An improved LOD3 through photogrammetry for generating digital twins

Saruul Altankhuyag[1]*, Bilguuntugs Tovuusuren[1], Bolorchuluun Chogsom[2]

[1] Monmap LLC, Mongolia

[2]Department of Geography, National University of Mongolia, Mongolia

Saruuul0912@gmail.com

Abstract: *Digital twin technology creates an integrated spatial system in a virtual environment that represents real-world objects and systems, ensuring their interconnection through the use of geographic information systems (GIS). This system connects to real-time data derived from generated datasets, enabling monitoring, analysis, and improved decision-making. This study aims to explore the potential for generating base data for a Level of Detail 3 (LOD3) digital twin model using stereophotogrammetry and GIS, with a pilot implementation in the 100 Ail area of Ulaanbaatar, Mongolia. This area was selected because it contains a diverse mix of ger districts, built-up zones, bridge structures, rivers, and green spaces. As base data, aerial imagery captured in 2023 by MonMap LLC's WingtraOne GEN II unmanned aerial vehicle was used. The aerial photographs were processed using stereophotogrammetric methods to create a 3D spatial model. Orthophotos, a digital surface model (DSM), and a digital terrain model (DTM) were produced, with the aim of developing both schematic and high-precision 3D models of buildings and structures. As a result of the study, an LOD3 3D model was created. Spatial elements such as buildings, roads, and green areas were represented in 2D form, while the models accurately reflected roof shapes, façade structures, and heights. This enhances the potential applications of digital twin systems in urban planning, building monitoring, and smart city analytics, among other fields.*

Keywords: *Digital Twin, LOD3, Stereophotogrammetry, GIS, Spatial Base Data Model*

Introduction

Digital Twin is a dynamic, self-evolving virtual model or simulation of a real-world object (e.g., a component, machine, process, person, etc.) that reflects the current state of the physical counterpart. This model operates based on real-time data exchange and the storage of historical data. The digital twins not merely a monitoring tool but also a foundation for analysis, management, and automated decision-making (Emmert-Streib, 2023). This system enables comprehensive assessment across all sectors of major cities. It is highly effective in supporting decision-making in urban planning, environment, socio-economics, transportation, engineering infrastructure, cultural heritage, and many other areas.

In digital twin modeling, levels of detail (LOD) are used to achieve realistic visualization, and with the advancement of technology, visual accuracy continues to improve. At the LOD3 level, buildings can be represented with high precision in terms of geometry, facades, and roofs, allowing for realistic depictions of external appearances. Since LOD3 data requires not only geometric accuracy but also visual fidelity comparable to real-world conditions, stereophotogrammetry has become one of the most optimal approaches.

The stereophotogrammetric method utilizes pairs of aerial images to calculate spatial points with three-dimensional coordinates at high accuracy, thereby generating dense and detailed 3D spatial models.

International examples show that cities adopting digital twin technologies are actively developing LOD3-level 3D models using stereo spatial data, which demonstrates the significance of this approach. For Ulaanbaatar, localizing this methodology will establish the technological foundation necessary for innovative and intelligent urban planning policies, leveraging the spatial data accumulated at the national level.

Literatur Review

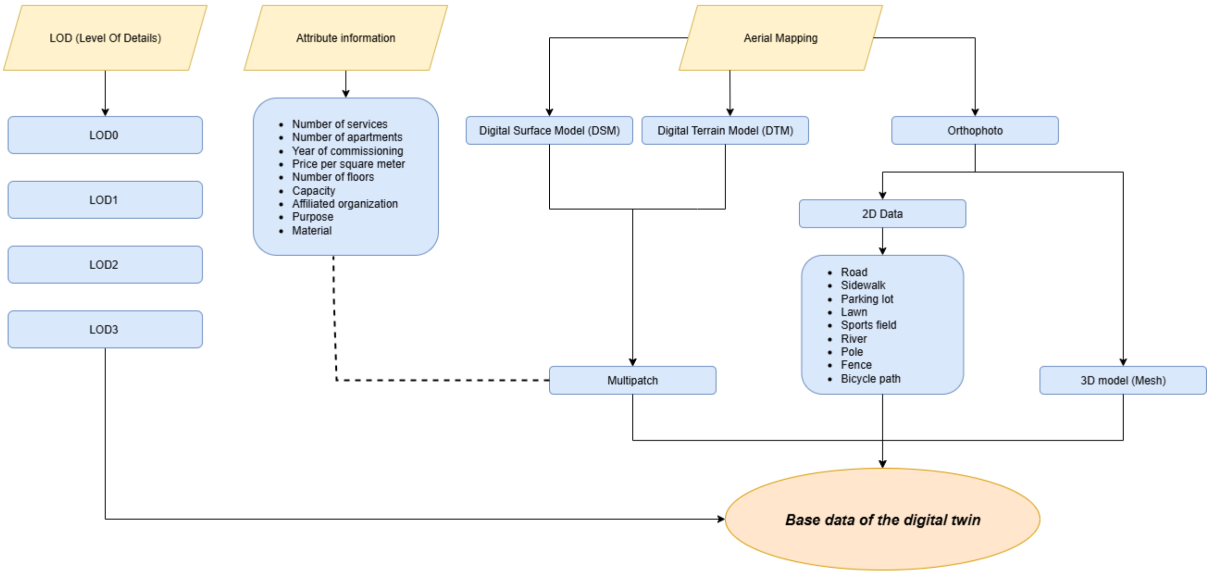
The concept of the Digital Twin was first introduced in 2002 in the research of NASA engineer Michael Grieves, with the aim of creating a digital representation of a physical object in a virtual environment to support monitoring, prediction, and management. Today, digital twin technology is widely applied across diverse fields, including urban planning, infrastructure, energy, environment, industry, and healthcare. (Esri, 2025)

Table 1. Researched status

Project	Country	Research Focus	Methodology

Prague Institute of Planning and Development	Czech Republic	Climate change, urban dynamics, public spatial organization	Climate modeling, urban heat island analysis, public participation analysis, GIS-based data simulation
Cross River Rail	Australia (Brisbane)	Urban infrastructure digital planning, Building Information Modeling (BIM)	Construction progress simulation, structural–mechanical–time integration analysis using digital twin, geotechnical monitoring and analysis
Vodafone	United Kingdom	Digital twin applications in high-resolution spatial network planning and communication design	3D spatial digital twin for network planning, communication system integration, network performance correlation and data analysis
The Nature Conservancy	USA	Ecosystem regional planning and conservation optimization	Use of environmental datasets (satellite imagery, field data), habitat mapping, spatial planning of ecosystems, ecosystem simulation

Methodology



Scheme 1. Methodology

The aerial imagery was acquired using the latest WingtraOne Gen II unmanned aerial vehicle, developed by the Swiss company *Wingtra*, equipped with a 61 MP camera.

An aerial survey covering an area of 9,688 hectares was processed using stereophotogrammetric techniques. The aerial images were processed with the Drone2Map software developed by *Esri (USA)*, resulting in an orthophoto with a spatial accuracy of 1–3 cm.

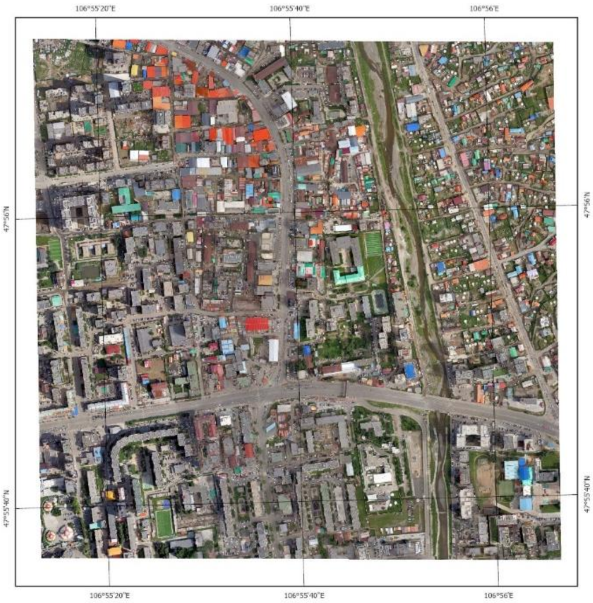


Figure 3. Orthophoto

Elevation model (DSM/DTM)

Figure 4. Digital Surface Model (DSM)

The Digital Surface Model (DSM) is a digital representation that captures the elevation of the highest points of all objects present on the ground, including buildings, trees, and other structures.

Min (minimum)	1300.78 m
Max (maximum)	1366.28 m
Mean (average height)	1313.08 m

The Digital Surface Model (DSM) is a digital representation that contains the elevation of the highest points of all objects on the ground, such as buildings, trees, and other structures.

Min (minimum)	1301.13 m
Max (maximum)	1335.42 m
Mean (average height)	1308.92 m

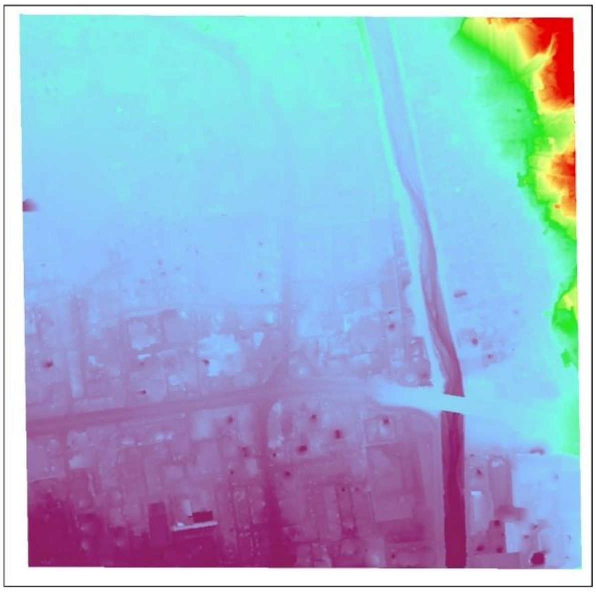


Figure 5. Digital Surface Model (DSM)

Mesh model

A mesh model is a process that uses point cloud data to generate a triangular irregular network (TIN), thereby converting the surface of an object into a continuous three-dimensional representation.

Figure 6. General view

2D data

To create a digital twin model, spatial data must be prepared with high accuracy and across multiple levels. In this context, the base datasets were processed in feature class format using ArcGIS Pro. The generated data were exported in shapefile (shp) format, including key elements such as buildings, roads, green spaces, and utility networks.

Figure 7. 2D data preparation

3D web model

By subtracting the DTM from the DSM, a normalized DSM (nDSM) is obtained, which represents only the heights of objects. This enables the geometric differentiation of the vertical extent of each object. Based on this dataset, the building footprints represented as 2D polygons can be extruded into three-dimensional space by linking them with the nDSM values, resulting in multipatch geometry or 3D vector representations. An attribute refers to the descriptive information of vector data, containing details such as the name, type, size, height, and purpose of a given object.

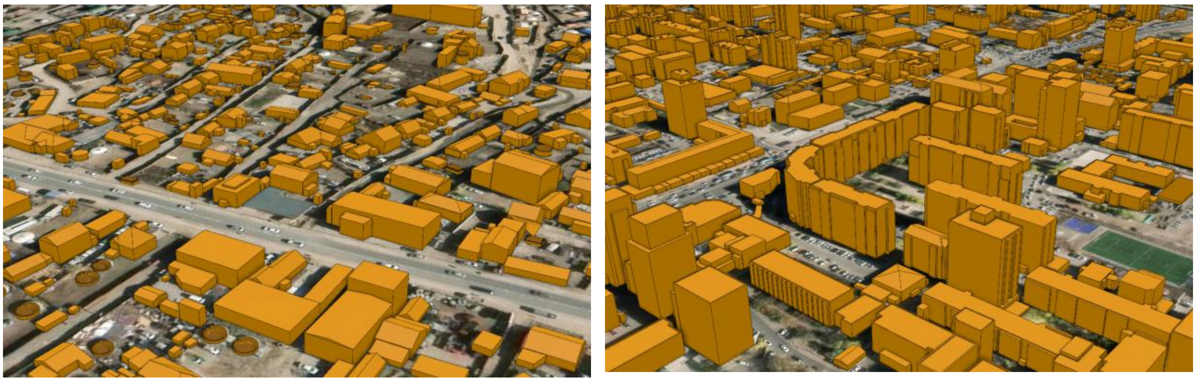


Figure 8. 3D data preparation

3D web model

At the scale of the study area, all spatial and attribute data were integrated and processed within the ArcGIS Pro environment, and subsequently published as a 3D web scene in a virtual environment. Building heights were calculated based on the difference between the DSM and DTM, and building footprints (polygons) were converted into multipatch features to generate a 3D building layer.

Figure 10. General view

Figure 11. Ger district

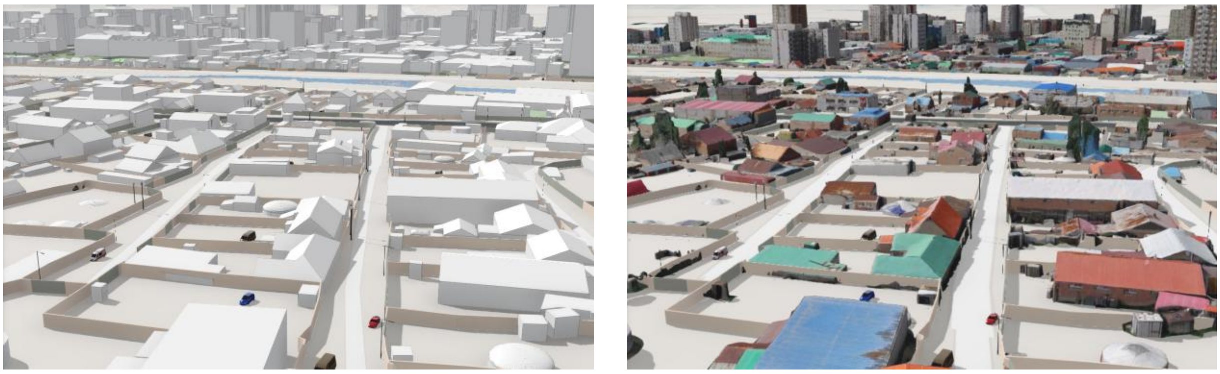


Figure 14. Fence view

In the study area, a flood risk analysis was conducted using the 3D web scene model to identify water flow directions, elevation differences, structural protection, and the probability of inundation. The flood risk was assessed based on a 100-year flood scenario, incorporating data from the 2023 flood event.

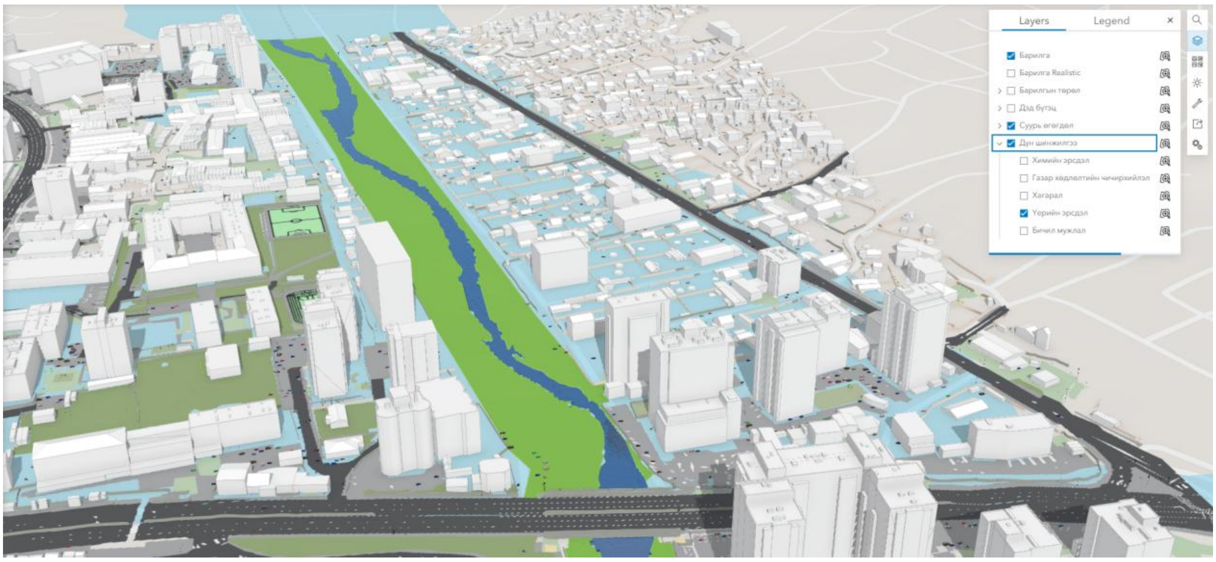


Figure 15. Flood risk analysis 1

In this study, the car detection deep learning model from the ArcGIS Living Atlas was applied to a 123-hectare area around the “100 Ail” district. High-resolution aerial imagery was used to automatically detect and count car footprints. As a result of the experiment, a total of 3393 cars were detected, demonstrating the strong capability of the deep learning model for accurate object extraction. The car detection outcomes can be utilized for applications such as traffic flow analysis, parking lot utilization, and urban planning, as well as serving as a proxy for certain economic indicators.

Figure 16. Car detection

Conclusion

Within the scope of this research, a three-dimensional LOD3 model was created using stereophotogrammetric methods for a total area of 9,688 hectares in the central part of Ulaanbaatar city. This work successfully demonstrated the feasibility of generating base data for a city-scale digital twin model.

The main outcomes of the study are as follows:

- High-resolution mapping: The aerial imagery acquired by an unmanned aerial vehicle achieved a spatial accuracy of 3 cm.
- Digital twin model**:** Three-dimensional representations of buildings, roads, and other urban elements were successfully generated, demonstrating their applicability for urban planning and infrastructure management.

These results highlight the potential of using digital twin models to process spatial information and to support applications in urban planning, infrastructure management, and environmental analysis. Compared to digital twin technologies being implemented worldwide, this study is innovative in its integration of stereophotogrammetry and GIS for generating highly accurate 3D urban models.

Reference

Ministry of Construction and Urban Development. (2016). *Norms and rules for using microzonation maps for earthquakes /BNbD 22-04-16/* (in Mongolian).

Bolorchuluun, Ch. (2005). *Building detection and exclusion in digital terrain modeling. MUST Research Proceedings*, No.1/71, Ulaanbaatar, 133–141 (in Mongolian).

Bolorchuluun, Ch. (2021). *Digital photogrammetry and aerial imagery processing course material* (in Mongolian).

Bolorchuluun, Ch. (2023). *Spatial data analysis and modeling course material* (in Mongolian).

Bolorchuluun, Ch., & Tuvshinbayar, D. (2006). *Systems for integrated 3D geoinformation. Geo-Siberia-2006*, Novosibirsk, 344–362 (in Mongolian).

Bolorchuluun, Ch., Batkhuu, H., Amarsaikhan, D., Tsogtdulam, M., Battsengel, V., & Nominsetseg, H. (2017). *Use of unmanned aerial vehicles for disaster situations: Mapping methodology (example of Phantom 2 Vision). Geography and Geoecological Issues of Mongolia*, Special Issue, 206–213 (in Mongolian).

Bolorchuluun, Ch., Tsogtdulam, M., Zuchi, S., & Anudar, B. (2018). *3D mapping topology relationships and their potential use in cadastral mapping. Land Relations, Agroecology*, 11(01), 35–44 (in Mongolian).

Parliament of Mongolia. (2020). *"Vision–2050" long-term development policy of Mongolia: Resolution No.52 of the Parliament of Mongolia, 2020.* http://www.parliament.mn/n/pv3q (in Mongolian).

Ahmed, N., & Kim, H. (2023). *Intelligent decision support systems for smart city applications.*

Andrews, C. (2021, January 11). *ArcGIS: A Foundation for Digital Twins.* Esri. Retrieved April 19, 2025, from https://www.esri.com/arcgis-blog/products/arcgis/aec/gis-foundation-for-digital-twins

Andrews, C. (2021, January 11). *ArcGIS: A Foundation for Digital Twins.* Esri. Retrieved April 19, 2025, from https://www.esri.com/arcgis-blog/products/arcgis/aec/gis-foundation-for-digital-twins

Batty, M. (2023). *Decoding the smart metropolis.*

Bilguuntugs, T., Adiya-Ochir, G., & Tsolmon, O. (2024). *Digital Twin Technology Example of Ulaanbaatar city.*

Chen, M., & Zhang, Y. (2025). *Blockchain and digital twin applications in smart agriculture.*

Emmert-Streib, F. (2023). *Defining a Digital Twin: A Data Science-Based Unification.* Machine Learning and Knowledge Extraction, 5(3), 1036–1054. https://www.mdpi.com/2504-4990/5/3/54

Esri. (n.d.). *Digital Twin Technology & GIS.* Retrieved April 19, 2025, from https://www.esri.com/en-us/digital-twin/overview

Esri. (2021). *ArcGIS: The Foundation for Digital Twins.* ArcUser. Retrieved April 19, 2025, from https://www.esri.com/about/newsroom/arcuser/arcgis-a-foundation-for-digital-twins

Green, B., & Patel, R. (2024). *Revolutionizing cities with emerging technologies.*

Harris, T., & Miller, A. (2023). *Geographic information systems in urban planning and management*

Institut plánování a rozvoje hlavního města Prahy. (2024). *3D model Prahy [3D model of Prague].* from https://www.iprpraha.cz/3dmodel

Jones, C. (2024). *Digital twin technology and applications.* Auerbach Publications.

Li, H., & Brown, D. (2019). *GIS-based simulation and analysis of intra-urban commuting.*

Müller, P., & Wang, K. (2024). *Generation and update of a digital twin in a process plant.*

Nguyen, T. (2023). *The digital twin.*

O'Connor, L. (2024). *The smart city.*

Rasheed, A.; San, O.; Kvamsdal, T. (2020). *Digital twin: Values, challenges and enablers from a modeling perspective.* IEEE Access, 8, 21980–22012.

Sharma, R., & Liu, M. (Eds.). (n.d.). *Handbook of artificial intelligence for smart city development: Management systems and technologies.*

Singh, M.; Fuenmayor, E.; Hinchy, E.P.; Qiao, Y.; Murray, N.; Devine, D. (2021). *Digital twin: Origin to future.* Appl. Syst. Innov., 4, 36.

Smith, J., & Zhao, L. (2024). *Digital twin: Architectures, networks, and applications.*

Taylor, R., & Clark, S. (2023). *Regional and urban change and geographical information systems and science: An analysis of Ontario, Canada.*