Protecting Cultural Heritage through

Augmented Reality (AR) Immersion of Historic Sites

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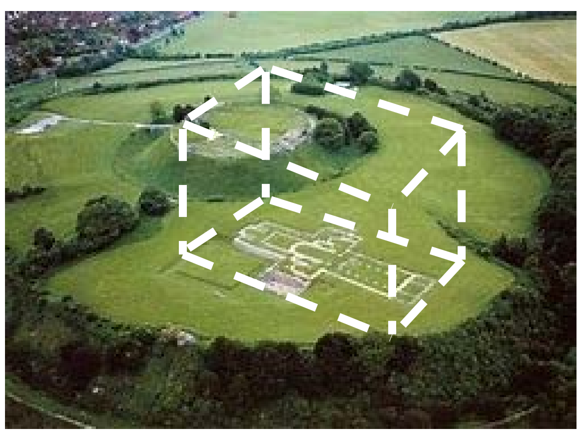
Executive Summary

Preservation of American historic sites has focused since the 1960s on extant buildings and archaeological sites. The lost buildings and vanished landscapes can only be addressed indirectly through historic records, artifacts and interpretation. Emerging technology however adds a new tool for preservationists with augmented reality (AR). Individual buildings and entire villages lost over time can be reconstructed and viewed with everyday digital devices such as smartphones and tablets. This project pilots a sequence of methods combining GIS and historic maps, 3D modeling with architecture, and AR visualization to recreate historic views lost to time but are significant heritage contexts for community commemoration and support preservation of surviving places.

Introduction

Tom Mayes, an executive for the National Trust for Historic Preservation, wrote "old places are important for people to define who they are through memory, continuity and identify[1] – that sense of orientation..."[2] But what occurs when these important old places disappear - through development and demolition, or neglect, or political forces? Do the communities' sense of place wither and fade? Do their absence also lead to the demise of connections with ancestors or the sacred or history, individual or collective? When the structures are gone, can we reclaim the ties to these places as they were?



Site of Old Sarum Cathedral, Salisbury, England

[1] Mayes identified fourteen ideas why old places matter – continuity, memory, individual identify, civic and national identify, beauty, history, architecture, sacred, creativity, learning, sustainability, ancestors, community, and economics.

[2] Mayes, Thompson M., Why Old Places Matter: How Historic Places Affect Our Identify and Well-Being, Lanham, MD: Rowman & Littlefield, 2018, pg. xxiii.

How will we know it's us without our past?"

— John Steinbeck, The Grapes of Wrath

Problem Statement

Preservation of American historic sites focuses on extant building and archaeological sites[3]. Since the enactment of the National Historic Preservation Act in 1966[4], policy, methods and standards, and professional practices aim to identify, define, and then protect and preserve important heritage sites, for the nation, regions, and communities.

However lost buildings and vanished landscapes have no similar direct tool set. Without that built environment, at best the lands can be protected by public and private agencies with open lands and parks on the former sites. More often, with the loss of the tangible structures, the land is redeveloped, further eroding the heritage of the area, and speeding the diminution of memory.

Historians and preservationist address the loss of tangible structures indirectly through acquiring and exploring historic records and managing artifacts. From these, views of historic sites can be crafted through interpretation, creating visual representations display using images and film, and set out in the vacant landscapes with signage and landmarks.

Emerging digital technologies offer a new means to preserve landscapes and buildings to supplement above-ground preservation and below-ground archaeology. Can a combination of geographic information systems (GIS), digitized historic and contemporary raster maps, 3-dimensional (3D) modeling of buildings, and augmented reality (AR) visualization add a new tool for preservationists? Can these methods produce inspiring immersive experiences with virtually reconstruct buildings and villages when viewed with people's everyday digital devices such as smartphones and tablets?

Approach

This project pilots a sequence of digital methods to transform information from historical sources into a 3D visualization of lost structures at the exact site where they once stood. The novelty of the project is to view virtual buildings outdoors at any location in the world with a device that most everyone carries every day.

The work begins with the collection of germane historic records including maps, photographs and descriptive information of the lost buildings. Two parallel workflows produce digital output products – a precise geolocation and a 3D model of the buildings. These are combined in the third work sequence to generate the full-scale recreations that are geolocated outdoors and viewable through smart devices. A workflow diagram (Figure 1) shows the two tracks of determining the location and creation of a digital model, followed by the application of the siting and 3D model into the AR environment. These steps are explained in detail is the section below.

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[3] Pennsylvania Historic and Museum Commission, Preservation/About/Forms and Guidance, https://www.phmc.pa.gov/Preservation/About/Pages/Forms-Guidance.aspx accessed Dec 22, 2021.

[4] Advisory Council on Historic Preservation, "National Historic Preservation Act", https://www.achp.gov/digital-library-section-106-landing/national-historic-preservation-act accessed Dec 22, 2021.

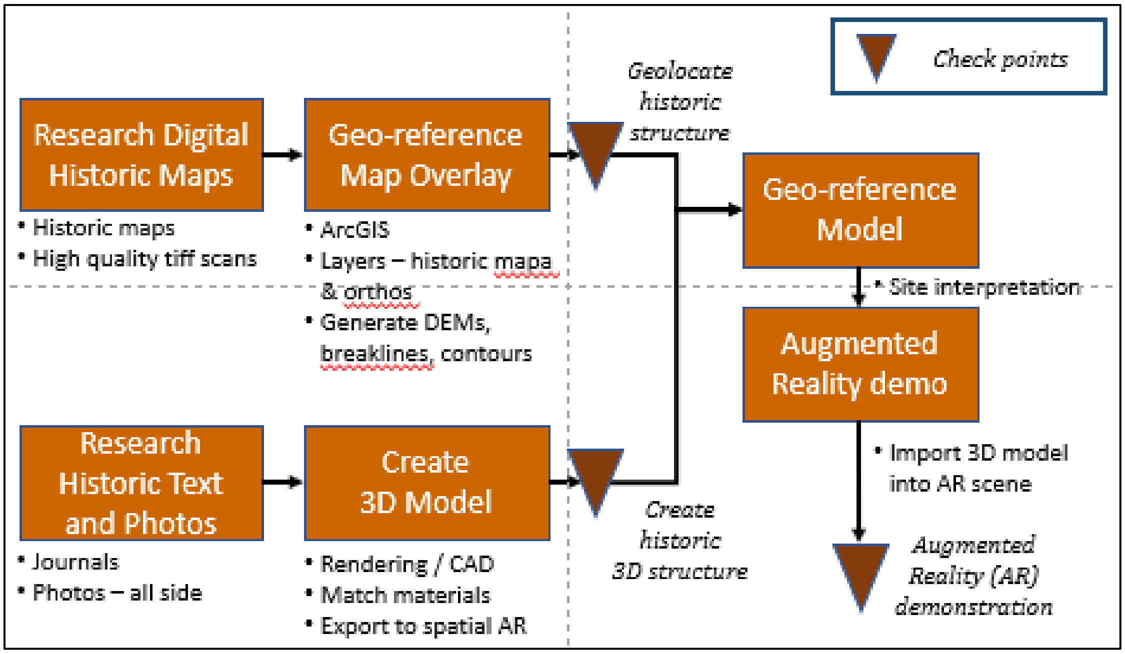

Figure 1 – Project Workflow including Intermediate Quality Checkpoints

A pilot project tests the feasibility and viability of the proposed novel capability. The test structure is the Paoli Inn, once a crossroads tavern located in Tredyffrin Township, Chester County, PA, 13 miles west of Philadelphia. The Inn was an important 18th century waystation along the Lancaster Pike westward and later the Paoli rail yards of the Philadelphia & Columbia Railroad and subsequently the Pennsylvania Railroad. The Inn was the life center life in the village of Paoli that today is still a transportation juncture and commercial business hub for the township and region.

The checkpoints identified in the workflow serve to examine the quality throughout the pilot. Qualitative assessments are made at the completion of each process step. These quality checks are:

1. Geolocate historic structure
2. Recreate 3D historic structures virtually
3. Augmented reality (AR) field demonstration

General Workflow

Success for the project goals starts with aggregation of sufficient records to produce both the geographic location and the physical features of the subject structures. With sufficient fidelity of both historical records, a rendering of the buildings can be generated and affixed to a location anywhere in the world. If either the location or dimensions and details of the structure are in question, the visual experience necessarily will be more generalized and less impactful to the viewer. For structures of a specific era or architectural style, generalized features can substitute for the unique aspects of the building but doing so may results in loss of the local character. For these reasons, sufficient research is necessary to assure the quantity and quality of the maps, descriptive and photographic records.

The Paoli Inn was established in 1769 and expanded in 1778 and 1812. The Inn burned in 1899 and the site razed a few years later (Figure 2). Fortunately, Philadelphia area historical organizations reposit high quality maps, photographs and text[5] records from the 1880-1890 prior to the fire.

Figure 2 – Paoli Inn in 1888 (left) and after the 1899 fire (right)

The location and outline footprint of the Paoli Inn is well defined in regional atlases of 1887 and 1897 (Figure 3), including the building's wrap-around porch in the latter instance.

Figure 3 – Map details showing the Paoli Inn in 1887[6] (left) and 1897[7] (right) maps

Based on local knowledge of contemporary Paoli geography, the approximate location of the Inn's 1899 footprint at the time of the catastrophic fire is shown in the aerial photograph below (Figure 4). Using the historic maps as a layer in GIS with contemporary maps and aerial images, a more exact siting is expected.

[5] Sachse, Julius, The Wayside Inns on the Lancaster Roadside between Philadelphia and Lancaster, 2nd ed., Lancaster: New Era Printing Co., 1915.
[6] Baist, G. Wm. (topographical engineer), (1887), "Plate 29", "Atlas of Properties Along the Pennsylvania R.R. from Overbrook to Malvern Station 1887", Philadelphia: J. L. Smith.
[7] Kiser, Ellis Barthel, Otto & Ogier, St. Julian (civil engineers), (1897), "Plate 12", "Atlas of Properties on Line of Pennsylvania R.R. from Rosemont to West Chester 1897", Philadelphia: A.H. Mueller.

Figure 4 – Approximate location of Paoli Inn over aerial photograph of Paoli

Process 1 - Historic Maps and GIS

The novelty of the project is the geolocation of the historic structures at their exact historical location. Locating the original sites is best achieved with historical maps that are digitized and overlaid onto contemporary maps in a GIS.

The ArcGIS Desktop 10.8.1 application was used to produce map layers. High resolution .tiff scans of the maps of the 1887 and 1897 maps were required to produce satsifactory geo-referencing. 2008 PAMAP orthographic[8] and LIDAR[9] imagery provided the contemporary map layers for geolocation.

The selection of ground features to georefence is vital. It is understood that many locations to select as ground control points likely differ after a century of change. These changes include shifts and widening of roads, disappearance of landmarks, and development of surrounding properties.

The positional accuracy of historic maps is assumed to be low across the extent of a historic map whereas relative positions of features that are close in proximity in the map are likely relationally accurate. Thereby, georeferencing a historic overlay is feasible when using control points closer to the subject area of interest. Seven (7) control points were selected around the full arc of the Paoli Inn on the historic maps (Figure 5).

[8] Pennsylvania Spatial Data Access (PASDA), PAMAP Program - Color Orthophotos Cycle 2, 2007 – 2008, accessed Dec 20, 2021, https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1323

[9] Pennsylvania Spatial Data Access (PASDA), PAMAP Program - LiDAR Breaklines, 2006 – 2008, , accessed Dec 20, 2021, https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1246

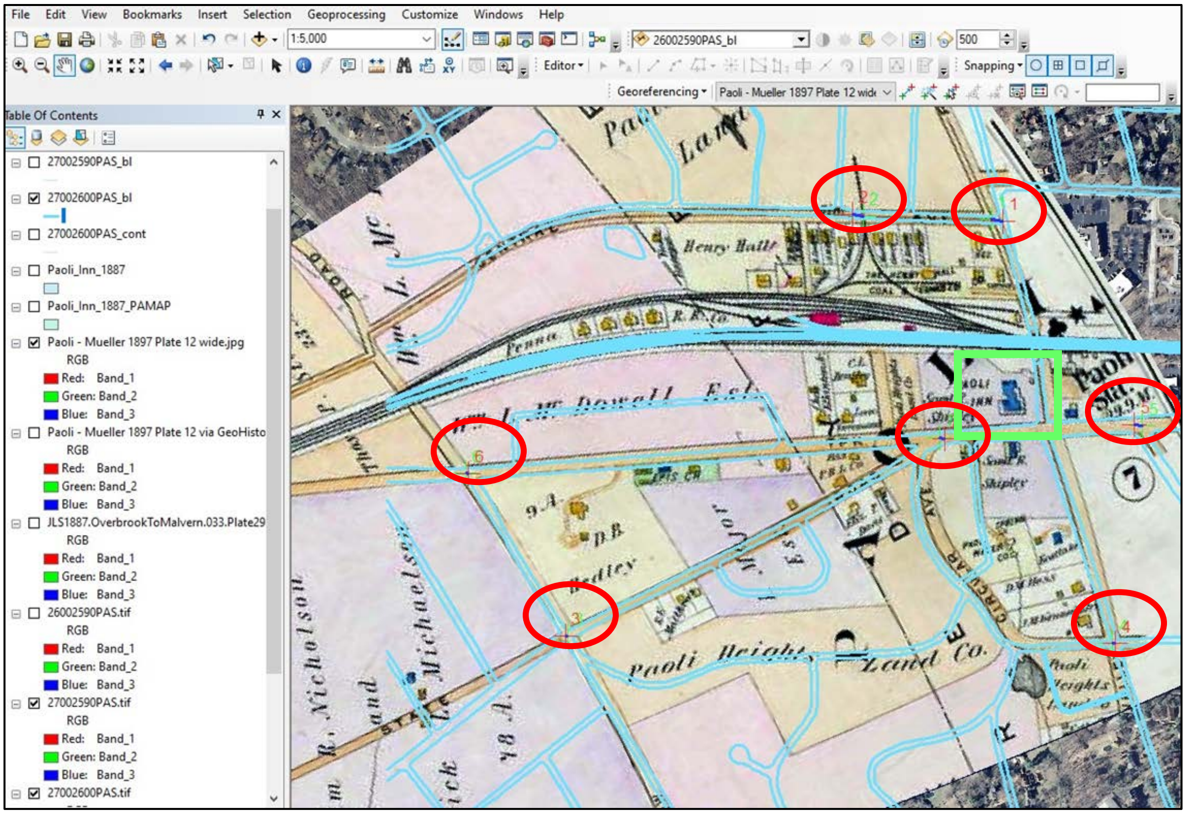

Figure 5 – Georeferencing controls points (red), breaklines (blue) and Paoli Inn (green)

Achieving quality alignment between the map layers was difficult knowing the inherent inaccuracy of the historic maps. Experiments with several alternative alignment techniques were tried. Evaluations were conducted with PAMAP ortho and DEM raster data and LIDAR contour and breakline vector files.

LIDAR breakline layers wound up being the best suited for the task. Breaklines are the abrupt transitions of surface elevation in LIDAR data, most notably created by edges of modern roadways. Adjusting the control points to achieve centerline alignment along stretches of roadway between the historic map and ortho raster layers yielded better quality orientation and satisfactory warping of the historic map (Figure 6).

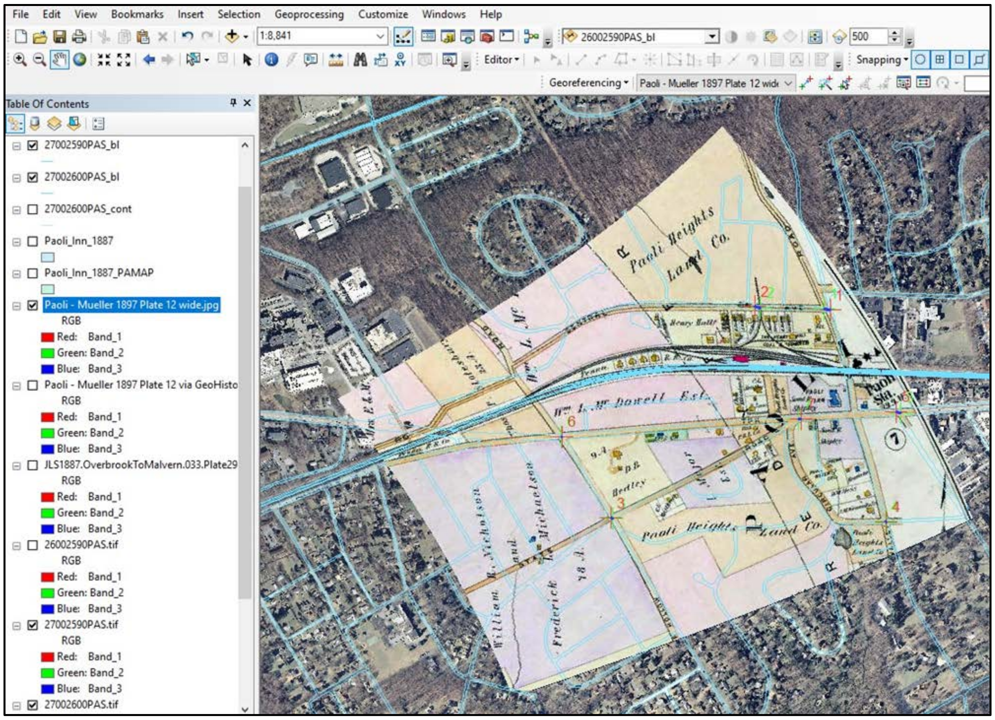

Figure 6 – Georeferencing the 1897 map warped to align with 2008 ortho layer

With the historic map overlay oriented to the contemporary ortho imagery using breaklines, the location of the Paoli can be precisely determined within the accuracy of the historic map. Polygons using the outline of the Inn's footprint in the 1887 and 1897 maps were created. The historic overlay is removed and the Inn's expected position is revealed onto today's landscape (Figure 7).

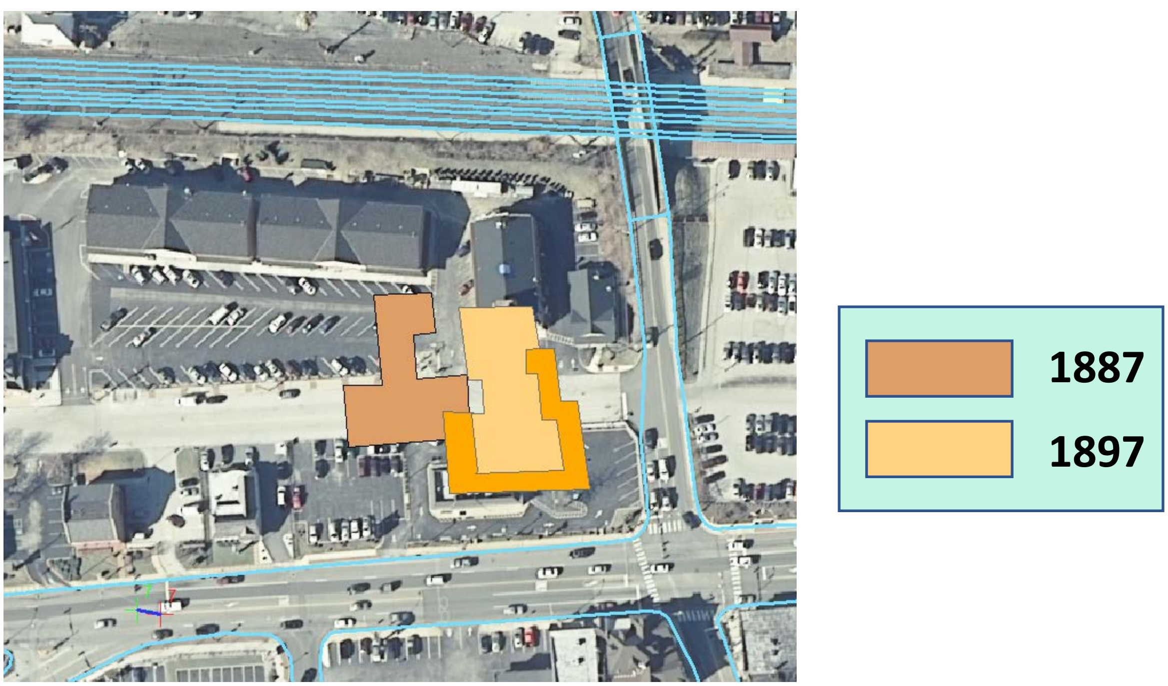

Figure 7 – Georeferenced Paoli Inn footprints as polygons on 2008 ortho layer

The locations differ noticeably between the two polygons. Among the possible sources of this error is the accuracy of the building outlines in the 130+ year old maps, or the changes in the road locations used for breaklines and control points. The maps are understood to be representative of the area and not survey grade maps, so this source of error cannot be corrected. While care was taken to georeference both maps, refinements in locating control points may improve the correlation.

Process 2 - Historic Records and 3D Modeling

The next step is reconstruction of the buildings. Several techniques can be used to establish the dimensions, faces and facades, and overall appearance of vanished buildings. The truest are photographs of the building, preferably from many sides. This however may be a challenge as many records show only front facades. Sketch drawings of buildings can also be used, but these may introduce liberties or errors of the artist. Finally, similar buildings of the vicinity and era of the lost structure can provide guiding instruction for creating a fair representation of the subject building.

Fortunately, a well-documented record of the Paoli Inn exists in photographs and text. The dimension of the original 1769 Inn and two additions are recorded in Sashse's Wayside Inn volume.[10] The sections and dimensions are:

- 1769 – 42 x 30 feet
- 1778 – 27 x 30 feet
- 1812 – 81 x 38 feet

The three segments of the building clearly can be seen in the four view photographs from the Sashse book (Figure 8).

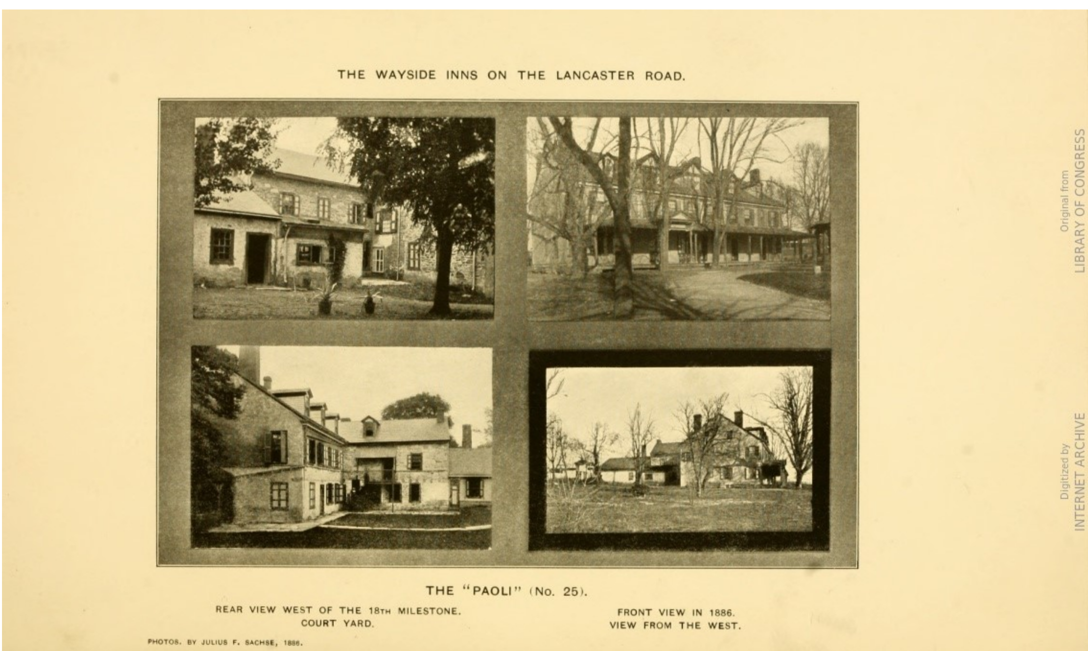

Figure 8 – 4-views of the Paoli Inn, Sachse, 1888

[10] Sachse, pgs 120, 123, and 131.

Fabricating buildings is a well-developed practice in architecture using computer-aided-design (CAD) systems. The Penn State GIS program uses the drawing application, SketchUp, and used with this pilot. Rather than rendering 3D solid models, SketchUp instead uses vertices, edges, and planes to produce 3-D visual representations. Rendering the 3D model requires balancing requirements to produce sufficient fidelity for the users' perceptions and file size to be imported in the AR software platform in the final process step. For this pilot, a rendering with all facades, window penetrations, gables, columns and porch, and material facings also minimized the file size for ease of use (Figure 9).

Figure 9 – SketchUp model of Paoli Inn

Process 3 - AR Platform Development and Implementation

Augment reality (AR) takes many forms and is constantly evolving with technological advances. Users will view the AR images through their personal smart devices, both tablets and smartphones. 3D entities appear as layers atop the camera view of the surroundings. The objective of each AR project drives decisions on selection of AR platform, operations and use.

Indoor applications abound where consumers can view virtual furniture in empty rooms or creatures pop off the page in children's books. For the popular outdoor multiplayer game Pokémon Go, imaginary creatures appear through users' devices in front of the person where they can interact. For heritage sites, the virtual buildings will be fixed in one location with one orientation such that visitors to the site may walk around the grounds viewing buildings before them.

Two important implementation decisions are required – triggers and platform. First, the AR images must be triggered to appear on the device displays. Triggers include "marker-based" such as images or QR codes typically used with indoor applications, and "markerless" that include wireless geolocations for outdoor use.[11] For the pilot project virtual building application, markerless GPS and cellular signals trigger the device that an object is located nearby for viewing.

Creating the 3D AR images requires a development environment, much like any digital application. Both Apple and Google provide AR systems development kits (STK) used to create apps for the smart devices. Users then find and downloaded from the companies' app stores. However, many

[11] Qiao, Xiuquan, et.al., "Web AR: A Promising Future for Mobile Augmented Reality—State of the Art, Challenges, and Insights", Proceedings of the IEEE, vol 107, no. 4 (April 2019), pgs. 651-666.

consumers are leery of downloading new apps for privacy and performance concerns. Thus, app-based AR systems create user friction and dissuade adoption. An alternative emerging option is "web AR" that does not require an app download. The AR visualization works with the native browser on the device.

The dual decision to employ markerless GPS triggers and app-less browser AR led to the decision to select the "awe.media" platform.[12] awe provides GPS AR functionality with browser ease of use. In the awe web platform, developers upload the building model in one of several standard 3D file types (e.g., .obj, .fbx) and fixes a location with the awe map interface. After a short time of processing, the building can be viewed with an awe URL and view the building overlaid on a camera-view (Figure 10).

Figure 10 – Paoli Inn - 1888 photograph and 3D model as viewed through awe website

Using the awe website, the 3D model of the Paoli Inn from Step 2 was converted into an AR "object". Next the object was pinned to the location in Paoli identified through the geolocation Step 1 (Figure 11). Finally, the AR application was tested in the Paoli location by walking around the shopping center parking lot. Video recordings capture the experience of walking around the virtual Paoli Inn (Figure 12).

Figure 11 (left) – map indicating the pinned location of the AR object at the Paoli location

Figure 12 (right) – screen capture from video of AR view of virtual Paoli Inn in Paoli parking lot

[12] awe.media

Results

Assessments of the quality of each process step were completed. Overall the total pilot workflow was a success and resulted with viewing the 3D model of the Paoli Inn at its location historic location and the ability to walk around the building AR image across a wide expanse.

Details on the quality of each process step is described in the table below:

Process Step	Rating	Quality Measure
Geolocate historic structure	• Success	• Generate GIS map overlays, position historic features on modern map
Recreate 3D historic structures virtually	• Success • Satisfactory	• 3D model dimension from text and photos • 3D model has sufficient detail compared to historic photos; representative but not photo-realistic, modeling tool used misses some surfaces
Augmented reality (AR) field demonstration	• Success • Satisfactory	• 3D model imported and displayed in AR view • 3D model pinned to geolocated historic site; stability limited by GPS & processing on mobile device

Discussion

The pilot provided a first demonstration of a method to convert information from historical maps, photographs and texts into a 3D visualization of a building lost 120 years ago and now viewed by an everyday person of their local heritage. A user can once again view the center of Paoli village life from more 250 years ago. Such revelation surely will cause today's shoppers, merchants and residents to reconsider the ground on which they walk. Conestoga wagon drivers, British troops with tankards of ale, and Pennsylvania Railroad engineers and passengers all enjoyed a meal or spent a night in the "Paoli." The visual and spatial AR experience has the ability to refresh communities' ways of retelling their histories and to contemplate the preservation of the building that still exist from those eras.

The cost for creating such experiences is low. The technologies have finally arrived wherein local historians and preservationists with a modest technical tool kit can generate these walkable scenes. Most everyone has the processing power required right in their smartphone with no need to download questionable apps. To view a scene from history merely requires a weblink.

Preservation practices can now fill the void in the suite for above-ground and below ground historic resources. Now "history in the cloud" can be as tangible and real as a walk through a National Historic Park or community historic village.

Future Development

While the pilot demonstrated a first end-to-end process success, each of the process steps can be improved with added research and development. Listed below are several areas of immediate attention:

Process area	Improvement opportunity
Mapping	• Refine requirements for historic map selection • Improve geo-referencing warping method
Modeling	• Change modeling tool from SketchUp for improved AR platform compatibility (e.g., Blender, architectural CAD) • Examine the National Park Service's Historic American Buildings Survey (HABS) for standards and apply to 3D modeling for virtual reconstructions
AR Visualization	• Test location precision and stability with 5G wireless signals
Workflow improvements	• Create library of building elements by architectural style for rapid modeling • Accelerate learning curve to speed total process time
User Experience	• Survey historical museum & preservation communities

Conclusion

Current practices for historic preservation advance with adoption of new technologies. The adoption of AR adds a powerful above-ground fieldable technologies to reconstruct in situ virtual buildings and viewscapes of the past. This pilot project demonstrated a sequence of process steps melding GIS analysis, 3D modeling, and GPS-based augmented reality to establish a new tool for the historic preservation field.

Preservationist Tom Mayes laments "Almost all the attention is on new places – on placemaking rather than older and existing places."[13] With this work, we may also add "place re-creating."

Reflection

This capstone pilot project was well supported by the MGIS program's pedagogical breadth from foundational theory to a broad set of GIS tools and skills development. Further, the professional practices addressing system development, project management and quality assurance can be readily applied to further the development and refinement of this novel capability.

The author thanks the many MGIS faculty and fellow students for their time, teaching and support along the MGIS journey spanning many years. Gratitude is expressed for the two capstone advisors, Alex Klippel and Nathan Piekielek for their coaching and expertise in the fields of augmented reality and digital mapping, respectively. Further, tremendous thanks are given to mentors throughout the MGIS program – Dennis Bellafiore, Todd Bacastow, and Beth King. Their sustained encouragement and expansion of my GIS expertise will drive my continued pursuits in the field.

I am also thankful for the people who aided me with the many details of the project. Preservationists and historians who provided their insights and expertise include Jim Garrison, Amy Lambert, and Bart Van Valkenburgh. My tech partners in exploring the emergent frontiers of augmented reality include Riyon Harding of MiXXD, Inc. and Alex Young of awe.media. For institutional resources, this pilot project could not have succeeded without the rich archives of the Tredyffrin Easttown Historical Society and Radnor Historical Society. They all either made the journey smoother or boosted my flagging spirits when challenges arose. Our work together yielded success.

[13] Mayes, pg. xxi.

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Photographs

Tredyffrin Easttown Historical Society Image Collection - the2nomads.org/ImageDatabase/index.html

Software products and platforms

8th Wall - www.8thwall.com

Awe – awe.media

ESRI ArcGIS

- ArcMap Desktop - www.esri.com/en-us/arcgis/products/arcgis-desktop/overview
- Pro - https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

SketchUp - www.sketchup.com/

