

## A Dictionary-Driven Review of Digital Methods and Tools for Urban Patterns Decoding: SPATTERN Perspectives

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**Abstract:** The study explores the emerging intersection of urban morphology and digital technologies, focusing on the methods and tools employed to analyze and interpret urban patterns. With rapid urbanization and the resultant complex urban forms, understanding these patterns is crucial for sustainable city planning and design. This contribution presents the findings from the initial deliverable of the SPATTERN project which aims to advance environmentally sensitive urban development of spa settlements in Serbia through the affirmation of twin transition. First SPATTERN deliverable provides a comprehensive review of existing methodological approaches by synthesizing insights from an extensive literature review and content analysis, alongside showcasing relevant tools and methods. The research is performed through systematic literature review combined with the visualization of bibliometric networks and dictionary design and development through 4-cycle research protocol: (1) data search and selection, (2) data clustering and co-occurrence, (3) dictionary development, and (4) factsheets analysis. The review encompasses an extensive analysis of selected terms (keywords) highlighting how digital tools facilitate the collection, visualization, and analysis of urban data. Moreover, the review addresses the challenges and limitations associated with these methods, such as data quality, integration issues, and the need for interdisciplinary collaboration. This dictionary not only standardizes the terminology but also provides a conceptual map for researchers and practitioners navigating the complex nature of urban pattern analysis. By bridging the gap between traditional approaches for urban analysis and cutting-edge digital approaches, the findings advocate for a more informed and systematic use of digital tools and methods in urban morphology, thus promoting more resilient and adaptable urban environments.

**Keywords:** Urban Morphology; Digital Tools and Methods; Sustainable Urban Development; SPATTERN Project; Systematic Literature Review; Bibliometric Networks

## 1 Introduction

### 1.1 Background and Rationale

Urbanization, the increasing concentration of populations into urban areas, profoundly transforms the physical and social landscapes of cities. This process reshapes urban morphology, or the form and structure of urban spaces, by altering spatial expansion, density, land use patterns, and infrastructure (Yang et al, 2022). As cities expand outward and upward to accommodate growing populations, the resulting changes influence different urbanization aspects from street networks and public spaces to socioeconomic dynamics and environmental conditions including climate change-induced challenges (Güller & Toy, 2024) and effects of economic growth (Aziz & Nilufar, 2019). Understanding the multifaceted impacts of urbanization on urban morphology is crucial for developing sustainable and resilient urban environments, as phrased in the Sustainable Development Goal 11 (SDG 11) (UN General Assembly, 2015). In such context, decoding urban patterns is essential for sustainable city planning, as it enables planners and policymakers to understand the complex interactions between various urban elements (Đokić, 2009). By analyzing the spatial distribution of buildings, roads, green spaces, and social infrastructure, professionals can identify inefficiencies and opportunities for improvement. This knowledge facilitates the creation of urban layouts that promote efficient land use, reduce environmental impact, and enhance the quality of life for residents. Furthermore, understanding urban patterns helps in anticipating future growth (He et al, 2018) and developing strategies to manage it sustainably, ensuring that cities can accommodate increasing populations while maintaining ecological balance and social equity.

To adequately respond to the challenges of urbanization, the research arena of disciplines dealing with the observation of the built environment requires methodological innovation and the development of novel methods and tools. Digital tools and methods are instrumental in decoding urban patterns, offering sophisticated methods for analyzing and interpreting the complex structures of cities. Research on urban morphology is gaining renewed strength and interest related to urban history, environmental behavior studies, landscape ecology, place studies,

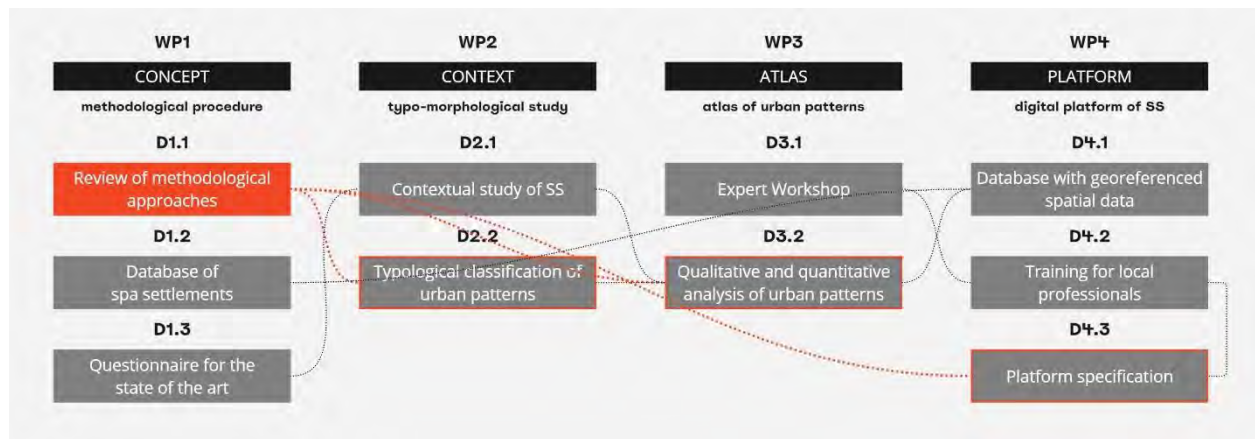
space-morphology and public policy (Scheer, 2008; Oliveira, 2012). At the core of this new awareness is strong interest in bridging the gap between urban morphological research, and urban planning and design practice (Gu, 2014; Whitehand, 2014). Urban planners, urban designers and architects have recognized the value of the theory of urban morphology but on the other side urban morphological techniques, as a category of design tool, are still complicated to deal with (Sanders, 2013; Kropf, 2018). In order to be implemented in the processes of architectural and urban design, and urban planning, morphological tools should be adjusted to different scales and development contexts. Having this in mind there are two initial problems that aim to identify potential links between urban contextual factors and other variables of interest: (1) how to quantify urban context at both social and physical levels, and (2) how to establish criteria for generating context-informed samples of urban areas. Current methodologies employed for these purposes have a range of limitations, and the need for robust quantitative and qualitative methods has been also recognized.

Digital tools play a crucial role in both qualitative (Mushtaha, 2017) and quantitative (Ye & van Nes, 2014) analysis of urban morphology and the typological classification of urban patterns. Quantitatively, geospatial technology (Lo, 2007) such as remote sensing, photogrammetry and GIS (including 3D GIS) enable the precise measurement and mapping of urban features such as building heights, street layouts, and land use distributions. These tools facilitate the statistical analysis of spatial data, revealing patterns and trends in urban development. Qualitatively, digital tools like 3D modeling and virtual reality (Badwi, Ellaithy & Youssef, 2022) provide immersive visualizations of urban environments, aiding in the assessment of aesthetic and functional aspects of design. Big data and machine learning algorithms (Wu et al, 2022; Wu et al, 2024; Lan, Gou & Hou, 2022) further enhance these analyses by classifying urban patterns based on a multitude of variables, enabling the identification of typologies that inform planning and policymaking. By integrating both quantitative and qualitative approaches, digital tools could offer a comprehensive understanding of urban morphology, guiding the creation of more efficient, sustainable, and livable urban spaces.

### **1.2 Research Scope: Introducing SPATTERN Context**

The research scope is positioned within scientific project SPATTERN (Future Heritage of Spa Settlements: Digital Platform for Advancing Knowledge and Innovation in Urban Morphology Approach for Environmentally Sensitive Development in Serbia; funded by Science Fund of the Republic of Serbia within the grant period 2023-2026) (more information: <https://spattern.org/>). SPATTERN is innovative and creative research aiming to decode environmentally sensitive urban patterns of spa settlements (SS) in Serbia. SPATTERN tends to foster new and sustaining knowledge in digitally enabled research infrastructure by dealing with sustainable land use, directed towards environmentally sensitive development. In previous research, developmental resources and touristic capacities for sustainable transformation of SS in Serbia were recognized, but systematization of research data does not allow their further operationalization and cross referencing in relation to specific criteria or scale. SPATTERN will fulfil a critical gap by providing a sound and flexible methodological framework for deriving local patterns through digital tools and methods that will be applicable across a range of scales and adaptable to distinct regional and local contexts.

The SPATTERN research is organized in 4 work packages (WPs) based on Typo-morphology studies, Critical and Historical-Interpretative studies supported by Unified Software Development Process (Figure 1): (1) WP1: Beyond State-of-the-Art for Enhancing Urban Morphology Approach towards Environmentally-Sensitive Development – which tends to establish general methodological procedure for urban pattern decoding, (2) WP2: Typo-morphological Study of Urban Patterns within SS – which will classify types of urban patterns that target ecological, cultural and environmental indicators, (3) WP3: Development of the Atlas of Urban Patterns of SS – which will anticipate perspectives for environmentally-sensitive urban transformation of SS in Serbia, and (4) WP4: Design and Development of the Digital Platform of Urban Patterns – which will develop a digital platform for processing and visualizing urban patterns within SS in Serbia.



**Figure 1** Diagram of SPATTERN research activities: Activities and position of D1.1 as the research outcome in focus

Following the overall SPATTERN design and ongoing outcomes, the focus of this paper is on the presentation of the results of the first deliverable (D1.1) which provides a comprehensive review of existing methodological approaches by synthesizing insights from an extensive literature review, alongside showcasing relevant tools and methods.

### 1.3 Paper Outline

Relying on the general background provided in the first part of the introduction, as well as the structure of the SPATTERN project, this paper aims to present the methodological approach to the design and development of a dictionary of digital tools and methods relevant to the field of urban morphology (D1.1). Additionally, it aims to present a post-analysis of the dictionary's content through a dual focus: (1) co-occurrence analysis of selected terms, and (2) practical implications of the presented tools and methods in urban morphology.

The dictionary-driven approach in organizing digital tools and methods is highly relevant due to its systematic and structured methodology. By adopting a dictionary-driven approach, researchers could ensure that terminologies are standardized, reducing ambiguities and enhancing the comparability of research findings. This approach also aids in the integration of diverse digital tools and methods, enabling a cohesive framework that supports comprehensive understanding of both general definitions and practical implications of tools and methods. Furthermore, it fosters collaboration across disciplines, as a shared terminology allows for more effective exchange of knowledge and techniques, ultimately contributing to the advancement of urban morphology as a field.

The paper is structured as follows. Section 2 of the paper provides an overview of the overall research design, as well as an elaboration of the research phases and the process of dictionary design and development. The methodology is presented through three sub-sections, which include (1) the design of the dictionary and the selection of reference terms (Section 2.1), (2) the process of dictionary development and the structure of fact sheets, i.e., the standardization of term representation (Section 2.2), and (3) the post-research phase after the formal design and development of the dictionary, including dual analysis (co-occurrence analysis and practical implications analysis) (Section 2.3). Section 3 contains two sub-sections in accordance with the post-analysis of the developed dictionary: (1) an overview of the dictionary content with the results of the co-occurrence analysis of terms (Section 3.1) and (2) a critical insight into the practical implications of the reference digital tools and methods in the field of urban morphology (Section 3.2). Finally, Section 4 focuses on the summary of key findings, presenting contributions to the field and future research directions (both on a general level and within the SPATTERN scope).

## 2 Methodology

### 2.1 Dictionary Design

The study begins with the investigation and selection of literature within the Scopus database based on the following defined keywords that link the domain of urban morphology and digital technologies: (“built AND environment”) OR (“urban AND morphology”) OR (“urban AND typology”) OR (“urban AND form”) AND, (“digital AND tools”) OR (“digital AND methods”) OR (“data AND visualization”). The initial sample resulted in 5261 literature documents. After application of selection criteria (language limitation, subject area, and date range (2013-today)) sample was narrowed down to 2124 literature documents. Furthermore, literature documents were screened according to relevance to topic and methodological rigor resulted in final sample of 509 literature documents which were imported in *VOSviewer* (version 1.6.20), a software tool for constructing and visualizing

bibliometric networks. *VOSviewer* supported identification of relevant keywords based on their occurrences – the minimum number of occurrences was set at 5 resulted in 193 relevant keywords grouped in 4 thematic clusters.

In the next step, a screening of the initial sample of 193 keywords was conducted through a brainstorming session by an interdisciplinary team with the aim of selecting only those that are relevant for the typological classification of urban patterns, qualitative and quantitative analysis of urban patterns, as well as platform specification. Based on the screening conducted, 30 terms were selected for the development of the dictionary (Figure 2).

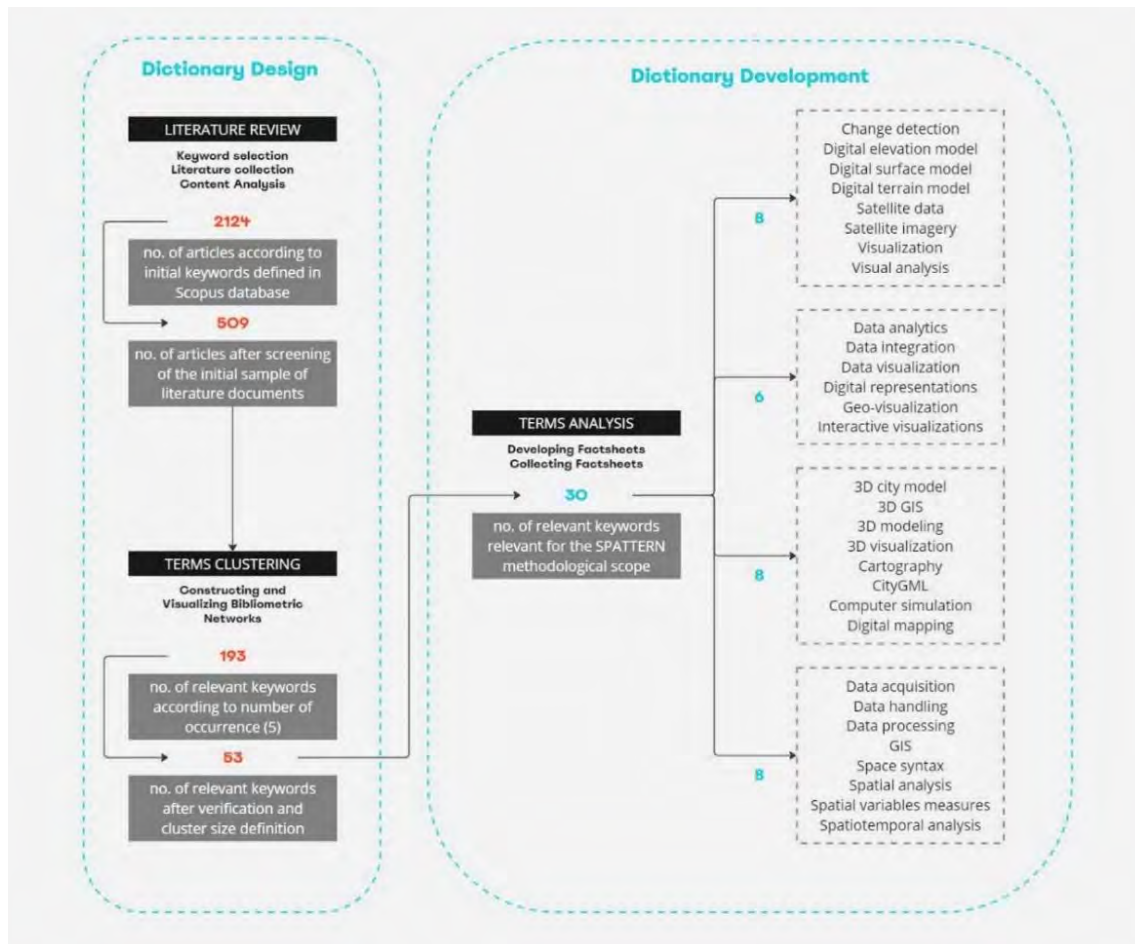


Figure 2 Methodology scheme: Dictionary design and development with selected terms

## 2.2 Dictionary Development

The development of the dictionary was established through four key principles (Figure 3): (1) *standardization* – to ensure a consistent and uniform use of terminology, which is crucial for clarity and precision in further research phases, (2) *interoperability* – to understand the potential and ability of different digital tools and methods to work together, (3) *comparability* – to establish framework for easier comparison of research findings leading to more robust meta-analyses and syntheses of existing knowledge, and (4) *collaboration* – to streamline the research process so researchers from different SPATTERN fields can communicate more effectively, share insights, and develop integrated approaches.

To achieve the recognized principles, a factsheet was designed to present all 30 reference terms (Figure 4). Factsheets ensure that each term is defined and described consistently, promoting uniformity across the dictionary. This standardization is crucial for clarity and precision, reducing ambiguities and enhancing communication among researchers and practitioners. They provide a detailed account of each term, including definitions, practical implications, related terms, scales of applications, limitations and risks, as well as demonstrations and references. This comprehensive documentation facilitates future updates and expansions of the dictionary. Moreover, the detailed structure of factsheets allows for advanced analyses, such as co-occurrence and practical implications analysis. These analyses can uncover relationships between terms and provide insights into their application and relevance in the field.

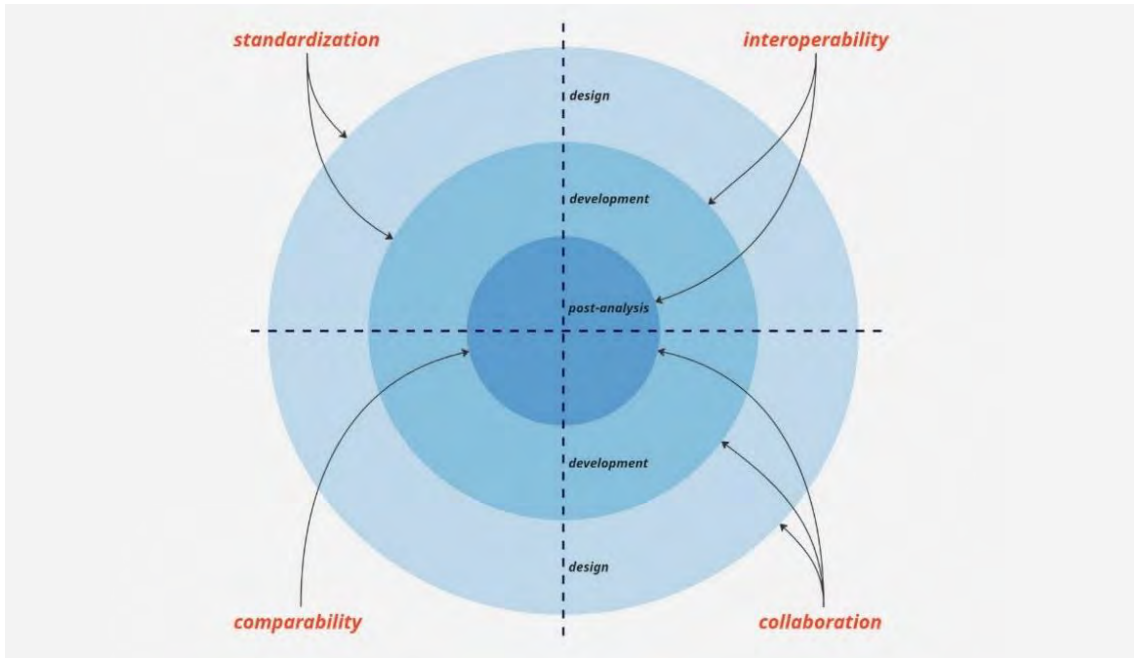


Figure 3 Dictionary design and development principles



Figure 4 Factsheet structure

### 2.3 Factsheets Analysis

The post-research phase after the formal design and development of the dictionary involves a comparative analysis of the completed factsheets. The first level of analysis focuses on identifying and understanding the interrelationships between terms. For each term in the dictionary, up to five related terms were identified, which were then mapped onto a co-occurrence scheme, with quantitative mapping of the number of established connections. Based on the graphical representation within the co-occurrence scheme and the quantitative indicators of connectedness, terms were categorized into groups according to their strength of connections: (1) central terms (9-12 connections), (2) highly connected terms (6-8 connections), (3) moderately connected terms (5 connections), and (4) terms with fewer connections (2-3 connections). Additionally, specialized terms with no connections were identified. The second level of analysis is qualitative and involves identifying the practical implications of the 30 reference methods and tools in the field of urban morphology. By examining the practical implications, as well as the risks and limitations described in the factsheets of each term, practical application domains were recognized.

### 3 Results and Discussion

Figure 5 depicts a co-occurrence scheme of interconnected terms from SPATTERN dictionary (30 terms in total). Co-occurrence analysis indicates that data visualization stands out as a crucial component, likely due to its application across various aspects of spatial data representation and interpretation. Also, GIS is another pivotal term, underscoring the importance of geographic information systems in managing and analyzing spatial data. Terms such as Spatial analysis, Data acquisition, Data processing, and Spatiotemporal analysis are also significant, reflecting their roles in gathering, managing, and analyzing spatial data over time. Terms like 3D modeling, 3D visualization, Digital elevation model, and Digital representations indicate specialized areas within the broader context of spatial data handling and GIS. The term Space Syntax is also specific, as it is individually connected to certain terms in the dictionary, yet it holds an autonomous position when the connection is considered in the opposite direction. This means that it is a highly specialized method, which is still growing within the subject domain of research. In that order, the co-occurrence reflects a comprehensive ecosystem where data acquisition, processing, integration, and various forms of analysis are all interconnected through central concepts of data visualization and GIS.

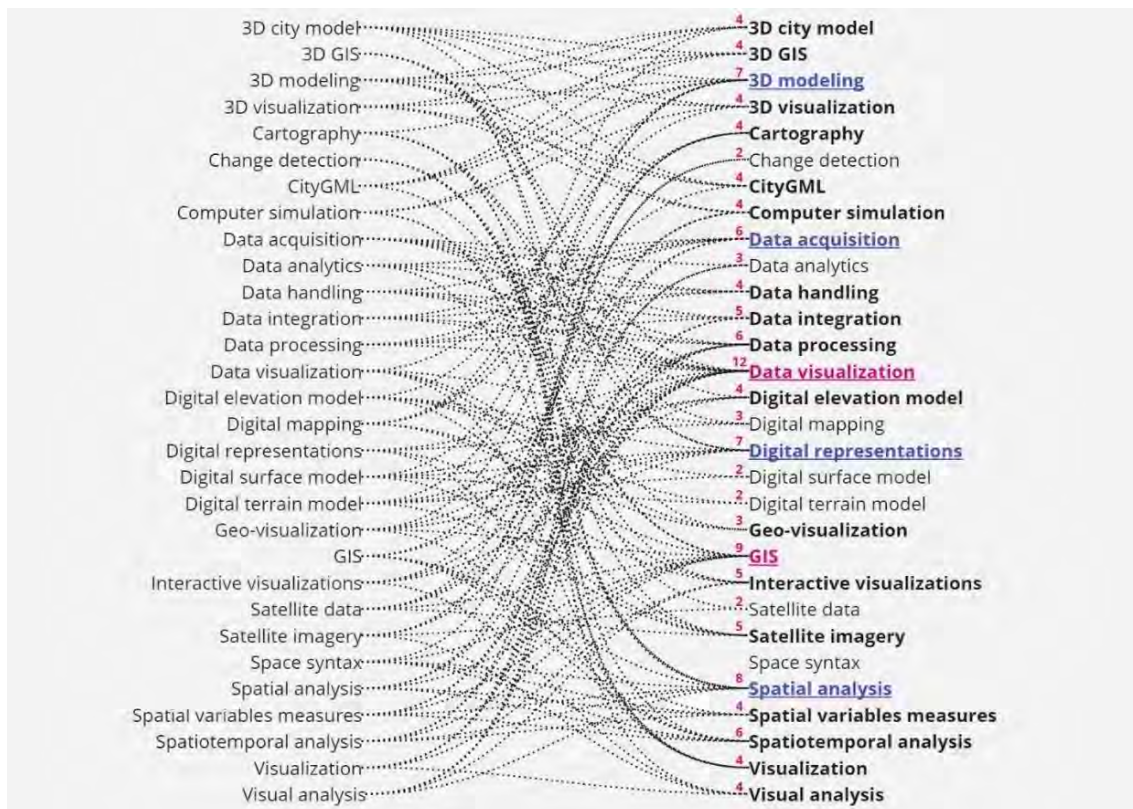


Figure 5 Co-occurrence analysis of selected terms

The following discussion will focus on the terms in accordance with their categorization into groups according to the strength of their connections (as previously explained in section 2.3 Factsheets Analysis). For each term, an

overview will be provided regarding its position in the network and co-occurrence, as well as the general definition established in the dictionary (Djokić et al, 2024).

- **Central Keywords:**

- **Data visualization (12):** This term has the highest number of connections, indicating its central importance in the co-occurrence chart. Connectivity indicates that "Data visualization" serves as a central node in the network, connecting a diverse range of related terms. This centrality underscores its crucial role in the field of urban morphology to represent spatial data in the form of maps, graphs, and 3D models. Visualization tools help in identifying spatial patterns within cities, such as the clustering of certain types of buildings, the organization of street networks, or the distribution of land use.

- **GIS (9):** This term also has a high number of connections which suggest that "GIS" is indispensable for integrating data from multiple sources, facilitating comprehensive spatial analysis, and providing visualization tools that enhance understanding and decision-making in various applications. GIS enables easy integration of multiple data sources (geographic data with socioeconomic, demographic and environmental data, as well as interactive data) that can be obtained from public networking platforms where GIS works into a single location-based plan.

- **Highly Connected Keywords:**

- **Spatial analysis (8):** The connections suggest that "spatial analysis" involves multiple steps, including data acquisition, integration, processing, and visualization, with tools like GIS and data sources like satellite imagery playing pivotal roles. Conducting "spatial analysis" often employs the combination of GIS to integrate data from various resources, statistical methods to incorporate temporal dimension into the analysis, and other tools like spatial modelling, spatial visualization and remote sensing techniques.

- **Data acquisition (6):** Its connections to data handling, integration, processing, visualization, digital representations, and GIS highlight its critical role in collecting accurate and reliable data that feeds into the entire data lifecycle. Data acquisition helps in gathering spatial data such as maps, satellite images, and GIS data which are further used to analyze the physical layout, street patterns, building forms, and land use in urban areas. Moreover, Data acquisition enables the measurement of spatial metrics, such as density, connectivity, and accessibility, which are critical for quantitative analysis in urban morphology.

- **Data processing (6):** The keyword "Data processing" serves as a critical node in the network, connecting to essential aspects of the data lifecycle, including acquisition, handling, integration, visualization, and spatial analysis. Its connectivity highlights its fundamental role in transforming raw data into actionable information that can be used to understand and shape urban forms. In urban morphology, data from multiple sources (e.g., satellite imagery, GIS data, historical records) need to be combined and standardized. Data processing facilitates the integration of these diverse datasets into a unified format, making it easier to analyze complex urban systems.

- **Spatiotemporal analysis (6):** The keyword "Spatiotemporal analysis" serves as a critical node in the network, connecting to various essential aspects of data analysis that involve both spatial and temporal dimensions. Its connections highlight its importance in understanding and interpreting changes over time within spatial datasets. Spatiotemporal analysis plays a critical role in urban morphology by enabling the study of how urban forms and structures change over time and across different spatial scales.

- **Moderately Connected Keywords:**

- **Data integration (5):** The keyword "Data integration" connects various aspects of data management and analysis. Its connections to data acquisition, handling, processing, visualization, and GIS highlight its importance in creating unified and coherent datasets from diverse sources. These connections emphasize the role of data integration in multiscale analysis by integrating data at various spatial scales (e.g., neighborhood, city, region) and temporal scales (e.g., historical, contemporary). Data integration allows for the combination of historical and contemporary datasets, enabling longitudinal studies that track changes in urban morphology over time.

- **Interactive visualizations (5):** The keyword "Interactive visualizations" connects various aspects of data visualization and analysis. Its connections to data visualization, geo-visualization, GIS, spatial analysis, and visualization highlight its importance in enhancing the interactivity and engagement of data exploration. Interactive visualizations enable users to manipulate data in real-time, such as zooming in on specific areas, filtering data by criteria (e.g., time periods, land use types), or changing the scale of analysis. Moreover, interactive visualizations are powerful tools for engaging stakeholders, including community members, policymakers, and developers.

- **Satellite imagery (5):** The connections emphasize the role of satellite imagery in facilitating comprehensive and dynamic analyses, supporting better decision-making and understanding of geographic phenomena. By integrating satellite imagery with other tools and methods, organizations can derive valuable insights and

monitor changes effectively in various fields. Satellite imagery offers detailed and accurate maps of urban areas, capturing the layout of streets, buildings, green spaces, and other urban elements. Primary, satellite imagery is used to monitor the expansion of urban areas over time by comparing images from different periods.

- **Keywords with Fewer Connections:**

- **Digital mapping (3):** Its connections highlight its importance in creating accurate and effective maps using digital tools and data. These connections emphasize the role of digital mapping in enhancing the visualization and representation of spatial data, making it a crucial tool for various applications. Digital maps are used to identify and analyze spatial patterns within cities, such as the arrangement of streets, the distribution of land uses, and the configuration of urban blocks. Digital mapping tools can calculate distances, travel times, and accessibility to services and amenities. This type of analysis is essential for understanding how well-connected different parts of a city are and how the urban form affects mobility and access.
- **Data handling (3):** Its connections highlight its importance in ensuring data quality, reliability, and usability throughout the data lifecycle. These connections emphasize the role of data handling in facilitating efficient organization, cleaning, transformation, and storage of data, which are fundamental steps in preparing data for analysis and decision-making. Urban morphology relies on a wide range of data, including spatial data (e.g., maps, satellite images), demographic data, historical records, and environmental data. Data handling involves the careful acquisition of these datasets from various sources, ensuring that they are relevant and of high quality.
- **Geo-visualization (3):** The keyword "Geo-visualization" serves as a specific node in the network, connecting key aspects of data visualization, GIS, and interactive visualizations. By integrating historical maps and data with contemporary spatial information, geo-visualization enables the exploration of how cities looked in the past and how their forms have transformed. This is essential for understanding long-term trends and patterns in urban development. Geo-visualization provides interactive platforms where decision-makers can explore various planning options, compare different scenarios, and make informed decisions. These platforms often include tools for measuring distances, calculating areas, and assessing accessibility, all of which are vital for effective urban planning.
- **Digital terrain model (2):** The keyword "Digital terrain model" serves as a specialized node in the network, connecting key aspects of terrain representation and spatial analysis. Its connections to Digital Elevation Models and GIS highlight its importance in accurately representing the Earth's surface for various geospatial applications. Digital Terrain Models (DTMs) are invaluable tools in urban morphology, providing detailed information about the terrain that influences urban form, infrastructure, and environmental sustainability. By offering insights into topography, elevation, and landforms, DTMs support a wide range of applications, from urban planning and disaster risk assessment to environmental management and historical studies.
- **Change detection (2):** The keyword "Change detection" serves as a specialized node in the network, connecting aspects of data visualization and spatiotemporal analysis. Its connections highlight its importance in identifying and analyzing changes in spatial data over time. These connections emphasize the role of change detection in providing insights into temporal dynamics and trends. Change detection techniques are used to monitor the expansion of urban areas, often referred to as urban sprawl. By comparing spatial data from different time periods, researchers can identify where and how cities are expanding, which is crucial for understanding patterns of growth and planning for sustainable development.
- **Satellite data (2):** The keyword "Satellite data" serves as a critical node in the network, connecting essential aspects of data acquisition and GIS. Its connections highlight its importance in providing detailed and extensive spatial information for various applications. Satellite data, particularly from radar and LiDAR satellites, is used to create 3D models of urban environments. Satellite data helps document significant transformations in urban areas, such as the development of new neighborhoods, the decline of industrial zones, or the regeneration of city centers.

#### 4 Conclusion

The SPATTERN project's initial deliverable provides a comprehensive review of existing methodological approaches for decoding urban patterns through digital tools. The study emphasizes the importance of a dictionary-driven approach to standardizing terminology and organizing the diverse methods available in urban morphology research. The SPATTERN project's dictionary is particularly relevant as it systematically categorizes and evaluates digital tools and methods, promoting more cohesive research outcomes in urban pattern analysis. One of the key contributions of the SPATTERN project is the advancement of digital methods in urban morphology. By integrating these digital tools into a standardized framework, the project tends to enhance the ability to decode complex urban patterns, which is crucial for sustainable urban planning and land

transformation. The dictionary-driven approach also contributes significantly to the field by providing a conceptual map that helps researchers navigate and apply these tools and methods effectively. This not only bridges the gap between traditional urban morphology methods and modern digital approaches but also supports interdisciplinary collaboration.

Looking ahead, the SPATTERN D1.1 sets the stage for future research and development in urban morphology from a methodological perspective. It recommends the further exploration of digital tools and their integration into urban planning processes, encouraging the adoption of such technologies in the broader field. The project's findings advocate for ongoing refinement of the dictionary and the expansion of its application to different urban contexts.

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