Trasimeno Smart Land: 3D geospatial data integration for sustainable territorial management

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Abstract

The *Trasimeno Smart Land* project presents an innovative application of Digital Twin technologies to support sustainable governance across a fragmented rural territory in central Italy, encompassing eight municipalities. The PITER Integrated Territorial Platform combines multi-source geospatial data, real-time sensor feeds, citizen-reported issues and extensive field survey datasets into a unified, dynamic platform, developed through a collaboration between local administrations, the Department of Civil and Environmental Engineering at the University of Perugia and private companies. Unlike traditional urban-focused Smart City models, PITER addresses the complexity of low-density areas characterized by dispersed settlements and extensive cultural and natural heritage, enabling advanced spatial analyses for infrastructure monitoring, public works management, land-use planning and environmental protection. The platform incorporates real-time data from IoT sensors, citizen reports, street-level surveys and continuously updated municipal records, structured across 24 thematic layers. Key functionalities include advanced spatial analyses, participatory governance tools and thematic dashboards supporting decision-making for land management, infrastructure monitoring and sustainable development. PITER's architecture ensures high interoperability, data quality control and adaptability, offering a replicable model for similar fragmented contexts. The platform's modular design allows for continuous updates and seamless scalability, providing a replicable model for other fragmented territories with complex administrative and infrastructural needs. By bridging technological innovation with administrative processes, *Trasimeno Smart Land* redefines territorial governance models beyond urban cores, contributing to a broader Smart Land paradigm.

Figure 1. View of the Digital Twin of the Trasimeno Lake district within the WiseTown Citiverse module of the PITER platform. Source: unionedeicomunideltrasimeno.wise.town.

1. Introduction

In the last two decades, the concept of Smart City has emerged as a key framework for rethinking urban governance, technological infrastructure and spatial planning (Jiang et al., 2022). At its core, the Smart City paradigm seeks to harness digital technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI) and Digital Twins (DT), to enhance urban efficiency, sustainability and citizen engagement (Batty, 2018; Grieves & Vickers, 2017; Nastjuk et al., 2022). However, as widely acknowledged in contemporary literature, the Smart City is far from a neutral or universally applicable model. Its implementation often exposes critical limitations, including systemic data fragmentation, unequal access to digital infrastructure, governance asymmetries and ethical concerns related to surveillance and data ownership (Kitchin, 2014; Söderström et al., 2020; Vanolo, 2014). Moreover, the predominance of top-down, technocentric approaches tends to reinforce rather than resolve existing spatial and social inequalities (Bianconi et al., 2015; Bianconi & Filippucci, 2017; Greenfield, 2013; Mattern, 2016).

These limitations become even more pronounced when the model is applied to low-density or polycentric territories, such as rural, lacustrin or mountainous areas, where socio-economic dynamics and governance needs differ substantially from those of urban contexts (Crivello & others, 2013; Ratti & Mattei, 2013).

In response to these challenges, the notion of Smart Land (Azadi et al., 2023; Bonomi & Masiero, 2014) has begun to take shape as a complementary and, in some respects, alternative paradigm. Rooted in territorial specificities rather than urban universals, the Smart Land model foregrounds the relational dimension between data, communities and landscapes. It shifts the focus from purely technology-driven optimization to a form of context-aware intelligence, calling for digital infrastructures that are not only interoperable and responsive, but also intelligible, inclusive and capable of generating public value (Nam & Pardo, 2011; Vianello, 2013). In this perspective, innovation is not merely about digitizing governance, but about reconfiguring it through ethical, cultural and participatory lenses (Adade & De Vries, 2025; Bianconi & Filippucci, 2020; Parrinello & Picchio, 2023).

Given the persistent challenges identified in prevailing Smart City models and the limitations still present in early Smart Land prototypes, this research sets out to fill a critical gap in both theoretical and operational domains. Its objective is to define a coherent methodological framework and develop a practical solution capable of integrating the digital governance of wide, non-metropolitan areas with the need to streamline administrative processes and promote effective stakeholder inclusion. The ambition is to move beyond technocratic paradigms by proposing a scalable, context-sensitive model of territorial intelligence that is both practically effective and democratically grounded.

Within this framework, the *Trasimeno Smart Land* project, developed as part of the ITI Trasimeno Territorial Strategy, originates from an interinstitutional collaboration between the Union of the Municipalities of Trasimeno and the University of Perugia's Department of Civil and Environmental Engineering, alongside three local companies. PITER (*Piattaforma Integrata TERritoriale*, Integrated Territorial Platform), the main outcome of the project, constitutes a scalable and replicable digital infrastructure, specifically designed to address the unique characteristics of dispersed and rural territories such as the Trasimeno Lake district. Funded through European structural funds (Art. 36, EU Regulation N. 1303/2013), the platform seeks to integrate territorial, historical, environmental and participatory data in support of informed and inclusive decision-making processes.

The project articulates its actions around four thematic domains: the construction of a territorial DT (Fig. 1), the enhancement of cultural heritage through immersive technologies, the digitalisation of historical cadastres and the deployment of tools for collaborative governance. Thanks to its modular structure, comprising the components Thematic Dashboards, WiseTown Issue Manager and Citiverse, PITER offers an operational model for the intelligent management of Smart Lands and constitutes a methodological benchmark for future applications at both national and international scales.

2. Methodological framework

2.1 State of the art

The initial phase of the research involved a state of art analysis of the concepts of "Smart City", which is widely spread and stratified in the literature (Nguyen & Nhu, 2020), and "Smart Land", the extreme disproportion of which as keywords present in article titles, keywords or abstracts denotes the emerging character of the latter notion. Indeed, although considering 5.007 peer-reviewed publications available on Smart Cities linked to urban planning, land governance and urban management, the field narrows by almost 360% when referring to the concept of Smart Land. The scientometric analysis conducted thus returned a quantitative and qualitative view of the thematic tracks common to both concepts, mainly pertaining to the area of climate change, sustainability, resilience, ecology, territorial governance, data and digital transformation (Bellone et al., 2021; K'Akumu & Alhamoudi, 2025; Shao & Min, 2025; Vavrová et al., 2025; Zeng, 2025). Instead, a greater focus on Internet of Things, smart grid and mobility turn out to be exclusive for the Smart City concept (Humayun et al., 2020), while keywords related to ecosystem services, rural development, land use and territorial governance emerge for Smart Land (Asefa et al., 2025;

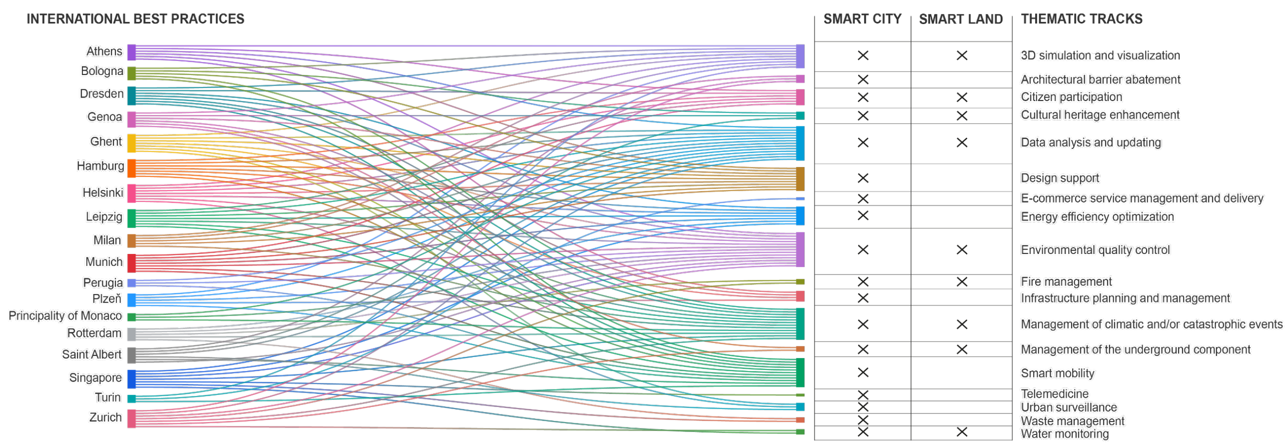

Figure 2. Comparative map of international best practices in Smart City and Smart Land models, with thematic domain correspondences. Graphic design by the authors.

Schulte et al., 2016). Therefore, if in the former case, thematic recurrences prefer aspects related to the city infrastructure interpreted as a digital node that interweaves sustainability and governance (Shao & Min, 2025; Vishnivetskaya & Alexandrova, 2019; Zeng, 2025), for the emerging Smart Land concept a systemic approach, centred on the landscape as a living network, with a more ecological declination of the smartness concept, with an emphasis on peripheral, rural or non-metropolitan spaces, appears widespread (Zhou & Li, 2025).

The quantitative imbalance between the occurrences of the terms "Smart City" and "Smart Land", which is also evident in the analysis of co-occurrences between the respective keywords, is clearly reflected when moving from the terminological level to that of design practices. To deepen this conceptual and operational distance, a comparative analysis of international best practices was conducted, with a major focus on the European context, aimed at investigating the ways in which DT are adopted as tools for informed land governance.

The selection included cases of technological and organizational excellence, such as Helsinki, where DT are deployed for environmental monitoring and planning (Hämäläinen, 2019, 2021; Martikka et al., 2018; Tesse et al., 2021); Zurich, which integrates urban simulation and participatory platforms (D'Amanzo & Feijoo Rivas, 2021; Schrotter & Hürzeler, 2020; Shahat et al., 2021); and Singapore, an emblem of technological centralization, albeit with limited public accessibility (Aloupogianni et al., 2024; Johnson, 2021). Other examples, such as Hamburg, Rotterdam, Genoa, Perugia, and St. Albert, show different trajectories, but all share an investment in the digitization of urban and spatial processes (Fig. 2).

The methodology relied on heterogeneous sources and the development of fact sheets and interactive visualizations to relate topics, technologies, and intervention scales. Although the analyzed projects are not formally labeled as "Smart Land", many share recurring themes, such as sustainability, resilience, and governance, that suggest an integrated approach beyond urban boundaries. As the results indicate a partial thematic coherence between Smart City and Smart Land, the comparative study of best practices and literature highlights the need for codified strategies to guide territorial planning and the governance of dispersed areas aligned with the emerging notion of Smart Land.

While DT framework proves effective in supporting adaptive and sustainability-oriented decisions, the existing literature on Smart Cities and Smart Land reveals a significant gap in the formulation of replicable guidelines and robust strategies for a structured development of Smart Land systems.

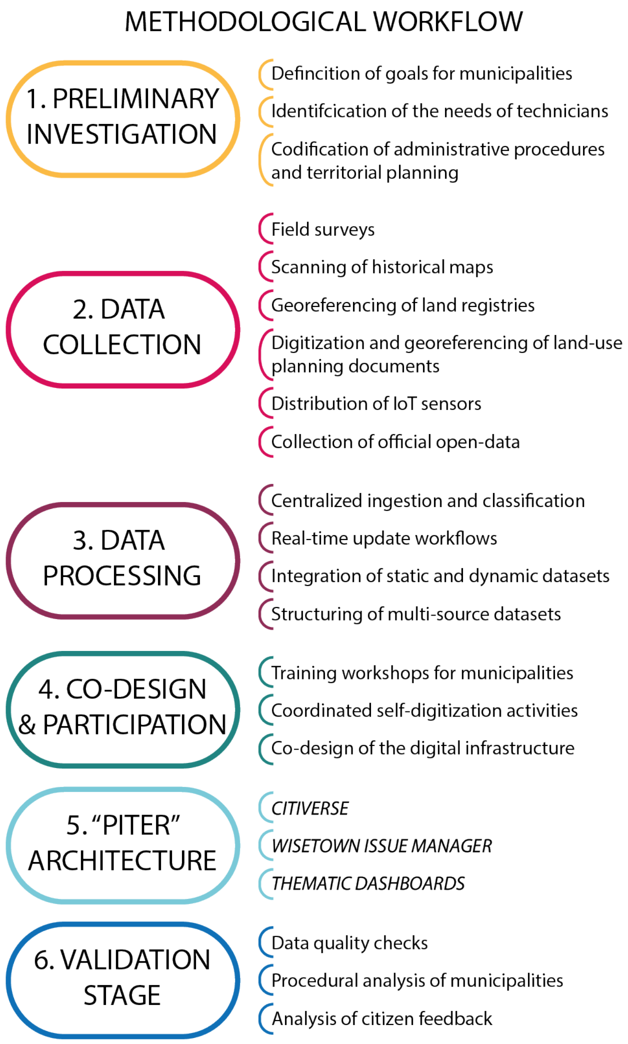

Figure 3. Visual representation of the methodological workflow for the Trasimeno Smart Land project. Graphic design by the authors.

2.2 Methodological workflow

The preliminary analysis of the state of the art provided the conceptual foundation necessary to define an approach suited to the specificities of the Trasimeno area, characterized by low population density and a complex and fragmented administrative structure (Fig. 3).

The research started with the definition of strategic governance objectives, developed in close collaboration with local administrations and involved stakeholders. Through co-design sessions and participatory workshops, a continuous dialogue was established to identify priorities, needs, and territorial challenges, laying the groundwork for the development of an integrated and functional digital platform.

The subsequent phase involved the collection and integration of territorial data from multiple sources, including historical and current cartographies, environmental sensors, direct citizen reports and field surveys. The harmonization of this data was essential to build a solid and up-to-date information infrastructure capable of faithfully representing the complexity of the territory. On this basis, the PITER digital platform was conceived as a modular and scalable system integrating advanced spatial analysis tools and dynamic DT model. This infrastructure enables real-time monitoring of environmental and infrastructural phenomena, supports territorial planning and promotes transparent and participatory decision-making processes.

The platform validation stage directly involved end-users, including public entities, technicians and citizens, through iterative testing sessions and feedback meetings aimed at improving the system's functionalities and usability. This participatory approach ensured that the platform effectively responds to the real needs of territorial governance, facilitating its future adoption and replicability in similar contexts.

3. Results

3.1 Data acquisition

The acquisition and updating of data within the PITER platform constitute a strategic and foundational element to ensure the quality, reliability and informational continuity required for the intelligent management of the territory. The platform has been conceived as a flexible and dynamic system, capable of integrating heterogeneous data originating from institutional sources, real-time sensor networks, detailed survey campaigns and participatory contributions from the local population, thus constructing a continuous, structured and constantly updated information flow (Fig. 4). The system is based on a microservices architecture and a modular structure that allows the progressive integration of new data sources and datasets, ensuring the scalability and long-term evolution of the platform.

Within this infrastructure, the statistical data provided by ISTAT play a structural role and are fully integrated into the construction and continuous updating of the territorial knowledge framework. The platform has been specifically designed to systematically and inter-operably integrate demographic, economic and social data obtained from official channels, which are periodically updated in accordance with census campaigns and statistical publications. These datasets feed the centralized Data Lake of PITER and are processed to be made available for consultation and analysis within the Thematic Dashboards. The integration of ISTAT data with geospatial and infrastructural components allows for the construction of a multi-level and dynamic reading of the socio-demographic transformations within the Trasimeno district, overcoming the traditional fragmentation of data and ensuring consistency and interoperability between diverse information sources. The platform's multi-cloud structure ensures the secure storage and immediate accessibility of data, even for non-specialist users, promoting cross-sectoral use of information for administrative, management and strategic purposes. The information flow related to ISTAT data is fully integrated and can be continuously updated, enabling a synoptic reading of local dynamics and allowing direct correlation with environmental data, services and territorial infrastructures.

One of the primary sources of continuous updating within the platform is the real-time connection to the environmental monitoring networks managed by ARPA Umbria. The data provided by ARPA are used both for the construction of thematic maps, such as analyses related to mobile network coverage and as a reference for the validation and comparison with meteorological data acquired locally. The platform integrates a comprehensive environmental information flow based on the continuous and real-time acquisition of meteorological data collected from a network of eight monitoring stations distributed across the municipalities of the Trasimeno Union. These stations have been strategically positioned to ensure reliable and widespread microclimatic representation of the territory. The stations employ radio-based devices, a low-consumption and long-range solution that allows the direct transmission of data, uniquely identified by a specific code, to the platform's servers. The recorded parameters include air temperature, atmospheric humidity and precipitation, which are continuously monitored and made immediately available for consultation.

In addition to institutional and environmental data, the platform continuously acquires and updates three-dimensional datasets derived from extensive survey campaigns covering over 380 kilometers of roadway network. These surveys generated large volumes of high-density geospatial data, organized as three-dimensional point clouds that document with centimeter-level detail the spatial configuration of the territory and infrastructural assets along the road network. The acquired data were classified and processed to enable the targeted extraction of relevant elements, including tree canopies, vertical signage, urban furnishings and surface drainage structures. This information flow directly feeds the spatial component of the Trasimeno DT, providing high-resolution metric data that support multi-scale analyses and operational applications related to territorial maintenance and management. The point cloud data are integrated into the PITER platform via the Citiverse module, where they are made available within a three-dimensional GIS environment and accessible through an interactive interface, ensuring spatial coherence, traceability and interoperability with historical and thematic data already stored in the system.

An additional critical data stream was developed through the Grand Tour Trasimeno project, which has been a fundamental component for the enhancement of the cultural and museal heritage of the territory. The project involved over thirty sites of historical, artistic and landscape interest, whose digital documentation was achieved through terrestrial laser scanning, aerial photogrammetry via drones and the acquisition of 360° spherical panoramas. The primary objective was to produce high-resolution three-dimensional models and immersive image datasets directly integrable within the territorial information system. The acquired data were subsequently processed using 3D rendering engines to optimize model quality and ensure smooth and interactive user experience. The entire acquisition process was tracked and organized into structured information flows, guaranteeing the classification, integration and synchronization of data within the PITER platform, particularly through the Citiverse interface and the dedicated WebGIS system. The datasets collected by the Grand Tour Trasimeno extend beyond the survey phase, being published and made accessible through a dedicated web portal that enables interactive consultation of georeferenced data, visualization of videos, panoramic images and immersive virtual tours, as well as personalized navigation of cultural content for each municipality within the district. The portal is linked to the territorial DT, allowing localization and query of the cultural sites directly within the platform's dynamic map. The project foresees ongoing activities for digital content updates, system maintenance and periodic review of immersive experiences to ensure sustained quality and informational consistency over time. The data flow architecture developed for the Grand Tour Trasimeno was designed to guarantee synchronization among metric data, historical sources, multimedia content and their georeferencing within the PITER environment, thus ensuring information coherence and transversal accessibility. A fundamental component of the

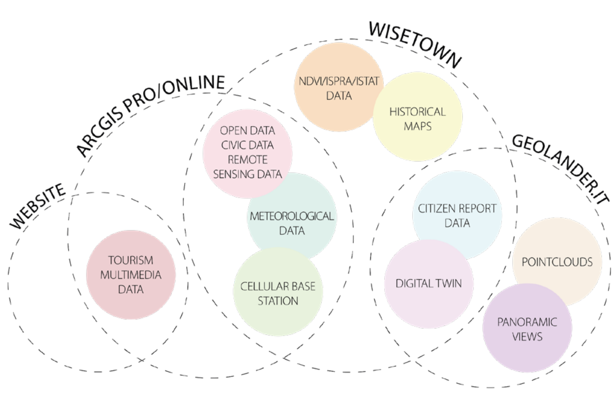

Figure 4. Diagram of the data categories integrated into the PITER platform. Graphic design by the authors.

acquisition processes concerns historical and cartographic digitization, developed with the aim of structurally integrating historical data within the active information flows of the Trasimeno DT. The Digital Historical Cadastre constitutes a systematically organized archive of historical cartographic data, obtained through high-resolution scanning campaigns of historical maps, cadastral documents and administrative archives. The digitized sources, including the Tirol Cadastre, Church Cadastre and Gregorian Cadastre from the State Archives of Perugia, were processed to ensure quality, consistency and full compatibility with the platform's data structures. The maps were georeferenced by identifying control points and cross-referencing with contemporary cartography, enabling full integration into the platform's GIS systems while maintaining topological coherence and spatial traceability. Historical data were organized into thematic layers and hierarchical structures encompassing georeferenced maps and geospatial footprints, i.e., vector polygons precisely delineating the geographical extent of each digitized cadastral sheet. This spatial metadata system allows dynamic querying, visualization and overlaying of historical data, facilitating integration with contemporary datasets and ensuring full multi-level usability through Citiverse and ArcGIS Pro. The digitized historical datasets are fully embedded within the platform's active information flows and managed to guarantee traceability, versioning and digital preservation in accordance with international best practices in Historical GIS.

3.2 Data processing

Taken as a whole, the data acquisition, management and updating processes within the ITI Trasimeno project constitute a continuous and complex information network, sustained by flows originating from institutional sources, real-time sensor networks, three-dimensional survey campaigns, participatory contributions and systems for interactive publication and consultation. The PITER platform has been designed to ensure data quality, integrity and circularity throughout its entire life cycle, guaranteeing the internal consistency of the system and its capacity for evolution over time through the integration of new technologies and additional information sources, within a framework of advanced, data-driven territorial governance. The data acquired through the diverse sources integrated within the PITER platform are subject to structured and continuous processing workflows that ensure their real-time updating, semantic consistency and interoperability across the system's various components.

The platform is designed to manage both static and dynamic datasets, combining periodic data ingestions, such as census updates, with real-time data streams from sensor networks and mobile data collection campaigns. The data processing architecture is configured to guarantee the timely ingestion, validation and synchronization of heterogeneous information sources within the centralized data center, where they are indexed, classified and made accessible through the platform's analytical and geospatial tools.

A key element of this architecture is the integration of ArcGIS Open Data, which is natively embedded within the PITER system and enables the direct publication and consultation of georeferenced datasets through open data protocols. This integration enhances transparency and promotes the sharing and reuse of territorial information by both institutional users and the broader public. The processing chain ensures that datasets acquired from mobile surveys, environmental sensors and service operators are dynamically updated within the system and immediately visualizable through interactive dashboards and GIS environments. Data from real-time sources, such as the meteorological stations and ARPA Umbria's environmental monitoring network, are continuously streamed into the platform through IoT connectors and undergo automated processing pipelines that guarantee data integrity, time-stamping and validation against authoritative sources.

The platform's multi-tiered access structure differentiates between the profiles of institutional operators and citizens, ensuring data security and appropriate levels of information granularity for each user group. Local administrations have direct access to high-resolution datasets, real-time environmental indicators and operational management tools through dedicated dashboards that support planning, maintenance and emergency response activities. Conversely, citizens are provided with simplified interfaces that allow them to consult aggregated and open data, report issues via participatory systems and access immersive cultural content through web-based portals linked to the DT.

Data processing workflows within PITER have been developed to guarantee full interoperability with external systems and compliance with national and European standards for public data sharing, including alignment with INSPIRE and OGC specifications. The modular and scalable design of the platform's information architecture allows the seamless integration of new data sources and services over time, ensuring the adaptability of the system to future governance needs and technological advancements. Overall, the data processing strategies implemented within PITER support a coherent, continuously updated and accessible territorial information ecosystem, capable of enabling data-driven decision-making processes at multiple levels of governance.

3.3 PITER architecture

As an outcome of the *Trasimeno Smart Land* initiative, the PITER platform represents the synthesis of an extensive review of the state of the art and existing Smart City and Smart Land paradigms, combined with a rigorous and methodical process of data acquisition, validation and processing. It embodies the design and development of an accessible, interoperable digital infrastructure specifically tailored to address the complexities of dispersed, low-density territories. This foundation enables PITER not only to integrate diverse data sources but also facilitates their validation, processing and dynamic visualisation within a unified system designed for effective territorial governance.

In contrast to DT systems traditionally developed for metropolitan contexts, which primarily serve high-density urban areas, PITER responds to the need for scalable and flexible digital infrastructures adapted to polycentric rural landscapes characterised by ecological diversity, fragmented built environments and limited technical resources. Its architectural and operational structure reflects a process-oriented vision that prioritizes interoperability, inclusiveness and multi-scalar management of extended territorial systems.

The platform's architecture is defined by three synergistic core components: Citiverse, Issue Manager and Thematic Dashboards (Fig. 5), all interconnected through a flexible, modular framework that enables vertical and horizontal integration of data sources. The system encompasses 24 thematic and functional layers, including geospatial, environmental, socio-demographic and infrastructural data, thus forming a multidimensional and interrogable knowledge base (Fig. 6). These layers are continuously updated via real-time sensors, street-level surveys and civic participation inputs, ensuring the platform maintains both temporal accuracy and spatial granularity.

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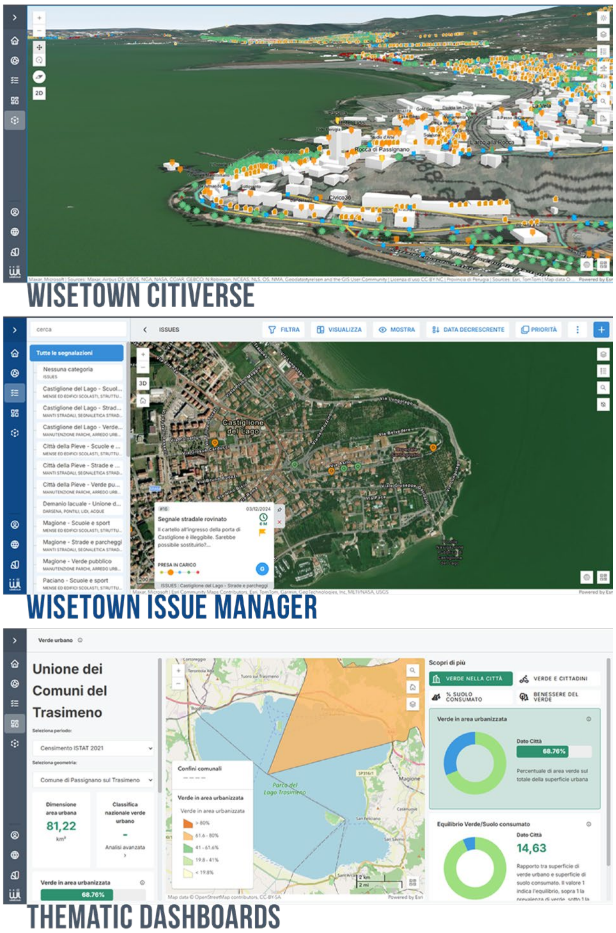

Figure 5. Interfaces of the three core modules composing the PITER platform. Graphic design by the authors.

The first component, WiseTown Citiverse, functions as the geospatial engine of the platform, integrated with Esri ArcGIS, it constitutes the operational DT of the Trasimeno district. It consolidates a comprehensive dataset comprising cadastral maps, planning instruments, technical-regulatory zoning, land use constraints and municipal cartography, as well as high-resolution point clouds and environmental layers. Its three-dimensional model supports multi-scalar spatial analysis, ranging from localised interventions (e.g. tree inventories or drainage mapping) to broader planning scenarios. Data generated from survey campaigns have enabled the extraction and categorisation of detailed street asset inventories, thereby significantly enhancing the platform's capacity for micro-scale planning and maintenance management.
The second component, WiseTown Issue Manager, introduces a participatory governance layer to the platform. It enables residents to submit geo-referenced reports concerning urban infrastructure, services and environmental issues. These reports are integrated directly into the DT, allowing public administrations to visualise, prioritise and respond to citizen concerns within the platform's digital environment. This functionality supports an iterative feedback loop between administration and community, effectively operationalising participatory principles within digital governance.
The third component, the Thematic Dashboards, functions as the analytical core of the system. These dashboards aggregate open and proprietary datasets, such as ISTAT census data, meteorological readings from IoT devices, welfare and public health indicators and urban green management statistics, into dynamic, interactive visualisations. They are designed to support data-driven decision-making at both strategic and operational levels, facilitating the monitoring of territorial trends, service quality, and socio-environmental impacts.

3.4 Data validation

The effectiveness and reliability of the PITER system were assessed through an integrated, multi-level approach designed to address both the technical requirements for data accuracy and the managerial needs related to territorial impact. This process combined quantitative and qualitative methodologies, incorporating cyclical feedback from stakeholders to validate not only the technological robustness of the platform but also its ability to generate public value in complex contexts.
The first validation dimension concerned data quality, a critical element for a system that integrates heterogeneous sources such as environmental sensors, LiDAR point clouds and civic reports. The validation of geospatial data was carried out through a systematic comparison with existing cartography. This approach was based on the direct overlay of three-dimensional models derived from scans onto official maps of the Umbria Region, including high-resolution orthophotos, technical cartography, and updated topographic databases. Specialized operators visually examined the alignment of distinctive territorial elements such as road profiles, the outlines of historic buildings, and river patterns, finding an almost perfect match in the vast majority of the investigated areas, with the exception of zones affected by recent construction work not yet updated in the maps.
The assessment of the platform's effectiveness within municipal authorities was conducted through a structured engagement process, divided into two distinct phases. Initially, training sessions were held for the eight participating municipal administrations, during which the project team presented the operational functionalities, analytical capabilities, and usage procedures of the digital tools. Following a three-month operational trial period during which the platform was integrated into daily workflows, targeted feedback sessions were organized to evaluate the real impact. These meetings revealed broad consensus on the tool's usefulness, particularly appreciated in territorial planning activities and the management of civic reports. Notably, several proposals emerged for expanding the application areas through the integration of additional thematic data sources.
Real-time IoT sensor streams were validated by cross-referencing the readings with the ARPA Umbria regional

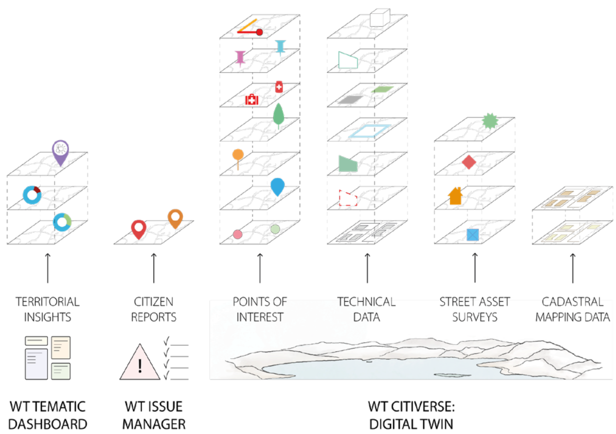

Figure 6. Conceptual diagram of the PITER platform architecture. Graphic design by the authors.

network, showing a Pearson correlation of 0.98 for thermo-hygrometric parameters. Civic reports, collected through the WiseTown Issue Manager module, were validated on the ground by municipal technicians within 96 hours, with a geographic accuracy rate of 92% based on a random sample of 100 cases. In parallel, quantitative performance metrics were defined to evaluate the platform's operational efficiency. During the three-month pilot phase, continuous monitoring recorded an uptime of 99.4% with data ingestion latencies below 5 seconds for IoT streams.

4. Conclusions

The conducted analysis and the obtained results highlight how the proposed methodological approach, based on iterative co-design, data interoperability, and the development of tailored digital tools, constitutes an effective and replicable strategy for the creation of adaptive and functional DT, even in territorial contexts characterized by extensive, fragmented, and heterogeneous dimensions.

Compared with other platforms, PITER's pioneering contribution lies in redefining the scope and function of the territorial DT. While other models focus mainly on the urban sphere, PITER extends this paradigm to non-urban and territorially extended landscapes, integrating cultural, ecological and historical dimensions within the digital framework, thus making it an archive of territorial identity, in which digital representation becomes a narrative device capable of expressing the complexity of places. PITER is also distinguished by its holistic and transversal architecture, capable of integrating a plurality of services: urban mobility analysis (through the World Traffic Service), monitoring of construction sites, enhancement of cultural heritage through dedicated web platforms (such as Grand Tour Trasimeno) and access to survey data through Geolander.it. Data interoperability is ensured by the adoption of open standards, which allow integration with regional and national platforms, facilitating the smooth exchange of information between different administrative levels.

A key strength of PITER lies in its process architecture, which is grounded in an iterative co-design methodology. The development process engaged multiple stakeholders, local governments, researchers, private developers and community representatives, across all phases, from requirements definition and data retrieval to system validation and implementation. The effectiveness of the proposed methodology lies in its ability to combine technological, administrative and identity requirements into a single coherent ecosystem. The active participation of local stakeholders ensured a high degree of adherence to the territorial context and greater acceptance of the system.

The maturity of the platform progressively evolves in relation to the growing recognition of the needs expressed by stakeholders, requiring strategic investments and a strengthening of civic engagement. This consolidation process confirms a positive track record in terms of effectiveness, customization and replicability. To support this evolution, the structured collaboration between the University and local governments ensures a constant dialogue between research and governance, fostering the sustainable development of the platform and the integration of future developments through applied research, methodological experimentation and technology transfer activities. Among the evolutionary perspectives already outlined are predictive management of maintenance activities, automatic classification of civic reports, and adaptive monitoring of public policies, with the goal of strengthening the platform's orientation toward a dynamic, inclusive, and strongly decision-supportive model of spatial intelligence.

In conclusion, PITER gives rise to an unprecedented type of DT, capable of overcoming traditional urban boundaries and addressing the specificities of rural and peri-urban environments through a fully integrated, participatory and adaptive system. While the Smart City has historically represented the benchmark for digital innovation in urban contexts, PITER proposes an alternative trajectory that recognizes and enhances the complexity of rural and polycentric territories, positioning itself as an original and methodologically solid contribution to the emerging Smart Land model.

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References

Adade, D., De Vries, W. 2025: A systematic review of digital twins' potential for citizen participation and influence in land use agenda-setting. *Discover Sustainability*, 6. doi.org/10.1007/s43621-025-01204-x.

Aloupogianni, E., Doctor, F., Karyotis, C., Maniak, T., Tang, R., Iqbal, R. 2024: An AI-Based Digital Twin Framework for Intelligent Traffic Management in Singapore. *2024 International Conference on Electrical, Computer and Energy Technologies (ICECET*, 1–6. doi: 10.1109/ICECET61485.2024.10698642.

Asefa, A., Haile, M., Berhe, M., Zenebe, A. 2025: Climate smart land management practices for livelihood resilience in Ethiopia: A systematic review. *Heliyon,* 11 (6), 1-13. doi.org/10.1016/j.heliyon.2025.e42950

Azadi, H., Robinson, G., Barati, A. A., Goli, I., Moghaddam, S. M., Siamian, N., Värnik, R., Tan, R., & Janečková, K. 2023: Smart Land Governance: Towards a Conceptual Framework. *Land*, 12(3), 600, 1-20. Doi.org/10.3390/land12030600.

Batty, M. 2018. *Inventing Future Cities*. Mit Press, New York. Doi.org/10.7551/mitpress/11923.001.0001.

Bellone, C., Andreassi, F., Naselli, F., Ranucci, P. 2021: Territorial Planning, Smart Cities, and New Governance. *Proceedings of Sixth International Congress on Information and Communication Technology. Lecture Notes in Networks and Systems,* 216, 253-260. Springer, Singapore. doi.org/10.1007/978-981-16-1781-2_24.

Bianconi, F., Filippucci, M. 2017. La materia del Moderno in Umbria in *Aid Monuments 2015. Materials techniques restoration for architectural heritage reusing,* 2, 723–733. Ermes edizioni scientifiche, Milano.

Bianconi, F., Filippucci, M. 2020. Digital Draw Connection: la sfida culturale della rappresentazione della complessità e contraddizioni nel paesaggio. *Connettere. Un disegno per annodare e tessere. Atti del 42° Convegno Internazionale dei Docenti delle Discipline della Rappresentazione*. Franco Angeli, Milano.

Bianconi, F., Filippucci, M., Andreani, S. 2015. Smart cities e contratti di paesaggio: l'intelligenza del territorio oltre i sistemi urbani. *LE ISTITUZIONI DEL FEDERALISMO*, 1, 895–926.

Bonomi, A., Masiero, R. 2014. *Dalla smart city alla smart land*. Marsilio Editori, Milano.

Crivello, S., 2013. Circolazione, riproduzione e adattamento di un'idea di città smart. *Smart city. Ibridazioni, innovazioni e inerzie nelle città contemporanee,* 25–38. Carocci Editore, Roma.

D'Amanzo, C., Feijoo Rivas, S. C. 2021. *Urban digital twin come strumento a supporto delle prassi di pianificazione a scala urbana per il cambiamento climatico. Analisi di cinque casi studio in ambito internazionale= Urban digital twin as a tool to support urban-scale planning practices for climate change. Analysis of five international cases*. Politecnico di Torino.

Greenfield, A. 2013. Against the smart city (*The City is Here to Use)*. Do projects.

Grieves, M., Vickers, J. 2017. Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. *Transdisciplinary perspectives on complex systems,* 85–113. Springer, Cham. doi.org/10.1007/978-3-319-38756-7_4.

Hämäläinen, M. 2019: A framework for a smart city design: digital transformation in the Helsinki smart city. *Entrepreneurship and the community: a multidisciplinary perspective on creativity, social challenges, and business,* 63–86. Springer, Cham.

Hämäläinen, M. 2021: Urban development with dynamic digital twins in Helsinki city. *IET Smart Cities*, *3*(4), 201–210.

Humayun, M., Jhanjhi, N. Z., Alamri, M., Khan, A. 2020. Smart Cities and Digital Governance. *Employing Recent Technologies for Improved Digital Governance* , 87-106, IGI Global, Hershey PA. doi.org/10.4018/978-1-7998-1851-9.ch005.

Jiang, H., Geertman, S., Witte, P. 2022: Smart urban governance: an alternative to technocratic "smartness." *GeoJournal*, 87(3), 1639–1655. doi.org/10.1007/s10708-020-10326-w.

Johnson, B. 2021: Water reuse and recovery facility connected digital twin case study: Singapore PUB's Changi WRP process, control, and hydraulics digital twin. *Proceedings of the Water Environment Federation,* WEFTEC.

K'Akumu, O. A., Alhamoudi, A. M. 2025: The smart city as policy concept in the Arab world: a critical research into the strategic visions of urban development in Abu Dhabi. *Journal of Asian and African Studies*, *60*(3), 1456–1470. Doi.org/10.1177/00219096231192316.

Kitchin, R. 2014. *The data revolution: Big data, open data, data infrastructures and their consequences*. SAGE Publication Ltd, London. Doi.org/10.4135/9781473909472.

Martikka, M., Salo, S., Siilin, K., Ruohomäki, T., Tuomaala, P., Nykänen, E. 2018: Smart city resilience with active citizen engagement in Helsinki. *2018 International Conference on Intelligent Systems (IS)*, 162–167.

Mattern, S. 2016. Interfacing urban intelligence. *Code and the City,* 49–60. Routledge, London.

Nam, T., Pardo, T. 2011: Conceptualizing smart city with dimensions of technology, people, and institutions. In *ACM International Conference Proceeding Series*. Doi.org/10.1145/2037556.2037602.

Nastjuk, I., Trang, S., Papageorgiou, E. I. 2022 Smart cities and smart governance models for future cities. *Electronic Markets*, *32*(4), 1917–1924. doi.org/10.1007/s12525-022-00609-0.

Nguyen, Q. T., Nhu, D. T. 2020 Smart urban governance in smart city. *IOP Conference Series. Materials Science and Engineering*, *869*(2): 022021. doi.org/10.1088/1757-899X/869/2/022021.

Parrinello, S., Picchio, F. 2023 Digital Strategies to Enhance Cultural Heritage Routes: From Integrated Survey to Digital Twins of Different European Architectural Scenarios. *Drones*, *7*(9). Doi.org/10.3390/drones7090576.

Ratti, C., 2013. *Smart city, smart citizen*. EGEA, Milano.

Schrotter, G., Hürzeler, C. 2020: The Digital Twin of the City of Zurich for Urban Planning. *PFG - Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 88, 99-112. doi.org/10.1007/s41064-020-00092-2.

Schulte, R. P. O., O'Sullivan, L., Coyle, C., Farrelly, N., Gutzler, C., Lanigan, G., Torres Sallan, G., Creamer, R. E. 2016: Exploring climate smart land management for atlantic europe. *Agricultural & Environmental Letters*, *1*(1), 160029. Doi.org/10.2134/ael2016.07.0029.

Shahat, E., Hyun, C. T., Yeom, C. 2021: City digital twin potentials: A review and research agenda. *Sustainability*, *13*(6), 3386. Doi.org/10.3390/su13063386.

Shao, J., Min, B. 2025: Sustainable development strategies for Smart Cities: Review and development framework. *Cities*, *158*, 105663. Doi.org/10.1016/j.cities.2024.105663.

Söderström, O., Paasche, T., Klauser, F. 2020: Smart cities as corporate storytelling. *The Routledge companion to smart cities*, 283–300. Routledge, London.

Tesse, J., Baldauf, U., Schirmer, I., Drews, P., Saxe, S. 2021: Extending Internet of Things Enterprise Architectures by Digital Twins Exemplified in the Context of the Hamburg Port Authority. *Proceedings of the Americas Conference on Information Systems (AMCIS),* 1.

Vanolo, A. 2014: Smartmentality: The smart city as disciplinary strategy. *Urban Studies*, *51*(5), 883–898. Doi.org/10.1177/0042098013494427.

Vavrová, K., Šarlina, I., Kostiuk, Y., Konečn\`y, M. 2025. Smart City 4.0 as the concept of strategically managed sustainable urbanism. *Strategic Management-International Journal of Strategic Management and Decision Support Systems in Strategic Management*.

Vianello, M. 2013. *Smart cities*. Maggioli Editore, Santarcangelo di Romagna.

Vishnivetskaya, A., Alexandrova, E. 2019: "Smart city" concept. Implementation practice. *IOP Conference Series: Materials Science and Engineering*, *497*(1), 12019. doi.org/10.1088/1757-899X/497/1/012019.

Zeng, H. 2025: Practice of Smart City Concept in Urban and Rural Planning. *Forum on Research and Innovation Management*, *2*(12).

Zhou, C., Li, X. 2025: Impact of Smart Cities on Urban Resilience: The Roles of Land Green Utilization Efficiency and Industrial Structure Transformation. *Land*, 14(7), 1373. Doi.org/10.3390/land14071373.