Exploring the Creative Possibilities of Infinite Photogrammetry through Spatial Computing and Extended Reality with Wave Function Collapse

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Abstract

Modern extended reality systems that merge virtual and augmented reality provide a unique design space for creative applications. These devices have begun to incorporate spatial computing, or methods of runtime digital photogrammetry which translate the physical world into the virtual. In this study, we examine the use of extended reality for "infinite photogrammetry," a system of mapping the physical world into a virtual experience and procedurally generating an infinite version of the scanned architecture. We explore our system through a use case of mapping a residential home for infinite photogrammetry with the Magic Leap Spatial Computing Headset, Wave Function Collapse Algorithm, and Unity Game Engine. We conclude with a discussion on the creative applications of infinite photogrammetry and considerations for future research.

Introduction

Modern extended reality (XR) systems have gone a long way technologically in enhancing user immersion through widening the field of view, increasing frame-rate, leveraging low latency motion capture, and providing realistic surround sound (Beccue and Wheelock 2016). As a result, we see a new wave of mass adoption of commercial XR Head-Mounted Displays (HMDs) such as the Magic Leap One, Microsoft Hololens, HTC Vive, Oculus Quest, PlayStation Morpheus, and more that have entered the market with nearly over 200 million projected systems sold since 2016 (Beccue and Wheelock 2016). These systems are becoming ever more mobile and intrinsic to the average consumer's entertainment experience, enabling a mode of full-body engagement combining the physical and virtual world (Chang and Chen 2017; Liu 2019). More recently, these devices have begun incorporating simultaneous localization and mapping to transfer the physical world's architecture into the digital environment, as seen with the photogrammetry like spatial computing and meshing capabilities of the Magic Leap One (Leap 2019b). These mediums provide new opportunities to explore tools for casual creation and generative computing.

The use of XR and photogrammetry have been increasing due to the benefits that result from this combination. The main usage of this combination has been to reconstruct objects or locations from the real world to a mixed reality environment. Virtual reality (VR) has been getting most of the attention for recreating real-life objects and locations, but what is not mentioned is the time it takes to develop these things. VR usually takes a lot more time, precision, and accuracy to develop an object as compared to AR. Portalés et al. have found that utilizing AR with photogrammetry has been more cost-efficient to create such objects (Portalés, Lerma, and Navarro 2010). Not only that, but the time saved using AR with photogrammetry is almost more than 50% (Portalés, Lerma, and Navarro 2010). AR and photogrammetry have their advantages not only for being more time and cost-efficient but also for providing accessibility to people. Two examples where AR and photogrammetry were utilized to create more accessible environments are Drap et al.'s VENUS project and Pietroszek's mixed reality exhibition. Drap et al. used photogrammetry to survey marine areas of the Pianosoa island. It is a step forward to having archaeologists investigate untouched and unreachable areas of the deep ocean (Drap et al. 2007). This is a great way to digitally archive and preserve underwater findings without compromising them. In a related application, Pietroszek created a mixed reality exhibition to make it more accessible for people who cannot visit a normal exhibition due to location, disability, or socioeconomic status (Pietroszek 2019). From these works, we argue that the incorporation of extended reality devices may provide unique opportunities for casual recreation.

In 2015, Compton & Mateas defined an alternative design space for system creation: "A Casual Creator is an interactive system that encourages the fast, confident, and pleasurable exploration of a possibility space, resulting in the creation or discovery of surprising new artifacts that bring feelings of pride, ownership, and creativity to the users that make them" (Compton and Mateas 2015). These tools emphasize creativity and design support by enabling a flow of choice and rapid iteration while providing both passive and active automation (Compton 2019). Moreover, the curious users of casual creators have been hypothesized to be driven primarily by the curiosity and capability of a system's design space (Nelson et al. 2018). In this study, we explore the usage of an XR headset to understand the potential of these devices for the use of photogrammetry, converting the physical world into the virtual. We also examine autonomy for XR enabled photogrammetry to explore how it can be extended for generative experiences through examining procedural content generation (PCG).

PCG algorithms applied to photogrammetry may produce some interesting design artifacts for game and experience design. As games have been evolving rapidly, so has the use of PCG (Hendrikx et al. 2013). Designers use PCG to implement content that has been automatically generated from assets at random (Togelius et al. 2011). In this definition, content is a broad term for what researchers, game designers, and academics would want to generate. Applying PCG to photogrammetry helps game designers create infinite possibilities for levels, non-playable characters, and many more objects in a digital game. This combination allows for more opportunities to surprise users and even the designers themselves.

An algorithm for PCG that has been gaining traction in the creative design world is Gumin's WaveFunctionCollapse (WFC) (Gumin 2016). WFC is a non-backtracking, greedy search algorithm that enables large output generated from a small number of constraints determined by a window of input media. The algorithm has attracted the attention of game creators, PCG researchers, and level designers over the past years (Karth and Smith 2017; Sandhu, Chen, and McCoy 2019). It enables designers to speed up the time and production costs of asset creation while providing them with constraints to manipulate pattern generation. For our study, we are interested in extending this algorithm to 3D world generation by utilizing photogrammetry with an extended reality headset. To the best of our knowledge, this study is one of the first to bridge spatial computing with WFC for Infinite Photogrammetry. We hope to examine the combination of these technologies to demonstrate a proof of concept and consider its creative applications for future research.

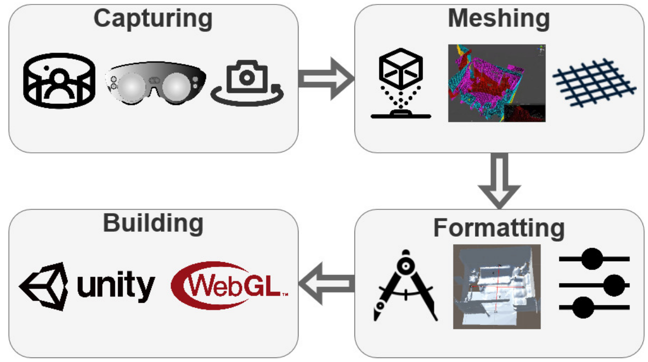

Figure 1: System Pipeline for Infinite Photogrammetry Experience.

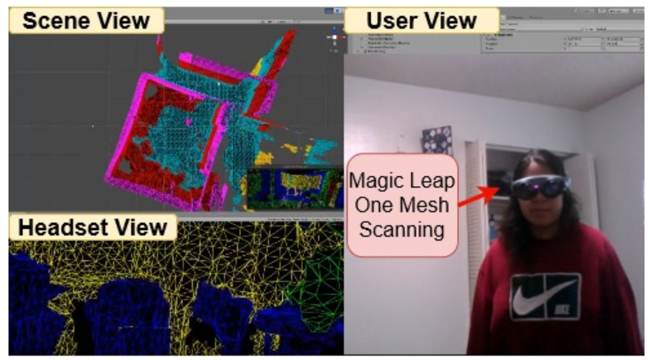

Figure 2: A user walks around their home with a Magic Leap One. House geometry is procedurally meshed in the unity game engine and stored as mesh for manipulation with Wave Function Collapse.

System Design

This project leverages the capabilities of the Magic Leap Spatial Computing Headset when combined with the Wave Function Collapse Algorithm and the Unity Game Engine. The goal was to create a playable experience that generates infinite photogrammetry of a scanned environment. To this end, we designed our system to (1) create a methodology of translating physical world geometry into virtual 3D environments with Magic Leap, (2) adapt a prior Wave Function Collapse algorithm to generate new architecture via Unity3D, and (3) to explore the application of infinite photogrammetry. This process can be described in four stages: capturing, meshing, formatting, and building, as shown in Figure 1. In this section, we discuss the tools we used to enable this system's design.

The Magic Leap One (MLO) headset, an extended reality interaction system, is a "spatial computing" headset that overlays augmented reality while performing simultaneous localization and mapping on the physical world (Leap 2019b). MLO was examined as a development platform because, at the time of this study, little to no evaluations were found in academia for development testing of our proposed application. Seeing the physical world around the user is critical for safety when mapping environments. The untethered headset differs from other commercially available XR HMDs by projecting light directly into the user's eyes while also enabling higher input modalities through hand tracking, eye tracking, dynamic sound fields, and 6-Degree of Freedom (DoF) controllers with haptic feedback (Leap 2019b).

To enable the visualization and interaction with the virtual world, the Unity Game Engine was chosen as the primary driver of our experience. Unity is a flexible real-time 3D development platform that enables the creation, operation, and rapid prototyping of interactive virtual content (Unity Technologies 2019). Unity was chosen due to its flexible capabilities, which allows it to build the same experience between multiple operating systems such as WebGL, Magic Leap, HTC Vive, Windows, Mac, and more (Unity Technologies 2019). Thus, we developed our experience in Unity 2019.1.5f1 through two separate build instances: Lumin (MLO SDK 0.21) and WebGL (OpenGL 4.5).

To obtain a mesh of the physical world, we utilized the MLO World Reconstruction Spatial Mapper, an algorithm to detect real-world surfaces and construct a runtime virtual mesh to represent the real world's collisions for game engine

(Leap 2019a; DeTone, Malisiewicz, and Rabinovich 2017). We converted the world reconstruction mapper into a serialized mesh during runtime, which is then stored as an asset for later manipulation. This process allows us to capture the rough geometry of the user's surroundings as they walk through and map their desired game architecture, as shown in figure 2. From there, we translate the asset into a playable scene to allow the user to walk through and navigate their scans virtually.

We examined this process during a ten-minute session as a user walked through their home. This consisted of rapidly scanning a 1459 square foot residential home with two bedrooms, two bathrooms, one office, a living room, and a kitchen. The results of this process can be seen in figure 3, where some of the rooms are reconstructed for the user to virtually walk around their scans in the unity game engine. After the scanned geometry is captured and serialized to independent mesh assets, we then proceed to format the assets for WFC.

To enable PCG, we modified Kleineberg's Infinite City adaption of WFC (Kleineberg 2019). Using the serialized meshes of the geometry scanned by the MLO spatial mapper, we divide the rooms into one-meter voxels and define WFC constraints through mapping the six sides of the room with numbered adjacency keys as shown in figure 4. The user is then able to define the WFC generative adjacency of rooms through one-meter voxels chunks. Such rooms become generated through chunks in relation to the user's world position in the unity engine. As a result of this process, we end with a unity experience that can generate an infinite form of photogrammetry produced from the MLO Mixed Reality headset. The infinite house produced from this process can be seen in Figure 4. A demo of the experience can be found at `https://github.com/avivelor/InfinitePhotogrammetry`.

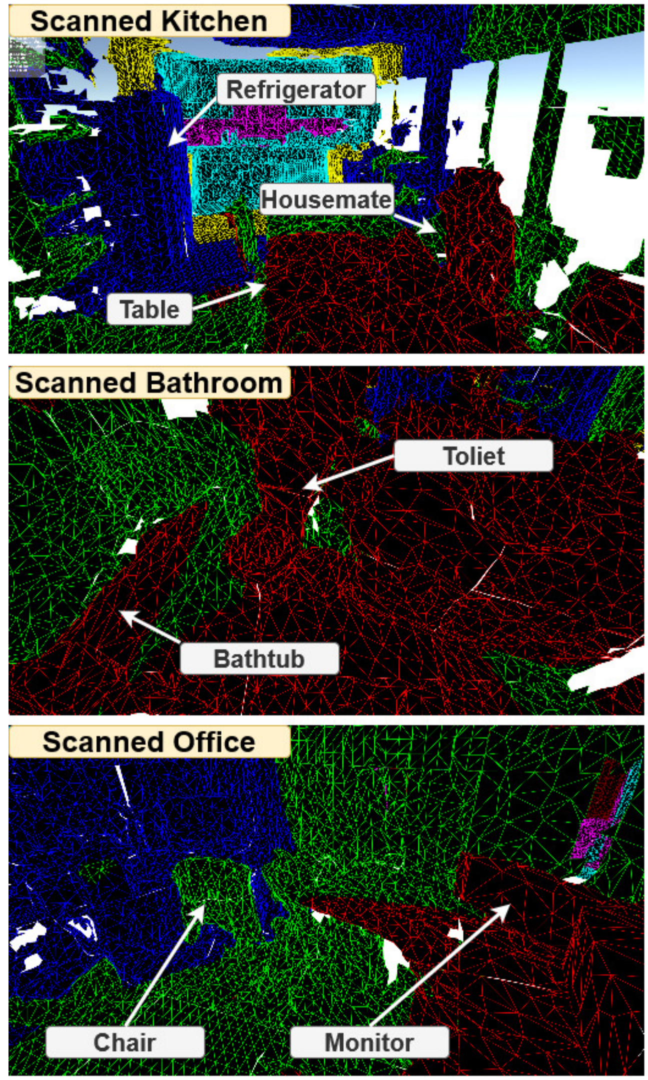

Figure 3: Examples of stored mesh geometry from a user during a ten-minute scanning session. A custom depth shader is applied and overlaid over the physical world to represent scanned geometry for the user with distance correlating to color. The user can review the scans by walking through the house in the unity engine through an MLO headset, a standalone build, or a WebGL build.

Results and Discussion

We were able to successfully test our system in a residential home and generate an infinite version of the house from a ten-minute scanning session. This produced a virtual experience in which the user was able to re-visit the scanned geometry and walk through both a static and an infinite WFC generated version of the home. Subsequently, our exploratory system may suggest that utilizing the spatial computing capabilities of modern XR devices can produce interesting virtual artifacts from both a static and generative perspective. In this section, we reflect on our system design for creative use and consider future research areas to understand how Infinite Photogrammetry could be better tailored as a creative tool.

Spatial computing systems are becoming ever more mainstream with consumer applications such as Snapchat, Instagram, and Facebook, who leverage augmented reality filters for social communication in videos and photos (Harborth 2017). As XR devices become more affordable, we may see a similar trend in this adoption and should consider the creative possibilities of XR's enhanced input modalities and full-body interaction. More creative applications, such as Minecraft Earth, are beginning to utilize AR for users to build block-based game worlds within their own homes (Khanna 2019). Other researchers are exploring extended reality for creative tools within architecture, art, design, games, media, and e-publishing (Abbasi, Vassilopoulou, and Stergioulas 2017). This includes extended reality creator tools such as collaboration and education (Andone and Frydenberg 2017; Serafin et al. 2017). Such tools and environments have been shown to positively impact mental health (Potts et al. 2019), learning (Papanastasiou et al. 2019), and physical exercise (Kunze et al. 2017; Elor, Teodorescu, and Kurniawan 2018).

For our proposed Infinite Photogrammetry application, more work must be done to determine its creative possibilities and refine its uses toward a casual creator. More evaluation must be done with Infinite Photogrammetry on more architectures such as museums, outdoor parks, and historical sites. In addition, efforts must be made to increase understanding of user perception and creativity within the tool. From this end, we believe that Infinite Photogrammetry may be of interest to be explored within the following fields:

- Video Game Designers interested in mapping real-world architecture for generative or static game levels;
- Artists of virtual environments interested in emergent design patterns from real-world terrain;
- Film producers scouting physical locations for filmmaking and or capturing virtual assets for special effects;
- and curious creators interested in exploring the design space of infinite photogrammetry for world-building and manipulation.

To this end, Infinite Photogrammetry may enable a system of creators to capture real-world environments with ease and creatively manipulate them from both static and PCG perspectives. We hope to refine this system for multiple extended reality devices such as mobile augmented reality with ARKit, ARCore, and WebXR (Linowes and Babilinski 2017; Maclntyre and Smith 2018). Additionally, it may be interesting to influence infinite photogrammetry with emotion personalization, which can be tuned from an immersive virtual environment (Elor and Song 2020). More significant input systems should be crafted and explored to enabled runtime creator tools such as manipulating WFC adjacency, smoothing scanned world geometry, and translating base color texture from world reconstruction.

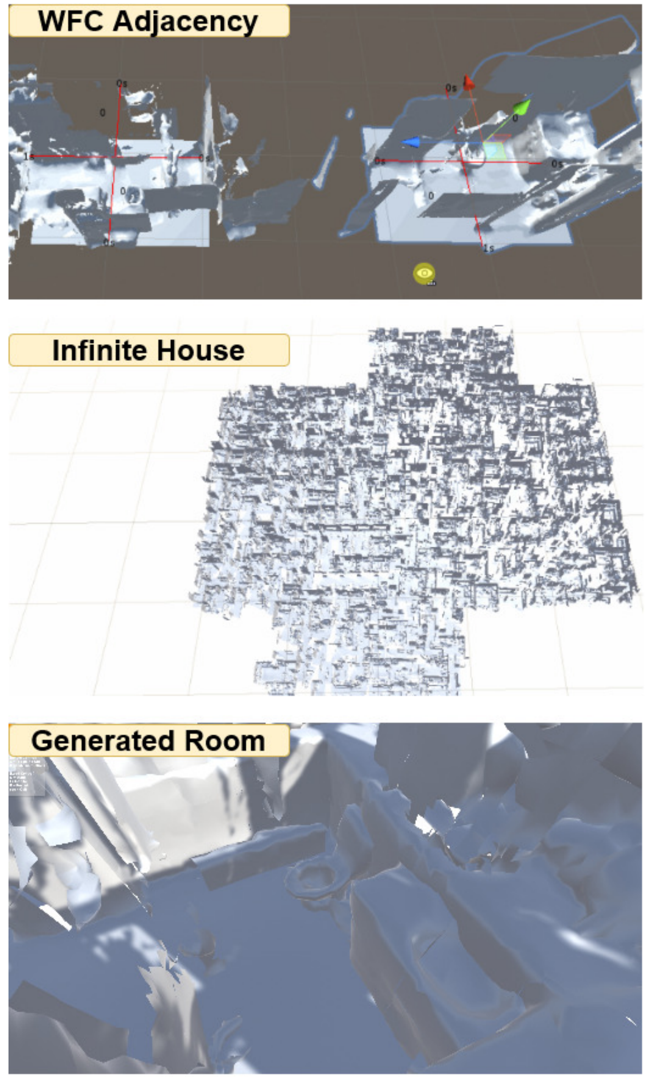

Figure 4: An infinite house generated by the users scanned geometry and wave function collapse. The user is able to define the WFC generative adjacency of rooms through chunks of the scanned geometry represented by one meter voxels. The rooms are then generated through chunks in relation to the users world position in the unity engine.

Conclusion

In this paper, we presented the creative application of Infinite Photogrammetry. We discuss how modern extended reality headsets can be utilized for Infinite Photogrammetry to translate the physical world into a virtual environment. We piloted our system through scanning a residential home to transfer a user's surrounding into a playable experience that can be infinitely generated with the Wave Function Collapse algorithm. Lastly, we considered the creative possibilities of this application as well as areas for future research. Although more work is to be done, a step towards Infinite Photogrammetry may enable a deeper dive into the creative manipulation of the physical world through the virtual.

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