GeoTerrace-2026-026

A Conceptual Framework for Developing Digital Twins of Territorial Communities through the Integration of LiDAR, UAV and GIS Technologies

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SUMMARY

The full-scale war in Ukraine has caused extensive damage to residential, engineering, and transport infrastructure, creating an urgent need for the rapid acquisition of accurate geospatial data to support the effective planning of territorial community reconstruction. In this context, digital twins have emerged as integrated digital models that combine spatial, engineering, and analytical data to facilitate informed decision-making. This study aims to propose a conceptual framework for developing Digital Twins of territorial communities through the integration of laser scanning data, Unmanned Aerial Systems (UAS), and geoinformation technologies. The results demonstrate that the integration of laser scanning data, cadastral information, urban planning documentation, and aerial imagery enables the development of a comprehensive digital model of a territorial community. Such a model supports asset inventory, damage assessment, infrastructure condition monitoring, and the simulation of territorial development scenarios. The findings indicate that digital twins significantly improve the efficiency of spatial planning and the management of post-war reconstruction processes. It is concluded that digital twins represent a key instrument for the digital transformation of territorial governance in the context of post-war recovery and provide the foundation for the implementation of next-generation integrated geoinformation systems.

Keywords: Digital Twin; Laser Scanning; Geographic Information Systems (GIS); Unmanned Aerial Systems (UAS); Spatial Planning; Territorial Reconstruction; 3D Modelling; Geospatial Data.

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Introduction

The full-scale war in Ukraine has caused extensive destruction of residential, industrial, and engineering infrastructure, posing an unprecedented challenge to spatial planning and territorial management systems. Under these circumstances, the availability of up-to-date, accurate, and comprehensive geospatial information on the condition of territories, real estate assets, and engineering infrastructure has become a critical prerequisite for effective post-war reconstruction.

Conventional approaches to territorial inventory and planning are unable to provide the required speed of data acquisition, updating, and integration into a unified information environment. Consequently, advanced geospatial technologies, including Light Detection and Ranging (LiDAR), mobile Simultaneous Localization and Mapping (SLAM) systems, Unmanned Aerial Systems (UAS), Geographic Information Systems (GIS), and the concept of Digital Twins, have become increasingly important.

A Digital Twin is defined as a dynamic digital representation of a physical asset or territory that is continuously updated using real-world data in near real time, enabling monitoring, analysis, and predictive modelling of system development (Sharma et al., 2022). As noted by Fuller et al. (2020), Digital Twins constitute one of the key enabling technologies of digital transformation in infrastructure management by integrating heterogeneous data sources into a unified decision-support environment.

In the context of Ukraine's post-war recovery, Digital Twins have the potential to serve as a fundamental technological framework for territorial development planning, damage assessment, investment management, and the simulation of reconstruction scenarios.

The proposed framework illustrates the integration of heterogeneous geospatial datasets into a unified Digital Twin environment supporting territorial planning and post-war reconstruction.

Method and Theory

The concept of Digital Twins is based on the integration of the physical environment, its digital representation, and the continuous exchange of data between them. According to Sharma et al. (2022), a Digital Twin is a cyber-physical system that integrates sensor data, analytical models, and predictive algorithms to support informed decision-making.

The data integration workflow combining LiDAR/SLAM, UAV imagery, GIS layers and sensor-based Internet of Things data for generating a Digital Twin of a territorial community is illustrated through the data-flow UML diagram in Figure 1.

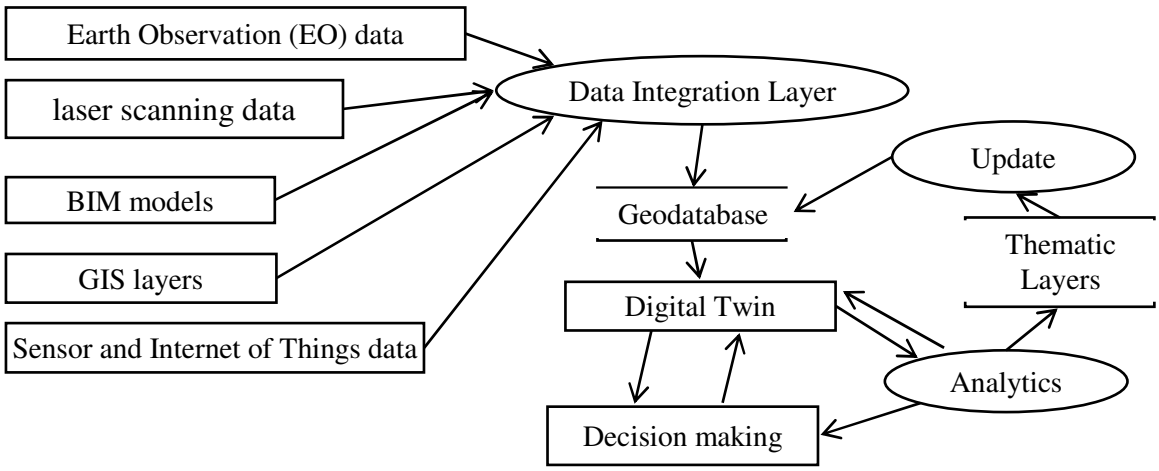

Figure 1. *Data integration diagram for generating a Digital Twin of a territorial community*

Agrawal et al. (2022) emphasize that the effectiveness of Digital Twins largely depends on the integration of spatial data acquired at different levels of accuracy and spatial scales, making three-dimensional (3D) territorial modelling a fundamental component of Digital Twin implementation.

One of the key technological directions is the development of digital models of cities and territorial communities. Naserentin and Logg (2022) demonstrate that the automated generation of 3D urban models based on laser scanning and cadastral data significantly improves the accuracy of spatial simulations while enabling their application in urban modelling and planning.

At the global level, the development of Digital Twin technologies is supported by several European Union initiatives. According to the European Commission (n.d.), the Destination Earth (DestinE) initiative aims to develop highly accurate digital replicas of the Earth for modelling both natural and anthropogenic processes. Furthermore, the United Nations Committee of Experts on Global Geospatial Information Management (n.d.) identifies geospatial information as a fundamental component of modern public administration and sustainable territorial development.

Results

Developing a digital twin of a territorial community requires a coherent combination of heterogeneous spatial data and analytical procedures. The proposed model demonstrates a holistic approach to integrating LiDAR, UAV, GIS, cadastral and engineering information to support management decisions and reconstruction planning. The UML diagram illustrates the sequence of developing a Digital Twin of a territorial community (Figure 2.)

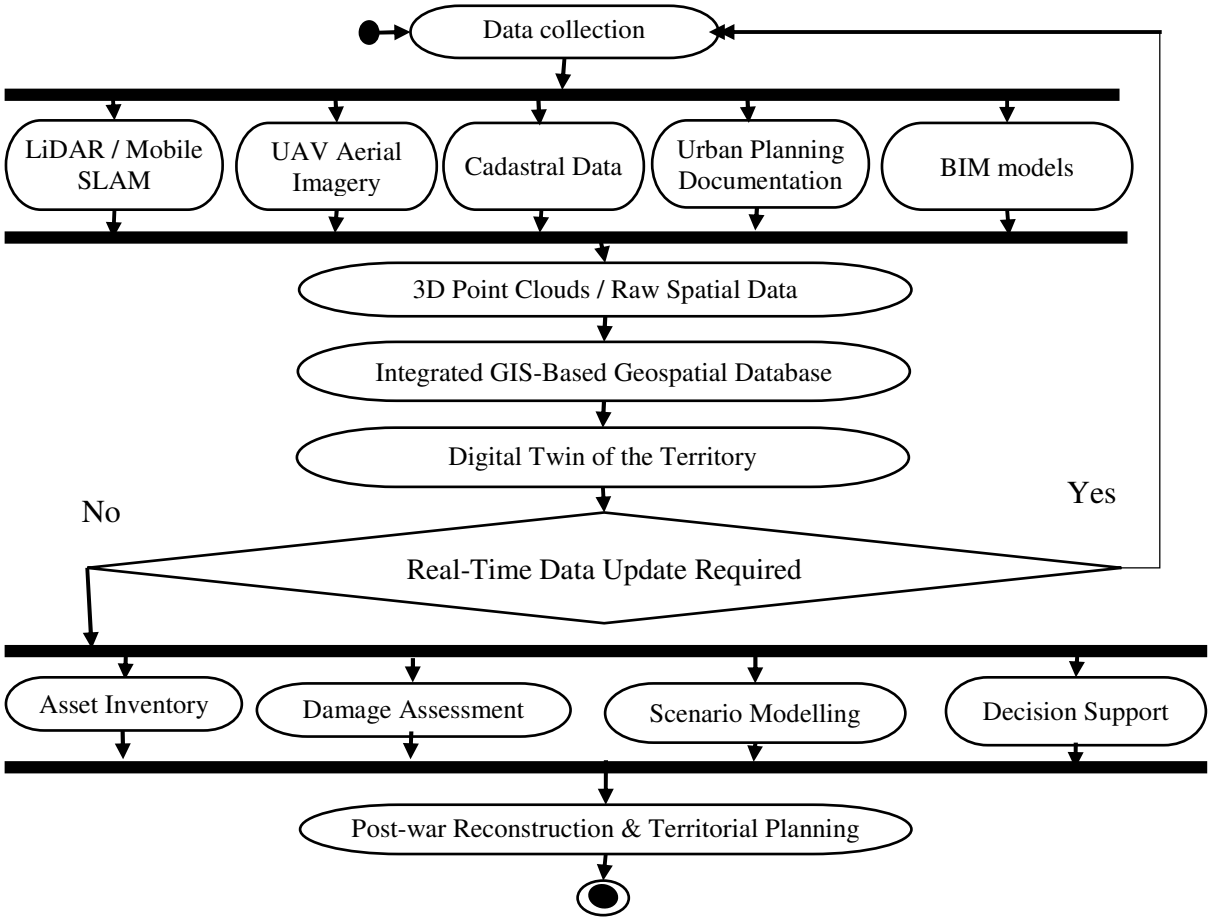

Figure 2. *Proposed conceptual framework for developing a Digital Twin of a territorial community based on the integration of LiDAR, UAV, GIS, cadastral and engineering data*

As shown in Figure 2, the development of a Digital Twin begins with the acquisition of foundational geospatial datasets. Among these, LiDAR and mobile SLAM technologies play a central role due to their ability to capture accurate three-dimensional information. Unlike conventional geodetic surveying methods, LiDAR enables comprehensive three-dimensional representation of physical objects, rapid data acquisition, and efficient surveying of complex and difficult-to-access environments. Particular attention should be paid to mobile Simultaneous Localization and Mapping (SLAM) systems, which simultaneously determine the scanner's position while generating a three-dimensional model of the surrounding environment. This substantially improves the efficiency of field surveying and makes the technology especially suitable for the rapid assessment of territories damaged by military actions. Within the context of territorial community management, laser scanning can be applied to: inventory of buildings and infrastructure assets; assessment of infrastructure damage; development of digital models of utility and engineering networks; monitoring of transportation infrastructure; updating urban planning and cadastral documentation; generation of baseline datasets for spatial planning.

The integration of these heterogeneous datasets within a unified geoinformation environment enables the creation of an up-to-date digital representation of a territorial community. Such a model can be employed for spatial analysis, territorial development forecasting, risk assessment, investment planning, and the management of post-war reconstruction activities.

An important methodological foundation of this study is the author's previous research on the GeoBIM concept (Mykhailyk & Poltavets, 2026), which proposed a conceptual framework for integrating Building Information Modelling (BIM) and Geographic Information Systems (GIS) as a basis for the development of a 3D cadastre and advanced spatial analysis.

In the present study, GeoBIM is regarded as an intermediate level of data integration, whereas the Digital Twin represents a more advanced and dynamic system that: supports real-time or near-real-time data updating; integrates continuous sensor data streams; incorporates predictive analytical models; enables scenario-based simulation of territorial development.

Accordingly, GeoBIM may be considered the technological foundation of a Digital Twin, while the Digital Twin represents the evolutionary advancement of the GeoBIM concept.

The post-war reconstruction of Ukraine requires a transition toward integrated digital territorial governance. Digital Twins facilitate rapid damage assessment, prioritization of reconstruction activities, optimization of investment decisions, increased transparency in governance, and improved coordination among the various stakeholders involved in reconstruction.

Furthermore, Digital Twins enable the simulation and evaluation of multiple territorial development scenarios, including infrastructure reconstruction, modernization strategies, and changes in land-use patterns. These capabilities provide decision-makers with reliable analytical support for sustainable territorial development and long-term recovery planning.

Conclusions

The conducted analysis demonstrates the considerable potential of Digital Twins to support the post-war reconstruction of Ukraine. The integration of laser scanning, SLAM technologies, Geographic Information Systems (GIS), and Unmanned Aerial Systems (UAS) enables the development of highly accurate digital models of territorial communities, providing an effective foundation for managing reconstruction processes.

The findings indicate that integrating laser scanning data with cadastral, urban planning, and engineering datasets creates the necessary conditions for the development of comprehensive Digital Twins of territories. Such models can be applied to asset inventory, change detection, damage assessment, and decision-support processes in territorial management.

Future research will focus on the development and practical implementation of the proposed conceptual framework for Digital Twins of Ukrainian territorial communities based on the integration of mobile laser scanning, Unmanned Aerial Systems, and advanced geoinformation technologies

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