19th WORLD CONFERENCE OF THE ASSOCIATED RESEARCH CENTRES FOR THE URBAN UNDERGROUND SPACE
Belgrade, Serbia, November 4-7, 2025.

ACUUS BELGRADE 2025

Paper No: 5.5.184
DOI: 10.46793/ACUUS2025.5.5.184

INTEGRATION OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) FOR UNDERGROUND SPACE MAPPING ON THE EXAMPLE OF BELGRADE

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Abstract: The use of Geographic Information Systems (GIS) for underground space mapping is becoming essential in big cities where managing subterranean spaces is crucial for urban growth. Belgrade faces challenges due to its historical layers, complex infrastructure, and dense environment. GIS helps by mapping and managing underground areas such as public facilities, utility networks and transportation systems. GIS database creates detailed maps of various underground structures, helping city planners in visualizing the spatial relationships between different elements, which are essential for maintenance and new projects.

By integrating real-time data, authorities can monitor underground conditions, predict risks, and improve resilience to hazards.

Additionally, GIS enhances coordination between stakeholders, ensuring that underground infrastructure aligns with surface-level urban planning. This is particularly important for large projects like metro construction, where precise mapping is required to avoid conflicts with existing structures and ensure safety.

GIS also supports sustainable urban growth by optimizing underground space use for transportation, utilities, and infrastructure.

Therefore, Belgrade as a metropolitan city of 2 million inhabitants where important projects involving underground spaces are currently underway, represents a good case study and polygon for the implementation of a GIS system and database.

Keywords: underground, GIS, urban planning, innovation

1. INTRODUCTION

1.1. Context and importance of underground spatial mapping

In the past few decades, cities have seen a drastic increase in urbanization, density and growth due to an increase in population. Cities are rapidly growing horizontally and vertically creating a strain on recources and damaging the quality of life of its inhabitants.

While underground space is not something new, it has been used traditionally for transportation and infrastructure tunnels but at large it remains an underutilized space.

Underground urban planning is the systematic development of subsurface space for urban use. Optimizing underground space relieves pressure on above ground infrastructure and opens spaces for much needed urban spaces: green and open spaces or other public facilities.

Our primary objective is to develop a comprehensive and interoperable spatial database of Belgrade's underground space

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2. GIS AS A TOOL FOR URBAN PLANNING

The development of artificial intelligence and technology has greatly impacted our roles as urban planners, it has affected the speed, sorting, implementation and gathering of data that we use in planning. GIS is one tool that has become increasingly important in the process of gathering and analyzing data, it plays a transformative role in how cities are planned and managed.

With the use of data integration and visualization in spatial and urban planning we can better understand and optimize the space around us, it allows for a complete picture of our space and if used correctly can analyze and define potential problems as well as determine the value of proposed solutions.

3. METHODOLODY FOR BUILDING SPATIAL DATABASE FOR UNDERGOUND SPACE IN BELGRADE

Creating a **spatial database for underground space in Belgrade** relied on a structured methodology that addresses data collection, integration, management, and application. The successful creation of a spatial database requires a multi-phase methodology that begins with identifying and engaging relevant stakeholders. These include the City of Belgrade Urban Planning Office, the Serbian Geodetic Authority, various utility providers (such as those responsible for water, gas, electricity, and telecommunications), academic institutions, and various literature. Their collaboration is essential for the integration and standardization of fragmented data sources.

The data inventory and collection phase involves both existing records and new field data acquisition. Existing data sources include utility cadastres, construction permits, geological and hydrogeological surveys and historical plans.

Once data is collected, it must be standardized and preprocessed. This involves converting diverse datasets into consistent GIS formats, georeferencing legacy and harmonizing data according to a unified coordinate reference system—typically EPSG: 32634 – WGS 84 / UTM zone 34N (used for Serbia including Belgrade in many projects with GPS coordinates in meters).

We started with basic literature analysis, the analysis of underground planning and global trends as well as detailed analysis of cities that have developed underground spaces

The analysis was carried out in multiple iterations and from various perspectives. First, a general and comperhasive analysis of a larger number of cities worldwide through their thematic frameworks: quality of life, development of underground infrastructure, integration of underground spaces into the urban landscape, perservation of green areas, sustainability of underground projects, water and waste managment, technical execution, financial aspect, social acceptability and innovation.

Next, a targeted and more detailed analysis of ten cities was preformed through a literature review based on a previously established matrix, which includes key characteristics of urban underground space development, such as: economic, sociological and environmental aspects, typology, use, realization mechanisms, legal framework, planning, the depth of object placement and the model of planning. Cities worldwide are using three models of urban underground space planning: incremental, independent and independent.

The most important motives for cities to develop underground have been identified based on previous research such as: climate extremes, lack of land as a resource and terrain configuration.

Specific conclusions and criteria were defined for the anlysis and systematic presentation of the characteristics of existing underground spaces in Belgrade.

The database design phase focuses on developing a 3D spatial data model suitable for underground features as well as mapping existing underground spaces in Belgrade.

The data model is structured to include essential layers: utility networks (including sewage, water, electricity, and telecommunications), transportation structures (like subways and underpasses), geological strata, and underground cultural heritage sites. The database schema includes depth values, material types, construction dates, maintenance responsibility, legal constraints, and condition assessments.

Underground spaces such as basements of residential buildings, military structures and linear infrastructure at depths of up to 3 meters were not part of our study.

The implementation of the spatial database leverages GIS platforms such as PostGIS for open-source environments or ArcGIS Enterprise for advanced functionality and integration with other systems like AutoCAD Civil 3D and BIM tools.

The synthesis of the obtained data led to conclusions about the current development of underground space in Belgrade and suggested possible needs and realistic directions for future endeavors.

An analysis of planning and legal regulations, cadastral management of underground facilities, and the economic aspect of underground construction were performed, as key aspects necessary for the development of urban planning in this area.

A key step in the methodological process towards defining the areas of interest for planning and development of the underground space in Belgrade is the investigation of limitations and potentials from the aspect of natural and created characteristics, environmental conditions, regulatory framework and economic domain. The investigation of spatial limitations and potential also resulted in a graphical representation.

The synthesis of the results obtained in the previous research steps and their sublimation through a targeted set of criteria represents the final research step of our Study and results in a graphical representation of the areas of interest for planning and development of underground spaces in Belgrade.

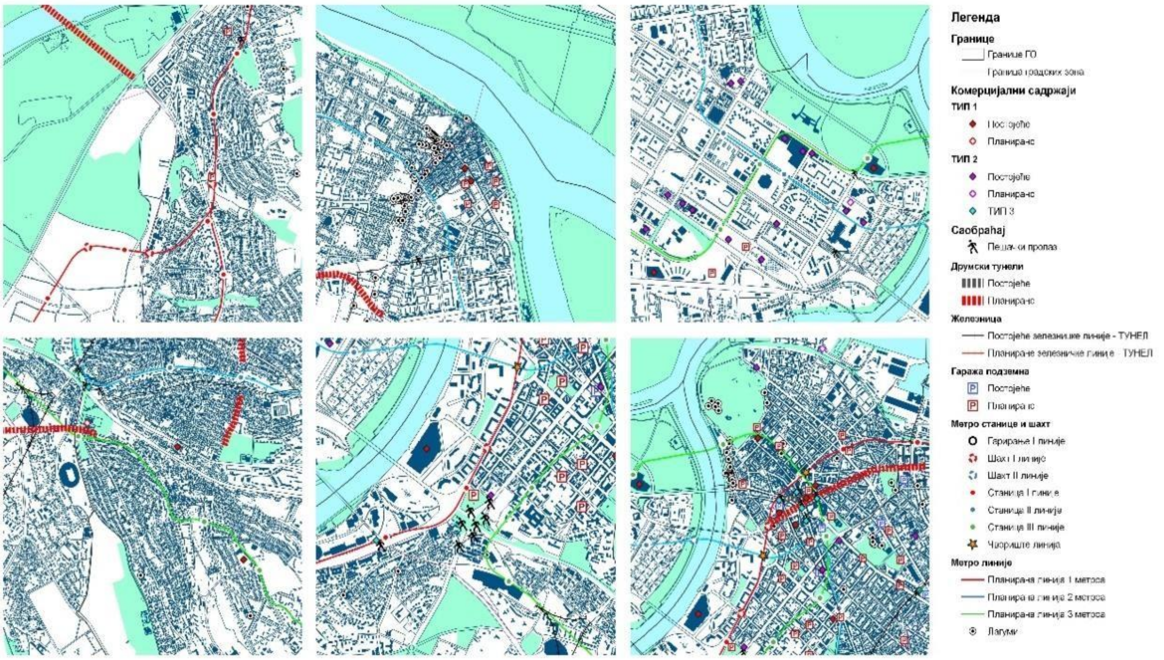

Figure 1. *Segments from the QGIS database*

4. IMPLEMENTATION IN THE CONTEXT OF BELGRADE

The implementation of a spatial database for underground space in Belgrade carries significant implications across multiple sectors of urban planning, infrastructure management, and disaster resilience. As a historic city with complex layers of development, Belgrade presents a compelling case for integrating Geographic Information Systems (GIS) into underground spatial planning.

One of the primary applications of such a database lies in the coordination of urban infrastructure systems. Belgrade's subsurface utility networks—including water supply, sewage, electricity, gas, and telecommunications—are often inadequately documented, especially in older and densely built neighborhoods. The development of a centralized spatial database enables planners and engineers to visualize the full extent of underground infrastructure, reducing the likelihood of spatial conflicts during excavation or maintenance activities. This approach supports safer and more efficient construction practices, mitigates service interruptions, and facilitates interdepartmental coordination by enabling all stakeholders to access a unified data environment.

Another major implementation concerns the streamlining of construction permitting processes. The current permitting system in Belgrade frequently relies on fragmented and outdated spatial data, which can lead to project delays, increased costs, and legal complications. By incorporating reliable underground data into the permitting workflow, municipal authorities can make more informed decisions. Developers and engineers can simulate construction impacts on nearby underground features and adjust designs proactively, reducing the likelihood of technical or regulatory setbacks. This shift toward data-driven permitting enhances transparency, compliance, and overall urban governance.

Transportation infrastructure development is another area where this technology can yield substantial benefits. Belgrade is currently undertaking major transportation projects, including the long-anticipated Belgrade Metro. In such projects, accurate knowledge of the subsurface environment is essential to avoid conflicts with existing utilities, historic tunnels, or geological hazards. A GIS-based underground database allows for detailed 3D modeling, route optimization, and clash detection, thereby improving project feasibility and reducing risk during execution.

Environmental risk management is also enhanced through the application of underground spatial data. Belgrade faces several environmental challenges, including riverine flooding, soil instability, and aging infrastructure. An integrated spatial database allows for improved modeling of subsurface conditions, enabling authorities to assess the vulnerability of critical infrastructure and to develop more effective mitigation strategies. This supports the implementation of early warning systems and improves the city’s capacity to respond to emergencies, particularly those involving underground assets.

Finally, this spatial database aligns with Belgrade’s aspirations to evolve into a smart and sustainable city. By creating a digital twin of the underground environment, the city can support long-term urban planning, real-time asset monitoring, and predictive modeling for infrastructure maintenance and urban growth. The integration of spatial data into governance practices enables better collaboration among public institutions, private sector actors, and civil society stakeholders, fostering a more transparent, efficient, and resilient urban system.

5. CHALLENGES AND LIMITATIONS

Despite the substantial benefits of implementing a spatial database for underground infrastructure in Belgrade, several challenges and limitations must be acknowledged. These span technical, organizational, legal, and financial domains and can significantly affect the development, maintenance, and utility of such a system.

A primary technical challenge lies in the **incompleteness and inconsistency of existing data**. Much of Belgrade’s underground infrastructure, particularly in the historical core, was developed in phases over decades with minimal documentation. Utility maps, if they exist, often vary in accuracy and may not reflect changes due to unregistered modifications or unauthorized constructions. The Republic Geodetic Authority has so far recorded underground structures only upon the request of investors. Some underground structures are represented merely as entry and exit points to the underground, without any information about their dimensions or other data that would allow determination of ownership, type of structure, purpose, area, or depth. Developing a 3D cadastre would help overcome the aforementioned obstacles. These inconsistencies present a risk of misinformation when attempting to visualize or simulate subsurface conditions (Aleksić et al., 2017). In some cases, the lack of precise depth (z-axis) data makes it difficult to construct reliable 3D models, which are essential for modern underground planning applications.

Data standardization is another significant obstacle. Institutions responsible for infrastructure—such as water, gas, telecommunications, and electricity—often use different formats, classification schemes, and coordinate systems. The absence of a legally enforced interoperability framework in Serbia complicates efforts to integrate datasets into a unified GIS platform. While national initiatives such as the Spatial Data Infrastructure of the Republic of Serbia (SDI-RS) provide some support, local implementation remains fragmented (Aleksić et al., 2017).

Institutional challenges are also considerable. Interagency cooperation in Belgrade is often hindered by **jurisdictional fragmentation**, lack of communication, and occasional competition between public and private stakeholders. This has been especially evident in large infrastructure projects such as the Belgrade Metro, where overlapping authorities and delayed decision-making have impeded progress (Suboticki & Sørensen, 2021). In the absence of formalized data-sharing agreements, many agencies remain reluctant to provide full access to their records, citing legal and security concerns.

From a legal perspective, there are **limited regulatory guidelines specifically addressing underground spatial planning** in Serbia. Existing urban planning laws primarily focus on above-ground development, and legislation governing data sharing, privacy, and security often lacks clarity or enforceability in the context of subsurface assets. This regulatory vacuum can lead to both administrative uncertainty and increased risk for developers. Also, there is also an **issue of defining ownership of underground spaces.** This Study aims to contribute to decision-making regarding the depths at which the owners of underground spaces are the same private individuals who own the above-ground spaces, while the ownership of all other underground levels belongs to the city or the state.

Financial limitations also constrain the feasibility of building and maintaining a high-quality spatial database. The technologies required—such as ground penetrating radar, 3D GIS software, and sensor-based monitoring systems—require significant upfront investment. Budgetary constraints at the municipal level can limit the continuity of data collection and hinder staff training, reducing the long-term viability of the system.

Finally, **public accessibility and digital literacy** represent potential social barriers. While the idea of a webbased GIS portal is appealing, its successful implementation depends on the availability of intuitive interfaces and ongoing public education. Without these, the system may be underutilized by planners, engineers, or citizens who could otherwise benefit from its insights.

6. RESULTS AND IMPLICATIONS FOR URBAN PLANNING PRACTICE

The establishment of a spatial database for underground space in Belgrade has yielded significant insights and practical benefits for urban planning and infrastructure management. The integration of historical, geotechnical, and utility datasets into a unified geospatial framework has revealed previously unknown or undocumented subsurface structures, clarified ownership boundaries, and allowed for the 3D visualization of complex underground networks. As a result, urban planners, engineers, and policymakers are now equipped with a more accurate and interactive representation of the city's subterranean environment.

One of the most impactful results has been the ability to perform **multi-layer spatial analysis**, which has greatly enhanced coordination between agencies during infrastructure planning and development. For instance, proposed projects such as the Belgrade Metro and flood-resilience upgrades in lower-lying areas have been optimized to avoid costly utility relocations and minimize excavation risks. The system has also enabled more effective **scenario modeling**, allowing planners to test the impact of different design alternatives in densely built urban cores, particularly in neighborhoods with narrow streets and overlapping underground systems. Also, one of the outcomes of the GIS database of existing underground spaces in Belgrade is the formation of a zone of interest for the further development of urban underground structures and facilities.

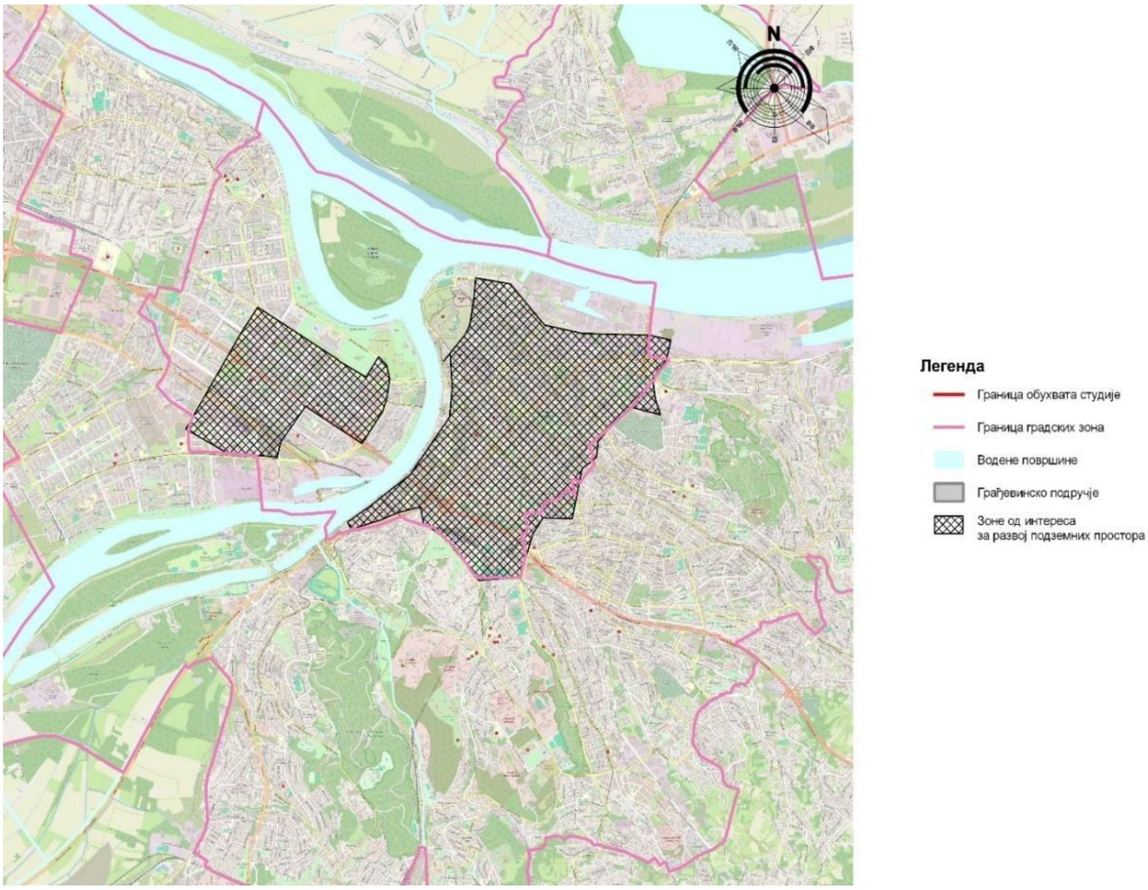

Figure 2. *Diagram of the zone of interest for underground planning development in Belgrade*

The availability of a dynamic underground database has improved the transparency and efficiency of the **construction permitting process**. Building permit applications can now be evaluated against a verified subsurface model, reducing the approval time and decreasing the incidence of planning errors. Developers benefit from early warnings of spatial conflicts, such as proximity to gas pipelines or protected heritage structures, allowing them to adapt their designs at an early stage and avoid costly delays.

On a broader scale, the database has also contributed to **policy development and regulatory reform**. City authorities have begun incorporating underground space into urban master plans and land use strategies, treating the subsurface not merely as a constraint but as a functional layer of the urban environment. This shift has led to the delineation of underground development zones and the identification of areas suitable for underground parking, storage, and pedestrian passages. In turn, this has helped alleviate pressure on surface land use and facilitated more compact, vertically integrated urban growth.

Furthermore, the database has enabled Belgrade to adopt a **risk-based approach to underground infrastructure management**. By integrating geotechnical data and infrastructure condition assessments, authorities can now identify critical vulnerabilities in aging networks and prioritize maintenance interventions accordingly. This capability is particularly valuable in areas at risk of flooding, subsidence, or seismic activity, where the failure of underground systems could have cascading effects on above-ground infrastructure and public safety.

Perhaps most importantly, the successful implementation of this system has begun to foster a **culture of data sharing and interagency cooperation**. Institutions that previously operated in silos have begun to collaborate more actively, facilitated by clear data governance frameworks and shared digital tools. This institutional shift not only improves operational efficiency but also lays the groundwork for future smart city applications, including real-time monitoring, predictive maintenance, and integration with Building Information Modeling (BIM) systems.

The GIS database is an initial step in the further underground planning of the city of Belgrade and a means through which many benefits can be achieved. The maintenance of outdated infrastructure would be facilitated and improved, the construction and management of major infrastructure projects would be made easier, and an integrated approach to viewing both above-ground and underground layers would be introduced in the development of urban planning projects and documents. Public access to this data by all relevant institutions in Belgrade would also contribute to their interconnection and facilitate the assessment of the existing conditions before any interventions in the space are made.

The implications for urban planning in Belgrade are profound. With the underground environment now made legible and actionable through spatial data, planners are better equipped to manage the city's growth in a more sustainable, resilient, and spatially efficient manner. As Belgrade continues to densify and modernize its infrastructure, the underground space will increasingly serve as a strategic asset rather than a blind spot in urban policy. The experience also positions Belgrade as a regional leader in underground spatial data infrastructure, offering a transferable model for other Balkan and Eastern European cities facing similar urban challenges.

7. CONCLUSIONS

Belgrade is a city experiencing a growing population, increasing traffic congestion, decreasing amount of land available for the expansion of built structures and also densely built-up city center, where there is no room for new open public spaces and green areas. It is essential to guide the underground development of Belgrade in a way that allows the release of above-ground space for contemporary design solutions and planning of scarce land uses, which can integrate existing public, commercial, and residential functions without compromising the existing green infrastructure — instead, they further enhance it. Such solutions contribute to the creation of more humane and attractive spaces that ensure a healthier and higher-quality living environment.

The spatial database for Belgrade's underground space represents a critical step toward smarter and more sustainable urban development. Through the integration of GIS technology, systematic data collection, 3D modeling, and multi-agency collaboration, the city can unlock the potential of its subsurface environment. **This methodology provides a roadmap for the creation and implementation of a functional, accurate, and dynamic underground spatial data infrastructure.** With appropriate investment, policy support, and technical implementation, Belgrade can enhance urban resilience, reduce planning conflicts, and foster innovation in subsurface space management.

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