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Toward Systemic Reuse

A GIS-Based Model for Adaptation in Spatial Planning

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Abstract

The research proposes a replicable and scalable GIS-based operational model to support early-stage evaluations of the reuse potential of vacant and abandoned buildings, supporting the fragmented knowledge of municipalities. The objective is to facilitate and incentivize the adaptive reuse of decommissioned buildings spread throughout the country, fitting into the systematic processes of spatial planning activities. This tool automates a preliminary screening process that helps determine whether, and to what extent, a building may be a viable candidate for adaptive reuse. The model integrates open geospatial data, Multi-Criteria Decision Methods and automated scoring to rank assets by morphology, location and regulatory context. Buildings' reuse potential is calculated with respect to objective parameters, such as area, height, accessibility to public transportation, proximity to residential areas, urban constraints, state of disuse, building type and solar orientation and the analysis and scoring for each is automated in a GIS environment, made accessible to technicians and stakeholders through an easily navigable graphical interface. Implemented within a territorial Digital Twin in Italy, the tool exposes results through dashboards for technicians and stakeholders, enabling priority mapping of reuse candidates and alignment with investor searches. This research shows that early stage automating evaluation processes through GIS can become a powerful tool to support urban planning and foster adaptive reuse strategies with a systematic shift for Italian municipalities, becoming a substantial element of territorial governance. In this way, reuse feasibility is framed as an enabling step for informed, context-sensitive interventions capable of empowering the historical, morphological and cultural layers embedded in the built environment.

Keywords: Adaptive Reuse, GIS-Based Tool, Preliminary Reuse Potential

Introduction

In recent decades, building abandonment has become increasingly widespread, affecting both architectural heritage and the ordinary building stock (Plevoets, Van Cleempoel 2019; Stone 2019). While much attention has been paid to adaptive reuse strategies of iconic historic buildings (Plevoets, Van Cleempoel 2019; Stone 2019), a substantial share of the vacant and deteriorated building stock remains under-recognized, unmonitored, and unaccounted for (Buitelaar et al. 2021), specifically in peripheral and rural territories. This form of urban and territorial fragility is exacerbated by the lack of systematic mapping tools and reliable databases, making it difficult to quantify abandonment and to develop data-

driven regeneration policies. As a matter of fact, at both the institutional and civic level, such limited visibility and awareness of vacant or underutilized buildings result in missed opportunities for adaptive reuse and sustainable planning. In the absence of geospatial inventories detailing location, condition, and contextual constraints and opportunities, evidence-based recovery strategies are significantly slowed. In response to this gap, this research proposes a pilot methodology to calculate the "Preliminary Reuse Potential" (PRP) of vacant and abandoned buildings. The integration of this tool into territorial planning processes would trigger a cultural shift, ensuring a comprehensive recognition of the state of conservation of the built environment.

The model is designed to be replicable and scalable and has been implemented within the Digital Twin's Integrated Territorial Platform, known as PITER, of the eight municipalities of the Unione dei Comuni del Trasimeno (fig. 1), in the Umbria region of Italy. By leveraging open geospatial data, "Multi-Criteria Decision-making Methods (MCDM)" and GIS-based analysis tools, the proposed model supports early-stage evaluations of reuse feasibility and fosters a more transparent, informed and dynamic approach to adaptive reuse-oriented governance.

Fig. 1. Lake Trasimeno in the Umbria region of Italy (Anna Massini, 2022)

Current Research and Trends Regarding Buildings' Vacancy Mapping

Mapping the built environment is a widely adopted strategy for understanding territorial dynamics and supporting the management of existing buildings (Pasquinelli et al. 2019). Three main trends in building mapping can be identified, depending on how the mapping process is initiated. Top-down institutional inventories involve the census of vacant and abandoned sites and buildings, systematic activities that mainly concern specific uses and building types characterized by high rates of abandonment, such as former industrial facilities. Emblematic examples of such mapping can be found at the institutional level, usually commissioned by public bodies at the urban or regional scale, such as the experience of the City of Turin and the Lombardy Region for brownfields. These mapping solutions provide hotspots on national and international territory with variable levels of detail and are mainly restricted to institutional boundaries. Top-down in nature but linked to statistical analysis institutions, there are also national-level datasets for territorial monitoring, although designed for purposes other than planning, as in the case of "HUD-USPS Vacancy" in the United States. Lastly, bottom-up mapping, based on civic platforms and crowdsourcing, also stands out. Examples include OpenStreetMap (OSM) and the "Urbexology" initiatives,

which expand coverage and granularity, albeit with semantic heterogeneity and data quality issues.
The main challenge in managing existing datasets lies in integrating sources with different levels of detail and achieving effective collaboration between them, which currently limits the development of shared guidelines and homogeneous international platforms.

Materials and Methods

This research presents a quantitative study of the Preliminary Reuse Potential (PRP). The proposed methodology (fig. 2) is structured into four main phases: spatial and architectural data collection, data processing, Analytic Hierarchy Process (AHP) integration, and PRP calculation and comparison within a predefined area of assessment.

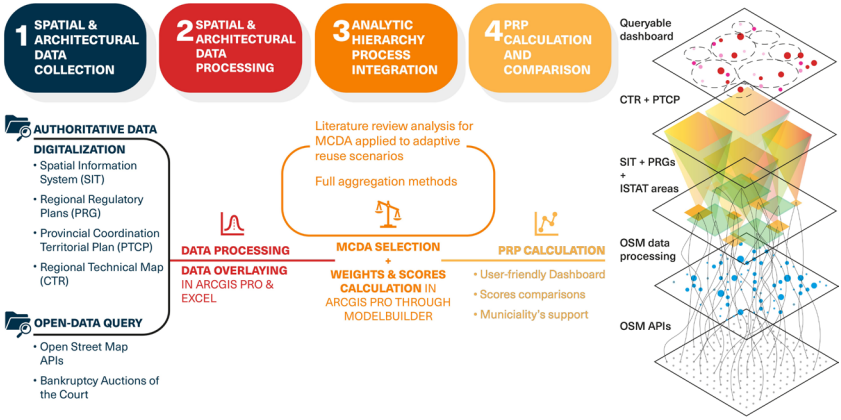

Fig. 2. Methodological workflow

The first phase focuses on the collection of spatial data from authoritative institutional sources, including the municipal *Spatial Information Systems* (SIT), the *Regional Technical Map* (CTR), the *Provincial Territorial Coordination Plan* (PTCP), and current *Regulatory Plans* (PRGs). In the absence of a centralized and structured national database of the building stock, this phase relied on open geospatial data from the OpenStreetMap (OSM) platform. Building footprints were extracted using the OSM APIs through the "Overpass Turbo" graphical interface, which enables custom spatial queries based on tags architecture. A typical query structure included the definition of the target area, the selection of building entities and the hierarchical output of their geometries and attributes. The resulting data were exported in GeoJSON format to ensure seamless integration into GIS software environments.
The second phase involved data processing to ensure compatibility and comparability across datasets. Data obtained through OSM APIs required post-processing in Excel and ArcGIS Pro due to varying levels of completeness and semantic heterogeneity. Attributes such as building type, height, number of floors and usage are frequently absent or inconsistently tagged, especially in rural or peripheral contexts, where civic-mapping activities are less conducted. Therefore, the extracted geometries were subsequently enriched through cross-

referencing with institutional data sources and manual validation. The consolidated dataset is a normalized, georeferenced feature layer classified by typological, dimensional and functional proxies, suitable for PRP analyses.

The third macro stage of implementing the AHP in the ArcGIS Pro environment was necessary for the rigorous calculation of the PRP. The method follows the classical AHP framework (Saaty 1982), which enables a fully aggregated MCDA based on pairwise comparisons and normalized weights. The selected criteria, derived from both literature review and stakeholder-informed considerations, included quantitative spatial parameters such as building footprint area, number of floors, building height, proximity to public transport nodes, distance from urban centers, presence of urban constraints, zoning class from regional plans, dismission status of the building and solar exposure potential.

The final phase of the methodology consisted of calculating the PRP through a structured and automated workflow developed within ArcGIS Pro using the ModelBuilder environment. This visual programming approach enabled the sequential integration of all previously standardized spatial indicators, i.e. morphological, locational, and regulatory, into a replicable scoring and weighting logic based on the AHP-derived framework. The heterogeneous data were normalized with a score ranging from one to five, considering the most critical constraints on reuse possibilities, especially related to urban environmental and nature protection uses. The model computes the final reuse potential score for each vacant building by applying a weighted summation of normalized sub-scores, each corresponding to a distinct criterion. The proposed model supports live updates, indeed, when inputs change the PRP is re-computed, enabling continuous monitoring. This ensures that the process remains adaptive over time, in line with the operational logic of Digital Twin frameworks, where automation and data integration enable continuous system updates.

Moreover, retaining the entire workflow within ArcGIS Pro allows seamless spatial visualization of the results which reflect both the degree of building abandonment and the distribution of reuse potential across the eight municipalities of the Unione dei Comuni del Trasimeno. These outputs provide local authorities with a high-resolution, georeferenced overview of degradation hotspots and reuse opportunities, highlighting which territories concentrate the greatest share of latent value and where to prioritize regeneration investments or policy interventions.

The Case Study of the *Unione dei Comuni del Trasimeno*

The methodology was tested as a pilot research activity on the heterogeneous territory defined within the institutional limits of the eight municipalities composing the Unione dei Comuni del Trasimeno. The Digital Twin of this predominantly rural and landscape-oriented territory originates from the Integrated Territorial Investment (ITI) Trasimeno Territorial Strategy, developed through an inter-institutional collaboration between the eight municipalities, the University of Perugia's Department of Civil and Environmental Engineering, and three local companies. Funded through European structural funds, this infrastructure mainly relates to the pioneering concept of "smart land" (Bianconi et al. 2025). It aims to enhance the historical, cultural and environmental values of internal areas as well as to promote urban planning efficiency through the analysis of data retrieved from sensors over the areas, registering street traffic, environmental pollution, weather data and the lake water level. The main result of the initiative has led to the development of PITER

("Piattaforma Integrata TERritoriale" or Integrated Territorial Platform), which constitutes the *Citiverse* of the eight municipalities where up-to-date data can be consulted and queried (fig. 3). The integrated operational platform has strengthened planning cooperation among the eight municipalities, primarily through the adoption of thematic dashboards and citizen reporting tools. Enriching this infrastructure through data of the operational status of existing buildings meets the Union's main aim of continuously improving the platform and its constituent data, ensuring its efficiency over time.

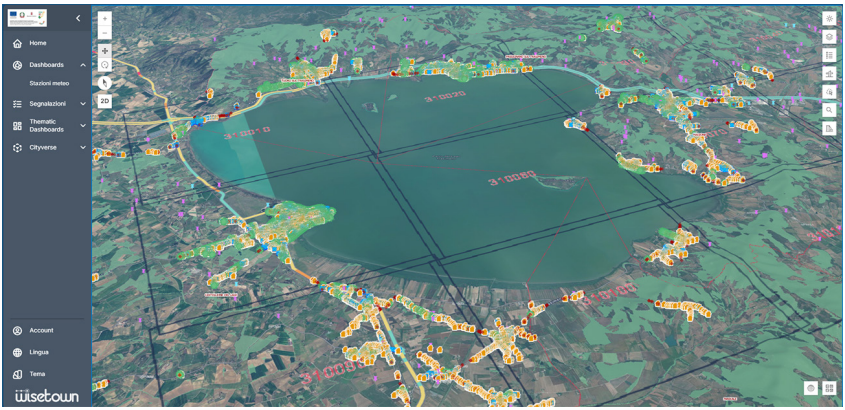

Fig. 3. PITER interface: the Digital Twin of Unione dei Comuni del Trasimeno (Wisetown website, 2025)

Therefore, the data collection process associated with the first phase combined the digitized institutional plans in the platform, such as the PRGs of the eight municipalities, existing SITs, the PTCP of the Province of Perugia, under which all eight municipalities fall, and the CTRs. After data normalization, the platform was further enriched with open data provided by the OpenStreetMap (OSM) initiative, which facilitates GIS-based data processing. By implementing existing building data obtained from OSM APIs, it has been possible not only to categorize them in terms of function, using a unique nomenclature defined by *ISTAT* data standardization for Italian functional macro-areas, but also to determine the state of decommissioning and abandonment of the building, recorded thanks to cross-referencing with online sources, including judicial bankruptcy auctions consulted on the platform of the Court of the Province of Perugia.

Furthermore, starting with the open data through analysis tools in ArcGIS Pro, the area of each individual building, the number of floors per building and the height of each one, as well as the municipality to which it belongs were obtained. By overlaying territorial datasets and official planning information, each building was assigned to a functional area based on PTCP classifications. Those are distinguished between "Consolidated urban areas or areas affected by urbanization processes included in areas of particular naturalistic and environmental interest (Class 1)", "Areas of intensive agriculture included in areas of particular naturalistic and environmental interest (Class 2)", "Main reference network system for zoonosis included in areas of particular naturalistic and environmental interest (Class 3)", "Areas of high naturalistic interest: areas with high floristic and vegetational

diversity, reported wildlife areas, extensive geotopes with the exception of the Gola del Bottaccione (Class 4a)", "Areas of very high naturalistic interest: Natura 2000 sites (SIC, SIR, ZPS), wildlife protection oases, geological singularities, and Gola del Bottaccione (Class 4b)"

In addition, each building received a tag stating the planning restrictions under the PTCP, when existing, such as the protected wooded areas, areas of natural beauty, protected parks or mountain protection restrictions. Subsequently, for each building, geospatial analysis tools were used to calculate the planar distances to historic urban centers and residential settlements, the distance from provincial, regional and national roads, the distance from urban mobility distribution hubs, considering both bus stops and railway stations and the distance from points of historical and artistic architectural interest, the solar exposure of each building was also assessed. Specifically, the dominant planimetric orientation of each polygonal building was calculated, if the rectangular envelope aligned with the long side reflects the building's exposure axis. Specifically, the dominant planimetric azimuth of the building was calculated through the "Minimum Bounding Geometry" analysis tool, which, while favoring a geometrically robust but approximate calculation at the planimetric level, allowed for values in degrees, consistent with the purpose of the PRP calculation.

The third phase defined value ranges for each criterion used in the AHP-based multi-criteria assessment, assigning scores from one (minimum) to five (maximum) to ensure comparability across parameters. Reference was made to the vast existing literature on MCDM, as well as considering the most recent contributions inherent in adaptive reuse, with reference to urban character assessments, in the spirit of the objectives of the present research. In this respect, the work of Della Spina is particularly relevant (Della Spina et al. 2023; Della Spina, Lanteri 2024), as it assigns weights to context-related parameters such as accessibility, proximity to services and public transport, and regulatory constraints. The results from the last step, through the ModelBuilder algorithm, led to the development of the interactive dashboard (fig. 4) within ESRI services that showcase the abandoned, vacant and precarious building stock within the eight municipalities, consisting of around 140 analyzed buildings, which can be further implemented and updated through reports from citizens and findings disseminated in the field through systematic study campaigns and daily activities as well, thanks to the Digital Twin framework.

Conclusions

This paper proposes a replicable GIS-based workflow to provide a preliminary evaluation of vacant buildings for reuse, shifting from sporadic bottom-up recognition to a top-down, building-scale awareness embedded in a territorial Digital Twin. This experience defines a clear replicable methodology for municipalities to align on building's vacancy mapping, combining both open data and authoritative ones, which indeed enhance also the digital transition of the public administrations. Moreover, when the process of mapping can be embedded within a Digital Twin platform, a mature level of land management and planning is achieved, thus marking a breakthrough in integrating and informing planning decisions through real-time data.

While the research still has some limitations in terms of incomplete data and difficulties related to the semantic heterogeneity of attributes, along with the fact that vacancies and building abandonment are dynamic processes that need to be constantly monitored

and updated, this work will be further developed through uncertainty control and field validation processes and the implementation of data with economic-financial metrics and governance variables.

The lack of alignment among municipalities in retrieving data and adopting such spatial environment databases is still a major challenge for digitalization goals (Choi, Lee 2016). However, experimental experiences adopting GIS-based tools in support of reuse-oriented planning, in addition to being more transparent and adherent to SDGs, align with multiple real-estate purposes, overcoming the silos among the construction sector (Buitelaar et al. 2021), and support a more systemic approach for buildings' reuse.

Overall, the results indicate that a data-driven, auditable PRP workflow embedded in a territorial Digital Twin can showcase and, therefore, accelerate the shift from diffuse knowledge of vacancy to actionable prioritization for adaptive reuse, supporting more transparent, equitable and decarbonization-aligned regeneration policies.

Notes

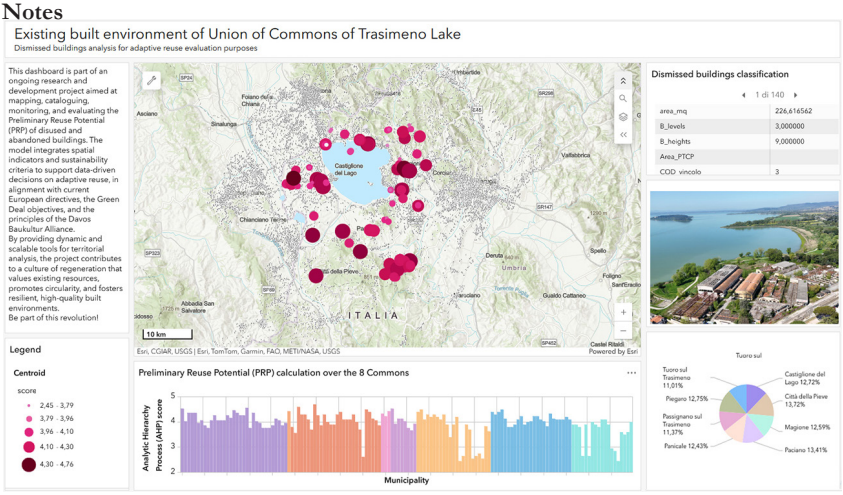

Fig. 4. Comprehensive dashboard mapping and showcasing the PRP scores for the vacant buildings within the Unione dei Comuni del Trasimeno through ESRI Dashboard service

The work was developed according to the inter-institutional collaboration agreement (ex art. 15 L. 241/1990) between the Department of Civil and Environmental Engineering of the University of Perugia and the Unione dei Comuni del Trasimeno as part of the research and implementation activities of Axis 4 ITI Trasimeno. The support provided by Giulio Cherubini, Silvio Cipriani, Andrea Cruciani and Luciano Concezzi was decisive for the supervision and intermediation activities conducted by the University.

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