An Architectural Metaverse that Combines Dynamic and Static 3D Data in XR: a Case Study at the Monastery of Simonos Petra

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Introduction

Originally a term from science fiction, the Metaverse is a shared 3D experience, converging physical, digital and fictional space, to facilitate a novel immersive experience. This is a computationally controlled non-topos (non-space), enabling seamless interaction between topologies. The Metaverse rejects the notion that physical space — though spatial and distributed — can only be experienced by individuals who are physically present. In fact, this paper explores the potential of combining spatial data, from architectural space and from the presence of humans, in different spatial realms that remotely allow immersive experience.

More specifically, this research introduces an XR spatial experience that allows humans to feel immersed within a digital twin of the monastery at Simonos Petra in Athos, Greece. The experience is composed of static 3D models of various spaces within Simonos Petra, and dynamic 3D data of humans, walking in both the physical space and/or in the Metaverse. Static data is a set of digital twins of photogrammetry models, produced by extensive 3D scanning of the original monastery's environment using drones and ground shooting techniques. Dynamic data, drawn from humans and elements within the architectural experience, brings XR fragments of reality from different realms – the Metaverse – to the experience of the monastery space.

Mount Athos

The regional complex of the monastic community of Mount Athos has developed gradually over the last twelve centuries, from solitary anchorites (late 8th to early 9th century) to the current mosaic of cenobitic monasteries. Twenty main monasteries partition the Athos peninsula into independent vicinities, within which each monastery governs smaller monastic formations (skiti, kellion, kalyvi, kathisma), and creates broader ekistic communities. The monastery of Simonos Petra, 13th in the official ranking (hierarchy) of Athos, is located on the southern coast of the peninsula. Based on its history, Simonopetra, as it is also known, was founded by Simon the Athonite in the 14th century. According to tradition, Simon had a dream in which he was miraculously instructed to build a sacred space on top of a stone cliff near his cave. The early form of Simonopetra at that moment was a small chapel on top of that formation, on which a multi-storied building with many chapels was constructed over the centuries. Today, there are various smaller monastic formations that are spread around Simonos Petra.

Throughout the centuries, monks and guests participate in liturgical practices that happen simultaneously in all monastic communities across the Athos peninsula. This Metaverse of spiritual activity inspired the creation of a computational method that could enable humans to immerse themselves in different sets of topologies which are in different locations. Within this scenario, humans can walk inside an immersive experience in XR of the monastery of Simonos Petra to see and engage with fragments from different realities.

Static Data

In 2018 and 2019, a collaboration between the MIT Design and Computation group and the monastery of Simonos Petra allowed extensive 3D scanning of the exterior and key interior spaces, including the main church of the monastery. On-site data collection utilized photogrammetry techniques using drones and handheld cameras, following the common rule of sequentially taking images that share 60% of their content from one to the next, under consistent lighting conditions.

For the main church of Simonos Petra, more than 60,000 individual images were recorded with a DJI Phantom 4 PRO+ drone to ensure consistent data collection for 3D reconstruction, post processing, and 25,000 images with a professionally grade DSLR camera. Aerial scanning is the only way that the iconography of the higher zone of the multi-vaulted structure could be captured. In addition, the higher angle shots from above ensured that sufficient data was collected, especially at the various narrow sides of the church. For the data processing of the Simonos Petra models, the software Agisoft Metashape Professional Edition was selected, running on a local server with GPU and RAM intensive capabilities. Regarding data post-processing, two different techniques were selected:

Photo Alignment → Depth Maps → Build Mesh → Build Texture.

Photo Alignment → Dense Cloud → Build Mesh → Build Texture.

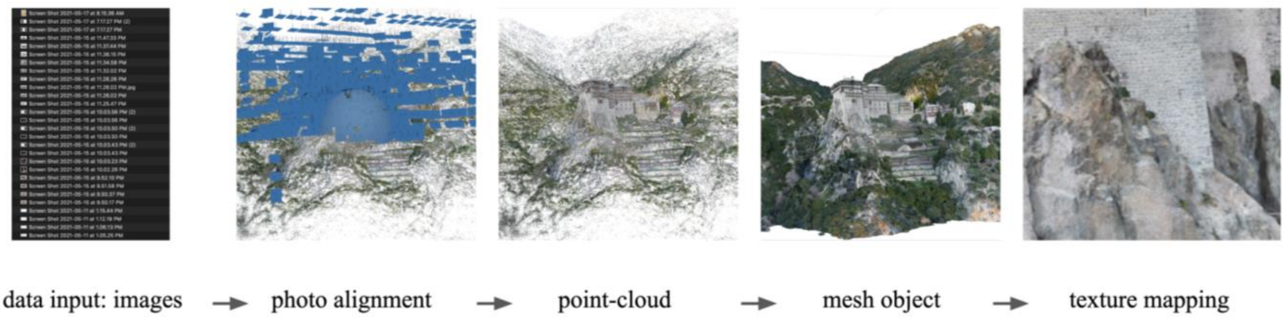

Fig. 1. Top: Steps of post-processing photogrammetry data in Agisoft Metashape – technique A (see text). Bottom Left: tie-points, point-cloud, 3D geometry with texture mapping of the main church interior space. Bottom Right: Perspectival view of Simonos Petra main courtyard and partially revealed the main church space.

Dynamic Data

Utilizing state-of-the-art depth sensors (Microsoft Kinect Developers Edition) and open source algorithms in the Unity Game engine, a real-time point-cloud generation system was tested to visualize spatial data. Due to the restrictions of the Covid-19 pandemic, the system was designed and tested at a residential space, rather than implemented at the monastery of Simonos Petra in Athos. More specifically, a set of four and three Kinect depth sensors streamed data from two different rooms in the residential space, while two users participated. User One was wearing a VR headset in Room 1, and User Two interacted with the physical space in Room 2. User One was able to walk around User Two in XR, as shown in the following images.

 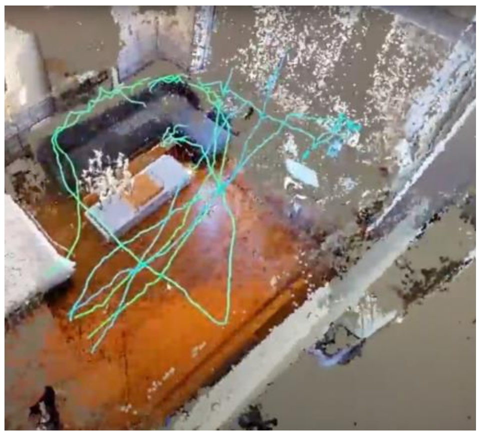

Fig. 2. Top: Volumetric capture using Kinect depth sensors without (left) and with (right) human motion tracking. Captured as it is shown in XR (Varjo VR-2 Pro headset). Bottom: Volumetric capture detecting the skeleton of human body and its joint points (Varjo VR-2 Pro headset).

The system was tested not only to stream spatial data, but also to detect the user's body movement. The integration of the human body SDK was an additional feature, allowing the collection of data that is useful for tracking motion and analyzing posture (individual control of the skeletal joint points) and will be useful for future research.

Combining Static and Dynamic 3D Data

Prior work in the field conducted by the PTC Reality Lab shows the convergence of static and dynamic spatial data (Reynolds et al, 2019) for remotely operating machines and robotic systems throughout augmented reality. Here, "Remote Spatial Programming and Collaboration Using a Real-Time Volumetric Capture Space" project utilizes remote visual access to a machine interface. This system allows for remote collaboration in which a remote environment is volumetrically captured in real-time so that users can view spatial data from smartphone, and another user can view the entire space from a desktop screen.

As shown in this paper, the combination of static and dynamic data allows humans to experience the architectural content of the monastery space, as described in the following scenarios:

a) Streaming data of humans in the physical space of the church, superimposed with the digital twin of the architectural model of the church. In this case, four Kinect cameras streaming data in the Unity Game engine are actively tracking humans. The XR user will experience the static model of humans moving in real-time. This scenario was implemented and tested in a personal residential space, as described in the previous section.

b) Streaming the data of humans not located in the physical space of the church and superimposing it onto the digital twin of the architectural model of the church. For example, we can imagine live-streaming humans, in different chapels in different time-zones, who can actually walk within Simonos Petra church.

c) Streaming the data of humans not located in the physical space of the church, and humans who are physically in that space, superimposing both of these onto the digital twin of the architectural model of the church. For example, we can imagine a ceremony that monks want to attend from all over Athos; to do so, they use XR to experience the ceremony within the Simonos Petra architectural space, with others from different locations.

d) Streaming data of a religious space or religious artifact within that space, superimposed onto the digital twin of the architectural model of the church. For example, we can access a famous chapel physically, located in another monastery, while actually being in the XR of Simonos Petra church space. Similarly, the user can visually access a rare Byzantine icon masterpiece, physically located outside of Athos, while experiencing the Simonos Petra church in XR.

The limitations of the above scenarios revolve around the requirement of having access to multiple Kinect depth sensors that physically recording data to be streamed in XR. In addition, internet connection and computational resources can become a real barrier for the implementation of the four scenarios.

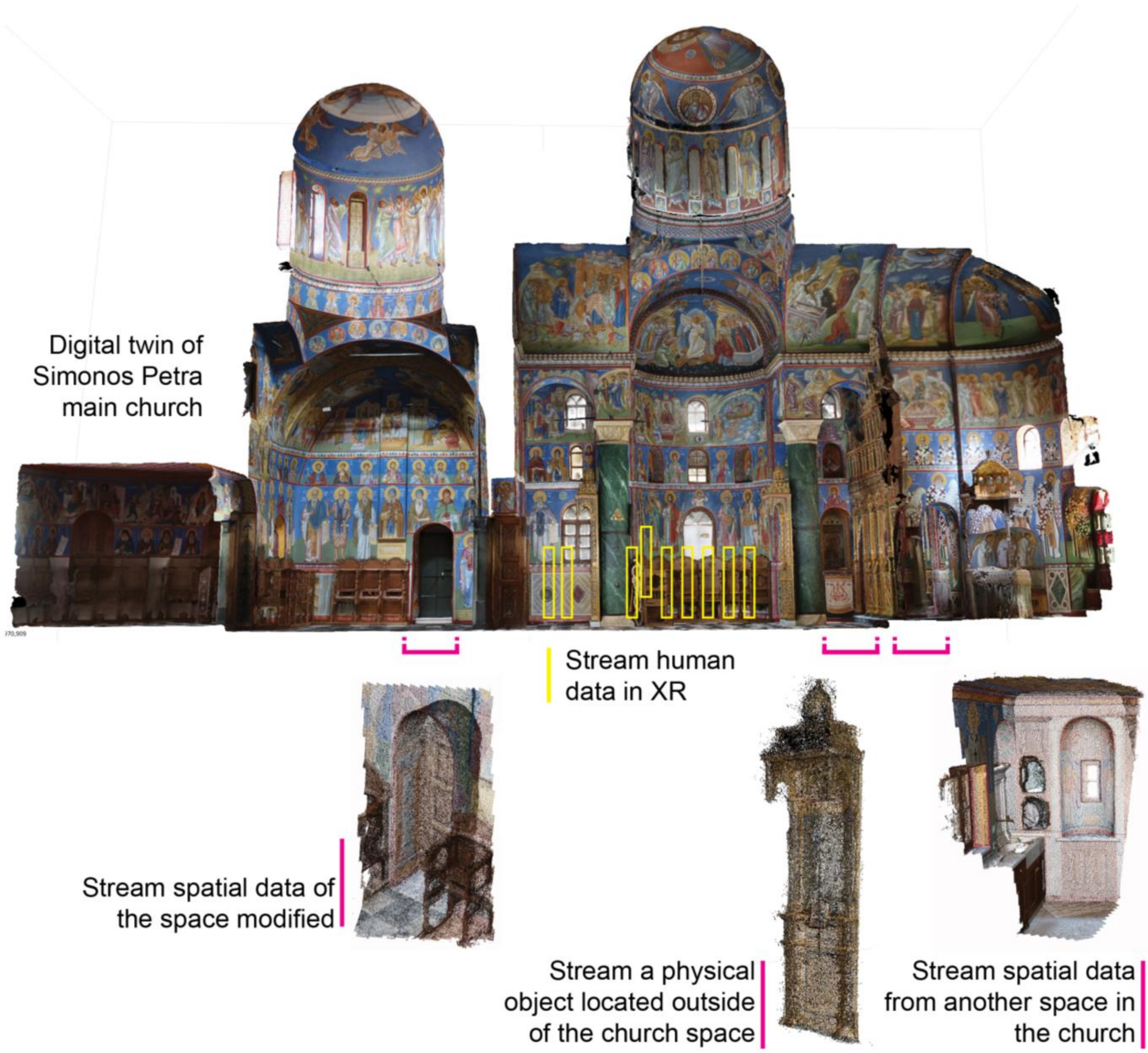

Fig. 3. Top: Static photogrammetry model (left), Dynamic human tracking data by Kinect Depth sensors (middle), combining Static and Dynamic data in XR (right). Bottom: Digital twin of Simonos Petra main church space as a result of photogrammetry 3D scanning. Diagram of possible scenarios of combining Static and Dynamic 3D data in XR.

Conclusion and Future Development

This paper describes the vision of an architectural Metaverse created by digital twins of physical spaces (static) and a volumetric streaming data of humans and remote spaces (dynamic). The case study of the monastery of Simonos Petra in Athos, Greece with its rich architectural qualities, captured in photogrammetry models, elucidated this vision. Due to Covid-19 pandemic, the implementation of the technical work took place in personal residential space rather than in the monastery environment. However, the feasibility of the computational method and the technical apparatus is successfully tested (basic scenario). As a next step, it is critical to utilize multiple topologies installing Kinect depth sensors and stream data simultaneously. The limitations of internet connection bandwidth and GPU capabilities seem to be the most difficult aspects towards full implementation. In addition, interaction design capabilities within the Metaverse will be critical to enhance the participation of humans and the engagement on the levels of human-human and human-space.

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References

Barcelo, J.A., Forte, M., Sanders, D.H. (2000) "The Diversity of Archaeological Virtual Worlds", Virtual Reality in Archaeology, eds. By J.A. Barcelo, M. Forte, D.H. Sanders ArcheoPress, Oxford.

Güleç Özer, D., Nagakura, T., & Vlavianos, N., (2016). Augmented reality (AR) of historic environments: Representation of parion theater, Biga, Turkey. *A/Z ITU Journal of the Faculty of Architecture* , vol.13, no.2, 185-193.

https://jag.journalagent.com/itujfa/pdfs/ITUJFA-66376-THEORY_ARTICLES-GULEC_OZER.pdf

Reynolds, B., Bedri, H., Heun, V., Fusté, A., & Vazquez, C. (2019). Remote spatial programming and collaboration using a real-time volumetric capture space. *ACM SIGGRAPH 2019 Virtual, Augmented, and Mixed Reality*, 1–1. https://doi.org/10.1145/3306449.3328821 Github: https://github.com/ptcrealitylab/vuforia-spatial-remote-operator-addon