Virtual reconstruction of the ancient city of Karakorum

Article *in* Computer Animation and Virtual Worlds · June 2022

DOI: 10.1002/cav.2087

CITATIONS
5

READS
43

3 authors:

Khorloo Oyundolgor
National University of Mongolia
7 PUBLICATIONS **38** CITATIONS
SEE PROFILE

Erdenebat Ulambayar
National University of Mongolia
13 PUBLICATIONS **162** CITATIONS
SEE PROFILE

Enkhbayar Altantsetseg
National University of Mongolia
13 PUBLICATIONS **96** CITATIONS
SEE PROFILE

Received: 14 May 2022 | Accepted: 15 May 2022

DOI: 10.1002/cav.2087

SPECIAL ISSUE PAPER

WILEY

Virtual reconstruction of the ancient city of Karakorum

Oyundolgor Khorloo | **Erdenebat Ulambayar** | **Enkhbayar Altantsetseg**

National University of Mongolia, Ulaanbaatar, Mongolia

Correspondence
Enkhbayar Altantsetseg, National University of Mongolia, Sukhbaatar District, University Street-3, Ulaanbaatar 14200, Mongolia.
Email: enkhbayar.a@seas.num.edu.mn

Funding information
National University of Mongolia, Grant/Award Number: P2018-3603

Abstract

Ruins of ancient cities hold valuable information for historians and archeologists and it allows them to learn about the society and culture of these cities. This paper explores the first attempt to virtually rebuild the historic city of Karakorum based on ruins and archeological findings from the 13th century AD. Further, the analytical and practical methods used to discover its unique urban planning and architectural form by reconstructing the city using various resources from archeological documents to historical science documents are introduced. We explore a digitized version of Karakorum city in an immersive and embodied manner because of the latest technological advances in virtual reality, and this allows us to conserve and visualize its cultural heritage. The research objectives of this study are to (1) create a three-dimensional visual model of the Karakorum city as close as possible to its real counterpart, and (2) use a game engine as a development platform for integration and interactive visualization.

KEYWORDS

3D reconstruction, cultural heritage, immersive exploration, virtual city, virtual reality

1 | INTRODUCTION

Many historical sites are at a risk of vanishing with the rapid transformation of modern life, and therefore, it is necessary to digitize the cultural heritage and historical sites for conserving and documenting purposes. In addition, it is essential to introduce, understand, and disseminate cultural heritage to the public.

One efficient approach for disseminating cultural heritage to the public, especially for the younger generation, is to use advanced immersive technology such as virtual reality. In this paper, we introduce an approach to virtually reconstruct the ancient city of Karakorum by applying immersive technology in digital heritage applications.

Karakorum was the capital of the Mongol Empire in the 13th century and a major cultural and commercial city at the time. It was a unique city where many nations, cultures, and religions coexisted. The ruins of this city are in Orkhon Valley, a UNESCO World Heritage Site, located 1.6 km north of Erdene Zuu, the earliest surviving Buddhist monastery in Mongolia. Figure 1 shows the aerial view of the ruins of Karakorum city. The reconstruction of the city of Karakorum not only provides evidence of its vibrant local and regional heritage but also supports heritage literature and its significance on understanding historical sites to unravel the past and how people used to live.

We use the archeological evidence of the city of Karakorum and resources about its past social and cultural life to build an architectural and urban design of the city. Thus, a virtual city will be constructed based on many years of research and historical findings reported by archeologists on the city of Karakorum.

Karakorum is an interesting case because there is no architectural documentation despite a substantial record of archeological documentation that spans decades. The site of Karakorum has attracted the interest of the international

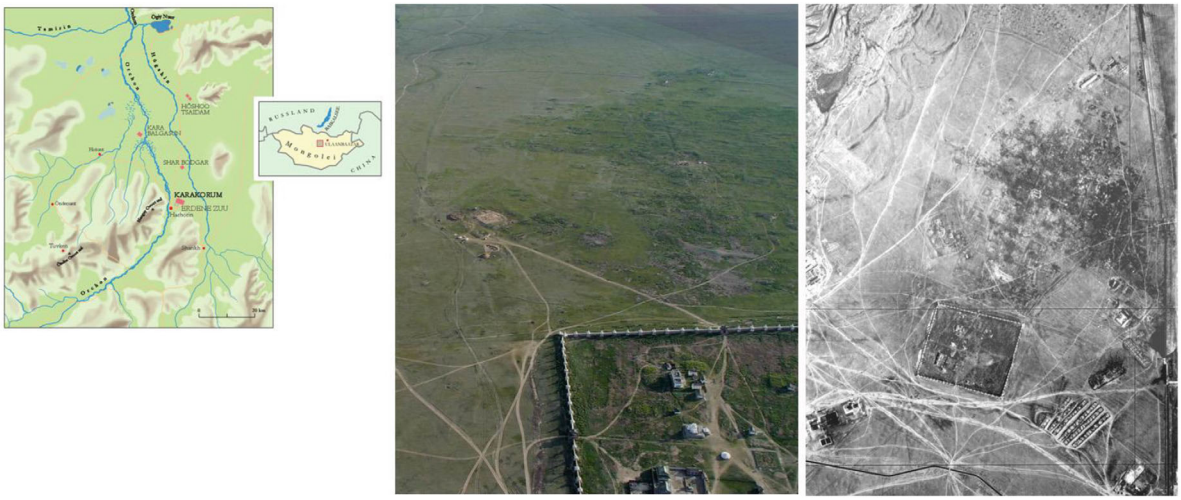

FIGURE 1 Overview of the situation of the ruins of ancient Karakorum city. Left: The Orkhon Valley, a UNESCO World Heritage Site is situated in central Mongolia, about 400 km west of the modern capital Ulaaanbaatar. Center: The ruins are located at the site of the monastery Erdene zuu, just north outside the wall of the monastery. Right: Aerial imagery reveals the still visible structures of the city, such as the outer wall and many remains of buildings.

research community since the late 19th century, and since then, it has been repeatedly surveyed and partially excavated by Russian, Soviet, Mongolian, and other researchers.

The international cooperation was extended after 1990. Since 2000, the site has been actively researched by Mongolian–German joint projects under the roof of the Mongolian–German Karakorum expedition. This research project has employed methods such as surveying, identifying, and organizing the historical and archeological data available about the city of Karakorum.

We plan to interpret the collected data and translate it into virtual three-dimensional data; this would make the city visually accessible to a broader scope of researchers and audiences.

2 | RELATED WORK

The virtual reconstruction and modeling of cities have important applications in many areas such as in gaming, movie industries, civil engineering, cultural heritage, and archaeology.[1,2] To this end, many techniques can be used independently to create 3D scenes of historic architecture and cultural heritage. Further, advanced tools such as the 3D-GIS digital city model, BIM technology, point-cloud scanning, and unmanned aerial vehicle aerial photography have been widely used to conserve and reproduce historical sites.[3–5] These technologies complement each other; however, no single technology can meet every need to build a virtual city. Thus, integrated hybrid modeling technology will be used to overcome various challenges in this project.[6]

The use of parametric models differs from using GIS in that they have various sources of information and they vary in scale.[7] BIM focuses on building-related information, whereas GIS focuses on spatial topology information and has a wide range of spatial analysis and processing capabilities.[8]

There are several challenges when it comes to restoring the archeological sites with partial architectural evidence,[9] However, the development of 3D modeling technology for historical and cultural heritage sites has achieved considerable progress. Several alternative studies have constructed 3D city models and classified them as procedural and image-based modeling. Procedural modeling[10,11] generates city components based on grammar, whereas image-based modeling[12] generates components based on available images such as street-level or aerial images. The probabilistic rules were extensively employed for the digital reconstruction of large cities.[1]

The 3D modeling technology of historical sites and cultural heritage expands from focusing on a single historic building to an entire street; this becomes more complicated for a whole city model because it requires enormous data that can be challenging when constructing a large city model.

Most research on 3D modeling technology or virtual platforms has focused on model visualization, prerendering graphics, dynamic simulation, and virtual tours of the scene. The rise of VR emerging from interactive displays and game technologies providing high level of interactive experience, effective communication, and integrated environments.

FIGURE 2 Abstract model of Karakorum city. The exhibit in the Karakorum Museum of Mongolia

The game-engine application in the 3D visualization of city models, high-quality virtual environments, and dynamic elements are required to create the architectural and urban design.[13] VR has the potential to provide the several types of interactive activities, and it enhances the users' awareness and understanding of the space and helps them make further space exploration and perform decision making.[14] Therefore, using virtual reality is one efficient approach for disseminating cultural heritage to the public.[15–17]

3 | OVERVIEW

This study is divided into three stages: requirements assessment, software selection, and platform selection and development.

City appearance is determined by two factors: city properties such as street patterns, density, and building type, and the distribution of various components such as roads, vegetation, water, and natural elements. Thus, the city modeling problem is reduced to questions such as where to generate the city, what to allocate in the city, and how to arrange its components.[18]

This paper relies on an interdisciplinary team supporting a mix of historical and qualitative research methodologies that involve interpreting historical and archeological descriptions into architectural and urban depictions. The virtual simulation process in this project is based on historical and archeological facts and data from the Karakorum expedition. Figure 2 shows the abstract city model of Karakorum created based on the archeological findings of the Karakorum expedition. The urban space of the city of Karakorum was dominated by palaces, along with religious buildings, gardens, streets, squares, and different residential districts.[19–21]

The site of Karakorum city was ruined and buried, and no historical and urban level details of the area survived. Although the use of 3D modeling software is pervasive for architecture and urban documentation and visualization, many challenges and complexities continue to exist in translating textual, oral, and physical data to virtual models.[2]

Game engines have been commonly employed in the development of virtual reality; it supports all major file formats and work with the most-related applications. In addition, it is the best choice for conversion between platforms. We chose the Unreal game engine as a platform for the development. Figure 3 shows the research tools and techniques, and we used in the reconstruction of the city of Karakorum.

4 | 3D MODELING AND RECONSTRUCTION

4.1 | Urban territory and landscape

Attempts to find the city abandoned for many years since its inception began in 1889. Archeologists from various countries begun excavations, and they revealed that Karakorum consisted of palaces, religious buildings, gardens, streets, squares, and residential districts with multiple cultures.[19]

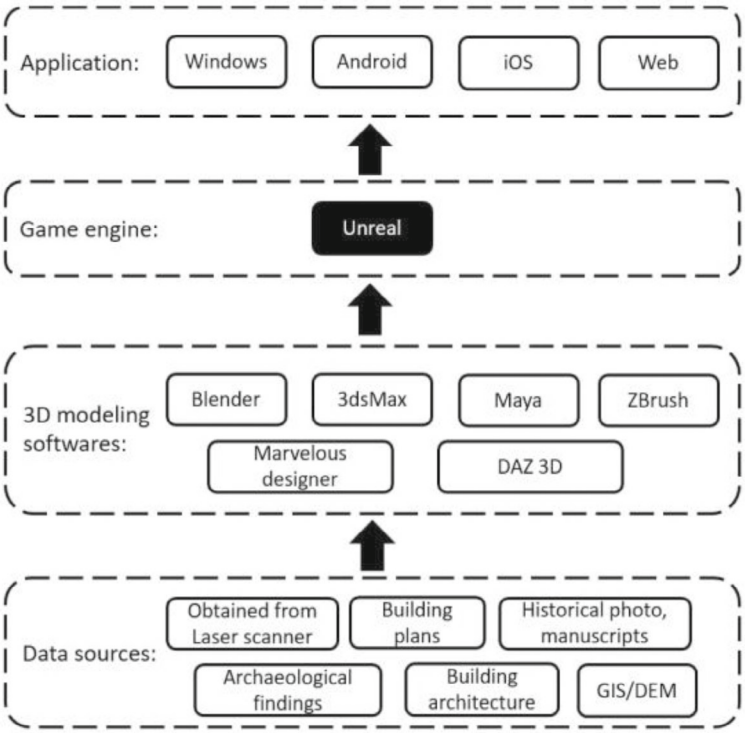

FIGURE 3 Research tools and techniques used in the city reconstruction

The researchers conducted a comprehensive geophysical survey of Karakorum using the superconducting interface device method,[21] which details the territory and structure of the city, as indicated in Figures 4 and 5.

Based on the archeologists' findings and historical manuscripts, we developed the structure of the virtual city Karakorum. The virtual city of Karakorum is surrounded by a 1.1×1.5 km^2 mud wall, with gates on all four sides, and with two main streets that intersect in the center.

However, GIS and DEM are developed for the needs of specific fields, and therefore, different fields require various levels of development, and for model quality, we used low-resolution DEM and aerial images to create the surrounding areas of the virtual city.

Rivers flowing through the city have been diverted to the current riverbed and added to the water-flow simulation. The lakes and ponds of the virtual city are restored based on historical facts and archaeology.

4.2 | Historical monuments

Near the city's ruin, there is a large stone turtle that is one of the few remains of Karakorum; it is the basis of a large inscription (Figure 6). The parts of an inscription stele embedded in its back shell with an inscription from 1346, were scattered throughout the town, and they have been collected by various researchers since the 19th century. The inscription describes a five-story building of 300 chi height,[19] presumably ca. 90 m, that was built as the capital in Karakorum, back in 1220.

We reconstructed a 3D model of the stone turtle statue using a photogrammetric method and restored the 3D model of the inscription based on fragments found during archeological excavations shown in Figure 6.

Archeologists unearthed the foundations and pillars of the 90-m-high temple mentioned in the statue.[19] Based on these sources, there were many religious monasteries in Karakorum; however, the 90-m-high temple was one of the city's tallest structures at the time.

The overall layout of the temple is slightly South Eastern, and it measures 61.9×42.5 m, 2 m high, and it has its own walls, pavilion, and ancillary buildings (Figure 7). Archeological data makes it possible to attempt to visualize the reconstructions of the past architecture. Two versions of the temple's reconstruction can be viewed here. Figures 8 and 9 show two versions of the reconstruction of the temple.

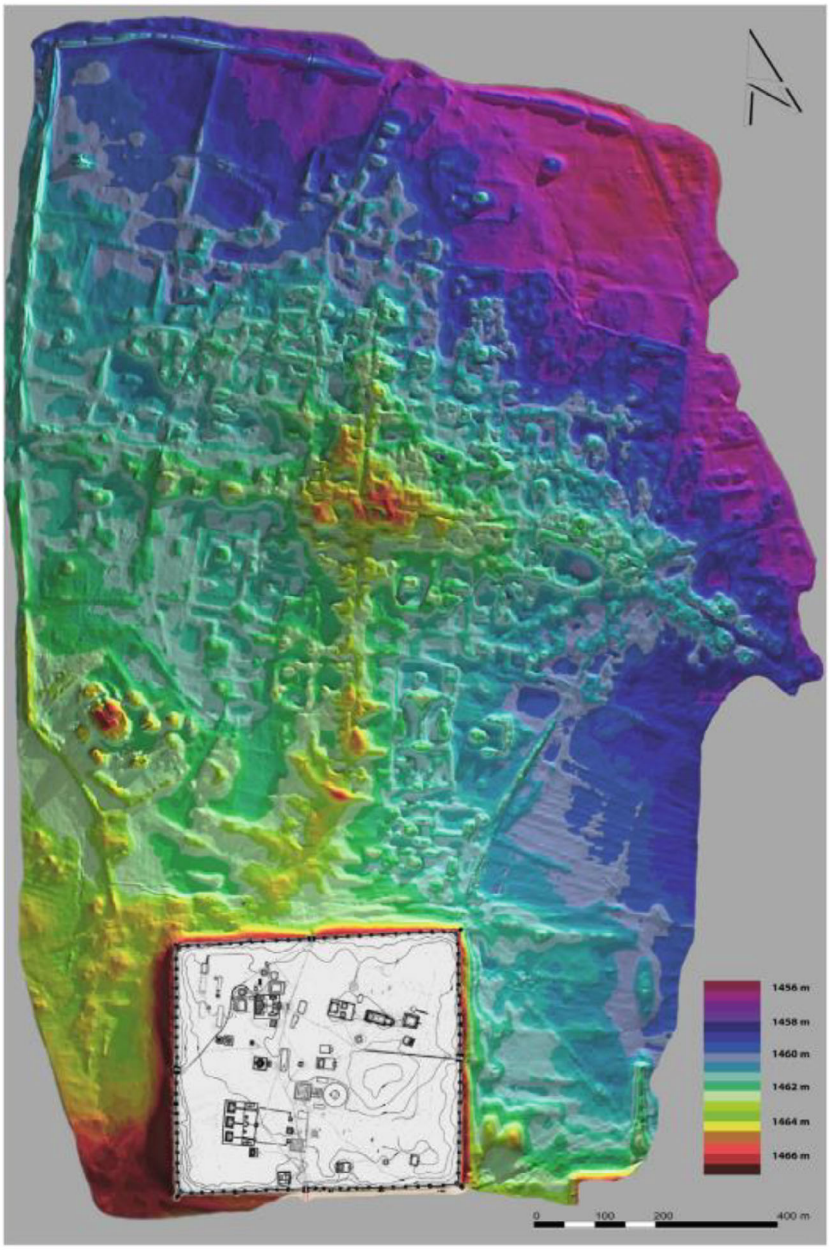

FIGURE 4 Map of the city of Karakorum. The territory and structure of the city are determined by a geophysical survey[19,20]

One of the most famous artworks in Karakorum was the Silver Tree. William de Rubruck, who visited the Karakorum, described the silver tree inside the royal palace in great detail as follows:

> In the entry of this great palace, it was unseemly to bring in skins of milk and other drinks; Master William the Parisian had made a great silver tree, and because its roots are four lions of silver. On the inside of it, there is a tube through which the white mare's milk is passed. In the tree itself, four tubes face upwards; their outermost ends are bent downwards from above. Around the ends of each of these tubes, a golden snake winds in the same way, and its tail is wrapped around the trunk of the tree. From one of these tubes flows wine, and from the other one, fermented mare's milk; from the third, Bal, the honey drink, and from the fourth, a rice wine. There is a silver utensil for each drink at the foot of the tree. At the top of the tree the artist has placed an angel statue holding a trumpet.[20,22]

Many artists depicted the Silver Tree and the royal palace from different viewing angles based on the above description (see the differences in Figures 10 and 11). Then, we decided to model the Silver Tree as shown in Figure 12 based on historical sources and paintings of artists.

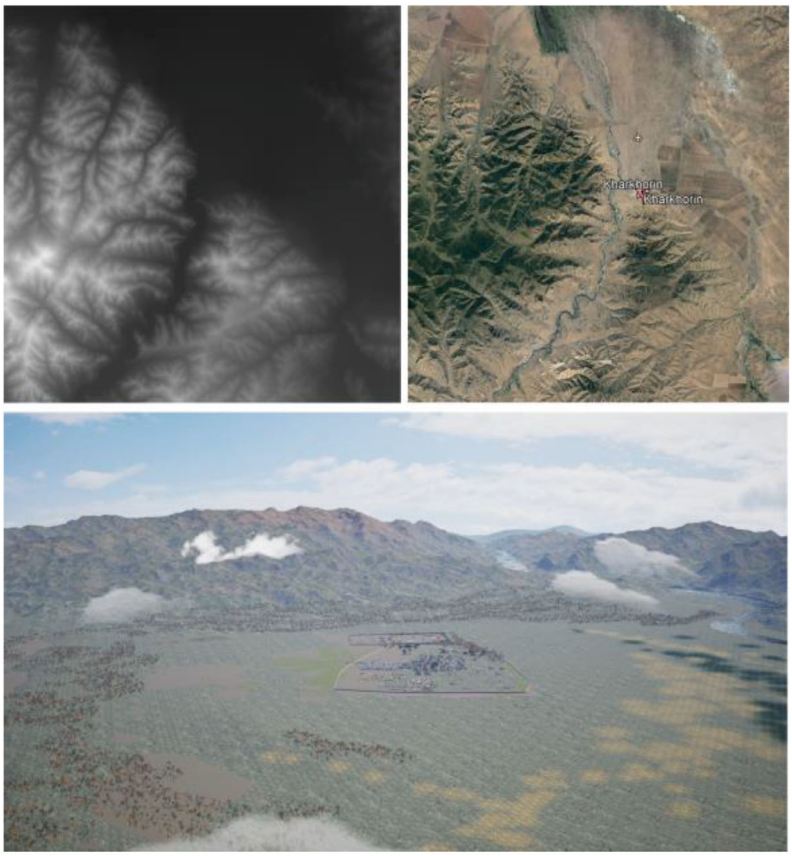

FIGURE 5 DEM map and aerial image of the virtual city territory of Karakorum

FIGURE 6 Stone turtle and its 3D restoration. Scene after restoring the inscription on the back of a stone turtle statue

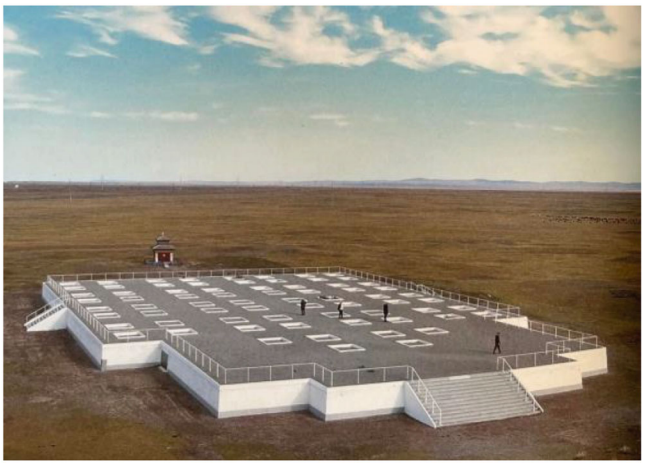

FIGURE 7 Archeological remains of the Buddhist temple were protected and constructed as an open exhibit[20]

FIGURE 8 Restored version of the Great Buddhist temple[20]

FIGURE 9 Another version of the Great Buddhist Temple used in the project of Virtual Karakorum

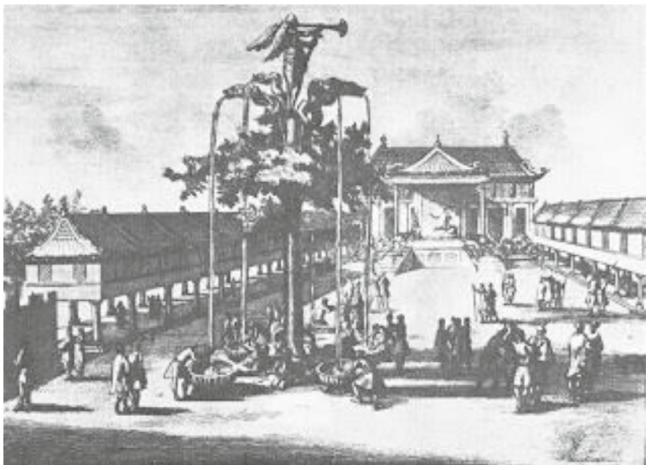

FIGURE 10 Möngke Khan's fountain based on the depiction from Pierre de Bergeron's Voyages faits principalement en Asie (1735)

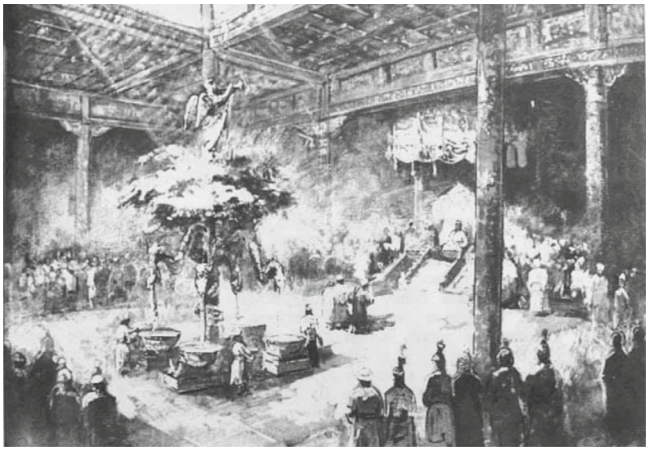

FIGURE 11 Artist B. Purevsukh's painting "Silver Tree"

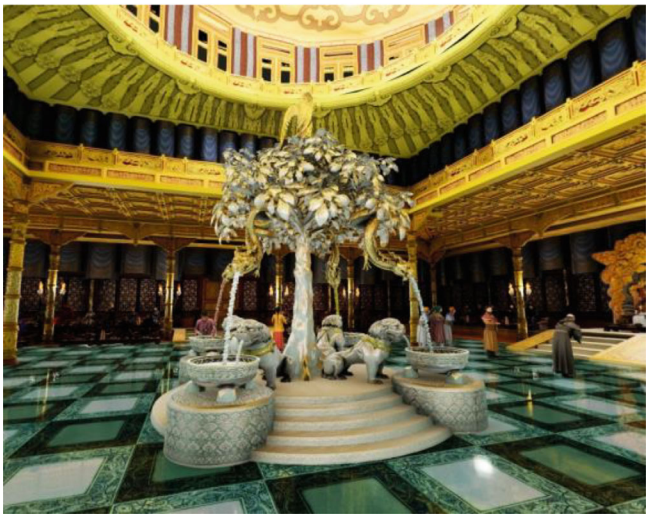

FIGURE 12 Silver tree at the center of the royal palace is used in the project

Figure 12 shows that the Silver Tree is built in the center of the palace, with four luxurious drinks flowing out of the mouths of the four dragons wrapped around the tree. Fluid flow simulation was added to the scene to make it look more convincing.

5 | CITY LAYOUT

The general layout of the city is as shown in Figure 13; the locations of the streets and roads are decided based on the studies reported in References 22,23. Some structures or monuments such as the Great Buddhist Temple and the Stone turtle statue were established on the site based on archeological excavations.

According to the written sources, the urban space of Karakorum was dominated by palaces along with religious buildings, gardens, streets, squares, the quarters of traders and craftsmen, and the quarters of Saracens and Nestorians, and those of Mongols.[23,24] The city map (Figure 4) shows that the city was surrounded by mud walls and divided by two main streets running N–S and E–W and leading towards the four main gates. These large main roads divided the city into four quarters, and they lead beyond city limits.

5.1 | Reconstruction of the city

The city needs to be reconstructed piece-by-piece, beginning with the building blocks using computer-aided design (CAD) to shift computer modeling. The modeling team began with historical records, and it continues with the construction of the oldest buildings one-by-one. A virtual model was challenging because it consumes time and needs extensive data analysis and efforts to transform information into the visual form. Although great detail can be arrived for certain buildings, there is little or no record of what the majority of the city blocks looked like; the disparity between the two conditions cannot be easily bridged.

The disparity in the level of confidence is important for large-scale archeological reconstruction models. To this end,[25] used the strategy of a single mega model of the city to create a database of different buildings at various levels of completion and resolution while retaining the mega mass/abstract model.

A challenge for the reconstruction of Karakorum was identifying how buildings used to look is unknown; it is yet to be archeologically examined in detail. A hint was provided by the different representations in the contemporary written source. Thus, a database of 3D buildings for each district was created for the reconstruction of the whole city layout. The buildings were selected with no repetition based on the city district area.

5.2 | Level of streaming

The virtual city comprises four level maps: main gate, city, outside and inside the royal palace, and surrounding area (Figure 14).

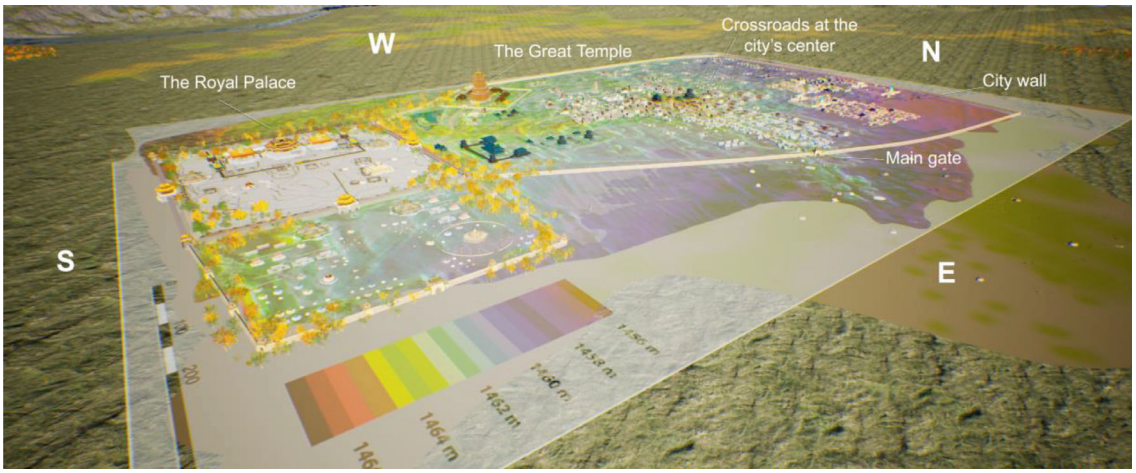

FIGURE 13 Scene of the reconstruction based on the elevation map of the city of Karakorum

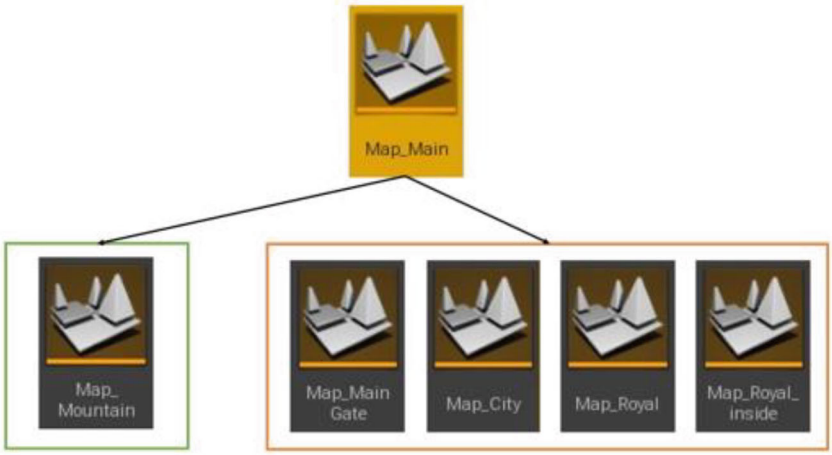

FIGURE 14 The level map of the city

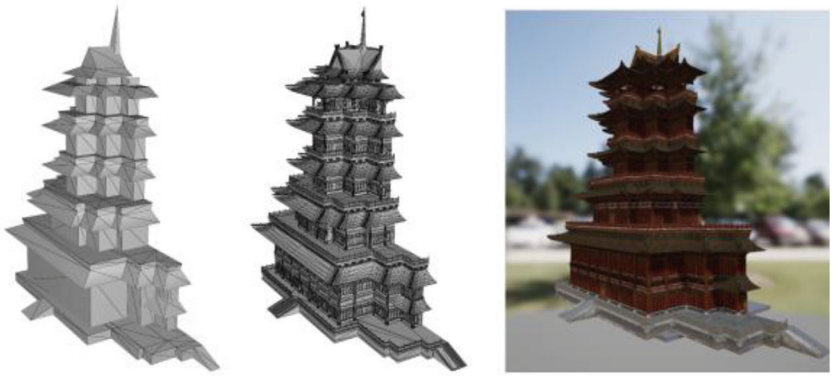

FIGURE 15 Level of detail in the 3D models used in the application

Only one of the four locations will be loaded into the application based on the user's location, for example, there is no need to see parts of the city and the royal palace when the user is outside the city, and therefore, the application turns off the unnecessary parts. This drastically reduces the load on the program. In order words, the only location is loaded as the default location for the "Map_Main" based on the user's location. However, "Map_Mountain" will be visible from anywhere, and thus, it is always loaded on the main site.

The level of streaming function of the Unreal Engine was used to implement the above approach. Level streaming works by loading a volume box to the sub level and loading the area when the user's location is within the box.

5.3 | Level of details

The quality of 3D models will be increased or decreased depending on the user's location. For 3D models used in the virtual city of Karakorum, models with various levels of reduction (3–8 levels) were created (Figure 15). It allows us to use the low-resolution model when user moves away from the site.

6 | RESULTS

Game engines can provide powerful tools to construct 3D virtual scenes, and the first-person and third-person exploration technologies that allow users to conduct better evaluation and analysis through data links between the 3D virtual scenes and real world. The game engine is introduced in real-time visualization, and it contributes to the development

FIGURE 16 Restoration of the Great Buddhist Temple

FIGURE 17 Reconstructed scene of the royal palace

FIGURE 18 Quarter of Saracens

of high-quality interactive architectural environments. Further, the game engine can add light, weather, sound, and animation to the object for better rendering.

Compared to Unity 3D, the Unreal Engine can create more accurate and smooth lighting. Further, the advanced dynamic lighting, which is a crucial element in the visualization, is better in the Unreal Engine. Most importantly, it provides a sense of reality, especially if it is done correctly. The unreal Engine can help achieve any type of visual style, which allows to create complex particle simulation systems. Therefore, the unreal engine is selected for this study.

The models of the city were imported as fbx files into the Unreal game engine to develop the VR application.

This project helps illustrate one moment of ordinary life in Karakorum city as shown in Figures 16–21. The animation of natural phenomena such as fire, liquid, and wind movement were added to provide users with a realistic feeling. The following three solutions were selected to deliver the results to the users.

FIGURE 19 Life outside the city wall

FIGURE 20 Around the city wall

FIGURE 21 Two main streets passing through the city, intersecting in the middle

- Develop VR application for use in tethered VR headsets such Oculus Rift: The advantage of using tethered VR headsets is that users can obtain a more realistic feeling, travel to their favorite place, experience the effects of natural phenomena such as water, fire, smoke, wind, and touch. The disadvantage is that it requires a high-capacity PC, and therefore, not everyone can use it.
- Use a stand-alone headset: 360° 3D images were captured using a virtual camera along the given route of the city. The user will only follow the prepared route, and there will be no natural scenes or touch.
- Offer web-based 360° virtual tours to the users: 360° images were captured along the pre-planned route and a web-based virtual tour was provided. It may not be immersive compared to the previous two methods; however, the user can access the environment via the web using a mobile phone or a computer. The virtual tour can be accessed from the URL in Reference 26.

7 | CONCLUSIONS

We reconstructed the ancient city of Karakorum in the virtual world, selected a game technology development platform, used 3D modeling software to build the city, and explored opportunities to support different devices. The implementation results were the first attempt to convey Karakorum's history. Reconstructing the city in a virtual environment not only provides a cultural heritage application of computer graphics but also support archeological and historical research. In the future, the results of the project are used as educational content in secondary schools and museum exhibits, and they are planned to be used in the metaverse.

ACKNOWLEDGMENTS

The study was funded by National University of Mongolia (No. P2018-3603). The research is based on the result of Mongolian–German Karakorum expedition. We are thankful for the students at Computer graphics and multimedia open research laboratory for their enormous assistant and support.

ORCID

Oyundolgor Khorloo https://orcid.org/0000-0003-3254-1154

REFERENCES

1. Dylla K, Frischer B, Müller P, Ulmer A, Haegler S. Rome reborn 2.0: a case study of virtual city reconstruction using procedural modeling techniques. Comput Graph World. 2008;16(6):62–6.
2. Ferwati MS, El Menshawy S. Virtual reconstruction of the historic city of Al-Zubarah in Qatar. Digit Appl Archaeol Cult Herit. 2021;21:e00177.
3. Ma YP. Extending 3D-GIS district models and BIM-based building models into computer gaming environment for better workflow of cultural heritage conservation. Appl Sci. 2021;11(5):2101.
4. Moghadam ST, Lombardi P, Mutani G, Osello A, Ugliotti FM. BIM-GIS modelling for sustainable urban development. In: Towards post-carbon cities, SBE16 Turin, Italy; 2016. p. 18–9.
5. Volk R, Stengel J, Schultmann F. Building information modeling (BIM) for existing buildings—literature review and future needs. Autom Construc. 2014;38:109–27.
6. Albourae AT, Armenakisa C, Kyan M. Architectural heritage visualization using interactive technologies. Int Arch Photogr Rem Sens Spat Inform Sci. 2017;18:42.
7. Del Giudice M, Osello A, Patti E. BIM and GIS for district modeling. In: ECPPM 2014 conference, Vienna; 2014 Sep 17.
8. Fosu R, Suprabhas K, Rathore Z, Cory C. Integration of building information modeling (BIM) and geographic information systems (GIS) – a literature review and future needs. In: Proceedings of the 32nd CIB W78 conference, Eindhoven, The Netherlands; 2015 Oct 27. p. 27–9.
9. Lynch J, Parcero-Oubiña C, Fábrega-Álvarez P. A field experience of documentation and analysis through 3D mapping and surface survey in the Hualfín Valley (Catamarca, Argentina). Digit Appl Archaeol Cult Herit. 2020;17:e00145.
10. Lipp M, Scherzer D, Wonka P, Wimmer M. Interactive modeling of city layouts using layers of procedural content. Comput Graph Forum. 2011;30(2):345–54.
11. Yang YL, Wang J, Vouga E, Wonka P. Urban pattern: layout design by hierarchical domain splitting. ACM Trans Graph. 2013;32(6):1–2.
12. Fan L, Musialski P, Liu L, Wonka P. Structure completion for facade layouts. ACM Trans Graph. 2014;33(6):210–1.
13. Koehler T, Dieckmann A, Russell P. An evaluation of contemporary game engines; 2008.
14. Huang X, Kimm G, Burry M. Exploiting game development environments for responsive urban design by non-programmers-melding real-time ABM pedestrian simulation and form modelling in Unity 3D.
15. Soto-Martin O, Fuentes-Porto A, Martin-Gutierrez J. A digital reconstruction of a historical building and virtual reintegration of mural paintings to create an interactive and immersive experience in virtual reality. Appl Sci. 2020;10(2):597.
16. Youn HC, Ryoo SL. VR and AR restoration of urban heritage: a virtual platform mediating disagreement from spatial conflicts in Korea. Buildings. 2021;11(11):561.
17. Ch'ng E, Cai Y, Thwaites H. Special issue on VR for culture and heritage: the experience of cultural heritage with virtual reality (part II): guest editors' introduction. Presence. 2018;26(4):iii–v.
18. Kim S, Kim D, Choi S. CityCraft: 3D virtual city creation from a single image. Vis Comput. 2020;36(5):911–24.
19. Erdenebat U. Qaraqorum-ancient capital of Mongolia. 2nd ed. Ulaanbaatar: NUM Press Publishing; 2020.
20. Franken C, Rohland H, Erdenebat U, Batbayar T. The capital of Mongol empire in the valley of the Orkhon; 2021.
21. Bemmann J, Ėrdėnėbat U, Pohl E, editors. Mongolian-German Karakorum expedition. Vol. 1: Excavations in the Craftsmen Quarter at the Main Road. Wiesbaden; 2010.
22. Jackson P. The mission of Friar William of Rubruck: his journey to the court of the Great Khan Möngke, 1253–1255. London : Routledge; 2017.
23. Bemmann J, Linzen S, Reichert S, Munkhbayar L. Mapping Karakorum, the capital of the Mongol empire. Antiquity. 2022;96(385):159–78.

24. Bemmann J, Reichert S. Karakorum, the first capital of the Mongol world empire: an imperial city in a non-urban society. Asian Archaeol. 2021;4(2):121–43.
25. Grellert M, Haas F. Sharpness versus uncertainty in 'complete models'. Virtual palaces, part II. Lost palaces and their afterlife. München: PALATIUM e-Publication 3; 2016. p. 119–48.
26. 360 Tour of Virtual Karakorum. [Accessed 13 May, 2022]. Available from: https://ds.ocurus.com/tour/NDQ3Mg==

AUTHOR BIOGRAPHIES

Oyundolgor Khorloo is currently an associate professor in Department of Information and Computer Science at School of Engineering and Applied Sciences of National University of Mongolia. Her research interests include computer graphics, virtual reality, noise-based animation, and simulation of natural phenomena. She received a B.S. degree in applied mathematics from National University of Mongolia in 1995 and an M.S. degree in computer science from University of Colorado at Denver in 2001. She received her Dr. Eng. in design and media technology from Iwate University in 2012.

Erdenebat Ulambayar (Ph.D. 2009, University of Bonn, Germany) is a professor and the head of the Department of Anthropology and Archaeology at the School of Arts and Sciences, National University of Mongolia, Ulaanbaatar. His research interests include the Medieval period of Eurasian nomadic cultures, the Mongol Empire, settlement archaeology, burial customs, Medieval dresses and textiles, cultural heritage preservation, and falconry.

Enkhbayar Altantsetseg received the B.S. and M.S. in mathematics from National University of Mongolia in 1995 and 1997, respectively. He earned his Dr. Eng. in design and media technology from Iwate University in 2013. He is currently a professor of School of Engineering and Applied Sciences of National University of Mongolia. His research interests include geometric modeling, virtual reality, augmented reality, and simulation.

How to cite this article: Khorloo O, Ulambayar E, Altantsetseg E. Virtual reconstruction of the ancient city of Karakorum. Comput Anim Virtual Worlds. 2022;e2087. https://doi.org/10.1002/cav.2087