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Modeling Historical Landscape and Architectures Utilizing Open Data for Enhanced Sightseeing Experience

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Abstract

In this paper, we explore an application of digital twin technologies to the field of digital heritage preservation, focusing on the historical city of Aizu-Wakamatsu, Japan. Leveraging open data and freely available software, we considered a methodology for the digital reconstruction of historical landscapes and architectural features, employing historical GIS data, 3D modeling, and virtual reality techniques. We applied our methodology to constructing a virtual historical representation of Aizu-Wakamatsu, with a specific attention to Tsuriga-jo, a famous castle in North-Eastern Japan. These reconstructions both enhance the cultural and educational experience of visitors, and contribute to the broader goals of heritage conservation. We discuss the potential of virtual tours to offer enriched, immersive, and interactive narratives of the past. Our study underscores the importance of preserving cultural heritage through digital technology and demonstrates the potential of digital twins in understanding and experiencing historical landscapes. The methodology and findings of this paper contribute to the emerging field of digital humanities and offer a scalable framework for future research in digital heritage preservation and virtual tourism.

Keywords: Historical digital twins, Open data, Virtual cityscapes, Virtual tour.

1 Introduction

In the burgeoning field of digital humanities, the concept of digital twins represents a groundbreaking shift in how we interact with and understand the physical world. By leveraging digital twins for real-time monitoring, simulation, and optimization, researchers are exploring the expansive potential for retrospective analysis through the construction of historical versions. Such historical digital twins hold immense promise for the conservation of heritage sites and urban landscapes, effectively providing an approach to resurrect and preserve spaces that have been lost or altered over time. They are becoming increasingly valuable in fields such as education, culture, and urban planning, where they offer a window into the past and facilitate informed decisions about future developments while maintaining sensitivity to historical and cultural contexts. The supporting technology solutions contribute to the vast domain of digital transformation by creating novel opportunities for sightseeing and learning experiences rather than solely digitizing the available artifacts.

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Significant efforts have been made in automating the graphical reconstruction of historical environments, as seen in pioneering projects that have meticulously recreated the Kyoto streetscapes of the Edo period using historical GIS data and three-dimensional modeling [1, 2, 3, 4]. These endeavors not only involve the construction of landmark models but also simulate landscape evolution over time, enhancing the tourism experience through immersive virtual "time-traveling" scenarios [5, 6]. However, despite achieving authentic virtual representations of historical landscapes, these reconstructions face challenges stemming from the incompleteness of historical maps and documentary resources and the complexities of integrating these into modern GIS software [7]. Additionally, advancements in three-dimensional graphics, including fast shading and soft shadowing, have been applied to the virtual reconstruction of Asuka-kyo, showcasing the importance of three-dimensional computer graphics representation of architectures [8, 9]. Furthermore, the detailed digital preservation of cultural heritage objects as three-dimensional data is of paramount importance. Their significance has been highlighted and explored in various studies, which have set a precedent for the meticulous digital preservation and analysis of heritage objects [10, 11].

Our research aims to address these challenges to enhance the educational experience for travelers interested in the historical aspects of a region. Focusing on Aizu-Wakamatsu, a Japanese city with a rich historical tapestry, we employed a variety of historical resources to model its past landscapes and architectures, significant for its heritage as a castle town. Grounded by our previous work [12], we continue the endeavor of digitally reconstructing the historical landscape of Aizu-Wakamatsu city. This project involves the detailed modeling of streets, buildings, and landmarks, some of which have vanished or changed over time. Specifically, we have concentrated on the area surrounding the famed Aizu-Wakamatsu castle, known as Tsuruga-jo, which remains a pivotal attraction for visitors. This effort is directed towards augmenting the range of tourism media available to those keen on exploring the historical depths of the region. Our aim is to provide a virtual yet authentic experience of the city in past time, enabling visitors to explore and appreciate the historical and cultural essence of Aizu-Wakamatsu through a digital medium.

To facilitate this study, digital open archives have been instrumental in collecting a wealth of historical cityscapes, architectural designs, and maps from targeted periods. These resources were primarily sourced from the digital archive [13] and the *Nanukamachi.com* platform [14], the latter being a contribution from a dedicated private archivist. This extensive use of public archival data plays a key role in maintaining historical accuracy and underscores the significance of preserving cultural heritage [15]. Our methodology also incorporates the use of Blender [16] for 3D modeling and the Unity platform [17] for developing interactive walk-through experiences, both of which are freely available tools that facilitate similar endeavors in other historic cities. Additionally, our work acknowledges and draws inspiration from related initiatives, such as the creation of digital museums, which meticulously reproduce and contextualize historical artifacts for access through various digital mediums [18]. While recognizing the current limitations of our project, we believe that initiating a discourse on its early design and conceptual framework will lay the groundwork for more sophisticated and pragmatic applications in the future. Through this research, we aspire to not only preserve the intricate tapestry of historical landscapes, but also to inspire and educate future generations by making the past accessible and engaging through cutting-edge technology.

The remainder of the paper is structured as follows: Section 2 outlines the methodology for creating three-dimensional terrain maps using publicly available geospatial data, emphasizing the extraction and utilization of elevation data for terrain modeling within Unity. We also address the challenges and solutions related to aligning historical maps with modern geographic data, utilizing geometric correction techniques and points of interest for map accuracy and cultural narrative enhancement. Then, the focus shifts to the reconstruction of historical buildings and architectural elements using free software to capture the essence of architectural heritage lost to time. Section 3 presents a prototype that enables virtual tours in two different scenarios, providing examples of immersive experiences. The discussion in Section 4 reflects on the broader implications of this work for digital heritage preservation and the challenges of creating comprehensive digital reconstructions of historical environments. Finally, Section 5 concludes the paper by summarizing the contributions of this study to digital humanities and cultural tourism, and outlining future directions for research in the field of digital heritage preservation.

2 Generating 3D Map from Open Data

2.1 Modeling of Terrains

The Geospatial Information Authority of Japan (GSI), which is under the Ministry of Land, Infrastructure, Transport and Tourism, is the organization responsible for surveying Japanese national land. One of their services includes providing Fundamental Geospatial Data (FGD), which is the digital data essential for determining positions in electronic maps. This data is made available to the public free of charge via the internet [19]. The FGD integrates two levels of accuracy, one in the resolution of 5 meters by 5 meters and another in 10 meters by 10 meters. Recently, higher resolution of data in 1 meter by 1 meter is provided within a restricted area. It includes information on various features such as geodetic control points, coastlines, administrative boundaries, roads, railroads, elevations, shorelines, building outlines, community boundaries, and street block boundaries. The data is crucial for various applications, including serving as background maps for local government offices and improving the accuracy of road maps.

To create terrain in Unity using elevation data from the FGD, we first extracted the topographic elevation data in the resolution of 5 meters by 5 meters around the Tsuruga-jo, and then its height map is exported as a grayscale image. The Terrain Tools package of Unity is useful for creating new terrain from imported heightmaps. This package can be downloaded through Unity's Package Manager. We employed the Terrain Tools to import our grayscale image as a heightmap. Fig. 1 shows the result of the terrain view in Unity. Although the height information would be different in the past time, these tools help create realistic terrains. If we can obtain a certain information of location of hills, rivers, canals in past time, this terrain can be a starting point.

2.2 Modeling of Historical Environments

2.2.1 Map Alignment and Scaling

Aligning historical maps with contemporary maps presents several challenges, including differences in completeness, orientation, scaling, as well as changes in place names and territories [20]. The study observed variations in the scale of buildings and transportation networks, depending on the map's creation date and methodology. Notably, the 1888 eruption of Bandai volcano significantly altered the local topography, affecting forests, river

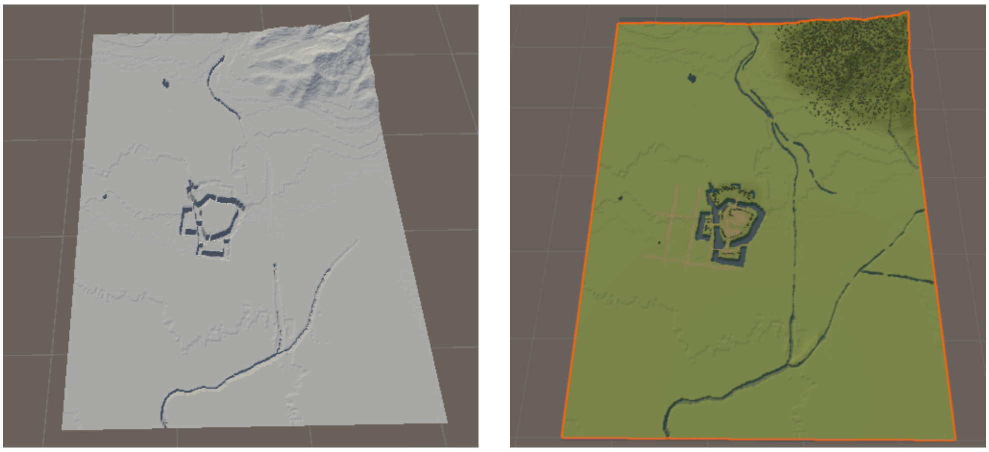


Figure 1: Appearance of terrain using FGD height map and Terrain Tools package of Unity. The left part shows the result of the simple rendering, while the right part shows the result with textures, trees, and water surface.

courses, and the formation of Goshikinuma lakes.

To address these scaling issues, a geometric correction approach using a Triangulated Irregular Network (TIN) can be used for the alignment of historical maps to the present-day coordinate systems. As a standard solution, this process involves using ground reference points for geometric distortion correction, commonly applying affine, projective, or polynomial transformations. For better connection to the task of improving the sightseeing experience, the reference points can be selected based on the actual points of interest (POIs) such as shrines, temples, or specific sections of castles, particularly those POIs that have been preserved in time, thus, leveraging the historically consistent locations as documented in literature [21]. Such landmarks serve not only as reliable spatial markers due to their relatively unchanged positions over time but also contribute substantially to the cultural and historical narrative of the travel experience, thereby offering a dual utility in both orientation and enrichment of the user's exploration. Fig. 2 illustrates an example of matching the POIs between a historical map and a present-day one.

Based on the selected reference points, the further geometric map correction could be necessary, for example using triangulated irregular network (TIN) model such as Delaunay triangulation maximizing the minimum angles of the triangles, to obtain a set of triangular regions as shown in [12]. It entails creating a triangulated network from three-dimensional (x, y, z) data, particularly beneficial in GIS for representing the terrain data. The TIN model on a plane utilizes POIs, defining a 3D-planar equation $z = h(x, y)$ for each triangle [22, 23]. Applying the affine transformation, the distance ratios along straight lines can be preserved. Thise process, as applied to the historical map of Aizu-Wakamatsu, is depicted in Fig. 3. The first row shows the reference POIs assigned to the past and current maps, which results in 31 triangular regions through Delaunay triangulation. The second row shows the transformation result, with the left part representing the pre-transformation image and the right part the post-transformation result. The geometric correction was applied to the map issued in 1911, representing the period of Gamo family ruling around 1600. We can observe similarities in transportation networks and residential areas between the historical and current landscapes.

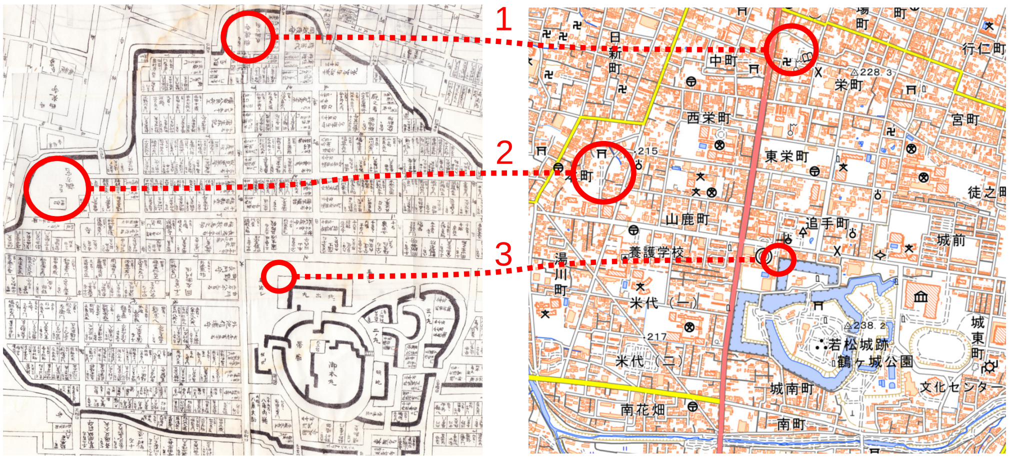
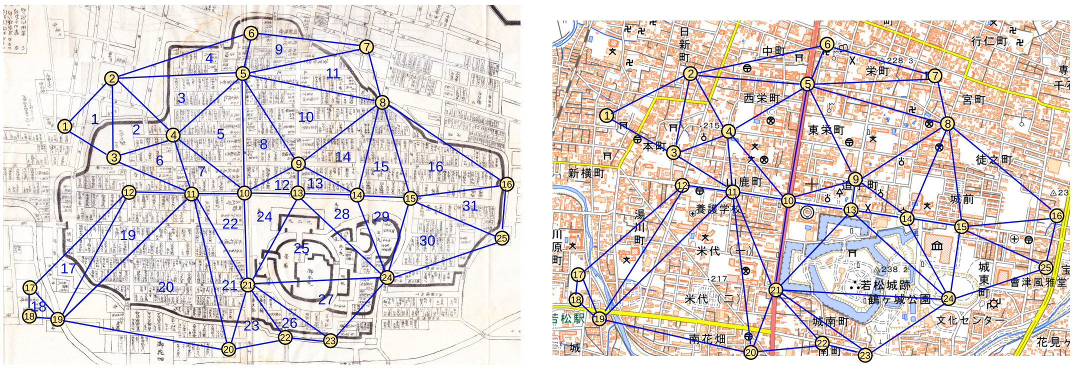
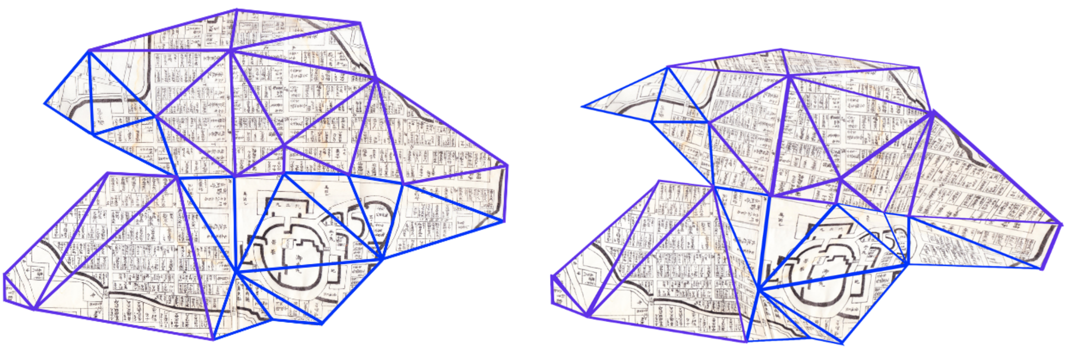


Figure 2: Matching old and present-day maps using reference points. The correspondence (1) is the Suwa-shrine, (2) is the Koutoku-temple, and (3) is the corner of a castle moat.



(a) POIs in the past and current maps



(b) Geometric correction in past map

Figure 3: Historical map transformation and mapping to the present-day map.

2.3 Modeling Past Time Constructions and Buildings

Reconstructing buildings as three-dimensional models holds profound importance for our application. For historical buildings, particularly those that have suffered damage or have been lost over time, three-dimensional models offer invaluable educational resources. They allow students and the general public to actively engage with various architectural styles,

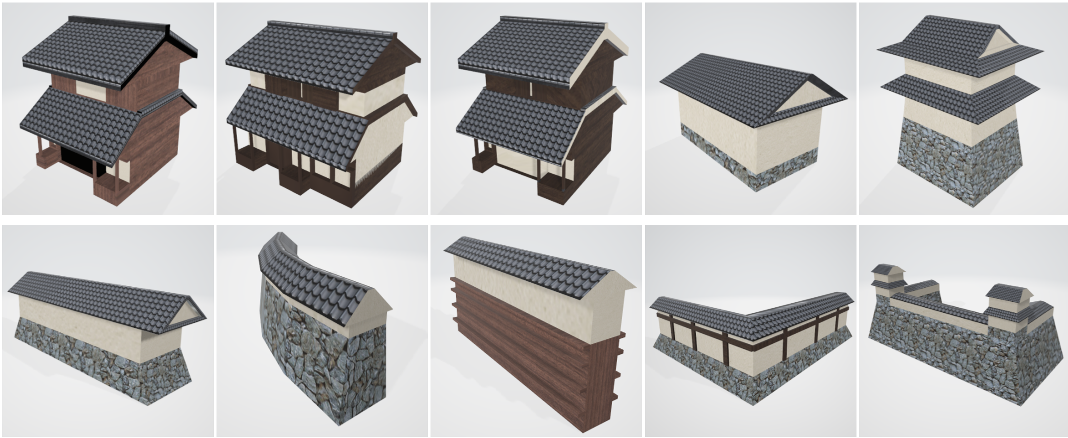


Figure 4: Examples showcasing the architectural styles and appearances of buildings around Tsuruga-jo.

as well as historical and cultural contexts. Such immersive experience greatly enhances the understanding and appreciation of history and architecture over time. However, a common challenge in this process is the lack of original architectural blueprints from the target period. Despite the inability to achieve precise reconstructions, we endeavor to capture the essence of these historical structures. Our approach involves consulting books and old photographs as reference materials to recreate the buildings in and surrounding Tsuruga-jo (Fig. 4). For the modeling process, we utilized the Blender software, and the resulting models were subsequently integrated into the Unity platform.

For the reconstruction of Tsuruga-jo's tenshukaku (main tower), we utilized the blueprint created during the recent refurbishment and seismic retrofitting of the structure (Fig. 5). Fig. 6 illustrates the modeled appearance of the Tsuruga-jo main tower, which was meticulously crafted based on the blueprint. In our application, the immersive experience of the virtual tour is enhanced through the detailed modeling of the main tower and its base, as well as the surrounding stone walls and the Shachihoko – a mythical fish-like creature usually attached on the roof of castle constructions and traditionally believed to protect buildings from fire (the latter, not surprisingly, being still the main cause of wooden castle collapses).

To achieve a realistic representation of the stone walls, we employed displacement mapping techniques allowing for a more authentic and textured representation of the stone surfaces. Displacement mapping intricately modifies the actual geometry of the surface, making the stones appear as three-dimensional models.

3 Software Prototype for Virtual Tour Experience

In the current software prototype, we have developed an immersive virtual environment allowing users to freely explore the space. This interactive feature enhances the virtual tour experience by providing a sense of presence and exploration within the digital world. To showcase the capabilities of our prototype, we present an example of a guided tour through some of the key locations within the virtual space, accompanied by screenshots to illustrate these points of interest.

In our illustrated example of a virtual tour, depicted in Fig. 7, the journey commences

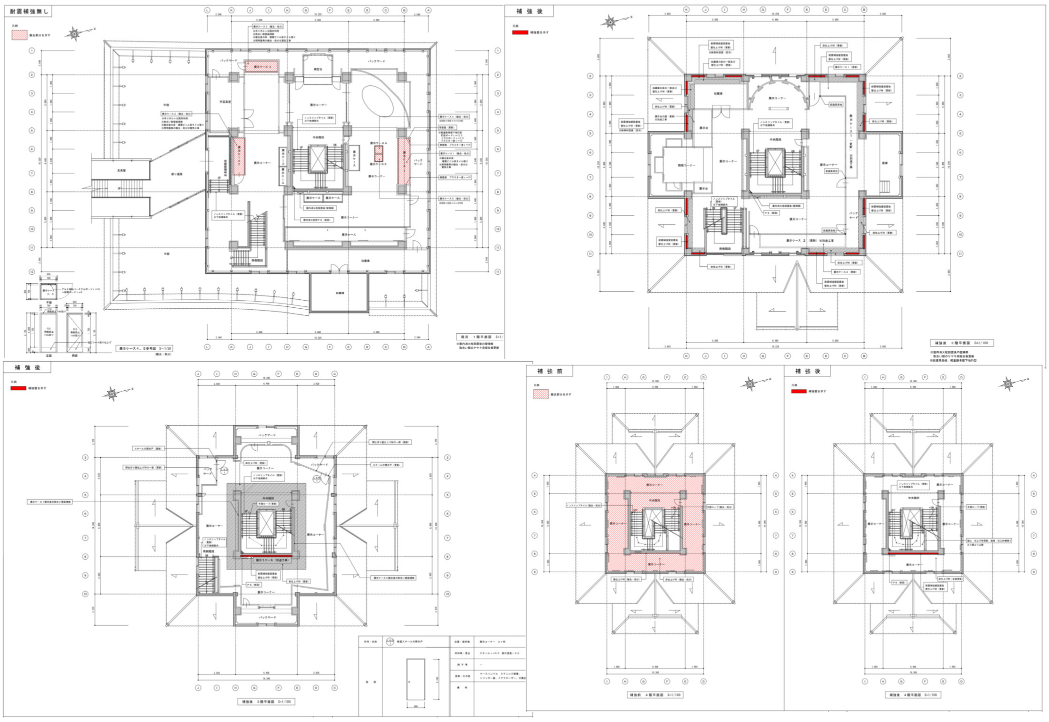


Figure 5: Blue-print of 1st to 4th floors of Tsuruga-jo main tower used for recent refreshment and seismic retrofitting. (Digital data was provided by courtesy of Mr. Hoshi, Aizu-Wakamatsu city office).

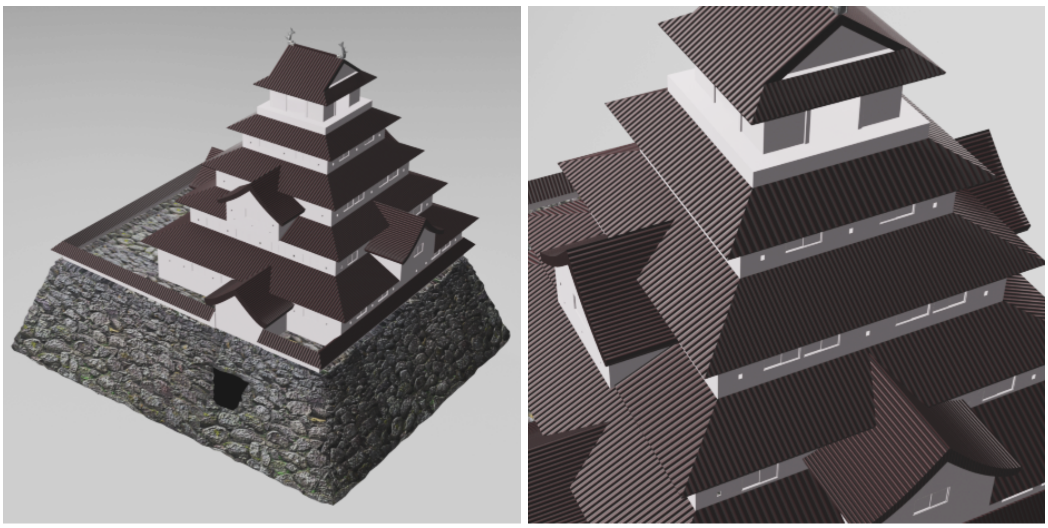


Figure 6: Appearance of the Tsuruga-jo main tower.

amidst the dwellings of middle-ranking samurai located at the east side of the castle. The first viewpoint offers a glimpse of the castle town's character, with the roof of main tower visible in the distance. To approach the main tower, visitors would traditionally consider the proximate yet typically inaccessible "Never-opened gate" (Akazu guchi), reserved for irregular use. Inhabitants would more likely utilize alternative entrances such as the "Hidden gate" (Uzumi mon) to the north or the "Kumano gate" (Kumano guchi) to the south. Accordingly, the second viewpoint situates the visitor within the third citadel, postulating entry through the Kumano gate. Progressing to the third viewpoint, one is strategically positioned to observe the main gate and the "Corridor bridge" (Rouka bashi), which serves as the entrance to the main citadel. Crossing this bridge leads to the fourth viewpoint, which reveals the "Tiger's mouth" (Koguchi), a narrow, fortified gateway designed to thwart attackers and safeguard the defenders. The fifth viewpoint affords a comprehensive view of the final defense: the stone walls that encircle the lord's residence. Ultimately, the tour culminates at the sixth viewpoint, situated optimally to observe the castle's main tower up close. This sequential navigation provides an immersive experience into the ambience of a traditional castle town as well as the architectural and strategic complexities of Japanese feudal fortifications, enriching the visitor's understanding of historical and a virtual situation of the samurai class.

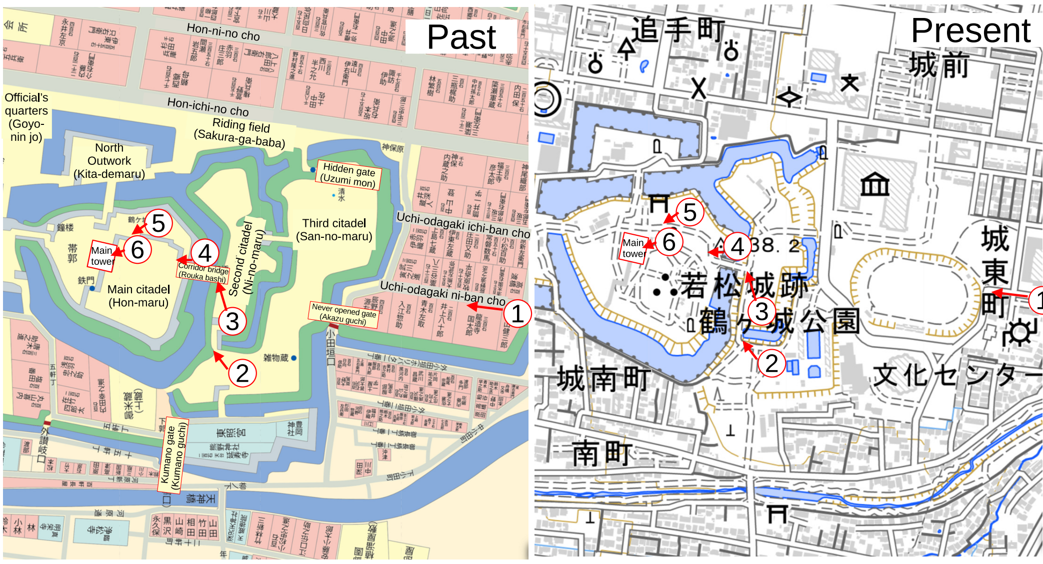
Fig. 8 illustrates another example of a virtual tour. This tour originates from the first viewpoint, situated at the intersection of Kouga-machi Street and Hon-yon-no-cho, offering a distant view of the castle's main tower. Along Kouga-machi Street, numerous residences of high-ranking samurai are present, reflecting the historical significance of this area. The tour then progresses to the second viewpoint, located at the juncture of Ō-machi street and Hon-yon-no-cho. Historically, Ō-machi Street, within the Sougamae (outermost enclosure of a castle), served as a vital arterial route linking to Nikko. Presently, it remains a principal thoroughfare traversing significant locales such as Aizu-Wakamatsu station, Shin-mei Street (central district), and pass through the western periphery of the castle.

At the third viewpoint, the tour features the North outwork (Kita demaru), a strategic fortification. Historically, while the principal gate was located on the eastern side before the Edo period, the north side evolved to become the main entrance during the Edo period, necessitating the strongest defenses. The fourth viewpoint offers a perspective of the corridor linking the North outwork to the main citadel, highlighting the transitional architecture and strategic design between these structures.

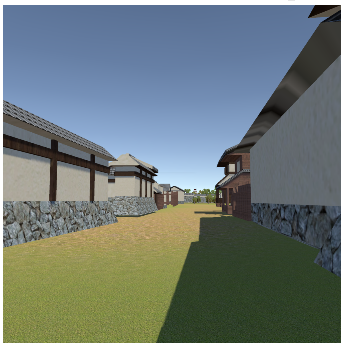
The fifth viewpoint reveals the West outwork (Nishi demaru) and the main tower, showcasing the architectural relationship and the gradient of the path connecting these two critical points of defense. Lastly, the tour culminates at the sixth viewpoint, providing an intimate observation of the main tower, now at the closest proximity. This virtual tour, through its sequential viewpoints, offers a comprehensive exploration of the castle's structure, its strategic components, and the surrounding historical urban landscape.

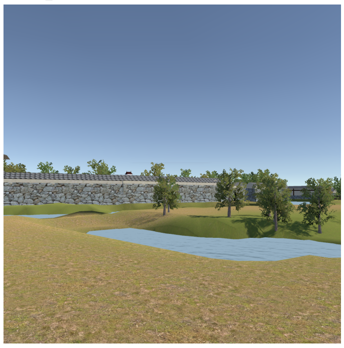
4 Discussion

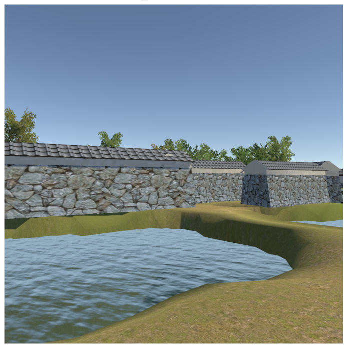
Upon contemplation of the breadth and consequences of this investigation, it is recognized that the present work constitutes merely a portion of the extensive research demanded by the burgeoning field of digital heritage preservation. This acknowledgment underscores the preliminary nature of our efforts within a vast and multifaceted domain, inviting further scholarly inquiry and collaboration to comprehensively address the intricate challenges and



Past and present maps and the location of viewpoints on map.


Viewpoint 1


Viewpoint 2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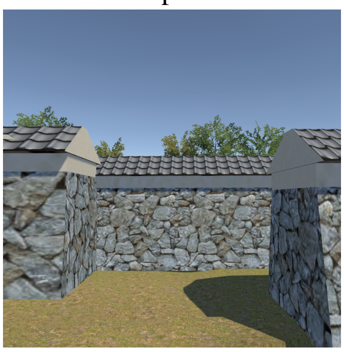
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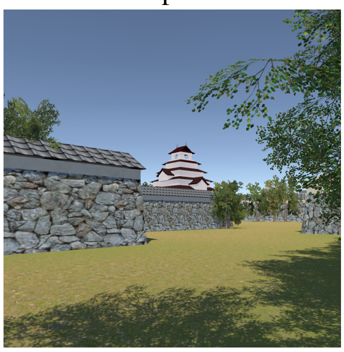
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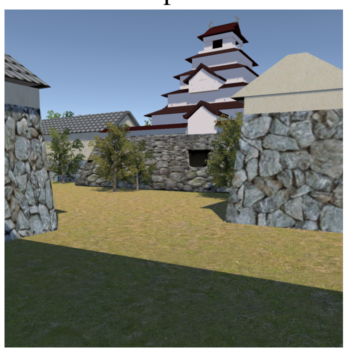
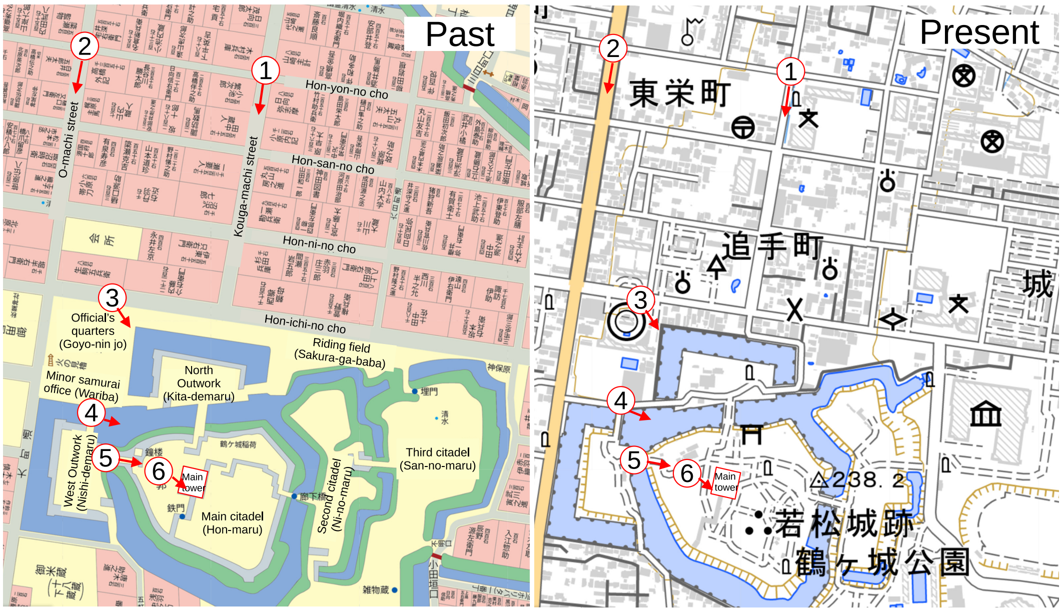
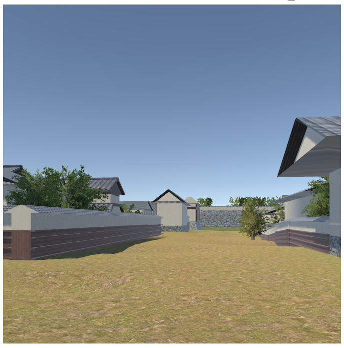

Viewpoint 6

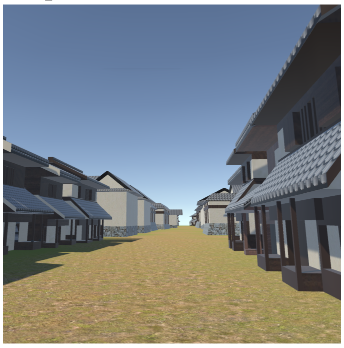
Figure 7: Virtual tour No.2, simulating a middle ranked samurai presenting oneself in the castle.



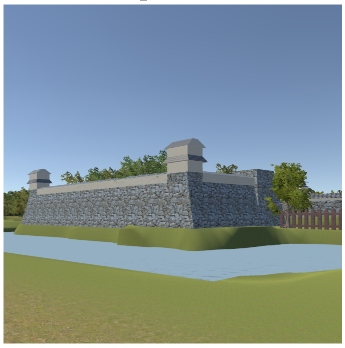
Past and present maps and the location of viewpoints on map.



Viewpoint 1



Viewpoint 2



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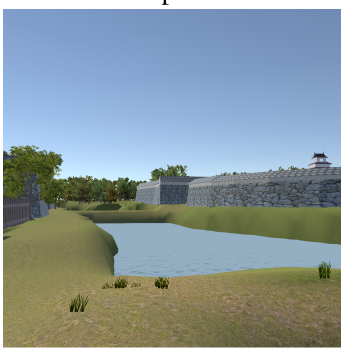
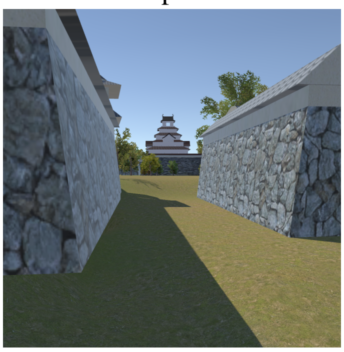


Viewpoint 4



Viewpoint 5

Viewpoint 6

Figure 8: Virtual tour No.2, simulating a high-ranked samurai presenting himself in the castle.

opportunities inherent in preserving cultural heritage through digital means. The methodology employed for generating initial terrains and the subsequent registration of ancient maps, leveraging open data and freely available software, in conjunction with the reconstruction of streetscapes using archival historical information, constitutes a preliminary exploration. This approach integrates geospatial technologies with historical research to reconstruct past environments, offering a foundation for further scholarly inquiry and methodological refinement. Through this initial investigation, we aim to establish a replicable framework that can be adapted and expanded upon by future research in the domain of digital historical reconstruction.

Particularly in the case of Aizu-Wakamatsu, a rural city with a more limited corpus of historical materials compared to metropolises like Tokyo or Kyoto, the challenges of comprehensively recreating historical landscapes are notably pronounced. Despite these limitations, the development of tools that enrich the historical narrative of a place holds considerable potential for bolstering local businesses and enhancing the travel experience through the lens of history, thereby contributing to regional revitalization.

However, the current study has yet to incorporate the critical aspect of positioning services and geofences, which would enable a seamless synchronization of virtual models with a traveler's real-time location. Implementing such features is a required step towards the integration of modeled landscapes with multimedia annotations, leveraging the traveler's positional data to augment the sightseeing experience.

Moreover, the tools developed to render historical perspectives through old maps and modeled virtual cityscapes contribute significantly to metaverse, a contemporary paradigm of interactive communication [24]. These innovations not only enhance virtual sightseeing platforms [25] but also pioneer new personalized experiences in physical sightseeing, particularly in regions that are less frequented or have suffered the loss of their tangible heritage. In places where historical edifices have been demolished or significantly altered, such as many former Japanese castle sites, virtual models offer a medium for exploring restorative possibilities and reconnecting with the architectural past. Excellent examples of such places can be found in [26].

By anchoring our work in these foundational studies and advancing the capabilities of digital modeling and virtual reconstructions, our research aims to make a substantive contribution to the fields of digital humanities and heritage preservation. It is our aspiration that through these technological advances, we may continue to inspire and educate by keeping the rich tapestry of cultural heritage alive and accessible for future generations.

5 Conclusion

In concluding this exploration into the realms of digital humanities and heritage preservation, it is pertinent to reflect upon the contributions of our research and outline future directions:

Scalable Framework for Digital Heritage Preservation and Virtual Tour: We present an approach to apply digital twin technologies in digital heritage preservation and examples of potential virtual tour, focusing on reconstructing the historical city of Aizu-Wakamatsu. It demonstrates how digital twins can enhance our understanding and experience of historical landscapes. The methodologies and findings from our study can be used as a scalable framework to be applied to other historical sites. The modeling of historical streetscapes and architectural elements of Aizu-Wakamatsu exemplifies the potential of digital twin technologies to revive and explore lost or significantly changed environments, enriching both academic research and public engagement with history.

Leverage of Open Data and Software: Our methodology emphasizes the utilization of open data and freely available software for the digital reconstruction of historical landscapes and architectural features. This approach highlights the accessibility of digital heritage preservation tools to a broad audience, ensuring that anyone with an interest can engage in similar projects with less proprietary technologies. This contribution is particularly significant in democratizing the field of digital humanities, allowing researchers, educators, and the general public to actively participate in the preservation and exploration of cultural heritage.

Historical GIS Data and 3D Modeling Integration: The integration of historical GIS data, 3D modeling, and interactive virtual environments represents a significant advancement in the field, opening new avenues for exploration and discovery, which are in line with many projects on creating virtualized environments for ancient and archaeological cities such as immersive augmented reality (AR) environment for reconstructing ancient fresco painting in Pompeii, Italy [27], three-dimensional visualization of the ancient Palace of Knossos, Heraklion, Greece [28], or mixing augmented reality and CNN for interactive exploration of archaeological site remains and artifacts in Thina, Tunisia [29], to cite a few.

Future Technological Integration: While the study acknowledges the ongoing need for technological and methodological refinement, the results attained underscore the transformative impact of digital reconstruction on heritage preservation and education. As we continue to build upon this foundation, we foresee a future where digital heritage sites become widely accessible, allowing people around the world to explore and connect with the historical narratives that have shaped humanity. In doing so, we not only honor and preserve our past but also inspire a deeper understanding and appreciation of our shared cultural legacy.

Enhancing the Immersive Experience: Looking forward, the integration of positioning services and advanced interactive technologies promises to further enhance the immersive experience of virtual tours, offering more personalized and contextually rich explorations of historical sites. The potential for these technologies to contribute to the emerging Metaverse, where virtual and physical realities converge, opens new frontiers for cultural engagement and heritage education. This study serves as an initial step towards a more nuanced and comprehensive understanding of our cultural past through digital means. As we continue to refine our methodologies and expand our collaborations, we contribute to a growing body of knowledge that bridges the past with the future, using technology to keep the tapestry of human history alive and vibrant for generations to come. It is our hope that this work will inspire continued innovation and dedication in the field of digital heritage preservation, ensuring that our shared history remains a dynamic and accessible legacy.

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