the support of the Municipality of Nicosia, and is co-funded by the EU. The aim of the excavation activity was to unearth and promote the historical continuity of the place from the Middle Ages until today as the gate operated without interruption during the Venetian, Ottoman period and the British rule (Figure 1). The spatial context of the site comprises: the buffer zone running through the site at its thinnest section, like a thread stretched against the medieval walls at the north side of the area (Figure 2 [step 5.3]), the Holy Cross Catholic Church of Nicosia (Figure 2 [step 5.2]), which lies on the buffer zone with each side of the building being accessible from the respective part of the city. The moat that runs around the medieval walls that encircle the old city (both sides of it), is understood as urban commons, as a resource of the city that can contribute to the identity of the historic core (Figure 2 [step 5.4]). Then there is a United Nations station overlooking the site, and also the Kastelliotisa hall, which was used in the past as a female convent and was originally part of the Lusignan palace (13^{th}-14^{th} c.) (Figure 2 [step 5.5]). The Police headquarters built on top of the gate - an addition that changed completely the structure and form of the Paphos gate (Figure 2 [step 5.6]), and the carcass of the Spitfire coffee shop across the road from the Paphos gate, which was popular, among the British soldiers, standing next to the gate reminiscent of the final years of British rule on the island.

Next to the Holy Cross Catholic Church of Nicosia and at the bottom of what used to be a narrow street that follows the direction of the Paphos gate are now barracks before the buffer zone that render it a dead street. This is one of a couple of areas across the Nicosia buffer zone that are considered by bi-communal initiatives to become open to the public as a checkpoint that will allow crossing to the other side. This was yet another very convincing reason behind the selection of this site by the authors of this research (see Acknowledgements) as a pilot for developing capacity and demonstrating the potential of the experimental practice presented in the chapter, together with the timing of the archaeological excavation by the Department of Antiquities. In the likelihood of opening the crossing this area will become a popular tourist destination, which together with the thousands of inhabitants of both sides of Nicosia (Turkish-Cypriot and Greek-Cypriot) who will be walking across - as it currently happens in the existing checkpoint at Ledras Street - will put a lot of stress on the circulation infrastructure. In this case the design and organisation of the public space in the area would be required to be pedestrian-friendly. These considerations influenced the scope and motivation of the presented research, as this was developed to lay the grounds for a practical tool that would be useful to planners and policy makers of the Municipality who would thus be enabled to engage scholars from various disciplines, stakeholders and the local communities in the dialogue and public consultation that should precede the implementation of design interventions in the contested historic urban space of Nicosia.

Figure 2. The workflow of the user engagement research on heritage management explained visually in steps.

WORKFLOW

The workflow of the presented research is a hybrid of complementary digital documentation techniques (e.g., terrestrial and aerial photogrammetric tools), immersive technologies for interaction and user engagement, and design and planning practices for the drafting of physical interventions in the site of study. In particular this workflow includes the following steps, as illustrated above in Figure 2:

1. Use precise 3D model of the urban environment created based on data provided by the Land Survey Department of Cyprus, cf. (Figure 2 [1;2]). Digital Terrain Model generated from contours every 5 meters.
2. Identify spatial issues that challenge the image and experience of visiting the site under study, e.g., obstructions, visual noise, poor signage, and barriers to pedestrian movement, unwelcoming environment for the elderly and physically disabled, safety problems, etc., cf. (Figure 2 [4])
3. Map real world observations of the pedestrian circulation around the site of interest in the 3D model of the city, cf. (Figure 2 [3]).
4. Represent and visualize the historical context of the site in the immersive environment for the users to explore and interact with in testing sessions of the virtual Reality platform, cf. (Figure 2 [5])
5. Enable users to draw their one walking path and platforms on the archaeological site with the motivation to explore the site while they walk in a virtual environment of the real city area. The interface involves a mobile app for the sketching of proposed routes in and around the historic site by moving the red points on the touch screen of a tablet, cf. (Figure 2 [6] ©Colter Wehmeier).
6. These routes are then automatically mapped in the virtual environment and generated as 3d objects in the virtual environment for the users to walk on, cf. (Figure 2 [7] ©Colter Wehmeier).
7. These routes are then available to their ‘creators’ to visit the site virtually and to assess the opportunities for exploration that their design offers to them, cf. (Figure 2 [8]).
8. Finally, the user-suggested routes inform the architectural design of the proposed intervention for the post-excavation management of the archaeological site, which the Department of Antiquities will implement, in collaboration with the research team and the Municipality of Nicosia, in their effort to re-integrate the site in the everyday life of the area, cf. (Figure 2 [9]).

Immersive Computing

The application of the concept of gamification (Squire 2011; Steinkuehler, Squire and Barab 2012) in community design and urban planning is an area of design research that is currently attracting significant attention from architects, civic authorities and policy makers, cf. (http://blockbyblock.org). It is considered that through the use of interactive visualizations of public space, it can enable participation of local communities and help individuals that are typically excluded to raise their voice.

In the presented research this becomes possible through the ‘virtual world creator’ feature of the platform. The virtual platform allows users to choose, sketch, follow and virtually explore paths and routes inside the projected space in order to offer their personal account of how the specific public space should operate and consolidate their understanding of the complex urban space (Figure 2). The real-time exploration of a projected space extends the participants’ experience of street walking into a journey of exploration, discovery and understanding innate spatial relations.

The research draws on computational approaches to perception, which hold that perception is the result of nervous system activity that modifies and processes raw sensations into reality (Bernstein et al. 2006). Hence

the presented research attempts to offer stimuli to specific sensations of the users' bodies, namely visual stimuli, auditory and bodily movement (via the VR kit that enables navigation in virtual worlds), in order to evaluate projected spatial scenarios. Arguably this is only a fraction of the multifaceted and polyvalent sensorial landscape of the human body, and spatial cognition is not simply a visual process, an issue that has been extensively discussed in the literature (Gaylean 1982; Wiley 1990). Additionally this research recognises the shortcomings of formalisation and the numerous difficulties in transferring the complexity of real-world situations –conditionally- in virtual environments, as well as in engaging the latter in interpretative research activities (Blanke et al 2010; Bowers 1996; Munoz-Cristobal 2015).

Visualization has been described as the 'inner landscape of our perceptions' (Samuels & Samuels 1975; Kosslyn 1983), and this is the starting point of the research presented, which contributes in the discussion about the use of virtual reality in educational activities (cf. McClurg 1992; Winn & Bricken 1992; Regian et al 1992; Bricken 1992; Bricken & Byrne 1993; and Byrne 1993). Specifically, the real time immersive technology employed in the research will hopefully allow the study and analysis of the impact of depth perception, interposition, relative size, height in the visual field, texture gradients, convergence, motion parallax and looming on the articulation of user experience. In the presented application the issue of motion sickness, as a result of the lack of sensory motor integration, was dealt by enabling movement via a point and transport type of interface, similar to the one implemented in Google Earth VR.

Crowd Simulation and Analysis

In support of this need for alternative means of interpretation of the many different ways citizens use - and therefore understand - common resources of the city, such as heritage sites, this research explores the potential of crowd simulation in projecting observational data within future conditions, in order to evaluate possible impact of planning scenarios that are under consideration by the relevant stakeholders of the city (authorities, etc.). Crowd simulation is the process by which multiple virtual characters are simulated in a given environment; this is a fairly complex process that includes various aspects such as character appearance, animation, collision avoidance and high level behaviour and overall crowd size and characteristics. Applications of crowd simulation include enhancing virtual scenes (e.g., for movies, games or VR) or analysing the behaviour of crowds in different scenarios such as evacuations or events helping in the process for better design of buildings or urban environments. Having realistic crowd simulation in the presented approach enhances the immersion of users and affects the way they make decisions on designing paths since heritage sites are often crowded.

Several methods have been developed to simulate crowds; these include flow-based (Treuille et al. 2006; Narain et al. 2009), force-based (Helbing and Molnar 1995), and geometrically-based approaches (Van den Berg 2011; Ren et al. 2016). Recently, data-driven crowd simulation methods have emerged as an attractive alternative to manually defining the crowd simulation model (Lerner et al. 2007; Charalambous and Chrysanthou 2014). The promise in these approaches is that agents will "learn" how to behave from real-world examples, keeping the natural crowd ambiance with a wide range of complex individual behaviours without explicitly defining a behavioural model. This research invests in utilizing data from real world crowds, both for simulation and analysis of crowd behaviour in different scenarios (e.g., different paths as defined by real users), hence the case presented focuses on data-driven approaches. Specifically, as a first approach of integrating virtual crowds in our system, actual crowds from videos of pedestrians were used to populate the area around Paphos gate (Figure 3). The process involved a) tracking spatio-temporal trajectories of people in image space, b) ortho-projecting them from image to world space and finally c) animating them by placing virtual characters on them. This

process results in virtual crowds that imitate exactly the behaviours observed in the input videos.

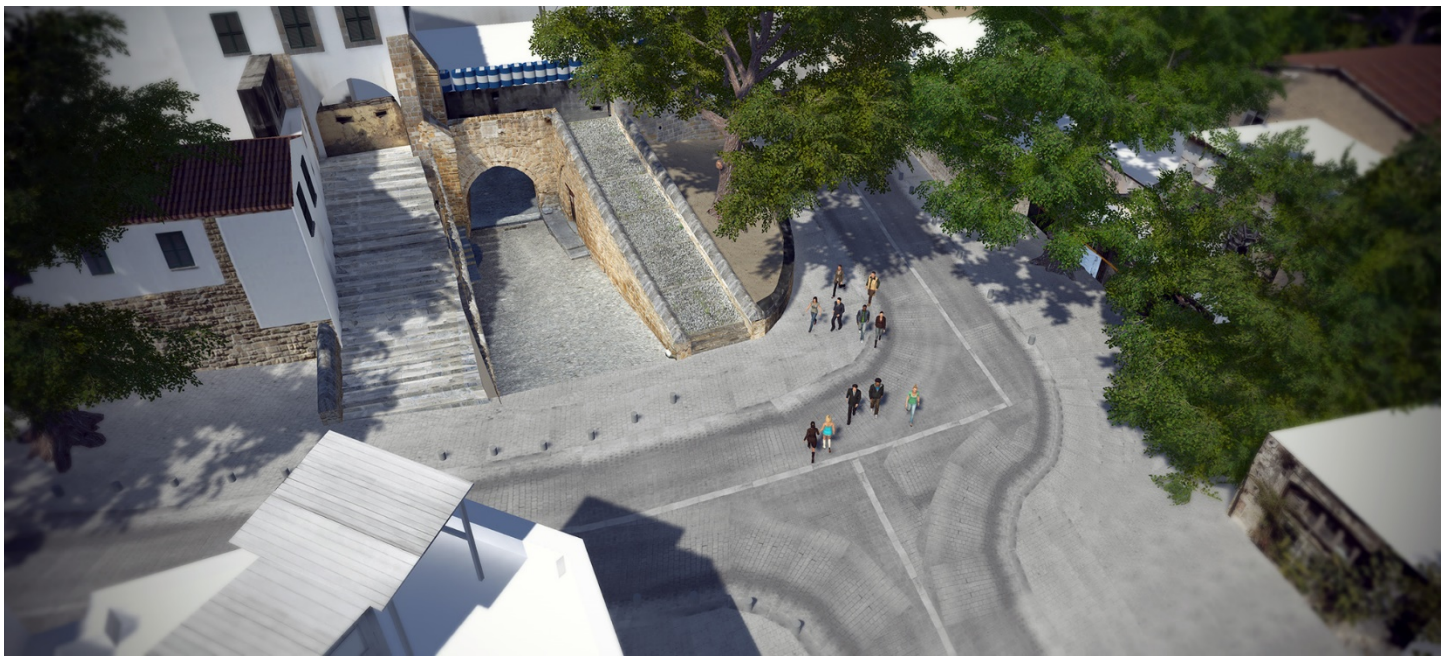

Figure 3. Data from real world crowds as tracked in videos have been used to populate the area around Paphos gate; the inclusion of virtual humans greatly increase the believability and quality of the virtual scene reconstruction (aerial view of the Paphos gate sidewalks in the virtual environment).

The next step involves the analysis of both real world and simulated crowd behaviours. In respect to this initiative, several methods have been proposed; some define metrics under different scenarios and tasks (Singh et al. 2009), others evaluate user presence in VR environments (Pelechano et al. 2008), and others compare against real world data (Guy et al. 2012; Charalambous et al. 2014). In this framework, the research presented will examine crowd behaviour (both for actual and simulated crowd data) using several of these approaches. In particular, necessary measurements will be defined for the crowd behaviour and will be compared against observation data collected from the real site in order to evaluate the experience of users in the (virtual) environment as they modify it. Measurements will include for example local flow and density information to identify places of congestion in the environment. Thus, mapping and exploring the site under study with these human agents enables better understanding of the impact of alternative spatial configurations (geometry and topology of space) on its usage with regards to accessibility and other important qualitative aspects of its projective integration in the urban fabric, such as visual connectivity.

USE OF VISUAL ANALYTICS, SIMULATION METHODS AND PRACTICES OF IMMERSION TO PROMOTE HERITAGE AS URBAN COMMONS

This paper presents considerations regarding the development of a research practice that brings together scholars and stakeholders of historic areas of Mediterranean cities, like Nicosia, with their citizens and everyday users. The scope of this practice is to develop and offer the means to the users so that they are enabled to contribute their views about the post-excavation management of a neglected urban site and its reintegration into the network of the city's public space. This effort is pursued by means of the co-creation of designing architectural interventions with the aim to reintroduce the site into the everyday life of the contemporary city of Nicosia.

In doing so this approach to urban space rehabilitation contributes to practices of cultural rights and inclusion (Dodd and Sandell 2001). The motive that drives the development of this practice is to contribute complementary considerations to the concept of smart cities regarding alternative digital methodologies of

social sustainability. Specifically it is acknowledged by policy-makers and relevant authorities[1] that this research enriches the agenda for the holistic development of contested areas and challenged sites by approaching heritage as a dynamic assemblage of events, activities, performances and identities that relates to space as well as people.

Digital methods of urban analysis (Batty et al. 2017) have been criticized for not integrating notions of bodily movement into space, since computational environments of architecture and urban modeling are often considered to be scale-less and body-less (Dyson 1998), and the present research is technically contextualised in an interdisciplinary effort to overcoming this limitation. It does so by means of the human-computer interface it employs, and the interaction with associated digital assets that occurs through a visual interface and a virtual reality gear that enables motion tracking (Artopoulos, Bakirtzis and Hermon 2015). The issues of spatial cognition and formalisation in setting up the simulations presented above are acknowledged and while recognising the limitations of such an approach, this method relies on users' engagement through content-driven immersive experiences.

The presented hybrid practice offers insights that facilitate steering the planning and site management process towards the right direction since all distinct groups of citizens and inhabitants should be offered opportunities to grow links with a historic space of the city. These opportunities emerge out of the co-development of common visions for their neighbourhood and the public spaces they occupy, their familiarization with social and cultural conditions, the topography of a place, its history and associated local narratives. Hence the focus of the presented research on integrating content and data relevant to these processes in an immersive environment that enables interaction and exploration of said narratives, cf. (Artopoulos and Bakirtzis 2016).

[1] In the publication of the final report to the Human Rights Council of the United Nations, Special Rapporteur Mrs. Karima Bennoune, acknowledges the role that the presented research can play in promoting social resilience and fostering cultural rights in the city, by means of co-design practices and citizen engagement (cf. Bennoune, K. *Report of the Special Rapporteur in the field of cultural rights on her mission to Cyprus*, 12 (2017). Retrieved May 20, 2017, from http://spinternet.ohchr.org/_Layouts/SpecialProceduresInternet/Download.aspx?SymbolNo=A/HRC/34/56/add.1&Lang=en).

Figure 4: Visualisation of a design scenario for the walking paths across the excavated archaeological site.

CONCLUSIONS

This research uses practices of immersion and creative opportunities offered through participation in the design of public infrastructure in the city in order to contribute to the reactivation of neglected open public spaces that used to be popular landmarks within the urban fabric of European cities. In the case of the presented pilot project, the Municipality of Nicosia and Cyprus Department of Antiquities are supporting this effort, and they are currently planning the construction of the proposed walking paths, along with the installation of WIFI beacons for wireless communication as well as a VR-enabled interaction device, in the archaeological site of the Paphos gate (Figure 4). The use of WIFI beacons for enhancing user interaction experience builds on the knowledge acquired in the context of H2020 COST Action TU1306[2], where the authors contribute (Zammit and Kenna 2017). The installation of these ICT points on site will offer the visitors opportunities of interaction with the historic context of the area both via immersive technological solutions (VR) (Figure 2), and by means of their mobile devices (explore 360 videos of historical content) (Figure 5). At the same time though usage of those interaction points on site will provide the researchers with observation data, automatically generated by the visitors (tracking movement coordinates, points of interest, etc.).

The practice presented enables the observation and assessment of the successful integration of the heritage site in the urban fabric through a number of recorded indicators, like the degree of information transmission and the successful communication of content, the accessibility of the site and its clear linkages with the rest of the circulation network of the city – e.g., both visual and physical connections, the image of heritage spaces as urban commons, or the relevance of the activities planned to take place on site.

Figure 5: the research project has developed a Unity mobile app for interaction with 360 videos of the area under study via smartphones, an opportunity that is planned to be offered to the visitors of the Paphos Gate archaeological

[2] Cyprus Member of Managing Committee member for HORIZON 2020, COST Action CyberPark - TU 1306: Fostering knowledge about the relationship between Information and Communication Technologies and Public Spaces supported by strategies to improve their use and attractiveness (CYBERPARKS) < http://www.cost.eu/COST_Actions/tud/Actions/TU1306> 2014-18.

site by means of QR codes and WIFI beacons.

ACKNOWLEDGMENT

This work was supported in part by the European Union's Horizon 2020 research and innovation program, project Virtual Research Environment for Regional Interdisciplinary Collaboration in Southeast Europe and Eastern Mediterranean VI-SEEM [675121].

This paper draws from research conducted at the Cyprus Institute by G. Artopoulos and N. Bakirtzis with S. Hermon, in collaboration with the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign (United States) and Colter Wehmeier; part of the ground work for the crowd simulation and analysis work has been done by P. Charalambous in close collaboration with Inria, France and the University of Cyprus. The authors also want to acknowledge the close collaboration of the Cyprus Department of Antiquities; in particular the director M. Solomidou-Ieronymidou and archaeological officer P. Christophi, as well as, the support of A. Petridou and A. Papadopoulou from the Municipality of Nicosia.

REFERENCES

Amin, A. (2008). Collective culture and urban public space. *City Journal*, *12* (1), 5-24.

Artopoulos, G. and Bakirtzis, N. (2016). Post-Digital Approaches to Mapping Memory, Heritage and Identity in the City. In Glenda Caldwell (Ed.), *Digital Futures and the City of Today*, (pp. 139-156). UK: Intellect Books.

Artopoulos, G., Bakirtzis, N. and Hermon, S. (2015). Spatially-Organized Virtual Narratives of Contested Urban Space: Digital Methods of Mapping the Spatial Experience of Shared Heritage. *University of Greenwich's London eScholarship Repository* [Academic Literature Archive] <http://gala.gre.ac.uk/>.

Batty, M., Hudson-Smith, A., Hugel, S., & Roumpani, F. (2018). Visualising Data for Smart Cities. In I. Management Association (Ed.), *Smart Technologies: Breakthroughs in Research and Practice* (pp. 453-475). Hershey, PA: IGI Global.

Bernstein, D.A., Penner, L.A., Clarke-Stewart, A., Roy, E.J. (2006). *Psychology*. Houghton Mifflin Company.

Bevan, R. (2012). Attack On Townscapes: the role of heritage in protecting common grounds. In Chipperfield, D. (Ed.), *Common Ground: A Critical Reader: Venice Biennale of Architecture 2012*, (p. 220). Venice, Italy: Marsilio.

Blanke, T., Candela, L., Hedges, M., Priddy, M., Simeoni F. (2010). Deploying general-purpose virtual research environments for humanities research. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, (pp. 3813-3828).

Bowers, J., Pycock, J. and Jon O'Brien. (1996). Talk and Embodiment in Collaborative Virtual Environments. *Proceedings of CHI '96*. New York: ACM Press.

Bricken, M. (1991). Virtual reality learning environments: potential and challenges. *Computer Graphics, 25* (3), 178-84.

Bricken, M. and Byrne, C. (1993). Summer students in virtual reality, a pilot study on educational applications of virtual technology. In Wexelblat A. (Ed.). *Virtual Reality, Applications and Explorations*. Cambridge, MA: Academic Press Professional.

Byrne, C. (1993). *Virtual Reality in Education*. Seattle, WA: Human Interface Technology Laboratory at the University of Washington, Technical Publications.

Charalambous, P. and Chrysanthou, Y. (2014). The PAG Crowd: A Graph Based Approach for Efficient Data Driven Crowd Simulation. *In Computer Graphics Forum, 33* (8), 95-108.

Charalambous, P., Karamouzas, I., Guy, S.J. and Chrysanthou, Y. (2014). A Data Driven Framework for Visual Crowd Analysis. *In Computer Graphics Forum 33*, (7), 41-50.

Dodd, J., & Sandell, R. (2001). *Including museums: Perspectives on museums, galleries and social inclusion*. Leicester, UK: Research Centre for Museums and Galleries.

Dyson, F. (1998). "Space," "Being," And Other Fictions in the Domain of the Virtual. In Beckmann, J. (Ed.). *The Virtual Dimension*, (p. 38). New York, NY: Princeton Architectural Press.

Galyean, B. C. (1982). The Use of Guided Imagery in Elementary and Secondary Schools. *Imagination, Cognition and Personality, 2* (2).

Gaffikin, F., Mceldowney, M. and Sterrett, K. (2010). Creating Shared Public Space in the Contested City: The Role of Urban Design. *Journal of Urban Design, 15* (4), 493–513.

Guy, S.J., Van Den Berg, J., Liu, W., Lau, R., Lin, M.C. and Manocha, D. (2012). A statistical similarity measure for aggregate crowd dynamics. *ACM Transactions on Graphics (TOG), 31* (6), 190.

Helbing, D. and Molnar, P. (1995). Social force model for pedestrian dynamics. *Physical review E, 51* (5), 4282.

Kosslyn, S. M. (1983). *Ghosts in the Minds Machine: Creating & Using Images in the Brain*. New York: W. W. Norton.

McClurg, P.A. (1992). Investigating the development of spatial cognition in problem-solving microworlds. *Journal of Computing in Childhood Education, 3*, 111-126.

Munoz-Cristobal, Juan A., Prieto, Luis P., Asensio-Perez, Juan I., Martinez-Mones, Alejandra, Jorrin-Abellan, Ivan M., Dimitriadis, Y. (2015). Coming Down to Earth: Helping Teachers Use 3D Virtual Worlds in Across-Spaces Learning Situations. *Educational Technology & Society, 18* (1).

Narain, R., Golas, A., Curtis, S. and Lin, M.C. (2009). Aggregate dynamics for dense crowd simulation. *In ACM Transactions on Graphics (TOG), 28* (5), 122.

Pelechano, N., Stocker, C., Allbeck, J. and Badler, N. (2008). Being a part of the crowd: towards validating VR crowds using presence. *In Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems-Volume 1*. International Foundation for Autonomous Agents and Multiagent Systems, 136-142.

Regian, J.W., Shebilske, W.L., & Monk, J.M. (1992). Virtual reality: an instructional medium for visual-spatial tasks. *Journal of Communication, 42* (4), 136

Ren Z., Charalambous P., Bruneau J., Peng Q., Pettré J. (2016). Group Modeling: a Unified Velocity-based Approach. *Computer Graphics Forum*. doi:10.1111/cgf.12993.

Samuels, M., & Samuels, N. (1975). *Seeing With the Mind's Eye*. New York: Random House.

Singh, S., Kapadia, M., Faloutsos, P. and Reinman, G. (2009). SteerBench: a benchmark suite for evaluating steering behaviours. *Computer Animation and Virtual Worlds, 20,* (56), 533-548.

Steinkuehler, C., Squire, K. & Barab, S. (2012). *Games, Learning and Society: Learning and Meaning in the Digital Age*. Cambridge, UK: Cambridge University Press.

Squire, K. (2011). *Video Games and Learning: Teaching and Participatory Culture in the Digital Age. Technology, Education-Connections (the TEC Series)*. New York, NY: Teachers College Press.

Treuille, A., Cooper, S. and Popović, Z. (2006). Continuum crowds. *In ACM Transactions on Graphics (TOG) 25*, (3), 1160-1168.

Van den Berg, J., Guy, S.J., Lin, M. and Manocha, D. (2011). Reciprocal n-body collision avoidance. *In Robotics research.* Berlin: Springer Heidelberg, 3-19.

Wiley, S. (1990). An hierarchy of visual learning. *Engineering Design Graphics Journal, 54* (3), 30-35.

Winn, W.D., Bricken, W. (1992). Designing virtual worlds for use in mathematics education: the example of experiential algebra. *Educational Technology, 32* (12), 12.

Wu, Jun Jie and Plantinga Andrew J. (2003). The influence of public open space on urban spatial structure. *Journal of Environmental Economics and Management, 46* (2), 288-309.

Zammit A. and Kenna T. (eds), *ICiTy, enhancing places through technology* (Portugal: Edições Lusófona, 2017).