Transferring Spatial Data from Unity to ArcGIS

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Abstract: Research in landscape architecture and adjacent fields uses game engines to create serious games and experimental environments, but precise quantification and analysis of those environments can be problematic when the visualization and analysis software are not directly compatible. In response, ESRI and Unity have developed a pipeline to port ArcGIS data into Unity, but the process of moving data from a Unity-based program back into ArcGIS has received considerably less attention. This descriptive paper, therefore, addresses the Unity-to-GIS pipeline by developing an open-source workflow for extracting spatial data from a virtual environment in Unity and transferring the same into ArcGIS Pro for spatial analysis.

Keywords: Unity, ArcGIS, Virtual Reality, spatial analysis

1 Introduction

In this paper we report the results of a new method for integrating game development engine and their products with relevant spatial analytics. This is a descriptive paper of a complex process. Gaming engines have been used for a wide variety of applications and research platforms across landscape studies (CARBONELL CARRERA & BERMEJO ASENSIO 2017, LAKSONO & ADITYA 2019). One of the significant advantages offered by these tools is a graphic user interface for crafting cinematic or interactive virtual worlds and experiences, which does not require extensive coding experience. Two of the most popular and publicly accessible gaming engines are Unity and Unreal Engine. Both offer a highly customizable platform with integration across a range of other software. The industry growth, publicly available support and tutorials and diversity of uses for gaming engines, including Unreal and Unity, hint at a future of continued use and likely growth in landscape architecture.

Disciplinary uses of the technology are currently focused on high quality representation, 3D design, and creating controlled experiments. However, these powerful tools could also benefit from integrated analytical frameworks for site and spatial analysis. Fortunately, gaming engines already have an explicit hierarchical and spatial organization. Further, the real-time user experience can be precisely documented so it would seem reasonable that an analytical framework could be developed. However, despite the game engine's robust capabilities to generate experiences, few open-access tools exist to analyze the immersive experiences or environments using real world metrics. Those tools that do provide such options are rather limited in their analytic capabilities (ESRI 2022b) and are not integrated bi-directionally between software. In landscape research, this limitation leaves a gap between the ability to visualize or interact with proposed landscapes and the ability to substantively understand the spatial metrics of those same environments.

This research project is one part to a much larger project, the latter that uses Unity to create immersive virtual environments and collect data about users' interactions and perceptions of those environments. We chose Unity because of custom work produced in prior iterations of the project making migration and comparison of our techniques across other gaming engines cost prohibitive. This sub-project examines how we can integrate ArcGIS Pro and Unity as

an analytical tool to understand those interactions. These programs, however, have only recently begun evolving integration capabilities. Currently, there are no fluid techniques to run the gamut of advanced spatial analytics available in GIS software using data generated from immersive virtual environments. Therefore, this project aims to address the lack of integration from Unity back to ArcGIS Pro. Our goal of developing integration from the gaming engine to GIS leads to the **primary question** of this sub-project: how can 3D mesh and point data in Unity be transferred to ArcGIS Pro for analysis while maintaining spatial fidelity?

In the physical world, spatial analyses provide valuable information about how environments drive various human behaviors (KWAN 2000). For example, for understanding the layout of an urban fabric or the spatial functioning of an ecosystem. Spatial analyses can provide information on the density of structures or populations, distributions of structures' sizes and shapes, trends of spatial relationships between environmental elements, or numerical counts. Unity does not intrinsically provide these kinds of information, but the data still exists or can be generated and then embedded in the virtual environments themselves. However, this analytical capacity already exists in Geographic Information Systems (GIS). We recognize there are various relevant tools for some of these analytics available within gaming engines, or that could be created within these engines, but these are often one-offs and require extensive technical capabilities. Therefore, significant advantages exist for integrating both GIS and gaming engines (e. g. Unity) together into an analytical framework.

There are several disciplinary applications where this integration could be beneficial. For instance, this integration provides significant advantages over traditional visual preference and scenic quality studies. Several previous studies involving self-reported, subjective ratings of visual scenes or landscapes were run as quasi-experiments with qualitative analyses of subjects' focal points and gaze paths (AL MUSHAYT et al. 2021, GUO et al. 2021, LI et al. 2022), and SIMPSON (2018) found results suggesting differences in gaze behaviors across demographic, environmental, and task context variables but lacked additional analysis or environmental data to quantify the spatial variables in the study. Further, SPIELHOFER (2021) found differences in gaze behavior and stated landscape preferences across similar development scenarios in different ecological settings. Each of these studies relied on real or virtual environments to elicit gaze behaviors or preference ratings, but none of the studies quantified the independent environmental variables potentially shaping the dependent behavioral outcomes. By creating a pipeline from Unity to ArcGIS, we can quantitatively relate environmental spatial variables to viewers' behavioral responses. For example, we may relate gaze behaviour patterns to scenes' ecological contexts using hotspot analysis or compare the spatial distribution of elements in a viewshed along a route to the distribution of a viewer's fixations. Additionally, scene-based perspective saliency maps (DUPONT et al. 2016) can be produced and related to a viewshed's visual magnitude (CHAMBERLAIN & MEITNER 2013) to validate these studies.

Additional studies have explored preference and realism ratings alongside physiological and behavioral variables using game engines or immersive environments. SIMPSON (2018) used a qualitative analysis of gaze behaviors in real-world environments to suggest variations across individuals, street settings, and task contexts. This suggestion supports further exploration of controlled virtual environments as potentially faster, cheaper, and more convenient to using real world environments to study gaze behavior. In that same vein, SCHROTH et al. (2015) found that Unity provided a highly accessible development platform for a "serious game" in environmental education, and in SORIA & ROTH (2018), participants demonstrated a greater spatial understanding of a proposed design after viewing an augmented reality (AR)

simulation allowing them to move freely through the space when compared to an AR simulation only allowing rotational exploration of a view from a single location.

In addition to visual-psychological studies, gaming engines offer several other opportunities to study the relationship between humans and our environment. For instance, BISHOP et al. (2011) used CryENGINE2 Sandbox2 editor to create a bushfire simulator to demonstrate fire hazards to Australian homeowners. The CryENGINE2 Sandbox2 editor supported a highly interactive virtual environment with a broad range of control over environmental variables. In the game, users were able to prepare their homes for a bushfire in ways that directly connected behaviors to fire outcomes. MANYOKY et al. (2016) also used CryENGINE to develop wind park simulations for comparison with real-world, on-site recordings of built wind parks. The comparison indicated high validity for the park simulations, and both conditions were presented to subjects using a cave-projection-like system. LINDQUIST et al. (2016) found that audio recordings significantly impacted subjects' realism and preference ratings for digital landscape representations. LINDQUIST et al. (2016) presented subjects with aural-visual representations generated from Google Earth imagery and audio recordings of the site. Participants rated the realism and their preferences for combinations of visual and aural components. In all these instances, having a direct pipeline to geospatial data to build the environment and then assess generated data or simulations could have offered time savings and potentially new insights.

Transferring the environmental spatial data (e. g., structural footprints, heightmaps, or behavioural point data) to a GIS is necessary since Unity does not provide the necessary analytic capabilities. This transfer raises two primary issues: compatibility between software and accuracy of data during transfer. The first issue arises from incompatible file formats when attempting to work directly from Unity to ArcGIS. Our Unity environments are primarily composed of 3D assets with mesh and texture data. These data are not readily imported directly to ArcGIS from Unity using previously integrated tools. Although recent collaborations between ESRI and Unity have facilitated the transfer of data from ArcGIS to Unity for visualization, relatively limited options are available for moving data in the opposite direction. The second challenge – maintaining spatial accuracy – comes from manipulating the virtual environment's spatial data through various formats to reach one compatible with ArcGIS. The data transformations must maintain the original environment's spatial qualities, and each transformation introduces threats to that validity. Consequently, we explored two sub-questions to answer our primary research question: 1) What processes and tools are needed to generate an integrated framework between Unity and GIS, and 2) How can spatial data about landscapes, objects and user interactions be bridged across the identified software?

2   Methods

2.1   Step-by-Step Process

To transfer our virtual environment (Figure 1) from Unity to ArcGIS for spatial analysis, we started from Unity 2021.3.15f1 (LTS) with access to the FBX Exporter package, moved into Blender 3.2 with the BlenderGIS addon, cleaned raster outputs in Adobe Photoshop, and finally reconsolidated the various data transfers into ESRI's ArcGIS v. 2.9. This section describes the full process in detail.

Fig. 1:   Perspective views of the virtual environment in Unity as seen by study participants

To begin in Unity, we organized the environment for export. "Prefabs", or pre-organized sets of individual 3D assets, are a convenient unit for export at this stage. We subdivided the virtual environment for export into predefined prefabs with an appropriate internal hierarchy that maintains the desired spatial units for later analysis. To export, we installed Unity's "FBX Exporter" package from the Package Manager, then used that extension to export each prefab to a .fbx in a "Binary" format.

We then used Blender to convert the .fbx files to shapefiles and to extract a single-channel raster heightmap of the environment. We began by importing the .fbx files in Blender. Since environment was subdivided into multiple prefabs, each imported prefab loaded at the project's origin, and manual rearrangement was necessary to reconstruct the environment. Using the "Snapping" feature to move the individually imported files into place helped maintain their spatial validity. Additionally, locking certain transformation axes (such as the z-axis) for all objects when moving the imported prefabs simplified the reassembly. Setting up other environmental elements (e. g. increasing the viewport clipping distance, adding a ground plane) streamlined the process.

Once the environment model was reconstructed in Blender, we began extracting spatial data (building footprints and heightmaps) for transfer to ArcGIS. The following process extracts two types of data: a raster heightmap and an environmental shapefile. To create the heightmap, there are two basic phases: setting up the virtual camera as well as compositing and rendering. The virtual camera must have an orthographic, top-down view of the entire environment and have an orthographic scale equal to the smaller value of the final render's pixel resolution. We set the output file format to "Targa Raw" and color to "BW"; finally, we included "Z" data under passes. When compositing and rendering, we used nodes in Blender's compositing tab and added a "Normalize" and an "Invert" node to the resulting console. We connected depth data from the Render Layers node to the Normalize node, and sent that output to the Invert node. We then connected the Invert node's output to the Composite Node to finalize the process. Using Cycles and an appropriate GPU, we rendered the output heightmap. The heightmap may have background noise on the otherwise flat ground plane. If necessary, this noise can be removed with digital imaging processing software, such as Gimp or Adobe Photoshop.

Blender can also produce shapefiles of the virtual environment using the BlenderGIS addon. This addon makes exporting shapefiles incredibly easy. To prepare the export, we first embedded additional data to attached to the mesh data; the BlenderGIS addon creates attribute

fields from each object's custom properties in Blender. For each value that would become a field in the shapefile's attribute table, we created a custom property named for each desired attribute. For a full analysis, we created each custom property for a single object then copied the properties to all other objects using the "Copy Custom Properties" addon from the "object_copy_custom_properties_1_08" package. Blender's Python Script tab allows for procedurally assigning values to these custom properties, such as object names or object parent names. These data can then be exported to a shapefile through the BlenderGIS addon. Simple environments may be exported as polygons, but for more complex environments or models, we recommend exporting as points due to a 2GB file size limitation on the export. With the shapefiles and heightmaps completed, all files were ready for ArcGIS. In our project, we created custom properties for "Object Name", "Parent Name", and "Block Name" to allow for grouping objects at the building and block-level for analysis in GIS.
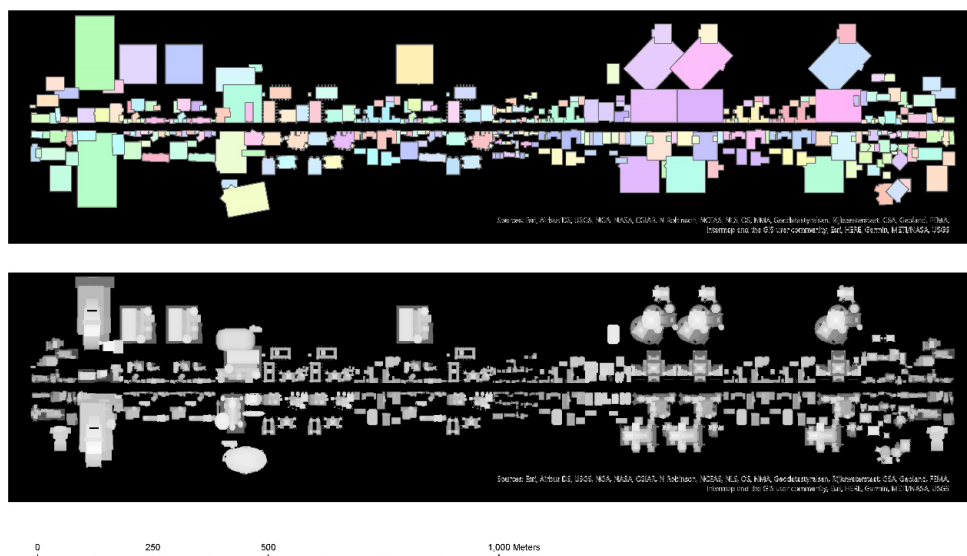

Fig. 2: Buildings' vector footprints (above) and a digital elevation model (below) generated in ArcGIS Pro using the virtual environment's spatial data extracted from Unity

Next, we created a new project in ArcGIS, established the appropriate folder connections, and added the heightmap and shapefiles to the map. Since the environment was not previously geolocated, our data loaded at <0,0>, and the shapefile and heightmap required some georeferencing for proper alignment. We defined a projection for each file, and since our shapefile was of points, we applied a minimum bounding geometry using the object name and object parent name as join fields. Dissolving the output by the desired field achieved a near finished set of building footprints (Figure 2). These footprints may be further refined using "Raster to Polygons" on the Heightmap and erasing the vector footprints by a selection of near-0 height polygons. The footprints may then be spatially joined to the maximum intersecting heightmap polygon. At this point, the Unity-to-GIS pipeline is complete. Additional data may be extracted from the experimental environment and joined to environmental components using the object name field as a join field.

2.2   Process Overview

To answer our research questions, we explored a range of processes and software in order to develop a method to transfer both the structural elements (simple and complex objects) as well as data generated during a user experience from Unity to ArcGIS Pro. Due to popular demand, the GIS-to-Unity pipeline has been well documented and recently formalized in the ArcGIS plugin for Unity (ESRI 2022a). This tool allows for accurate and interactive visualization of geospatial data, but relatively little documentation exists for the reverse workflow (Unity-to-GIS) and analysis of virtual environments.

To transfer our virtual environment from Unity to ArcGIS for spatial analysis, we started from Unity with access to the FBX Exporter package, moved into Blender 3.2 with the BlenderGIS addon, exported the necessary spatial data as raster data and shapefiles, cleaned raster outputs in Adobe Photoshop, and finally reconsolidated the various data transfers into ESRI's ArcGIS v. 2.9. More specifically, the Unity-based virtual environment and its components are exported to .fbx formats for working in Blender. Next, the .fbx files are imported to Blender – and rearranged to match their experimental composition, if necessary – from which a single-band raster heightmap can be rendered. Some additional denoising of the raster output may be necessary before using the file in ArcGIS. To extract vector data from the environment, the BlenderGIS addon (Domlysz 2014/2022) provides tools for exporting the environment in various shapefile types. In our case, we exported the experimental environment as a set of building footprints. These vector and raster data can then be aggregated for analysis in ArcGIS, as in Figure 3. This process can also be used during the design phase for new experimental environments by providing spatial metrics on the environmental components, which can then be sorted into categories for creating districts with controlled and distinct spatial properties. Figure 3 outlines the workflow we developed, and its components (software, tasks, and data) to address this gap. Each box represents a specific piece of software with its respective initial data or processing tasks. Each oval indicates the format needed to transfer data between programs.
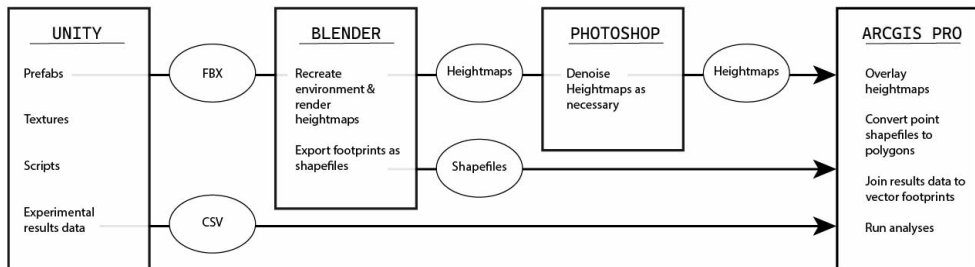

Fig. 3:   A flowchart depicting the overall workflow

3   Discussion and Conclusion

Ultimately, analyzing virtual environments offers the opportunity to empirically assess user interactions with virtual space. Preceding research has recognized this advantage and called for greater integration of critical spatial analysis with advanced visualization (MACEACHREN & KRAAK 2001), especially as research agendas turn towards examining dynamic spatial

phenomena like visual experiences (LIN et al. 2015). By combining Unity with virtual reality and eye-tracking software and hardware, we can quantify subjects' visual exploration of an environment, and through ArcGIS, we are then able to quantify the virtual environment. By using both types of software, we can explore quantitative relationships between an environment's spatial statistics and viewers' behavioral and physiological responses. Furthermore, we can tightly and easily control the environmental variables to explore relationships between behavioral responses and specific environmental parameters.

Our work demonstrates one method for achieving this integration between environmental visualization and spatial analysis while maintaining spatial accuracy across software. While ArcGIS's "3D Analyst" license can circumvent some of this workflow, our work demonstrates a work-around using Blender as a free, opensource replacement for extracting data from immersive virtual environments. This project opens possibilities for further and more accessible research examining relationships between quantified environmental parameters and human behavior, which could provide much needed empirical data for evidence-based design strategies.

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