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Analysis of Spatio-temporal Data in Virtual Historic Spaces

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Abstract

This paper presents a virtual reality workflow for citizen engagement in the management of neglected historic sites in contested cities, such as Nicosia, Cyprus, the last divided capital of Europe. It is contextualized in an ongoing research for the use of interactive visualization technologies for co-creation and co-management design practices in public space management. We demonstrate initial results from tracking the movement and gaze of users in VR walkthroughs of a historic site with and without user driven interventions and discuss on future directions.

1. Introduction

Current applications of digital technologies affect urban governance, planning, and management in various ways, e.g., through public participatory approaches augmented by ICT, big data processing of urban conditions and spatial interactions including security, spatial appropriation and emerging methods of urban visualization, planning and policy application on historic urban fabric. This paper presents a virtual reality workflow for citizen engagement in the management of neglected historic sites in contested cities, such as Nicosia, Cyprus, the last divided capital of Europe. It is contextualized in an ongoing research for the use of interactive visualization technologies for co-creation methodologies and co-design practices for public space management. Our aim is the development of a digital workflow, which through user interaction, visualization and analysis of movement data will enable the evaluation of alternative planning scenarios and design interventions.

This paper discusses theoretical considerations and practical challenges of the authors during the interpretation of a small sample of data collected from users interacting with the virtual environment and exploring a historic site during preliminary testing sessions conducted in the context of an EU-funded research activity. The paper reports on the provisions, measurements and methods used to collect, process, visualize and interpret spatio-temporal data collected from the on-going application of virtual reality tools for heritage co-management.

Historic Context. During 2013 and 2014, the part of the moat outside the Paphos gate was excavated by the Cyprus Department of Antiquities in collaboration with the Municipality of Nicosia, and co-funded by the EU, in an effort to not only preserve the history of the area and the medieval fortifications, but also to reactivate this neighbourhood of the city. 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. Despite its long history the area was 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. The monument of the Paphos gate is constructed from parts and building material in secondary use, which were sourced during medieval times from other nearby constructions and buildings. The site is considered as the locale of a *thick* slice of the palimpsest of the historic city. Its spatial context comprises of many points of interest loaded with cultural values and historical importance (Figure 1). The co-existence of all these topoi of historical activity, the historical transformations of their structures, which are eventually recognised as Nicosia patrimony, together with the contemporary activities of the city (e.g., the privately run tennis court on the moat, next to the archaeological site), arguably create a fragmented experience of the space for its users.

2. Related Work

The developed platform of virtual historic spaces captures data of virtual visitors' movement in space, and the paper suggests that these data could help better understand the impact of planning scenarios and design interventions in open public spaces that used to be popular among the citizens of the divided historic city. The application of the concept of gamification 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. The presented workflow draws its theoretical context from the analysis of people's behaviour in public spaces as presented by Goffman [Gof08], and the capacities of immersive virtual environments for bodily interaction [SU94]. Most importantly though it builds on the premise that as people move in public spaces that are

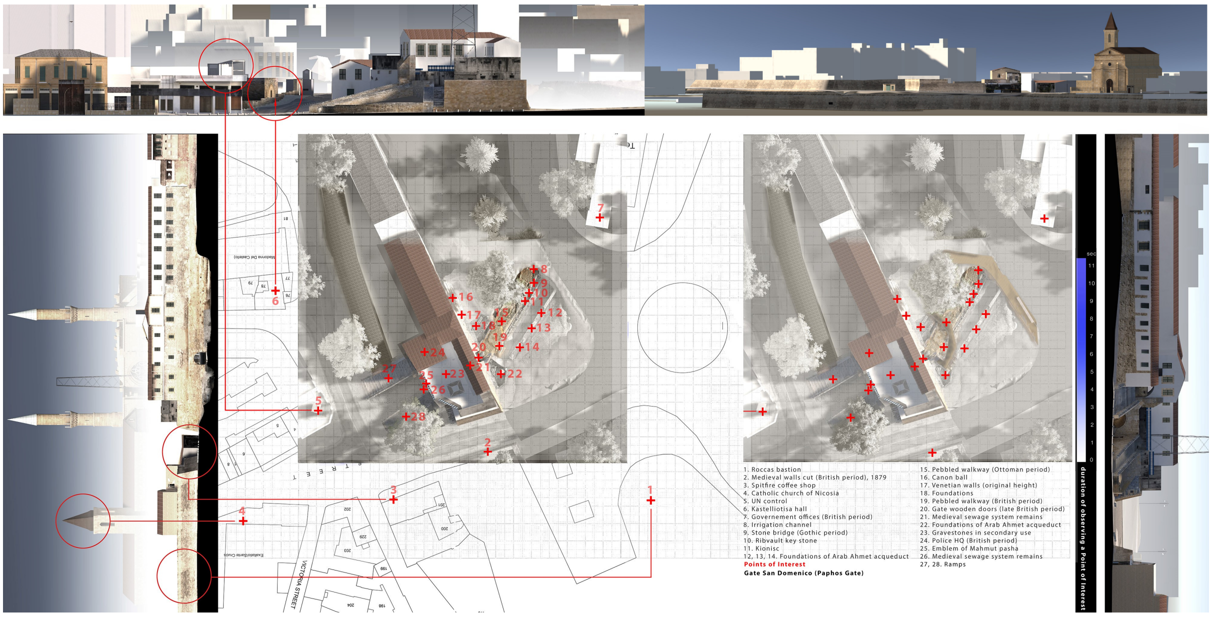

Figure 1: *Points of interest mapped on the site plan of the Paphos gate, and important landmarks in the area.*

associated with heritage places or historical events, they assume or exercise identities [PZC90].

Many researchers have been developing workflows for the visualization of movement data being interpreted in their spatiotemporal context or environment since early 1990s [HF93, ZLB*05, WK13]. Andrienko et al. [AAH11] and Bach et al. [BCD*17] developed analytical approaches based on the extraction of events from trajectories and treating the events as independent objects based on virtual reality for user-based evaluation of spatial conditions and phenomena, in urban environments. Bennett et al. [BZK14] use virtual reality to pursue archaeological enquiries. Ferreira et al. [FLD*15] apply data driven decision making in urban development, and Ho and Jern [HJ08] applied tools for use interaction in the development of 3d geovisual analytics. Wang et al. [WMZ*10] explored the use of game engines in virtual reality research. Others develop visual communication tools and methodologies, such as space syntax, in urban planning [SDD98, DHT05, KP04]. Furthermore, researchers from the crowd simulation and pedestrian dynamics communities develop methods to analyze the behavior of both actual crowds and virtual crowds using statistics [KWS*11], presence [PSAB08] and data [CC14, CKGC14, WOO17].

3. Methodology

The first step in the presented workflow involves the creation of a three-dimensional reconstruction of a historic site significant for Nicosia (Figure 2). This was produced based on archival material, photographs, as well as with the acquisition of data from the site by using laser scanning, Unmanned Aerial Vehicles (e.g., drones) and terrain Structure-from-Motion photogrammetric techniques. To highlight the transformations of the historic area through time, expand the representational capacity of the presented virtual environment, and go beyond the documentation of the existing conditions of the site under study, models of previous (historically documented) phases of the site were also created. Specifically, the presented platform currently hosts three different models of the area: a) one that represents its contemporary building context (in 2017), b) one that represents how the archaeological site will be when the proposed site management plan for an architectural intervention is implemented by the Department of Antiquities and the Municipality of Nicosia (in 2019), and c) one that visualizes the historic urban fabric as it used to be in 1951, before the division of the city.

The architectural interventions developed as part of the site management plan were created through a co-creation process (Figure 3) that allowed citizens of Nicosia to choose, sketch, follow and virtually explore paths and routes inside the projected space in order to suggest how they would walk across the archaeological site if it was integrated in the network of the public spaces of the city [AC19].

We then analyzed the behavior of users navigating the site in a VR setting; this was done in different sessions in the context of an EU-funded research activity. The first session discussed here was conducted with a group of 23 individuals. The users were acquainted with the challenges, pressing needs and current discourse in the field of urban studies, modelling, heritage studies and the application of ICT. Users consisted of different ages, disciplines and expertise, practitioners and academics, visitors and locals of the city; this provided the necessary plurality of the targeted group to the evaluation tests. These evaluations were conducted as preliminary tests to check the capacity of the tools and the virtual environment platform to convey the experiences pursued by the research. It is noted that wider and more balanced testing will follow the next development round of the tools (Section 4). The evaluation process included the observation and tracking of user interaction

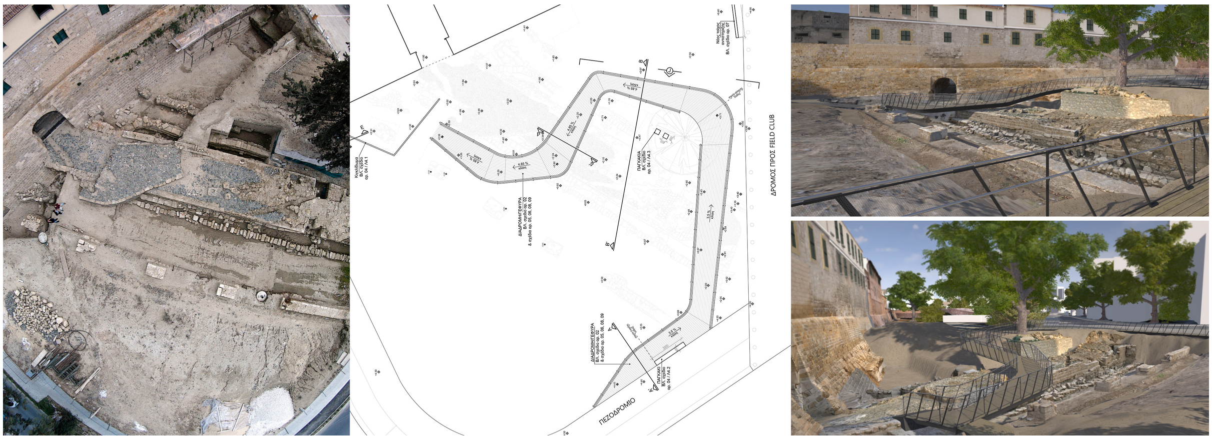

Figure 2: *(left) Aerial view of the site from the drone mapping process; (middle) proposed site plan; (right) visualization of the proposed walking platforms as seen in the virtual environment.*

Figure 3: *Users sketched proposed routes in and around the historic site using a mobile app.*

in the virtual environment and the collection of feedback by questionnaires. 75% of the participants were familiar with the site and thus were able to understand the spatial correlation of the historic elements between the physical and simulated environments. This process was structured around 28 identified, documented and digitally reconstructed elements of the physical space under study as well as of significant cultural heritage artefacts, which were used in anchoring the user experience of the virtual visit of the site to the real tangible aspects of the physical space (Figure 1). These elements functioned as points of interest during the evaluation sessions, and were organized semantically based on the historical period to which they belong, according to the archaeological study, spanning chronologically from the Frankish period to 16th century, Ottoman, British and the contemporary times.

Users navigated the environment using an HTC Vive. This allowed for different modalities in navigating and exploring the environment: a) by "teleportation" using the hand-held controllers, b) by head tracking and c) by tracking the local movement of the participant in an area of $2m * 2m$ using the base stations of the Vive. Over 85% of the participants who virtually visited the planned intervention on the archaeological site and walked on the proposed walking platforms, considered the impact of the proposed design on the accessibility and connectivity to the surrounding streets as positive (more details in [AC19]).This feedback was collected through the following questions:

- Can you see the excavation site from a distance;
- Are the interiors of the archaeological excavation sections visible from the outside;
- Do sidewalks lead to and from the adjacent areas of the site;
- Can people easily walk around the space;
- Can people with special needs visit the site;
- Do the paths take people where they actually want to go?

The results of these questionnaires were also correlated to the tracked movement data of the virtual visits to the space; i.e., users' positions and gaze (head orientation) were tracked at all times. Figure 4 shows the trajectories (red) and view volume (blue) of one participant in the 2017 and 2019 models of the site. In Figure 5 we show the combined results for all participants. The visitation heatmaps indicate the places where users moved. It is clear that in the 2019 case they moved on the virtually constructed rails in a more structured approach whereas the gaze coverage indicates that the users observed most of the points of interest uniformly. This capacity of the tools allows for a) the observation and visualization of users' movement and gaze in the virtual space before and after the introduction of the proposed walking platforms (Figure 5), and b) the recording of the points in space that attracted the interest of the users during the walkthrough (by means of points of stasis and their gaze) – especially of those elements that were associated with the historical narratives and archaeological finds of the excavation.

4. Discussion

The paper presented initial results from a VR based workflow that assists in the design and visualization of a more structured, organized walking experience through an archaeological site. The aim of the design of this walking experience is the integration of a historic site into the pedestrian network of the contemporary city. We demonstrate how we collect and process data from VR walkthroughs in order to better understand user movement in space and time; preliminary visualizations and data graphs illustrate the interpretation process of the data (Figure 5). These visualizations offer new insights to the authors regarding the proposed heritage site management intervention and its speculated capacity in offering a

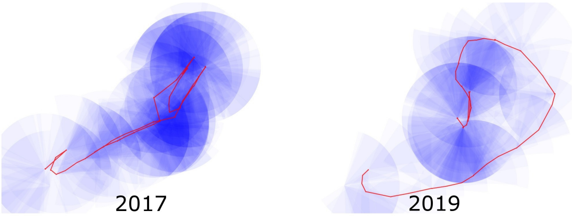

Figure 4: *Tracked data of an individual immersed in VR.*

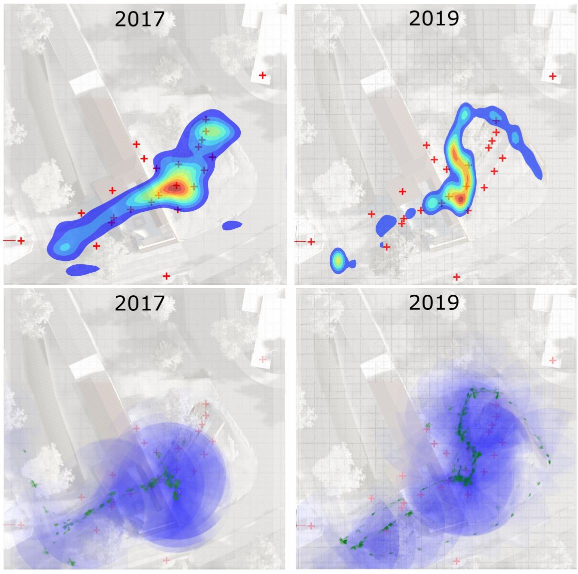

Figure 5: *(top) Combined heatmaps of user visitation; (bottom) gaze coverage by all users*

walk through path that is faster than a visit to the archaeological excavation site, but information-rich enough to impact positively the experience of the users. This new understanding of the users' response to the spatial configuration of the proposed architectural interventions facilitated the planning and stakeholder communication during the design and production of a management plan for the archaeological site. The next step of development of this research involves empirical validation through the engagement of a larger and statistically representative number of real users of the city in order to analyze the simulated data in relation to the identified movement patterns.

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