INDRAJA ELŽBIETA GERMANAITĖ

RESEARCH OF SPATIAL PATTERNS DESCRIPTION, IDENTIFICATION AND APPLICATIONSOLVING SPATIAL ANALYSIS TASKS

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Scientific Supervisor:

Prof. Dr. Rimantas BUTLERIS (Kaunas University of Technology, Technology Sciences, Informatics Engineering, T 007).

Scientific Advisor:

Prof. Dr. Kęstutis ZALECKIS (Kaunas University of Technology, Humanities, History and Theory of Arts, H 003).

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INDRAJA ELŽBIETA GERMANAITĖ

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Mokslinis vadovas:

Prof. Dr. Rimantas BUTLERIS (Kauno technologijos universitetas, technologijos mokslai, informatikos inžinerija, T 007).

Mokslinis konsultantas:

Prof. Dr. Kęstutis ZALECKIS (Kauno technologijos universitetas, humanitariniai mokslai, menotyra, H 003).

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ABSTRACT

Cities and regions are complex spatial systems, and their analysis is concerned with describing and identifying spatial patterns and various measures of shape, form, density, clustering, and centrality. Spatial patterns can be used to detect and evaluate environmental, social, and economic processes by using GIS. The currently available spatial analysis methods are not sufficient for the analysis of complex spatial systems, and even though there are quite a few ways for describing and/or measuring spatial patterns, such as qualitative and quantitative methods, some spatial patterns can currently be detected only by empirical observation.

The goal of this research is to create and test a configurable and expandable spatial pattern description, identification, and application methodology (SPDIAM) that would allow us to describe a spatial pattern in a computerised manner as well as to identify spatial patterns automatically so that they could be applied for the solutions of the planning and design problems emerging in the domain.

SPDIAM was developed as a structural, ruled-based spatial pattern recognition method that provides the structural description of a spatial pattern by using spatial metapatterns and morphological relationships and which uses Space syntax topology and visibility analysis in order to identify spatial patterns of the road network by using GIS. SPDIAM description consisting of the static and dynamic views covers the use cases based on SPDIAM phases: spatial pattern description, identification, and application. Also, it includes an SPDIAM spatial data preparation routine. The presently created IT artefacts can be used for spatial IS development involving the use of GIS technologies and for spatial pattern creation and problem-solving in complex spatial systems involving the use of the structural approach. The spatial pattern identification method combines the graph theory and Space syntax, properties of geographic models, and new normalised measures.

Case studies were conducted to test SPDIAM application and spatial pattern identification. The results of our experiments showed that SPDIAM is deemed to be appropriate to describe spatial patterns and identify them automatically; the general spatial pattern and metapatterns model and IT artefacts presented in this research can be used to describe and identify spatial metapatterns in the spatial data while taking into account problems of complex spatial system analysis; spatial pattern values can be calculated, and the automated decision can be made when using the evaluation of the identified spatial metapattern, map-defined measures, and simple user-defined rules.

SPDIAM was evaluated by comparing SPDIAM to the other currently available methods describing complex spatial systems, and also by comparing SPDIAM and other tools of spatial network analysis, as well as by calculating the identified spatial patterns and employing statistics data correlation. SPDIAM demonstrates the reusability, expandability, flexibility, and complexity compared to the other stand-alone spatial analysis methods, and, at the moment, there are no known limitations of this methodology as it can be expanded by creating new spatial metapatterns, adding new methods, measures, spatial structures, and forms. The major restriction

of SPDIAM is that it requires practical experiments to acquire spatial pattern values for the spatial pattern identification.

TERMINOLOGY, SYMBOLS AND ABBREVIATIONS

Term (Abbreviation)	Explanation	Representation in SPDIAM Model (Class)
API	Application programming interface	
ASAMD	Angular segment analysis by metric distance	
ATD	Angular total depth of node (Space syntax measure)	
CAD	Computer-aided design	
CAAD	Computer-aided architectural design	
CENTER	Center positioning (Space syntax measure)	
Comprehensive plan	This term shall mean a document of complex territorial planning which, based on the levels and tasks of territorial planning, establishes the spatial structure of a planned territory and mandatory provisions and requirements for the use of the territory as well as the principles of its protection [Register of Legal Acts 2020].	
CSS	Complex spatial system	*SpatialEntity*
Element	Element of the structure (node)	*Element*
Form	CSS physical or abstract form used in SP identification	*Form*
GIS	Geographic information system	
Indicator	Economic, social or environmental indicator with statistical spatial data that can be linked with the spatial entity structure	*Indicator*
IS	Information system	
IT	Information technology	
MEAN CENTER GRID CELL	Mean CENTER value of the segments in grid cell (Space syntax measure)	
Measure	Spatial or non-spatial measure	*Measure*
Measure target	Measure associated with the form: can represent the measure of the form, structure, or structure element	*MeasureTarget*
Method	Theoretical method to identify SP	*Method*
NAIN	Normalised angular integration (Space syntax measure)	
NACH	Normalised angular choice (Space syntax measure)	
NC	Node count at radius (Space syntax measure)	
Operation	Action performed on spatial entity data	*Operation*
Operation form	Step of SP method to calculate the value for the specific form	*OperationForm*
OS	Operating system	
POIS	Point of interest	
QGIS	Open-source geographic information system (GIS) application	
SP	Spatial pattern	*Pattern*
Spatial entity	CSS (region, city, district, site, etc.) that consists of spatial data	*SpatialEntity*
Spatial pattern method	Method to identify or to transform specific SP	*PatternMethod*
Spatial pattern	Value that SP can acquire	*PatternValue*

value		
Spatial pattern value measure	Measure that is used to calculate SP value	*PatternValueMeasure*
SPDIAM	Spatial pattern description, identification, application methodology	
Structure	Spatial entity physical structure	*Structure*
SPD	Spatial planning and design	
UCI	Urban compactness index (Space syntax measure)	
UPD practitioner	Urban planning and design practitioner – SPDIAM user	*User*
UML	Unified modelling language	
Variant	Variation of the original structure that can obtain values of maximum and minimum compactness	*SAttribute*
VGA	Visual graph analysis	

1. INTRODUCTION
1.1. Relevance of the Research

Information systems (IS) research examines more than the technological or social system or the two side by side; it essentially investigates the phenomenon that emerges when the two interact, thus IS as a design science does not attempt to develop concrete applications in the field of *Information Technologies* (IT), but rather general solution concepts that help to develop the concrete IT applications or specific solution concepts [Hevner and Chatterjee 2010; Germanaitė *et al*. 2022].

The *Geographic Information System* (GIS) can be viewed as an interdisciplinary area incorporating many distinct fields of study, such as geodesy (projects, surveying, cartography, etc.), remote sensing, photogrammetry, environmental science, city planning, cognitive science, and others [Prathibha 2014]. GIS is also a computerised system that facilitates the phases of georeferenced data entry, management, analysis, and presentation [Huisman and By 2009]. In order to represent the real word aspect inside a GIS, a geographic phenomenon as a manifestation of an entity or process that can be named, described, georeferenced, and assigned a time at which it was present shall be defined [Huisman and By 2009]. In GIS, the spatial phenomena occur in a 2D or 3D Euclidean space in which locations are represented by their coordinates, and distance along with direction can be defined with geometric formulas [Huisman and By 2009], but the definition of space is much more complex due to the multi-dimensional understanding of the urban space [Dimililer and Akyuz 2018]. The information in a GIS describes entities having a physical location and extent in some spatial region of interest, while queries involve identifying these entities based on their spatial and temporal attributes and relationships between entities, thus all the different problems and questions that arise from the integration of multiple disciplines make it much more than a simple tool [Prathibha 2014].

Cities and regions are complex, adaptive, self-organising systems [White *et al*. 2015], thus urban and regional analysis can be seen as concerned with the complex spatial system (CSS) [Wilson 2008]. CSS defines a spatial entity and is described by many variables, with high levels of interdependence between elements governed by nonlinear processes, and having a significant spatial structure [Wilson 2008]. Therefore, the analysis of the separate components does not give the full picture of CSS [Bölen and Kaya 2017], and nonlinearities in CSS analysis can arise in a variety of ways: the rates of change are non-constant; the distance effects involve a power or exponential function (like in the geographer's gravity model), etc. [Wilson 2008].

The methods of describing and identifying a spatial pattern (SP) and various measures of shape, form, density, clustering, and centrality include the domain-specific SP, such as patterns of towns, the clustering of diseases, the form of physical features, and the shape of economic regions, and the universal SP methods without reference to the subject areas, such as fractals, tessellations, scale, map projections and measures of centrality [Getis and Paelinck 2004]. The most significant benefit of the application of these methods is that SP, such as urban and transportation models, buildings and city blocks and land use patterns, area-class maps, and road networks, can be used to detect and evaluate environmental, social, and economic processes in the environment by using GIS [Germanaitė *et al*. 2020]. Although the taxonomy of SP has been studied extensively, there remains a lack of a clear and unanimous criterion for SP definition and automated identification [Yan *et al*. 2019].

The *spatial planning and design* (SPD) theorists evaluate and classify spatial phenomena differently. Hence, there is no unified system of how to evaluate SPD decisions and solutions for urban areas. As the existing assessment tools provide an ex-post evaluation but often fail in the process of guiding a holistic approach to decision making, *urban planning and design* (UPD) practitioners need SP identification and prediction tools to find the most sustainable SPD solutions and develop recommendations for SPD activities [Hill *et al*. 2014].

The goal of this dissertation is to create and test a configurable and expandable SP description, identification, and application methodology (SPDIAM) that would allow to describe SP in a computerised manner, identify SP automatically by using Space syntax as the primary method for the SP identification, and to apply SP for the solution of the planning and design problems emerging in the SPD domain [Germanaitė *et al*. 2020]. The developed methodology shall allow us to formulate descriptive, categorising, hierarchical, computational, and spatial properties of SP and methods of SP identification and to form a detailed specification.

SPDIAM is multidisciplinary as the analysis of CSS can be used in the demography, economics, geography, urban and regional analysis, engineering, architecture, planning, and other fields: thus we note the common elements of design and recommend an integrated approach for different areas [Wilson 2008]. Computer-based modelling and SPDIAM provide the framework for this.

SPDIAM operates the Space syntax method and normalised spatial and non-spatial measures and can be used with the statistical social, economic, and environmental indicators which are related to urban sustainability and spatial capital. The concepts that were created at the stage of defining SPDIAM can be used for the development of the spatial structure (such as a network or a grid) analysis tools in GIS. The Space syntax approach was chosen as the most appropriate for this research as it: a) views the urban spaces as a complex, constantly interacting network thus reflecting the nature of a city as a complex, dynamic system; b) uses mathematical methods and the mathematical graph model; c) offers a high variety of theoretically grounded and empirically tested both normalised and not normalised centrality measures which create abundant possibilities for spatial configuration analysis and comparison; d) could be seen as a tool to evaluate spatial capital [Zaleckis *et al*. 2020; Germanaitė *et al*. 2020]. Examples of disciplines where Space Syntax has been applied are anthropology, archaeology, architecture, urban planning and design, geography, psychology (wayfinding and the perception of safety), sociology, criminology, real estate development, and road engineering [Yamu *et al*. 2021; Germanaitė *et al*. 2020]. Space Syntax was applied in various urban design, strategic planning, and consultancy projects, such as the public realm design for Trafalgar Square, the new highway link through the city of Leiden (the Netherlands), the strategic plan for railway stations for North Holland, and the use of Space syntax in densification strategies in the city of Bergen (Norway), the master plan of Jeddah (Saudi Arabia), the redesign of Woolwich Squares in London, the regeneration of the areas around King's Cross Station in London, the upgrade of the Old Market Square in Nottingham (UK), the evaluation of the location of the Millennium Bridge in London, and the creation of spatial strategies for the city of Changchun (People's Republic of China), among others [Nes and Yamu 2021; Germanaitė *et al*. 2022].

SPDIAM is based on the spatial configuration and spatial capital [Marcus 2007] concepts as they closely examine the structure, constitution, and attributes of SP, and also on detailed research of SPDIAM problems and methods when using the *design science research in IS* [Hevner and Chatterjee 2010], the *complex spatial system approach* [Wilson 2008] and the *algorithmic approach* [White *et al*. 2015; Germanaitė *et al*. 2022]. As a result, an SPDIAM model is explained by using UML diagrams as the standard used for the visualisation of project models from the structure and behaviour points of view, and a practical experiment of using this model for describing and identifying SP is conducted. For the experiment, the new algorithm using the Space Syntax method, Visibility Graph Analysis (VGA), and VGA measures [Koutsolampros *et al*. 2019] is presented, and the results of the experiment are evaluated.

The SPDIAM flexibility, expandability, and reusability are demonstrated in comparison with the other alternative spatial analysis methods, specifically, cellular automata, agent-based modelling, fractal analysis, or stand-alone Space syntax.

SPDIAM allows us to identify SP automatically by using a defined description of SP and the created algorithm of the SP identification method (SPDIAM phase *SP identification* described in Section 4.5. SPDIAM Dynamic View), measures, and user-defined rules. The SP identification method combines several methods – the graph theory and Space syntax, the properties of geographic models, and new normalised measures proposed by the author of this thesis. The automated decision in which the SP value must be selected is taken by using the method composed of logical steps (as described in Section 4.5. SPDIAM Dynamic View) and quantifiable and scientifically based CSS measures (described in more detail in Section 5) performing assessment of CSS based on sets of measures. The created method presented in SPDIAM has not been applied yet to the description and automated identification of SP in CSS. Further in the text, the UPD practitioner (UPD P in diagrams) means the primary user and the further developer of the SPDIAM. In the diagrams of this dissertation, the blue-coloured UML classes mean the classes used in SPDIAM, and the white ones are added for the explanatory purpose only with the objective to express the main mechanics, opportunities, and flexibility of the SPDIAM model in general.

1.2. Research Field, Goal and Tasks

Field of the research: tools and methods of CSS analysis.

Goal of the dissertation: to improve the capabilities of the quantitative analysis of CSS with additional characteristics by using the tools and methods of SP description, identification, and application, and by solving the applied tasks of SPD analysis in GIS.

To accomplish this goal, the following **tasks of the dissertation** have been outlined:

1. To analyse the literature and the related technologies of the currently existing possibilities of spatial analysis in CSS.
2. To improve the possibilities of CSS quantitative analysis by using tools for the description, identification and application of SP.
3. To create the specification of spatial objects and a data model for SP identification and application.
4. To conduct the experiment of the developed methodology, during which, SP would be described and identified in CSS, and to evaluate the results of the experiment.

1.3. Research Problem, Object and Method

The main problem of this research focuses on the current lack of state-of-the-art methods and tools for a structural approach towards CSS and quantitative spatial analysis methods of spatial phenomena (or SP) instead of the qualitative ones.

The research objects are the methods and characteristics of describing, identifying, and applying SP in CSS.

There are two research methods used in this work: the *Design Science Research in IS* [Hevner and Chatterjee 2010] and the *Complex Spatial System Approach* [Wilson 2008].

1.4. Defended Statements

1. SPDIAM allows automated SP identification in CSS when using SP description and user-defined rules, thus extending the capabilities of the quantitative analysis of CSS with additional characteristics.
2. SPDIAM allows us not only to define the descriptive, categorising, hierarchical, computational and spatial features of SP, its identification methods and CSS, but also to develop the detailed specification and data model for SP, its values, identification methods and indicators.

1.5. Scientific Novelty

1. A multifaceted – i.e., consisting of several different ways of presenting spatial data and a spatial structure (network, segment/convex/VGA graph, grid) –

partial-comprehensive model of a CSS is proposed, together with the new spatial data input preparation algorithm and procedures.

2. SPDIAM expands the possibilities of spatial analysis and the possible applications of the cases of use of SPD analysis, as well as the methods used in spatial analysis tools using SP due to the reason that the currently existing methods only explore statistics and the functions of CSS while lacking the structural approach; they can only describe and identify user-defined SP in CSS to a limited extent, as the constructs created by the Space syntax and other methods of spatial analysis are excessively complex and too difficult to understand without the appropriate methodology.

3. The proposed SP identification algorithm combines several methods (the graph theory, the Space syntax, the properties of geographic models, and the new normalised measures) has – so far – never been applied to the description and identification of SP in CSS.

4. The proposed SP identification algorithm allows us to automate quantitative SP identification methods instead of the qualitative methods which are dominant in the SPD domain.

5. SPDIAM proposes the new measures for spatial analysis (CENTER, URBAN COMPACTNESS INDEX).

1.6. Theoretical and Practical Significance

Theoretical Significance:

1. The currently existing possibilities of CSS spatial analysis are researched, and the most important features, limitations, and cases of application use of SP and its identification method are identified in order to create the specification and data model of SP and SPDIAM.

2. SPDIAM provides a theoretical basis and a defined sequence of rules for the further research of CSS analysis, e.g., for the classification, identification, reuse, and improvement of the created and identified metapatterns and SP in CSS with the help of the developed IT artefacts and SPDIAM.

3. The descriptive, spatial, and computational parts of SP and the method of its identification are separated from each other, which allows to use SPDIAM integrally or to apply only certain parts of it.

4. When using SPDIAM, SP can be identified by using the calculated and scientifically based measures allowing us to compare SP and spatial entities to each other.

Practical Significance

SPDIAM IT artefacts allow us:

1. To define and computerise SP, their descriptive, categorising, hierarchical, spatial, and computational attributes, SP identification methods, and the results of spatial entity analysis in CSS.

2. To identify SP automatically according to the user-defined rules.

3. To aggregate the attributes, parameters, and indicators describing the spatial object into abstract logical entities, thus creating new IT artefacts necessary for solving the tasks of the SPD domain.

4. To evaluate the change of a spatial object in time, considering it as a CSS.

5. To describe SP and to analyse CSS by using the structural and functional points of view linking the physical form of spatial entities to their functional structure (a structural aspect of CSS).

6. To enable the user to contribute to the development of SP and its identification method and indicators, which would otherwise be difficult due to the complex spatial syntax and other methods of spatial analysis using complex and difficult-to-understand constructs.

7. To ensure the parameterisation of CSS.

8. To use the different methods for describing SP, which ensures the extensibility of SPDIAM.

9. To define the results of spatial object analysis, and to make decisions when evaluating and comparing SPD solutions.

10. To reuse the created IT artefacts and spatial metapatterns in order to solve the tasks of SPD analysis of CSS and thus to reduce the need for time and work resources. This reuse can also take place between different domains and thematic areas.

SPDIAM improves:

1. The quantitative and qualitative characteristics of the currently existing tools of spatial analysis by using aggregated, composite and normalised indicators which allow to compare spatial objects as CSS and use all spatial network information.

2. The quality of spatial analysis in CSS:

a. spatial entity is analysed based on quantitative, clearly defined, and measurable indicators, rather than expert (empirical) evaluation;

b. spatial entity analysis can be automated;

c. the assessment of a spatial entity without the developed method would not be possible in any other ways (e.g., by manual calculation).

1.7. Application Value in Different Areas and Reuse

Design science research combines the focus on the IT artefact with a high priority on the relevance in the application domain [Hevner and Chatterjee 2010]. Design research projects, first of all, provide an important strand of research which values research outcomes focusing on the improvement of an artefact in a specific domain as the primary research concern, and, then, seeks a broader, more general, understanding of the theories and phenomena surrounding the artefact as an extended outcome [Hevner and Chatterjee 2010].

SPDIAM is multidisciplinary as the analysis of CSS can be used in the demography, economics, geography, urban and regional analysis, engineering, architecture and planning, and other fields [Wilson 2008] thus serving the objective to note the common elements of design and to recommend an integrated approach for different areas – since modelling (and SPDIAM) provides the framework for this [Wilson 2008].

In general, SPDIAM can be used to describe SP and their identification methods and to identify SP for CSS in the SPD domain, and specifically these areas mentioned in [Wilson 2008]:

1. Regional systems (cities, regions, the European Union).

2. Urban systems (cities, while separately assessing their structure and functions).

3. Functional systems (economic (agriculture, resources, industry, service use, and service sectors), social environment, labour market).

4. Spatial systems (multi-city systems), interoperable systems (commuting flows), networks (transport, communication systems).

1.8. Scientific Approval

Articles in Journals referenced in *Web of Science* database:

2 articles presenting the dissertation results have been published in peer-reviewed scientific journals that are indexed in the *Clarivate Analytics Web of Science* database. Also, the results of this research have been presented at a international conference in Lithuania. The corresponding publications were published in the conference proceedings. A detailed list of publications is provided in the dissertation; see Chapter *List of publications of Indraja E. Germanaitė on dissertation theme*.

1.9. Structure of Dissertation

The dissertation consists of 7 chapters. Chapter 1 covers the introduction. Chapter 2 discusses the complex spatial system and the spatial pattern concepts together with methods of spatial analysis. Chapter 3 investigates the decomposition of the research problem and theoretical methods used in the research. Chapter 4 presents the created methodology. Chapter 5 describes the performed experiments serving the objective to evaluate the proposed methodology. Chapter 6 discusses the use case of the methodology. Chapter 7 outlines the results of the methodology evaluation. Chapter 8 contains conclusions and ideas for future work.

2. RESEARCH BACKGROUND OVERVIEW

2.1. Complex Spatial System as System of Interest and Algorithmic Approach

Cities and regions are complex, adaptive, self-organising systems [White *et al*. 2015], thus urban and regional analysis can be seen as being concerned with CSS [Wilson 2008]. CSS defines a spatial entity and is described by many variables with high levels of interdependence between the elements governed by nonlinear processes, and having a significant spatial structure [Wilson 2008]. Therefore, the analysis of the separate components does not give the full picture of CSS [Bölen and Kaya 2017], and the nonlinearities in CSS analysis can arise in a variety of ways: the rates of change are non-constant; the distance effects involve power or exponential function(s) (like in the geographer's gravity model), etc. [Wilson 2008].

Complexity is a general property of CSS that takes the form of a hierarchy – i.e., a recursive partition of a system into subsystems [Hevner and Chatterjee 2010]. Hierarchies are denoted by the property of *near decomposability*: the short-term behaviour of each subsystem is approximately independent of the other components, but the long-run behaviour of a subsystem depends on (the) other components in an aggregate way, and it simplifies the behaviour and the description of CSS [Hevner and Chatterjee 2010]. CSS description needs not be as complex as the system due to the *redundancy* property, and it may contain only a fraction of the connections [Wilson 2008]. Redundancy results from the fact that there are only a limited number of distinct elementary components, and CSSs are obtained by varying their combination [Hevner and Chatterjee 2010].

When defining CSS as a system of interest, its elements (people (agents), organisations, and infrastructure) can be assembled into systems in a large number of different ways at different scales. [Wilson 2008]. The entities that are components of CSS must be defined and categorised, many of them have to be located in space, and their behaviour has to be described over time [Wilson 2008]. Therefore, the important aspects are entitation, the number and breadth of categories, the spatial (the Cartesian coordinates or a discrete zone system), and the temporal representation of CSS [Wilson 2008].

Urban and regional analysis of CSS can be done through analytical human geography and the associated disciplines. An integrated system can be composed of the subsystem models (such as agricultural, industrial, residential location, service delivery, transport, demography, and economic systems [Wilson 2008] [White *et al*. 2015]), and its aims are: 1) handling interdependence of subsystems; 2) being able to represent the main elements of the urban structure. The four stages of CSS analysis [Wilson 2008] are: 1) a detailed system of interest and analysis of the associated analytical problems (this stage is often omitted in modern quantitative geography); 2) statistical analysis; 3) mathematical modelling and analysis of formal systems; 4) application in management or planning.

CSS has to be analysed in these cases when statistical analysis, mathematical modelling, and system analysis methods are not sufficient: when not enough is known about the system so that to make mathematical analysis possible, when the system is too large for feasible analysis, or when there are too many variables [Wilson 2008]. In such cases, the computer modelling and computer simulation do help, but the task of CSS modelling requires a methodology for analysis, and SPDIAM [Germanaitė *et al*. 2020] offers such a possibility based on the fact that, in CSS, the variables are properties of locations which are either the averages for the location (e.g., density), or functions of the whole surrounding environment (e.g., accessibilities) [Wilson 2008].

The key to modelling cities as self-organising systems is to treat them not only as IT artefacts but as processes, which means embedding the model in time [White *et al*. 2015]. From this perspective, the natural language of modelling is the algorithm (the *algorithmic approach*), since an algorithm is a representation of a process [White *et al*. 2015]. The original algorithm that captures the generic behaviour of the complex self-organising system was cellular automata, conceived in the late 1940s as a simple tool for exploring the nature of dynamical systems [White *et al*. 2015]. Fractal geometry was invented in the 1950s [Batty 1994]. Agent-based systems appeared near the end of the 1980s thanks to the combined evolution of artificial intelligence, object-oriented programming, and distributed intelligence [Langlois 2011], and other types of algorithms useful for investigating complex adaptive systems were developed, such as classifier systems, artificial neural networks and random Boolean networks [White *et al*. 2015]. For the public policy modelling of complexity science, such methodologies as the network science, data mining, and game theory were applied [Furtado *et al*. 2019; Samson *et al*. 2014], and other urban growth modelling initiatives included linear/logistic regression and decision trees [Musa 2016; Germanaitė *et al*. 2022].

2.2. Spatial Pattern

2.2.1. Spatial Capital and Urban Sustainability

The goal of the design science research in IS is IT artefacts, such as constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), instantiations (implemented and prototype systems), and better design theories [Hevner and Chatterjee 2010]. In order to fully understand and to create such IT artefacts, we need to analyse the origins of SP emergence and development.

The main objective of the SPD domain is urban sustainability. Negotiating urban sustainability is a complex challenge, as urban sustainability dimensions – the economy, environment, and society – are influenced by economic viability, prosperity, sociocultural cohesion, and environmental impacts, but the decisions are made by generally diverse and contradicting interest groups [Hill *et al*. 2014]. When targeting this problem, the spatial configuration plays an important role in the different dimensions of urban sustainability [Hillier 2009] and contributes additional value to the function of the city form, which is called the spatial capital [Marcus 2007].

Christopher Alexander noted [Alexander 1979] that the purpose of the pattern analysis is to detect invariant things in the infinite set of all possible variations [Germanaitė *et al*. 2018]. This principle can be applied in any system of interest that is based on spatial data and needs to be analysed by using spatial analysis tools. First, we have to distinguish and name the elements of which the system is made, then to detect that all parts of the system are made of the different combinations of the same parts that are members of the same class of the physical structures [Alexander 1979]. Secondly, we have to name the processes which create and build those patterns in the particular places, and then it is possible to compare them, to draw conclusions about what kind of system landscape we have when one or another process and pattern is used, to detect advantages and drawbacks, and to select the best solution suitable in that particular case [Alexander 1979]. For this purpose, IT artefacts that can describe SP come in handy. Another important insight made by Alexander [Alexander 1979] is that those system elements themselves are patterns of relationships, and this morphological law can always be expressed in the same general form $X \rightarrow r\ \ A, B, \ldots$, which means that, within a context of type X, parts A, B, . . . are related by the relationship *r*.

These patterns or relationships or the spatial configuration can play an important role in all three domains of sustainability: environmental, economic, and social [Hillier 2009]. According to the theory of the spatial capital [Marcus 2007], the urban form generates variations in the spatial accessibility and diversity, with effects on the social accessibility and diversity which are possible to measure, whereby, in turn, it is possible to measure the variations in urbanity as a socio-spatial category. The sustainability compass model [Bureau Urbanisme 2014] uses a similar spatial theory: the spatial quality looks at the value relationship between the physical environment and the experiential quality of using it. Thus spatial configuration (or SP) and spatial quality (or spatial capital) are closely related and must be considered together when we are assessing the requirements of CSS [Germanaitė *et al*. 2022].

2.2.2. Spatial Pattern Description and Taxonomy

In domains like IS or object-oriented software design, the pattern is a description of communicating objects and classes that are customised to solve a general design problem in a particular context [Gamma *et al*. 1996]. They can be grouped as language-provided patterns (e.g., *Java*, *Python*), structure-driven patterns (i.e., they can be identified by inter-class relationships), behaviour-driven patterns (by virtue of being designed to realise certain behavioural requirements), domain-specific patterns, generic concepts patterns [Nija and Olson 2006], etc. A design pattern has four essential elements: the pattern name, the problem, the solution, and the consequences or results of applying the pattern [Gamma *et al*. 1996]. The methods to detect such patterns are the graph mining approach [Murat *et al*. 2016], the source code metrics and machine learning [Uchiyama *et al*. 2014], the Prolog rules [Stoianov and Șora 2010], exact (canonicals) pattern detection [Ballis *et al*. 2008], the exact antipattern detection [Ballis *et al*. 2008], the approximate pattern detection

[Ballis *et al*. 2008], pattern description languages [Ballis *et al*. 2008], and the rule-based matching method [Ballis *et al*. 2008]. The patterns that target *structural aspects* analyse inter-class relationships (class inheritance; interface hierarchies; modifiers of classes and methods; types and accessibility of attributes; method delegations, parameters, and return types) [Nija and Olson 2006]. The patterns that target *behavioural aspects* use machine learning, dynamic analysis (they use runtime data to help identify the behavioural aspects of patterns), and static program analysis (they apply static program analysis techniques) [Nija and Olson 2006]. Patterns are also used in the service-oriented architecture and model-based system engineering [Holt *et al*. 2016].

In spatial analysis, SP depicts a complex physical entity or any kind of structure, spatial distribution, or a recurring feature that is represented as lines, areas, or bodies in a 2D or 3D map and can be described by pattern specification [Marshall and Gong 2009; Germanaitė *et al*. 2018]. The identification of SP types, properties, and measures can be performed by using the urban geometry, topology, and morphology. However, the urban system is a complex system that has powerful interrelationships among its components; therefore, the analysis of the separate components does not give the full picture of the complex system [Bölen and Kaya 2017].

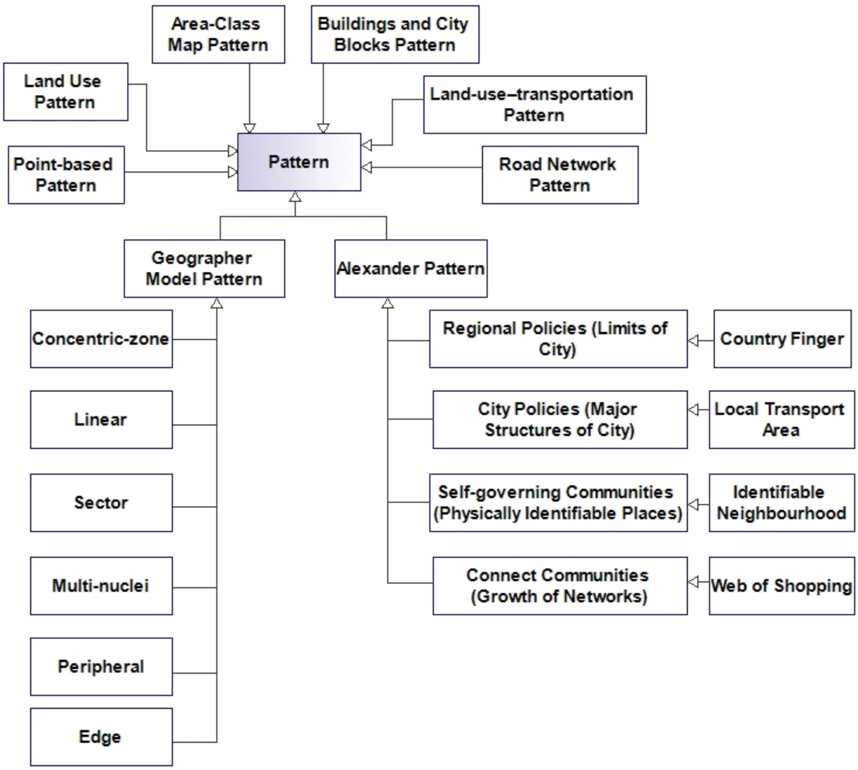


Figure 1 SP types and examples [Germanaitė *et al*. 2022]

The most common SP types are presented in Fig. 1 and overviewed in more detail below. The primary and the most comprehensive source of SP is Alexander [Alexander 1977] pattern language describing ~250 patterns of towns, buildings, and structures. The oldest SPs are urban models that can nowadays be defined as computer simulation models combining theory, data, and algorithms, and which are classified into basic models (scale, analogue, conceptual); mathematical models (normative, probabilistic, optimising) [Torrens 2000]; descriptive and analytical models [Seyed *et al*. 2015]. Land-use–transportation models are used to predict demographic and economic measures of land-based activities; the differentiating factor between descriptive, analytical, and land-use–transportation models is that the first two offer explanations as to how various urban phenomena emerge, but they do not analyse questions why those patterns *do* materialise [Torrens 2000].

Land-use patterns allow us to analyse the form of different land-use within the zone and to find correlations between the land-use types and morphological properties of parcels and their spatial arrangement indexes [Seyed *et al*. 2015]. Point-based patterns identify the configuration of various types of residential and commercial land use [Mesev 2005]. Area-class maps are referred to as categorical, nominal, data-driven, and dasymetric maps, and represent a single phenomenon in a defined area or data-driven patterns [Williams and Wentz 2008].

Urban DNA study [Bölen and Kaya 2017] highlights that, although the local characteristics of settlements differentiate the geometrical properties of urban patterns, universal principles exist in all patterns, and these properties have been analysed through classifying spatial elements into buildings, building blocks, and roads. Buildings and city blocks patterns refer to salient structures perceived individually or as a group in space, which can be at the city block scale divided into areas; in digital cartography, they can be identified as regular geometric shapes; and, from the perspective of visual cognition, they can be classified into linear arrangements [Yan *et al*. 2019]. Road networks are complicated physical entities with numerous complex elements, such as multilane highways or airports with several runways [O'Sullivan 2014], thus SP of road networks play an important role in the analysis of urban structure [Yang *et al*. 2010; Germanaitė *et al*. 2020].

Urban spaces are commonly defined by the street layout, which is an important component of urban morphology, as determined by the distribution of buildings on a certain site [Villaverde *et al*. 2013]. Street patterns have been classified as irregular, radial-concentric, rectangular and grid, star, satellite, linear, rectangular grid, other grid, baroque network and lacework, regular, concentric and irregular, and by over 100 additional descriptors for streets outlines, including radial, grid, tree and linear [Villaverde *et al*. 2013]. City morphology is classified according to the way streets are arranged; over time, several urban morphologies in a major community are influenced by various planning regulations and socio-economic conditions [Villaverde *et al*. 2013]. Urban morphology provides information about the structural characteristics of a city; it provides insight into the structural origins of and the impacts of historical change on the chronological processes concerning the construction and reconstruction of a city [Villaverde *et al*. 2013].

Alexander patterns can be used to describe the variety of SP, but they are based on the observation and comparison of the city and its processes; that leads to the subjective determination of SP, and only a few Alexander patterns cover the whole city; most of them are dedicated to the individual spaces. Classical geographer's models (further referred to as *geographer's models*) can cover the whole city, and they are based on the detailed statistical information of certain functional objects. Geographer's models can define the territories with different characteristics and use the configuration of the territory to define SP, which explains the functional features of the city. On the other hand, geographer's models lack details and can be used for modelling of only the generalised, explanatory SP, and they are also based on the top-down modelling principle [Germanaitė *et al*. 2020].

Though Alexander's patterns are primarily dedicated to identifying the cities and architecture patterns, they are suitable for the other domains where spatial analysis is required as well, and they can be used to describe and express the fundamental concepts of CSS. Furthermore, Alexander's patterns can be described by using geographer's models [Major 2018] and the same concepts and IT artefacts described in [Germanaitė *et al*. 2020; Germanaitė *et al*. 2022]. In the scope of SPDIAM, geographer's models and Alexander patterns are under consideration, as they offer the biggest functional and structural potential in the calculation of spatial capital [Germanaitė *et al*. 2022].

Although SP can be regarded as abstract types that allow generalisation and a better understanding of the spatial entities, there is no single correct way of classifying patterns or identifying the pattern types [Marshall and Gong 2009; Germanaitė *et al*. 2018]. Looking through the different SP types shows that, although the taxonomy of SP has been studied extensively, there remains a lack of a clear and unanimous criterion for SP definition and automated identification [Yan *et al*. 2019; Germanaitė *et al*. 2020].

2.2.3. Spatial Metapattern

The term *metapattern* refers to a pattern of patterns [Volk 1995], and, by analysing patterns – the interrelated structural, functional, and dynamical aspects of systems, their parts, and their contexts – we draw connections and ultimately make explanatory generalisations [Volk and Bloom 2007a]. Though the term *pattern* is usually understood as spatial or geometric aspects of a system, it can be successfully applied to the relations among parts within a system: the description of functional relationships or temporal dynamics of the system as a pattern in time [Volk and Bloom 2007a]. As such, we can expect 1) to develop conceptual constructs arising from the data analyses which are based on interacting sets of metapatterns embedded in the system; 2) since metapatterns appear throughout cultural and social contexts, to find transferability of these conceptual constructs across contexts [Volk and Bloom 2007b]. Thus, as a metapattern offers many modelling options, SP can be identified by using small indivisible spatial or logical elements (metapatterns) that could later be used to identify the SP of a different scale and complexity [Germanaitė *et al*. 2018; Germanaitė *et al*. 2022].

2.2.4. Spatial Pattern Attributes

Spatial objects are usually easily distinguished and named discrete and bounded entities [Huisman and By 2009]. The space between spatial objects is potentially 'empty' or undetermined, and the position of the objects in space is determined by a combination of one or more of the following parameters: location, shape, size, and orientation [Huisman and By 2009]. As shown in the classification of spatial objects [Billen and Zlatanova 2003], a spatial object is composed of at least one dimensional element. For a simple and composed spatial object, each dimensional element is joined to all the other dimensional elements; however, there is also a complex spatial object which can contain disconnected dimensional elements [Billen and Zlatanova 2003; Germanaitė *et al*. 2018].

The description of all Alexander patterns uses the same format: an example of the pattern, the context, the problem, the solution, the connection to other patterns, but they do not share similar abstract properties. Urban models focus on the spatial distribution of sites, structures of the city zones, the direction and distance of the spatial distribution of urban activities; land-use–transportation models represent dynamic functionalities, spatial resolution, visual representation, scaling, and zonal geography [Torrens 2000]. Buildings and city blocks patterns are using city blocks as spatial units for morphological properties to be derived [Yoshida and Omae 2005]. For land-use patterns, the morphological properties of urban features and socio-economic data are analysed to find the relationships between the urban features of different land-use and the corresponding socio-economic activities [Seyed *et al*. 2015]. The data of area-class maps is frequently represented as irregular tessellation with categorical attributes or discrete objects. For road networks, many different parameters (grid-like index; shape similarity; measures of consistent arrangement) to identify the SP are determined [Yang *et al*. 2010; Germanaitė *et al*. 2020].

In [Bölen and Kaya 2017] research, characteristics and differences in the urban pattern are analysed so that to understand the structure of the urban pattern. The spatial parameters that are used to analyse the physical space are classified into four categories [Bölen and Kaya 2017]: the basic features of the physical structure are *geometrical* features of the pattern, such as the dimensions of the spatial elements. The second category comprises *topological* characteristics of the physical space. The third category is focused on the measures related to the *visibility and perception* of space. The final category is the *complexity* of urban patterns which includes the mathematical relationship and hierarchical structure of the spatial systems. As the result, SP identification yields two main insights about the spatial structure: 1) the values which give information about the spatial characteristics and diversity of an urban pattern; 2) the spatial distribution map of a changing urban pattern reflects the unique structure of settlements [Bölen and Kaya 2017].

SP properties and analysis techniques depend on the chosen spatial data type and the space model. There are two basic data models for representing spatial data: the raster and the vector; space can be modelled as set-based, topological, Euclidean, metric, and network space; whereas data inputs can have non-spatial and spatial attributes [Shekhar *et al*. 2011]. Therefore, SP is a multidimensional concept where each dimension requires a specific measuring rod [Getis and Paelinck 2004; Germanaitė *et al*. 2020].

However, when creating IT artefacts that can be used in several different domains, it is not enough to analyse the characteristics of SP. The main concepts of spatial data, spatial analysis, and spatial entity (or CSS) as a whole should be analysed too. Below, there is a short survey of the most characteristic spatial features with some examples.

In a feature-based GIS, features are the fundamental representation of geographic phenomena, and they are both a real-world geographic entity and its digital representation. They thus share common attributes, relations, and functions [Tang *et al*. 1996]. A feature object may contain six components of a feature-based object [Tang *et al*. 1996]: 1) a unique identifier; 2) positional or geometric information (depending on the type of the feature and application); 3) non-spatial attribute data (such as the names or values of attributes); 4) topological relations among geometric objects (such as the boundaries, neighbours and interior); 5) non-topological relations (non-geometric links between features); 6) methods embedded in each object.

According to the other classification [Pinet 2012], the main objectives of the spatial information formalisms are to provide specific concepts and notations used in conceptual models in order to facilitate the following goals: 1) representation of the types of basic spatial objects (points, lines, etc.); 2) enumeration of spatial relationships between objects (such as an embankment is always adjacent to a river); 3) description of the evolution of spatial objects over time (birth and death, object shape changes); 4) modelling of multi-representation of objects; 5) description of objects with uncertain boundaries or positions (like areas of pollution); 6) representation of continuous spatial data (temperature, vegetation cover density); 7) modelling of the structure of networks (such as water systems).

The features of the spatial data model of geologic map database presented in [Soller *et al*. 2006] divide all data into four categories: 1) occurrence (spatial geometry for each geologic feature); 2) descriptor (descriptive information for each feature); 3) concept (essential concepts and definitions essential for querying the database); 4) symbol (cartographic entities for symbolising the map on-screen and in the printed form). The spatial database dedicated to the morphological research on architectural heritage [Xiaoqian *et al*. 2010] divides all data into two categories: 1) spatial data (a topographic map which shows the locations and the shapes of historic architectures, and the relation between them); 2) non-spatial data (including attribute data and architectural thematic data). These different but, at the same time, similar structures for the storage of spatial information must be reflected in the design of the general SP and metapattern model [Germanaitė *et al*. 2022].

From the analysis of SP properties, the conclusion can be made that SP properties are very diverse and are closely related to various statistical indicators which describe economic, social, and environmental activities and processes affecting the urban form (statistical indicators). However, the spatial properties of SP can be classified into four categories [Bölen and Kaya 2017]: 1) geometrical; 2) topological; 3) visibility and perception; 4) complexity [Germanaitė *et al*. 2020].

2.2.5. Spatial Pattern Application

The general object of SP application in the SPD domain is the urban development which covers the planning and design subjects of various structures in a different environment. The cases of SP application can be defined as 1) the evaluation of the possible impact on different urban sustainability dimensions; 2) the capture of the use-value and exchange-value of the spatial capital; 3) the measurement of urbanity which represents the urban form and generates variations in spatial accessibility and diversity [Marcus 2007]. There is no single and universally applicable sustainable solution for the urban area because a perfect solution for the economic dimension will likely impact the environment or social dimensions, so these SP application tasks require a series of layers of information that could allow both a meta-level discussion or a description of specific issues [Hill *et al*. 2014]. For this reason, the *indicator-based assessment model* can be used to compare the urban sustainability or spatial capital levels of cities and regions, visualise the phenomena, and highlight trends and indicators [Yigitcanlar and Dur 2010]. The exemplary indicators that can be used to detect urban sustainability levels or spatial capital values can be grouped into social (such as the crime rate), economic (such as unemployment), and environmental (such as energy use) [Germanaitė *et al*. 2020].

The plan consists of the settings of quantities that are controllable (for example, the number of houses permitted in each zone of the city), and the design of plans is tested through the analysis of the impacts [Wilson 2008]. It is possible to use optimisation methods, such as mathematical programming, in an attempt to generate an optimal plan [Wilson 2008]. *Planning* can be divided into three kinds of activities [Wilson 2008]: 1) *policy*: specification of goals and the evaluation of choice from several alternatives; 2) *Design*: generating alternative plans; 3) *Analysis*: system analysis (geographical analysis), predicting future problems and needs, the impact of plans and hence the material which forms the basis for evaluation procedures.

[Charalambous and Mavridou 2012] described the use cases that are relevant for the SPD practice: 1) to get the information on the constraints and opportunities of urban areas concerning the street network and how it can attract or deter pedestrian movement so that the land use strategy is better aligned to the pedestrian movement opportunities; 2) to offer insights on how the area can be optimised in its context regarding its commercial viability, the potential for retail, the design of sustainable development and the creation of vibrant and lively urban spaces; 3) to offer the possibility to test different strategic guidelines and design proposals.

2.3. Detailed Research Problem and Methods

There is a number of problems that require additional design science research in IS and make it difficult to develop spatial analysis tools that use SP in CSS analysis. User-defined SP has to conform to CSS problems and is critically dependent upon human cognitive (e.g., creativity) and social (e.g., teamwork) abilities to produce effective solutions [Hevner and Chatterjee 2010]; hence, SP must be flexible and configurable. The methods and tools are missing to understand what can be achieved through the deployment of generic tools and what has to be developed which is specific to that discipline, as many of the spatial problems, across domains, share many common features, but are distinguished by the different objectives of the units in those sectors [Wilson 2008]. Because of the high levels of connectivity between different entities and subsystems, there is a strong argument for building a highly comprehensive model, but the ideal solution is often impractical, and partial approaches thus have to be used [Wilson 2008]. The currently existing spatial analysis methods and tools can only describe and identify user-defined SP in CSS to a very limited extent, as the spatial analysis constructs created by these methods (such as the Space syntax) are too complex and difficult to understand. Although the taxonomy of SP has been studied extensively, there remains a lack of a clear criterion for SP definition and automated identification [Yan *et al*. 2019]. Even though SP can be regarded as abstract types that allow generalisation and a better understanding of the spatial entities, there is no single correct way of classifying SP or identifying SP types [Marshall and Gong 2009; Germanaitė *et al*. 2018]. There are already empirically determined urban patterns [Alexander 1977; Borgatti and EÍerett 1999; Major 2018; Volk 1995], but the tool that would allow the planning and designing practitioners to identify those SP and suggest various recommendations and indicators for commercial and social objects placement or utility indicators for the public and private sector needs is still missing. What concerns the presently existing quantitative GIS tools, the preliminary systems analysis and theorising cannot be done in such activities as entitation, scale context, spatial representation, model partial-comprehensive, and appropriate conceptualisation [Wilson 2008].

There are two main research methods used in this work: the *design science research in IS* [Hevner and Chatterjee 2010] and the *complex spatial system approach* [Wilson 2008]. Both of these methods are defined in Table 1 showing how the process and the goal of the design science research in IS can be aligned with the goal and the process of CSS analysis. The main concept of this work is to achieve (to analyse, design, and test in a computerised manner) the structural approach as it is defined by CSS theorists who define it as a methodology (SPDIAM).

Table 1 Research methods used to define SP problem in CSS

	Design Science Research in IS [Hevner and Chatterjee 2010]	**Complex Spatial System Approach** [Wilson 2008]
Process	1. Problem identification and motivation 2. Definition of the objectives for a solution 3. Design and development 4. Demonstration 5. Evaluation 6. Communication	1. Articulation of systems of interest (and representation for modelling purposes) 2. Theory development for that system (needs tool-kit of concepts to use in model-building) 3. Deployment of appropriate methods to operationalise the theory (methodological contributions to modelling)
Goal	The representation of this knowledge as **artefacts:** • Constructs (vocabulary and symbols) • Models (abstractions and representations) • Methods (algorithms and practices) • Instantiations (implemented and prototype systems) • Better design theories	The representation of this knowledge as **system models:** • **Functional approach** (or analysis): forms of organisations and institutions are taken as given and the emphasis is on the way they function both individually and in the relation to each other • **Structural approach**: explore the deeper structures and forces which create these particular forms of organisation

In a general sense, Design Science Research in IS addresses the problems characterised by unstable requirements and constraints, based on ill-defined environmental contexts, complex interactions among subcomponents of the problem, inherent flexibility to change design processes and design artefacts, and here one repeatedly stumbles upon the complex systems and their behaviour [Hevner and Chatterjee 2010]. The CSS approach could be divided into the *functional* (static) vs. *structural* (dynamic) approaches [Wilson 2008]. With the functional approach, the forms of organisations and institutions are taken as a given, and the emphasis is on the way they function both individually and in relation to each other, whereas the structural approach explores the deeper structures and forces which create these particular forms of organisations [Wilson 2008]. The functional analysis of the city is a statement based on the results of the empirical observation, which has limited explanatory possibilities and offers no prognostic potential. This is the simplest collection of data on the current situation – *who*, *where*, *when*, *how* – and so on. The functional approach (for example, a comprehensive plan developed in the territorial planning process) zones the territory (CSS) according to its functions, whereas the structural approach (e.g., SPDIAM) evaluates CSS connections and explores a structure that can perform a variety of functions. The more advanced approaches provide functional and structural analysis of a city modelled as a composition of several networks [Jguirim 2014].

SPDIAM with the help of Space syntax is essentially a structural approach because it evaluates the functional potential of a city through the network configuration (e.g., structure) measures which show the availability, the transit of the location, and so on. The Space syntax creates a simulation model based on the structure, connectivity, etc., and it corresponds to the real processes of the city. The functions themselves are shown by statistic data (or indicators), such as the building density, the points of interest, the flow, and so on. Thus, in the first case, we have only the essentially observational data (statistical indicators) without a model, while, in the second case, we have the model and the observational data to check the accuracy and to obtain additional information. For example, a transport model, if presented only as a result of the measurement of the flow, can be classified as a functional approach, yet, if it is based on a model, such as network analysis, it becomes a structural approach. In addition to the Space syntax, other methods belong to the group of structural approaches: agent-based modelling, cellular automata, and fractal analysis.

The main problem of the existing methods of CSS analysis and even spatial analysis in common is that these methods only explore the statistics and functions of CSS, but they lack structural approach [Wilson 2008] and use quantitative spatial analysis methods instead of the qualitative ones. When summarising all the problems described above, it can be concluded that there is a great need for the methods and tools for a structural approach to CSS and quantitative spatial analysis methods of spatial phenomena (or SP) [Germanaitė *et al*. 2022].

2.4. Spatial Analysis

The spatial analysis methods reviews presented in this section were published in [Germanaitė *et al*. 2018; Germanaitė *et al*. 2020].

2.4.1. Spatial Analysis Methods

Spatial analysis is the generic term for all manipulations of spatial data carried out to improve the understanding of the geographic phenomena that the data represents through discovering previously unknown patterns, or to build arguments on which to base important decisions [Huisman and By 2009]. A large number of methods for the analysis of the spatial structure of natural phenomena have been developed across a wide range of scientific fields [Gil *et al*. 2015]. The main groups of analytical GIS capabilities are 1) classification, retrieval, and measurement functions, that are performed on a single (vector or raster) data layer; 2) overlay functions allowing a combination of two (or more) spatial data layers and treating the areas of overlap and non-overlap in distinct ways; 3) neighbourhood functions evaluating the characteristics of an area surrounding a given feature's location; 4) connectivity functions working on the basis of networks representing spatial linkages between features [Huisman and By 2009].

There are quite a few methods for the analysis of a spatial structure, dynamic models, and spatial ontologies. The simplest and oldest measure of the spatial pattern is the Variance:mean ratio method based on the counts of individuals in some kind of sampling units, such as quadrats. In the quadrat variance methods, the spatial locations of the sample units are included in the analysis, and the data has to be collected as a complete census in strings or grids of contiguous quadrats [Dale *et al*. 2002].

Measures of spatial autocorrelation and autocovariance were historically derived from the familiar statistical concepts of covariance and correlation [Dale *et al*. 2002]. The spatial pattern analysis approach could be used to discover various location patterns. The ArcGIS Spatial Autocorrelation (Moran's I) tool was used to investigate the features of the fast food restaurant distribution in Jakarta, Indonesia. The clustered pattern was investigated by using Kernel Density Estimation in order to identify the clustered area of fast-food restaurants. Moran's I function was applied to find the clustered pattern of values across the study area by using a set of fast food restaurant locations [Widaningrum *et al*. 2017].

In the Neighbour networks method, the measures of autocorrelation, such as Geary's and Moran's, can be estimated by using not only the physical distance, but also for the values, counts, or other measures, at pairs of points that are defined as neighbours by a network of lines joining them [Dale *et al*. 2002]. Spectral analysis and the related techniques examine periodicity in the spatial pattern of the density data by fitting the sine and cosine functions to the data and determining which frequencies or wavelengths best fit the data [Dale *et al*. 2002]. Wavelet analysis analyses spatial data related to spectral analysis which uses a finite template or a wavelet rather than the sine and cosine functions applied over the length of the data sequence [Dale *et al*. 2002]. Fractal dimension describes phenomena that are continuous but not differentiable, thus it seems to deal with the fractional rather than the integer dimension [Dale *et al*. 2002].

As pervasive geographic data is becoming available in cities around the world, new and readily accessible tools are needed to make network analysis available to spatial analysts across disciplines [Sevtsuk and Mekonnen 2012]. A network is a connected set of lines representing some geographic phenomenon [Huisman and By 2009]. Network analysis can be performed on either raster or vector data layers, but it is more commonly done in the latter case, as line features can be associated with a network and hence can be assigned typical transportation characteristics, such as capacity and cost per unit [Huisman and By 2009].

The street layout is an important element of an urban morphology that informs on urban patterns influenced by the city growth through the years under different planning regulations and different socio-economic contexts. [Villaverde *et al*. 2013] It has been assumed by several authors that urban morphology is denoted by the monofractal or multifractal nature [Villaverde *et al*. 2013]. To perform multifractal analysis of urban morphology, street layouts are extracted by using a Space syntax algorithm, thereby obtaining axial maps to accurately represent spatial configurations [Villaverde *et al*. 2013]. The Sandbox multifractal method and lacunarity measurements based on the use of the Gliding Box algorithm are applied to describe street networks [Villaverde *et al*. 2013].

There are numerous other techniques, like the Run-length and join counts method for one-dimensional data; the Second-order point pattern analysis for mapped data for analysing the mapped positions of objects; the Mark correlation function method for the investigation of the interactions between neighbouring trees in a forest. In addition, they also mention the Local Index of Spatial Association method that evaluates how the strength of spatial autocorrelation varies with the location within the study area; the Circumcircle method expands the idea of counting points in circles for completely mapped point data; the Cluster detection method is used for detecting clusters of ‘diseased’ points in a point pattern; the Spatial Analysis by Distance gives the number of individuals in each of several quadrats; the and Mantel test is employed for assessing the relationship between two distance matrices where the distance may be of physical location or a measure of some other kind of dissimilarity [Dale *et al*. 2002].

Cellular automata and agent-based models are the two prominent dynamic models occupying a large portion of spatial discussions during the last two decades [Wahyudi 2015]. Cellular automata consist of four basic elements: cell, state, transition rules, and neighbourhood. The cell represents a spatial shape of cellular automata, the state conveys the possible situation that a cell could have, transition rules determine the changing state of a cell, and the neighbourhood represents the adjacent cells surrounding the centre cell [Wahyudi 2015]. Cellular automata gain considerable attention among geographers and urban planners because urban growth can be easily simulated in Cellular automata, and it gives intuitive simulation results [Wahyudi 2015].

The agent-based model can be defined as a combination of three elements: the agent, the environment, and the interaction. The agent in the agent-based model is anything which has a discrete entity with a distinct goal, the environment is the location where the agent performs its tasks, and there are two kinds of interaction: agent-to-agents, and agent-to-environment interaction [Wahyudi 2015]. The cellular automaton is a concept that suits best to represent the shapes (the fabric) of a city; the ribbon, leapfrog, natural development, whereas the agent-based model suits best with the cases where the interaction of actors involved in the urban system is of more than one way, and actors manifest complex behaviour including learning and adaptation [Wahyudi 2015].

Ontologies can be very useful in spatial analysis. They can be used for geographic and topographic data sets integration, geospatial data querying, topological querying of multiple map layers, and the discovery of geographic information services. Ontologies can be constructed for the conceptual dimensions of geographic objects, e.g., for geometry or topology, for the symbology of representations, and thematic contents [Uitemark *et al*. 2020]. The levels of ontologies can be used to guide processes for the extraction of more general or more detailed information, and the use of multiple ontologies allows the extraction of information in different stages of classification [Fonseca *et al*. 2002]. One of the advantages of using an ontology-driven GIS is the ability to have multiple interpretations of the same geographic feature [Fonseca *et al*. 2002]. Classes are typically defined hierarchically, by taking advantage of one of the most important concepts in object-oriented systems: inheritance [Fonseca *et al*. 2002]. In order to represent the diverse character of the geographic entities and avoid the problems of multiple inheritances, the objects with roles could be used [Fonseca *et al*. 2002].

Geographic data set integration (or *map integration*) is the process of establishing relationships between the corresponding object instances in different, autonomously produced, geographic data sets of a certain region [Uitemark *et al*. 2020]. Components of this formal approach are an ontology for topographic mapping (the domain ontology), an ontology for every geographic data set involved (the application ontologies), and abstraction rules (or the capture criteria) [Uitemark *et al*. 2020]. Abstraction rules define at the class level the relationships between domain ontology and application ontology. By using these relationships, it is possible to locate semantic similarity at the object instance level with methods from computational geometry (like overlay operations) [Uitemark *et al*. 2020].

Analytical mathematical methods are not sufficient for CSS analysis because not enough is known about the system to make mathematical analysis possible, the system is too large for feasible analysis, or there are too many variables [Wilson 2008]. The practised spatial analysis methods are reviewed in Table 2.

Table 2 Spatial analysis methods [Wilson 2008]

Statistical Analysis Methods	Mathematical Modelling and Systems Analysis Methods
Description of geographical entities (standard distributions and their properties and simple hypothesis of straightforward relationships)	**Algebra and analysis** (express functional relationships between variables that describe geographical systems)
Standard statistical models (general linear model of geographical relationships, elementary modelling of trend surfaces, time series, and spatial dependence. Now it is also possible to develop a nonlinear model)	**Entropy-maximising methods** (finding the most probable state of a system)
Models of spatial relationships (they investigate spatial structures as arising out of spatial processes, and geographers have developed their own techniques)	**Account-based methods** (interdependencies between elements of geographical systems force a number of accounting relations to hold between them)
Models of temporal relationships (modelling spatial dynamics)	**Optimisation methods** (many processes are concerned with maximisation or minimisation)
	Network analysis (a particular feature of geographical systems is that the flows of different kinds are carried on networks)
	Dynamical systems analysis (at the heart of the complexity theory)

Many basic geographical concepts and categories do not have exact definitions and are often open to interpretation by an expert for a particular application; thus representing spatial information with precise quantification would be misleading and could lead to faulty conclusions [Tavana *et al*. 2016]. In such situations, the clustering process creates a partitioning that can increase or decrease the granularity of the spatial domain, groups geospatial items that are considered indiscernible in the application, or bin-orders spatial domains into range groups [Tavana *et al*. 2016].

2.4.2. Spatial Pattern Analysis

Pattern recognition is a subject researching object description and classification method described by a collection of mathematical, statistical, heuristic, and inductive techniques executing the tasks on computers, but whether the decision made by the system is right mainly depends on the decision of the human expert [Dutt *et al*. 2012]. Pattern recognition techniques depending upon the method used for data analysis and classification can be categorised into statistical and structural techniques, template matching, the neural network approach, the fuzzy and hybrid model, but a comparative view of the pattern recognition models shows that, for the various domains, different pattern recognition models or a combination of models can be used [Asht and Dass 2012]. A pattern recognition system based on any pattern recognition method includes: 1) data building, which converts the original information into a vector; 2) pattern analysis which processes the vector (feature selection); 3) pattern classification which utilises pattern analysis information to accomplish the classification [Dutt *et al*. 2012]. Structural pattern recognition is based upon the language which provides a structural description of patterns in terms of pattern primitives and their composition and the morphological interrelationships present within the data [Asht and Dass 2012; Subba and Eswara 2011].

The discovery and the recognition of spatial and urban patterns are among the most popular tasks for most GIS applications and plug-ins. There are relatively many ways for describing or measuring SP, such as the *qualitative* methods which include morphological and morphographic descriptions, and the *quantitative* methods which include network component analysis, graph theory (e.g., the Space syntax), and the fractal dimension [Marshall and Gong 2009]. The identification of the urban pattern types, properties, and indicators could be performed by using the urban geometry – the geometric interpretation of urban geography – and urban topology – the mathematical study of configurations and relations between entities independently of their absolute (metric) dimensions [Marshall and Gong 2009]. Even though urban patterns can be regarded as abstract types that allow generalisation, there is no single correct or definitive way of classifying patterns or identifying pattern types, and the diversity of overlapping types and themes is both appropriate and inevitable [Marshall and Gong 2009].

Alexander's patterns can be detected by empirical observation [Alexander 1979]. The urban and transportation analytical models include analysis of the form and structure of the urban features based on the urban landscape model; the physical structure of cities by identifying the urban features from geographic data; the topology of road networks and the grid-like patterns [Seyed *et al*. 2015]. The method to derive morphological properties uses the urban landscape model and city blocks to derive and interpret morphological properties on the quantitative basis [Yoshida and Omae 2005] or for classifying residential and commercial land-use defined through stepwise binary logistic models [Seyed *et al*. 2015]. Various authors have focused on understanding the urban form by using spatial metrics: fractal analysis is used to quantify the irregularity in landscapes [Williams and Wentz 2008] and to analyse the growth pattern of metropolitan areas with the spatial metrics socioeconomic indicators. In the TOSS method [Williams and Wentz 2008], pattern analysis is performed with a metric that describes the spatial distribution of a non-spatial attribute.

In the automated building pattern identification, the rule-based method is used, and it consists of the representation of the spatial neighbour relationship using the mathematical graph; measurement of shapes to determine geometric or semantic homogeneities among a building group; the definition of rules for a specific pattern [Yan *et al*. 2019]. The cellular automata model replaces the traditional mechanics of urban models with rule-based mechanisms, and the agent-based approach seeks to represent actors in a given system, and this approach has been used to simulate urban systems and traffic dynamics [Torrens 2000]. Another strategy for classifying building patterns is based on machine learning algorithms. These methods depend on the training of labelled examples rather than on manual rule definitions for patterns [Yan *et al*. 2019].

The techniques that examine the spatial distribution of objects are the nearest neighbour and quadrat analysis, spatial tessellations and the application of Voronoi diagrams. They have been used to analyse the distribution pattern of points and spatial intensity [Williams and Wentz 2008]. The postal points methodology used in image pattern recognition is an effective way of integrating GIS data with remote sensing [Mesev 2005]. The graph-convolutional neural network model analyses graph-structured data representing grouped buildings, and the pattern features are extracted by training labelled data and classifying the building perceptual patterns [Yan *et al*. 2019]. For area-class maps and categorical data join count statistic technique is most commonly used [Williams and Wentz 2008]. The topology analysis method [Yang *et al*. 2010] is basically used to recognise the SP of the road networks.

Extracting SP from spatial data sets is more difficult than extracting patterns from the traditional numeric and categorical data due to the specific features of geographical data that preclude the use of general-purpose data mining algorithms; the data inputs for SP are also more complex because they include extended objects in vector representation and field data in regular or irregular tessellation [Shekhar *et al*. 2011]. Some SP, such as Alexander's patterns, can currently be detected only by empirical observation, though they also should be referred to as SP.

2.5. Space Syntax

2.5.1. Space Syntax Principles

Space syntax analyses cities as networks of space and lets the researcher observe how the networks relate to the functional patterns [Akkelies and Yamu 2018; Germanaitė *et al*. 2020]. Space syntax can be used as a computer model of space

[Jiang and Claramunt 1999] and address the issues pertaining to the formation of the land use strategy and location: to help boost the economy, revitalise central areas, increase social sustainability and improve cycling and pedestrian access, as it offers an evidence-based approach and a scientific and objective tool for the decision making and testing strategic interventions and design proposals [Charalambous and Mavridou 2012]. There are currently three methods available for Space syntax analysis: line-based (axial/segment) analysis, convex-space analysis, and grid-based analysis or VGA [Koutsolampros *et al*. 2019; Germanaitė *et al*. 2022].

Space syntax is based on the use of computer techniques to analyse urban configuration and to answer the question of how the various measures of the urban configuration are correlated with the aspects of social life [Rati 2004]. In its initial form, Space syntax focused mainly on the patterns of pedestrian movement in cities, but this has been extended to a number of other aspects, such as modelling urban traffic, predicting air pollution levels, assessing the occurrence of burglaries in different neighbourhoods, and estimating the potential for retail development in streets [Space Syntax 2021; Rati 2004].

Space syntax defines itself as a science-based, human-focused approach that investigates relationships between the spatial layout and a range of social, economic, and environmental occurrences, such as patterns of movement, urban growth, density, land use, societal differentiation, and safety and crime distribution [Dimililer and Akyuz 2018]. Space syntax is based on the topology and graph theory, as well as on quantitative analysis and geospatial computer technology, and it provides a set of theories and methods for the analysis of spatial configurations of all kinds and at all scales [Dimililer and Akyuz 2018; Kyu and Ban 2011].

The human movement at the city level is constrained by street networks; therefore, walkability or drivability are suggested as the basic notion for defining the axial lines [Liu and Jiang 2010]. Axial lines are defined as the least number of individual straight line segments mutually intersected along natural streets that are generated from street centre lines using the Gestalt principle of good continuity [Liu and Jiang 2010]. By representing a road and street network using an axial map, we can determine the scale-free properties of cities [Akkelies and Yamu 2018]. In the case of the axial map, the streets are the vertices of a graph, and their interconnections are the edges. The first concern of the newcomer to axial analysis would probably be related to its topological representation of the city which discards all metric information and all 3D information, and it does not take into account the land use [Rati 2004]. From the topological stance, Space syntax analysis can be considered an extension of network analysis concepts into architecture and urban planning [Rati 2004]. Space syntax adopts a connectivity graph consisting of nodes representing axial lines and links if the axial lines are intersected for the sake of understanding the underlying morphology [Liu and Jiang 2010]. The status of individual nodes in the connectivity graph can be characterised by defined Space syntax metrics, most of which have a closed link to graph theoretic metrics [Liu and Jiang 2010] and well-established topological parameters [Rati 2004], thus all axial lines are assigned some metrics for characterising their status within the axial map

[Liu and Jiang 2010]. In terms of understanding structure-function relations, the urban space seems to be globally topo-geometric but locally metric [Hillier *et al*. 2010].

At the first sight, *centrality* seems to be something static, and the central area along with its boundaries is well defined, requiring only the study of the spatial-economic layout [Akkelies and Yamu 2018]. However, when adding temporal aspects, the idea of a stable and clear centre fades: centres shift, expand, shrink or change their focus – and all this occurs in a non-linear manner [Akkelies and Yamu 2018]. Within this network, the growth of settlements entails a reorganisation of spatial systems, including the hierarchy of centres, and sub-centres, or *centrality* and *periphery* [Akkelies and Yamu 2018]. Human behaviour, expressed in the choices being made (e.g., shopping, travel behaviour), also influences the spatial form and plays a role in the constitution of centrality [Akkelies and Yamu 2018]. Space syntax measures the idea of centrality by using two logics: integration, representing *to-centrality*, and choice, representing *in-between centrality* [Akkelies and Yamu 2018]. Centrality in the networks of urban streets and centrality measures were initially developed in the social network analysis, and they are used to describe the status of individual nodes within a graph from different perspectives [Jiang 2009].

However, extensive knowledge based on the theory of Space syntax and the basic principles deriving from it is required to interpret the obtained results [Charalambous and Mavridou 2012]. Inadequate knowledge of the main concepts behind the analysis can confuse or lead to naïve and simplistic assumptions [Charalambous and Mavridou 2012].

2.5.2. Space Syntax for Spatial Pattern Identification

Space syntax as a method could be used to detect at least some of the urban patterns in spatial data. Space syntax is based on the topology and graph theory as well as on the quantitative analysis and geospatial computer technology, and it provides a set of theories and methods for the analysis of spatial configurations of all kinds and at all scales [Major 2018; Campagna 2005].

The road network pattern recognition offers good potential to identify the urban structure [Seyed *et al*. 2015], as the topology analysis method performs very well in detecting and classifying road networks, as it presents road networks by the node-edge topology in GIS [Yang *et al*. 2010]. Space syntax is a spatial network analysis method which incorporates the urban morphology and offers not only the main variables of the urban form (accessibility, density, and diversity) [Marcus 2007] but is also related to the user preference and perception of the open space [Bölen and Kaya 2017]. Space syntax can operate the axial, convex, or VGA maps and provide a range of spatial property parameters derived from the connectivity graph (connectivity, control, integration, and many others). Space syntax analysis based on different centrality measures allows us to find scale-free properties by using the normalised measures [Hillier *et al*. 2012]. The Space syntax angular segment analysis method adds improvement to the various integration analyses [Akkelies and

Yamu 2018], as it is not affected by the 'segment' problem; also, by varying the metric radius, research tends to identify more intricate local structures than it was possible with the axial analysis [Hillier 2009]. In 2018, the Space syntax *OpenMapping* project [Space Syntax Limited 2018] was released as a spatial layout model of Great Britain, and it is an open resource for urban planning, real estate analysis, and research; on top of that, Space syntax was already integrated into applications [Akkelies and Yamu 2018; Jiang 2015; Varoudis 2014].

Space syntax is both a theory of urban planning and design and a software-based technology [Charalambous and Mavridou 2012]. It is an evidence-based approach towards planning and design, with a focus on the role of spatial networks in shaping the patterns of social and economic transaction. Through configurational analysis of a street network, the Space syntax methodology investigates relationships between the spatial layout and a range of social, economic, and environmental phenomena [Charalambous and Mavridou 2012]. These phenomena include the patterns of movement, awareness, and interaction; land use density, land use mix and land value; urban growth and societal differentiation; safety and crime distribution [Charalambous and Mavridou 2012]. Research using the Space syntax approach has shown how movement patterns and flows in cities are powerfully shaped by the street network; this relation shapes the evolution of the centres and sub-centres that affect the well-being of people in the city; also, patterns of security and insecurity are affected by the spatial design; spatial segregation and social disadvantage are interrelated in cities; buildings can create more interactive organisational cultures [Charalambous and Mavridou 2012].

Space syntax was chosen for detecting spatial patterns as it demands four elements in urban analyses: it operates with a concise definition of the urban space; it offers techniques for analysing cities as networks of space; it involves techniques for observing how these networks of space relate to functional patterns; it makes possible the development of theories about how urban space networks relate to the social, economic and cognitive factors [Akkelies and Yamu 2018].

2.5.3. Space Syntax Methods

Space syntax describes spatial configuration through connectivity lines which cover all areas of a plane and makes an *axial map* [Rati 2004]. An algorithm works from an axial graph constructed by the use of axial lines as nodes and their crossing points as connections [Hillier 2009]. Based on the algorithm, the axial map is the minimal set of axial lines that are linked in such a way that they completely cover the space and preserve topological rings [Rati 2004]. Based on the visualised axial maps, it is possible to further assess the city legibility of the street patterns [Hillier *et al*. 2012].

The computational Space syntax model is based on a graph-oriented representation of the geographical space and is based on a two-step approach: 1) the representation of the large-scale space as a finite number of small-scale spaces; 2) the linking of these individual small-scale spaces so that to form a connectivity graph [Jiang *et al*. 2000].

The current CAAD systems with the building information modelling capability can recognise building components and spaces, but cannot yet perform spatial analysis that measures the topological properties of the building entities by using the Space syntax technique [Kyu and Ban 2011]. Sang Kyu [Kyu and Ban 2011] developed computational algorithms to evaluate design solutions by using Space syntax during the process of computer-aided architectural designing and proposed algorithms to extract topological information from design solutions and to recognise building information produced in the form of industry foundation classes, to deduce the necessary topological information, and to store the information in the form of matrices (two-dimensional arrays) [Kyu and Ban 2011]. The Space syntax theory is employed to evaluate the solutions based on the social properties of spaces in a building and to examine the potential for adding a spatial analysis function into CAAD applications [Kyu and Ban 2011].

Traditional CAAD programs internally represent data by using geometric entities such as points, lines, rectangles, and planes, and they cannot capture domain-specific information about entities [Kyu and Ban 2011]. To overcome the limitations of general-purpose geometric representations, researchers have been developing and using object-based data models that are specific to their domain. This translates to a data model that is built around building entities and their relationships [Kyu and Ban 2011]. The developed algorithms calculate the integration value for each space from the spatial connectivity based on *J-graphs* [Kyu and Ban 2011]. To validate the proposed algorithms, a program named *J-Studio for Architectural Planning* was developed to evaluate design solutions easily and quickly [Kyu and Ban 2011]. The validation results are as follows: 1) the topological information extracted from building information was recoded into a dimensionless representation and legible J-graph; 2) mathematical analyses for choosing a better design solution when conducting computer-aided architectural design were presented; 3) the examination of the privacy level of each space in a building through Space syntax analysis was discussed [Kyu and Ban 2011].

Angular segment analysis breaks axial lines into segments and then records the sum of the angles turned from the starting segment to any other segment within the system [Turner 2007]. This angular sum is treated as the *cost* of a putative journey through the graph, and, from it, a shortest (that is, the least cost) path from one segment to another across the system can be calculated [Turner 2007]. The angular segment analysis is not affected by the segment problem, e.g., when axial lines, when broken into segments, may have an associated higher transfer *cost* than the straight lines because each step to the next segment incurs a penalty [Turner 2007]. In angular segment analysis, because there is no angular turn to another segment that leads straight on, there is no associated cost, and thus a path that continues in the current direction is by definition continuous across the junction [Turner 2007].

Metric distance analysis measures are difficult to incorporate within Space syntax as the representation of the nodes as lines mean that an edge between the nodes (a line – line intersection) naturally has no distance component [Turner 2007].

Varying the metric radius tends to identify more intricate local structures than it was previously possible with the line-based technology [Hillier 2009]. The cities take a generic dual form: that of a *foreground network* of linked centres at all scales, from a couple of shops and a café at the smallest scale to the whole sub-cities at the largest, with all being set into a *background network* of mainly residential space [Hillier 2009]. The foreground network is made up of a relatively small number of longer lines connected at their ends by open angles, and forming a super-ordinate structure within which we find the background network made up of much larger numbers of shorter lines which tend to intersect each other and to be connected at their ends by near-right angles, and which form local grid-like clusters [Hillier 2009]. The least angle choice measures will normally identify the foreground network, and they do so at different scales by varying the metric radius of the measures, for example, at radius *n*, the choice identifies the main structure of global routes in London; at a radius of 750 meters, the same analysis identifies a much more localised network of small London 'villages' most of which do not feature on the larger scale map [Hillier 2009].

Space syntax measures the two primary *all-street-segments-to-all-others* relationships [Akkelies and Yamu 2018]. Firstly, it measures the to-movement – or accessibility – the potential of each street segment with respect to all others [Akkelies and Yamu 2018]. Secondly, it measures the through-movement potential of each street segment with respect to all pairs of others [Akkelies and Yamu 2018]. Each of these two types of relational patterns can be weighted according to three different definitions of distance [Akkelies and Yamu 2018]. The metric distance measures the city's street and road network as a system of the shortest paths, while the topological distance calculates the city's street and road network as a system of the fewest turns paths. Finally, the geometrical distance offers a picture of the city's street and road network as a system of the least angle-change paths. Each type of relationship can be calculated at different radii from each street segment, again defining the radius either in terms of the shortest, the fewest turns, or the least angle paths [Akkelies and Yamu 2018].

Global integration analysis implies calculating how spatially integrated a street axis is in terms of the total number of direction changes in relation to all other streets in a town or a city [Akkelies and Yamu 2018]. The fewer there are changes of direction, the higher is the global integration value [Akkelies and Yamu 2018]. The key to assessing the local integration of a built environment lies in calculating the average value of the mean depth of all streets in a built environment [Akkelies and Yamu 2018]. As research has shown, this varies in different cultures [Akkelies and Yamu 2018].

Angular integration analysis is an extension of visibility graph analysis and axial analysis. What the angular analysis adds to the various integration analyses is that the axial map is broken up into segments, from junction to junction, and each segment line is weighted by the angle of its connections to other segment lines [Akkelies and Yamu 2018].

Angular closeness. Space syntax practitioners use a measure of centrality similar to closeness by first calculating the mean depth from a location, and then applying a relativisation formula. The mean depth is calculated by simply taking the average length of all shortest paths [Turner 2007].

Angular segment analysis breaks axial lines into segments and then records the sum of the angles turned from the starting segment to any other segment within the system [Turner 2007]. This angular sum is treated as the *cost* of a putative journey through the graph, and, from it, a shortest (that is, the least cost) path from one segment to another across the system can be calculated [Turner 2007]. Angular segment analysis is not affected by the segment problem, e.g., by the situations when axial lines, when broken into segments, have the associated higher transfer 'cost' than the straight lines because each step to the next segment incurs a penalty [Turner 2007]. In angular segment analysis, because there is no angular turn to another segment that leads straight on, there is no associated cost, and thus a path that continues in the current direction is by definition continuous across the junction [Turner 2007].

Choice or Angular betweenness. Cognitive scientists have long suggested that the angle of turn has much to do with how people perceive the world [Turner 2007]. The angular relationship of streets plays a role in the way people orientate themselves through the built environment, e.g., people choose the straightest possible routes to avoid complexity when finding their way through urban street grids [Akkelies and Yamu 2018]. As the initial results have shown, the least angle analysis seems to be the best predictor of movement, followed closely by the fewest turns (based on the results of global and local integration analyses), and the metric distance comes far behind these two [Akkelies and Yamu 2018].

In addition, when calculating the topological distance, the metric distance and angular relationships are also taken into account [Akkelies and Yamu 2018]. The metric distance measures how metrically integrated a street or a road is in relationship to all others, while angular choice measurements show how integrated a street is in terms of the angular degrees needed to change from one street to all others in a system [Akkelies and Yamu 2018]. Angular integration analysis shows the 'to-movement potential' of a built environment, thus highlighting urban centres, while angular choice analysis shows the 'through movement potential', thus highlighting the main routes through a built environment [Akkelies and Yamu 2018].

Betweenness or *choice* is calculated by generating the shortest paths between all segments within the system (e.g., the journey with the lowest angular cost for each possible origin and destination pair of segments), and then the flow through each segment is summed up according to how many journeys are made through each segment, and divided through by the total number of possible journeys [Turner 2007].

VGA is a means to quantify the configuration of space as regular units which can then be used to identify the relationship of that space to the behaviour of the humans that occupy it [Koutsolampros *et al*. 2019]. For the graph, the notation is defined as $G = \langle V, E \rangle$ where V (the vertices) are the cells of the grid that are part of the graph: $V = \{v_1, v_2, \dots, v_n\}$ and E (the edges) are the pairs of mutually visible cells: $E = \{e_1, e_2, \dots, e_n\}$. For a specific vertex v_j neighbourhood (the other cells that are visible from it), it is defined as: $N(v_i) = \{v_j | e_{ij} \in E\}$ [Koutsolampros *et al*. 2019; Germanaitė *et al*. 2022]. An isovist is all the points visible from a specific point in space, and, in two dimensions, it can be thought of as a polygon [Koutsolampros *et al*. 2019]. Apart from providing a way to make the graph, isovists also allow for the creation of different metrics that describe the space that is around a cell, such as its area or perimeter [Koutsolampros *et al*. 2019]. The graph may also be limited in the visible distance when created; in this case, the cells that are within the isovist but beyond that limit will not be marked as within the visible area and thus are deemed to be not connected to the cell the isovist was generated from [Koutsolampros *et al*. 2019; Germanaitė *et al*. 2022].

2.5.4. Space Syntax Measures

The theory of cities with the use of Space syntax proposes that urban street networks have a dual form: a foreground network of linked centres at all scales, and a background network of primarily residential space in which the foreground network is embedded [Hillier *et al*. 2010]. The theory also notes a mathematical duality: on the one hand, topo-geometric measures which express the geometric and topological properties of the network at an extended scale (such as the integration and choice measures in axial maps or segment angular maps) are needed to capture the structure-function relations such as the natural movement patterns; on the other hand, at a more localised level, understanding of structure-function relations often requires an account of the metric properties (the phenomenon of the grid intensification so that to reduce the mean trip lengths in live centres, to induce the fall of movement rates with the metric distance from the attractors, and the phenomenon of the commonly observed decay of shopping when metric distance from an intersection increases) [Hillier *et al*. 2010]. In terms of understanding structure-function relations, the urban space seems to be globally topo-geometric but locally metric [Hillier *et al*. 2010].

Centrality has remained a fundamental concept in the network analysis since its introduction in structural sociology [Crucitti *et al*. 2005]. Each centrality (*closeness centrality*, *betweenness centrality*, *straightness centrality*, *information centrality*) captures a different aspect of one place's 'being central' in the geographic space, and, by the use of many centrality measures, it is possible to capture structural similarities and dissimilarities across cities and to find the correlation between the structural properties of the system and the relevant dynamics of the system, such as pedestrian/vehicular flows and the retail commerce vitality – all of this information has traditionally been associated to spatial graphs [Crucitti *et al*. 2005]. Some of these factors are more strictly correlated to some centrality indices than to others, thus giving informed indications for the strategies of SPD [Crucitti *et al*. 2005].

Space syntax provides a range of spatial property parameters derived from the connectivity graph: *connectivity*, defined as the number of nodes directly linked to each node in the connectivity graph, *control value*, defined as a parameter that expresses the degree of choice each node represents for nodes directly linked to it, and *integration*, which indicates the degree to which a node is integrated or segregated from a system as a whole or a partial system [Jiang *et al*. 2000].

Four analogous *metric distance* measures arrived at simply by substituting the graph distance calculation: metric closeness, length-weighted metric closeness, metric betweenness, and length-weighted metric betweenness [Turner 2007].

Radius measures are used within Space syntax to avoid edge effects or to observe a local phenomenon: rather than calculate the graph measure from a segment *x* to all other segments, the measure is calculated from *x* to all other segments within a certain number of steps of *x* [Turner 2007]. A metric radius should be used for the graphs, so the analysis can be limited to a metric radius within the boundary of the modelled area, and thus it does not encounter the edge of the graph [Turner 2007]. This means that 'edge effects' can be avoided in the central analysis zone of the graph [Turner 2007].

Angular segment analysis by the metric distance (ASAMD) is included in the axial analysis; furthermore, it also includes the angles of incidence between lines, the segmentation by the junction of the axial line, and the effect that metric radii would have on the choice of routes and the destinations of the trip [Charalambous and Mavridou 2012]. For ASAMD, the indicators that are used in addition to the axial lines connectivity and the topological distance are the axial lines segmentation by junctions (the segment map), the angularity between axial lines, and the metric distance measured on axial lines' segments [Charalambous and Mavridou 2012]. Consequently, this instrument is based on the axial lines segments between junctions; it allows three types (measures) of distance: [Charalambous and Mavridou 2012] metric (the shortest paths); topological (the fewest turns paths); and geometrical (the least angle change paths). ASAMD calculates two main measures [Charalambous and Mavridou 2012]:

• Integration (closeness): how close each segment is to all others under different types of distance and at a different scale; this is known as 'to-movement'. Integration describes how easy it is to get to one segment from all other segments. In practical terms, this would mean that pedestrians would end up in such a space more often and with less effort. This spatial attribute can then define the type of land use that would fit best in this space.

• Choice (betweenness): how much movement is likely to pass through each segment on trips between all other segments, again by using different types of distance and different radii. Choice describes how likely you are to pass through the segment on trips, and so estimates its potential as a route, from all segments to all others. Again, this spatial attribute can define the type of land use that would fit best in this space, and possibly certain land uses would require spaces with a high integration value.

The results indicate that spatial analysis based on a set of different centrality measures (properly extended for spatial graphs) allows: 1) visual characterisation of the structural properties of a city; 2) evidence that planned and self-organised cities belong to two different universality classes; 3) finding scale-free properties similar to those found in the degree distributions of relational (non-spatial) networks [Crucitti *et al*. 2005].

2.5.5. Space Syntax Software and Tools

A range of software [Gil *et al*. 2015] has been developed to perform Space syntax analysis, to handle geographic and geometric data associated with attribute information, to perform spatial, mathematical, and statistical calculations, and to visualise the results.

In this work, we use the main tool used by the Space syntax community: *DepthmapX* [Varoudis 2014]. There are 25 VGA metrics that *DepthmapX* can currently calculate, a mixture of the classic graph-theory metrics, metrics borrowed from the urban-scale Space syntax theories, and some VGA-specific metrics describing local spatial properties [Koutsolampros *et al*. 2019]. *DepthmapX* provides a set of global metrics, e.g., for each cell, the values are affected by every other cell in the set, and the aspect that provides this connection in VGA is *Visual depth* – the least amount of visual steps (a step from a cell to any other immediately visible cell) required to reach another point in the space, and given that the grid also functions as an undirected graph, the visual metrics can be thought of as the topological distance in steps [Koutsolampros *et al*. 2019; Germanaitė *et al*. 2022].

DepthmapX is a multi-platform software used to produce graphical visualisations or maps of open space elements that are related to various phenomena, such as intervisibility, overlap, and density [Turner 2001]. *DepthmapX* is a program designed to perform *visibility graph analysis* (VGA) of spatial environments. The program allows its user to import a 2D layout in the drawing exchange format (*.DXF), and to fill the open spaces of this layout with a grid of points. The user may then use the program to make a visibility graph representing the visible connections between those point locations. Once the graph has been constructed, the user may perform various analyses of the graph, while concentrating on those which have previously been found to be useful for spatial description and movement forecasting [Turner 2001].

Analysis of the segment map can be produced by *Depthmap* [Charalambous and Mavridou 2012]. *Depthmap* also offers the capability of extension through two levels of interface. The first level, a scripting interface based on the Python language, allows researchers to calculate newly derived measures as well as to add graph measures, such as circuit lengths, for each of the graph types. It also allows the ability to select groups of nodes according to the value or according to simple algorithms. The second level, the *Software Developers'*, allows programmers to write new forms of analysis [Charalambous and Mavridou 2012].

Depthmap embodies a theory of the city, and it also serves as a method for analysing the city [Hillier *et al*. 2012]. By solving the outstanding problems of the normalisation of measures, most notably the syntactic choice (mathematical betweenness), it permits comparison of cities of different sizes, and we can thus gain new theoretical insights into their spatial structuring [Hillier *et al*. 2012].

The basic element in *Depthmap* is the street segment between intersections [Hillier 2009]. *Depthmap* generates this automatically from the least line, or axial, map, and *Space Syntax Limited* has now developed algorithms to derive it from the road centre line data (thus allowing entire regions or even whole countries to be modelled). *Depthmap* allows 3 definitions of the distance between each segment and each of its neighbours: metric, that is the distance in meters between the centre of a segment and the centre of a neighbouring segment; topological, assigning a value of 1 if there is a change of direction between a segment and a neighbouring segment, and 0 if not; and geometric – assigning the degree of the angular change of direction between a segment and a neighbour, so straight connected points are 0-valued and a line is a sequence of 0-valued connections so that the linear structure of cities is captured [Hillier 2009]. It then uses these 3 concepts of distance to calculate two kinds of measure: syntactic integration, or mathematical closeness, which measures how close each segment is to all others under each definition of distance; and the syntactic choice, or mathematical betweenness, which calculates how many distance-minimising paths between every pair of segments lie on for each segment under different definitions of distance. Consequently, when using the metric definition of distance, we find the system of the shortest path maps for the integration and choice, and, with the topological definition, we find the system of the fewest turns maps, whereas, with the geometrical definition, we find the system of the least angle change maps [Hillier 2009]. Each of the 6 measures (2 measures with 3 definitions of distance) can then be applied with the 3 definitions of distance used as definitions of the radius at which the measures can be applied, thus giving a total of 18 measures which can, of course, be applied at any radius, so yielding a potentially very large set of the possible measures – for example, the least angle change choice at a metric radius of 800 meters – which would be infinite if we count the smallest variation in the metric radius [Hillier 2009].

Several authors have developed different computer programs for the construction of axial and segment maps: some programs have been implemented in GIS, such as *Axman* (a Mac-based application) and *Axwoman* (a Windows-based application), both used to draw axial lines and to analyse axial maps of urban and interior spaces [Villaverde *et al*. 2013]. Other software programs have been designed to generate axial and segment maps automatically – for instance, a universal-platform software called *Depthmap* can be used to perform a set of spatial network analyses designed to explain social processes within a built environment, or *AxialGen* – a research prototype for automatically generating axial maps in order to demonstrate that axial lines constitute a true skeleton of an urban space [Villaverde *et al*. 2013]. The most recent version of *Depthmap* now supplies a range of configurational analyses that include the original visibility analysis, the generation and analysis of axial maps, and segment analysis [Depthmap 2018].

Jiang [Jiang *et al*. 1999] implemented the Space syntax software prototype *Axwoman* in an *ArcView* extension. *ArcView* was chosen because of its user-friendly graphical user interface and its potential to extend spatial analysis using the built-in scripting language *Avenue*. This desktop GIS combines different analytical measures and data representation capabilities through a number of output representations, namely *View*, *Table*, *Chart*, *Layout*, and *Script*. Amongst others, the *Avenue* scripting language which is object-oriented permits the customisation of the interface and provides useful built-in classes for graphics manipulation, spatial queries, and basic arithmetic calculations [Jiang *et al*. 1999]. *Axwoman* was designed as a specific graphical environment by modifying the currently existing *ArcView* controls (menus, menu items, buttons, and tools), and linking scripts that embody the calculations necessary to implement Space syntax with new controls created in any of the available windows (*Project*, *View*, *Table*, *Chart*, *Lay-out*, or *Script*) [Jiang *et al*. 1999]. *Axwoman* is based on the vector data structure of a GIS to represent the graph components of the Space syntax [Jiang *et al*. 2000]. The three main functions (i.e., drawing, computation, and analysis) are implemented by using *Avenue* scripts with different interface modules: drawing with view, computation with view and table, and analysis with table and chart [Jiang *et al*. 2000]. The computed results are stored in a table corresponding to the axial map or polygon theme [14]. When using *Avenue*, the calculation of integration is rather difficult and time-consuming as it involves the calculation of the *total depth*, which shows the positional status of a node within a graph [Jiang *et al*. 2000]. The main principle of the algorithm for calculating the total depth is the *Breadth First Search* traversal approach, i.e., to begin at the root and find its neighbours, and then their neighbours, and so on, until one has traversed the entire graph and reached all nodes [Jiang *et al*. 2000]. Once the computation has been completed, all the computed results are stored in an attribute table, a new map theme is created, and it is coloured thereby representing the calculated values [Jiang *et al*. 2000]. The Space syntax implementation realised within *Axwoman* is currently oriented towards the analysis of the dual graph based on the axial line and convex polygon representations [Jiang *et al*. 2000].

The *Space Syntax Toolkit* is a Python plug-in for QGIS that integrates *DepthmapX*[net] and is used for spatial network and statistical analysis. This toolkit implements the basic workflow of axial and segment map analysis from the map production to the publication of the results, thus emulating in part the exploratory spatial analysis features of *DepthmapX*. It is primarily aimed at supporting the Space syntax methodology and enhancing it with GIS data, analysis, and visualisation [Gil *et al*. 2015].

The *Urban Network Analysis* toolbox is an open-source toolbox for spatial network analysis in the ArcGIS 10 software platform. It introduced two important modifications to the network representation of the built environment. First, it added buildings (or other location instances) to the representation, thus adopting a tripartite representation that consists of three basic elements: edges, nodes, and buildings [Sevtsuk and Mekonnen 2012]. Secondly, this toolbox introduced a weighted representation of spatial network elements: each building obtains a set of attributes that connect the building in the graph with the true characteristics of the corresponding structure in the city [Sevtsuk and Mekonnen 2012].

Computational algorithms to evaluate design solutions while using Space syntax during the process of computer-aided architectural designing were also developed [Kyu and Ban 2011]. These algorithms extract topological information from design solutions and recognise building information produced in the form of industry foundation classes so that to deduce the necessary topological information and to store the information in the form of matrices (two-dimensional arrays) [Kyu and Ban 2011].

2.6. Summary

In this chapter, CSS as a system of interest and the object of SP analysis was overviewed, and the decision was made that the CSS variables that have to be analysed are properties of locations which are either averages for the location (e.g., density) or functions of the whole surrounding environment (e.g., accessibilities) [Wilson 2008], but the CSS modelling task requires a methodology for such analysis. The main objective of CSS analysis in the SPD domain is the urban sustainability which can be measured by the spatial capital dimension.

After looking through the different SP types and description methods, the conclusion was made that, although the taxonomy of SP has been studied extensively, there remains a lack of a clear and unanimous criterion for SP definition and automated identification [Yan *et al*. 2019; Germanaitė *et al*. 2020]. The modelling options of the metapatterns were noted as SP can be identified by using small indivisible spatial or logical elements that could be used to identify SP of different scales and complexity. The different kinds of SP attributes were overviewed, and then four categories of SP spatial properties were selected as the most suitable options to describe SP: 1) geometrical; 2) topological; 3) visibility and perception; 4) complexity [Bölen and Kaya 2017; Germanaitė *et al*. 2020]. The main research methods used in this research have been chosen, and they are the *design science research in IS* [Hevner and Chatterjee 2010] and the *complex spatial system approach* [Wilson 2008].

The spatial analysis methods were overviewed concluding that analytical mathematical methods are not sufficient for CSS analysis because not enough is known about the system so that to make mathematical analysis possible, the system is too large for feasible analysis, and there are too many variables [Wilson 2008]. Spatial analysis can be used for describing or measuring SP while involving the use of qualitative methods which include morphological and morphographic descriptions, and quantitative methods which include network component analysis, the graph theory (e.g., Space syntax), and the fractal dimension [Marshall and Gong

2009], but some SPs, such as Alexander's patterns, can currently be detected only by empirical observation, though they also should be referred as SP.

Space syntax principles, methods, measures, and software tools were analysed, and, as a result, the Space syntax method was chosen for detecting SP as it demands four elements in urban analyses: it operates with a concise definition of the urban space; it offers techniques for analysing cities as networks of space; it involves techniques for observing how these networks of space relate to functional patterns; it makes possible to develop theories about how urban space networks relate to the social, economic and cognitive factors [Akkelies and Yamu 2018]. Also, it was indicated that spatial analysis based on a set of different centrality measures allows: 1) visual characterisation of the structural properties of a city; 2) to gain evidence that planned and self-organised cities belong to two different universality classes; 3) to find scale-free properties similar to those found in the degree distributions of relational (non-spatial) networks [Crucitti *et al*. 2005].

After conducting the research background overview, it was concluded that analytical mathematical methods alone are not sufficient for CSS analysis, and some SP can currently only be detected by the empirical research. This leads to a conclusion that there is a lack of methods and tools for spatial quantitative analysis.

3. SPDIAM ESSENTIAL ASSUMPTIONS
3.1. SPDIAM Problem Decomposition

Design science research in IS is guided by the specific research problem that is usually divided into more manageable sub-problems, which accepts certain critical assumptions, and requires collection and interpretation of data as well as creation of IT artefacts [Hevner and Chatterjee 2010]. The standard analytical CSS problems, which can be solved by SP, have a spatial, functional, and structural background. We may pose a number of target questions: Where is CSS's spatial, economic, social, or environmental capital? What is the pattern of that capital? Is the existing capital optimal? What/which parts of CSS are more important than the others? Is the planned spatial intervention, such as urban development, in synergy with the existing capital, or will it force to change – or even no longer use – the currently existing capital? The relation between such analytical problems, solutions (or SP), and objectives that could be set for CSS is presented in Fig. 2. Each solution has to be stated in such a way that it gives the essential field of relationships needed to solve the problem, but in a very general and abstract way, so that the analyst can solve the problem by adapting it to his/her preferences, and the local conditions [Alexander 1977].

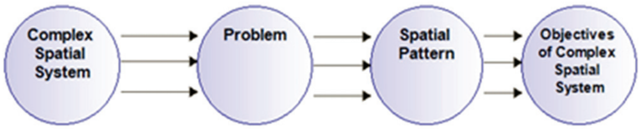


Figure 2 Relations between CSS, problem, SP and objectives of CSS future development

In CSS, the effectiveness of the developed methodology is the extent to which it can lead to efficient modes of analysis that will contribute to problem-solving in these contexts. For it, we have to aggregate the properties, measures, and indicators describing CSS into abstract logical entities, thus creating IT artefacts necessary for solving the tasks of SPD analysis. The main questions that arise with these goals are described below.

How to describe and analyse CSS? CSS has to be analysed in the case when statistical analysis, mathematical modelling, and system analysis methods are insufficient (e.g., whenever not enough is known about the system to make mathematical analysis possible; the system is too large for feasible analysis; there are too many variables) [Wilson 2008]. How do we describe a system of interest? How do we describe the associated analytical problems? In the available quantitative GIS tools, the detailed picture of the system of interest and the associated analytical problems are often omitted, and the preliminary analysis of systems along with theorising cannot be done in such activities as entitation, scale context, spatial representation, partial-comprehensive model, preliminary ideas about the theory (including the appropriate conceptualisation) [Wilson 2008]. Because of the high levels of connectivity between the different entities and subsystems, there is a strong argument for building a highly comprehensive model, within which, these points could be taken into account, but the ideal solution is often impractical, and partial approaches have to be used [Wilson 2008]; that is why, *managing consequences of interdependence* must be taken into account.

What are the examples of CSS that should be analysed? *Systems of interest* for spatial analysis [Wilson 2008]:

- Regional systems (Cities, Regions, the European Union);
- Urban systems (Cities disaggregated to show their structure and working);
- Functional systems (economic (agriculture, resource, manufacturing industry, consumer services, producer services), social, labour market);
- Spatial systems (point patterns (e.g., systems of cities), interactions (commuting flows), networks (traffic, communications)).

How to describe and analyse CSS analytical problems? For example, the standard analytical CSS problem that has spatial, functional, and even structural background is the question where there is the spatial, economic, social, or environmental capital in CSS. What is the pattern of that capital? Is the existing capital optimal? What parts of CSS are the more important ones? Are spatial interventions (urban development) being planned in synergy with the existing capital pattern or will it force some change or non-utilisation of the spatial potential? In CSS, the effectiveness of the developed methodology is the extent to which it can lead to efficient modes of analysis that will contribute to problem-solving in these contexts [Germanaitė *et al*. 2020]. For it, we have to aggregate the properties, measures, and indicators describing CSS into abstract logical entities, thus creating IT artefacts necessary for solving the tasks of SPD analysis.

How to contribute to problem-solving in these contexts? The difference between SPDIAM and the other methods is that the similar methods and the research are often limited to analysing the local spatial relationships as a basis, but we do not seek synergies with the models at the higher hierarchical levels. SPDIAM assesses the city at many scales and levels that are inseparable and interrelated, and can be modelled from the bottom-up to the higher hierarchical level by associating it with Alexander's patterns or geographical models, thus giving these known SPs a complex basis and thereby accessing the top-down models from the bottom-up side. SPDIAM improves the quantitative and qualitative characteristics of the already existing spatial analysis tools by using normalised indicators, which allows CSS to be compared with each other, and also allows all spatial network information to be used.

How do we describe SP in a computerised manner? SPDIAM allows us to define a method of SP description, identification, and application in CSS by using SPDIAM, which includes the static and the dynamic process description. How do we structure SP and its method properties, SP values, identification methods, measures and indicators, spatial presentations and cases of application uses? SP constraints and SP application use cases need to be analysed and described in order to develop a specification and data model for the methods aimed to describe, define, and apply SP.

How do we identify SP automatically? How can we evaluate the already identified SP? What generic and specific spatial tools can be used? SPDIAM allows us to identify SP automatically in CSS by using a defined description of SP and the created algorithm of the SP identification method, measures, and user-defined rules. The SP identification method proposed in SPDIAM combines several methods (the graph theory and Spatial syntax, properties of geographic models, and new normalised measures proposed by the author). To the best of our knowledge, so far, this method has never been applied to the description and automated identification of SP in CSS.

How do we use quantitative methods instead of qualitative ones? The method of SP identification proposed in SPDIAM allows automating quantitative SP identification methods instead of the dominant qualitative methods in SPD.

How do we define SP based on quantifiable and scientifically based measures? SP has to be described by using SP values that should be defined by using quantifiable and scientifically based measures depending on the method chosen for SP identification. Scientifically based measures are obtained according to a clear methodology that can be verified, and the same results can be obtained by the observers if the methodology is the same.

How can we measure spatial entity parameters? How do we perform a comprehensive assessment of a spatial entity based on parameter sets? We have to aggregate the properties, parameters, and indicators describing the spatial object (or CSS) into abstract logical entities, thus creating the artefacts necessary for solving the tasks of SPD analysis.

How do we apply SP? What are the cases of use? The most common cases of the use of SPD analysis are [Wilson 2008]:

1. *Policy* use cases (specification of the goals and evaluation of choice from alternatives):
    - the setting of quantities that are controllable (the number of houses permitted in each zone of the city);
    - measurement of costs and benefits.
2. *Design* use cases (generating alternative plans):
    - invention and testing through the analysis of impacts;
    - use of the optimisation methods to generate an/the optimal plan.
3. *Analysis* use cases:
    - system analysis (geographical analysis);
    - predicting future problems and needs;
    - impact of plans (the material which forms the basis for evaluation procedures).

How do we use SP with statistical data? How do we analyse spatial entities by using different dimensions (such as economic, environmental, social, etc.)? Statistical indicators with spatial data should be used to get additional information about the different dimensions of CSS.

How do we indicate the possible directions of SP changes in the future? We would like to assess the change in CSS over time: how CSS will change, and what the possible directions of these changes are. We may wonder if we can foresee them in advance.

How can we improve the quality of SP application: how can we make it more quantifiable, more complex? How do we add quantitative and qualitative improvement to the spatial network analysis tools in GIS? SPDIAM extends the possibilities of spatial analysis and the set of possible applications of SPD analysis and the methods used in spatial analysis tools by using SP.

How can we make SP flexible and configurable? User-defined SPs in CSS, same as in other IT artefacts, are critically dependent upon human cognitive (creativity) and social (teamwork) abilities to produce effective solutions, so they must be flexible and configurable [Hevner and Chatterjee 2010]. User-defined SPs can be described by using spatial or logical metapatterns and other SPs. Metapatterns can be used for the development and identification of other SPs, thus forming a library of spatial metapatterns and facilitating the solution of the applied SPD analysis tasks. The constructs created by Space syntax or other spatial analysis or spatial network analysis methods are sometimes too complex and difficult to understand. Some systems serving the objective of making these constructs simple and easy to understand must be designed.

How can we extend SPDIAM? Many spatial problems, across domains, share many common features but are distinguished by the different objectives in those domains. Many of the geographical problems, across sectors, have many common features but are then distinguished by the different objectives of the units in those sectors [Wilson 2008].

Summarising the assumptions from Chapter 2 and the considerations above, the proposed decomposition of SPDIAM problems is presented in Fig. 3. It reflects the complexity of the problem of applying SPDIAM and can be used as a basis for the further development of the proposal. Table 3 provides detailed descriptions of the components of the SPDIAM problems.

Table 3 Decomposition of SPDIAM problems and solutions

Question	Component of Problem	Solution	Concept
1. How can CSS be described?	1.1. How can a CSS model be created?	a) partially comprehensive model b) bottom-up model	Spatial Entity (CSS model)
	1.2. How can CSS analytical problems be described?	a) classify and assign solution (SP) to the problem	Problem
2. How can SP be described in a computerised manner?	2.1. How can SP properties and values be structured?	a) create SP b) create SP attributes c) create SP values	Pattern, Pattern Attribute
	2.2. How can user-defined and reusable SP be created?	a) create SP based on previously defined metapatterns and SP	Pattern Type Pattern Attribute
	2.3. How can SP be made configurable and extendable?	a) use SP value measures b) create new measures with new measure	Pattern Value, Measure, Measure

Question	Component of Problem	Solution	Concept
		attributes	Attribute
3. How can SP be identified automatically?	3.1. How can CSS properties be described?	a) define quantifiable and scientifically based CSS measures b) perform an assessment of CSS based on sets of measures	Spatial Entity Attribute, Measure, Measure Attribute, Pattern Value
	3.2. How can CSS properties be measured?	a) use whole CSS information b) combine different methods c) use generic and specific spatial tools d) make constructs created by method simple and understandable	Method, Operation Form, Structure
	3.3. How can the identified SP be evaluated?	a) use statistical indicators	Indicator
4. How can SP be applied?	4.1. How can the present CSS model be analysed?	a) assess CSS at different sizes and levels b) compare different CSS c) use SP with CSS statistical data d) use different dimensions e) associate SP with other patterns and models f) use quantitative methods instead of qualitative ones g) manage consequences of interdependence	Method, Measure, Indicator, Pattern Attribute
	4.2. How can the directions of SP changes in the future be indicated?	a) use CSS measures	Operation

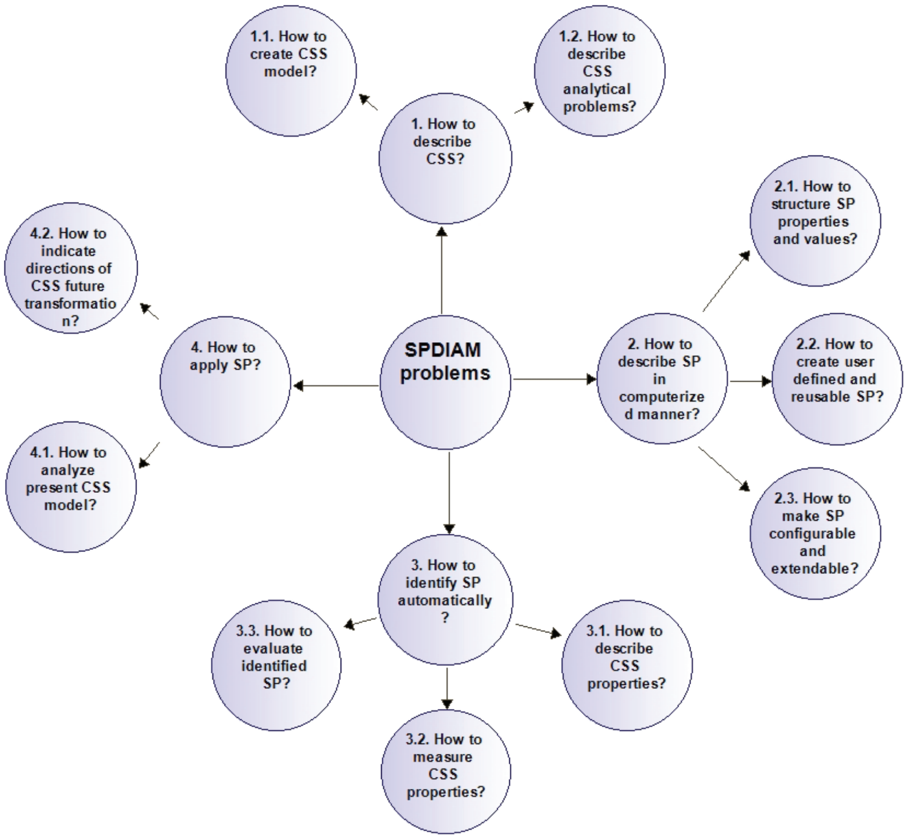


Figure 3 SPDIAM problems

3.2. SPDIAM Development Process

After decomposing SPDIAM problems, the next step should be to choose the appropriate SPDIAM development process that has to be guided by the IS design science research principles and, at the same time, to cover the features of CSS. In Table 4, there is a summary of the systematised basic concepts that need to be evaluated and pre-compiled so that to create SPDIAM.

Table 4 SPDIAM development (based on [Wilson 2008; Hevner and Chatterjee 2010])

System of interest definition	Theory development for the system of interest	Deployment of appropriate methods to operationalise the theory	Creation of IT artefacts
CONCEPTS			
CSS: described by many variables, with high levels of interdependence between elements, governed by nonlinear	**Essential assumptions** for the developing general SP model that solves problems in CSS:	**Essential assumptions for application:** • SPD solutions depend on parameters; • critical values of	**Artefacts within IS design science research** are knowledge containing:

System of interest definition	Theory development for the system of interest	Deployment of appropriate methods to operationalise the theory	Creation of IT artefacts
processes and having significant spatial structure. **CSS elements:** organisations and infrastructure – can be assembled in a very large number of different ways at different scales into systems **Entities:** are components of systems of interest that have to be <u>defined</u> and <u>categorised</u>, many of them have to be <u>located</u> in space, and their behaviour has to be <u>described over time</u>. **Basic entities with urban and regional analysis**: • Physical structures and facilities (all kinds of buildings and infrastructure, roads included) • Relational structures (the relations of any entity with any other) • Organisations (activities (dispersed or concentrated and processes)) • Commodities, goods, and services (products of organisations) • Land • People ('agents'): the agent is a subsystem. The agent's behaviour is partly determined by this structure; the structure can be modified by the agent.	1. There is SP formed by the existing distribution of variables across space. 2. Out of these distributions, certain aggregate quantities can be calculated (such as densities and accessibilities). 3. Aggregate quantities form part of the basis for ongoing decisions. 4. The decisions will generate changes in CSS as a whole.	parameters, when the emergent structure changes; • solutions depend on the initial conditions – illustrating path dependence. **Analysis is concerned with:** • the pattern of activities, the associated infrastructure, and flows (at different scales); • the process that is continually changing this pattern. **Additional analysis can be done through**: • analytical human geography; • associated disciplines. **Main geographical features** of systems that form the subject matter of theory: • location and land use mix; • associated infrastructure; • interactions and network flow between activities at different locations (interdependences). **Variables are properties of locations:** • averages for the location (e.g., density); • functions of the whole surrounding environment (e.g., accessibilities). **The choice of the method** is to be made concerning: • the complexity of the system and the associated theory; • available appropriate mathematical methods; • most often in practice: by the skills and training of analysts.	• design logic; • construction methods; • tool(s) to assumptions about the context in which the artefact is intended to function. **Artefacts:** • are synthesised; • may imitate appearances of natural things; • can be characterised in terms of the functions, goals, adaptation; • are often discussed in terms of both imperatives and descriptives.

System of interest definition	Theory development for the system of interest	Deployment of appropriate methods to operationalise the theory	Creation of IT artefacts
TASKS			
1. Entitation. 2. Levels of resolution with three sub-components: • sectoral (number and breadth of categories); • spatial (Cartesian coordinates or a discrete zone system (a square grid or administrative units); • temporal. 3. Spatial Representation.	1. Explaining the overall pattern at a particular point in time. 2. Explaining the rates of change at any time.	1. Preliminary systems analysis and theorising: detailed picture of the system of interest and the associated analytical problems: • Entitation; • Scale; • Spatial representation; • Partial-Comprehensive; • Preliminary ideas about theory (including the appropriate conceptualisation). 2. Statistical analysis (inductive approach) for the selection and categorisation of variables. 3. Mathematical modelling and formal systems analysis (deductive approach) for the goodness-of-fit tests and calibration procedures. 4. Application in management or planning.	IS design science research requires: • creation of an innovative, purposeful artefact for a special problem domain; • artefact must be evaluated to ensure its utility for the specified problem; • artefact must: - solve a problem that has not yet been solved; - provide a more effective solution.

In Fig. 4, we have presented how data artefacts based on [Hevner and Chatterjee 2010] are created in the IS design science research. The dark boxes above the diagram contain the main concepts that were used in the creation of SPDIAM: the theories in use, the created data artefacts, and the activities are performed to select, test, and evaluate the created IT artefacts.

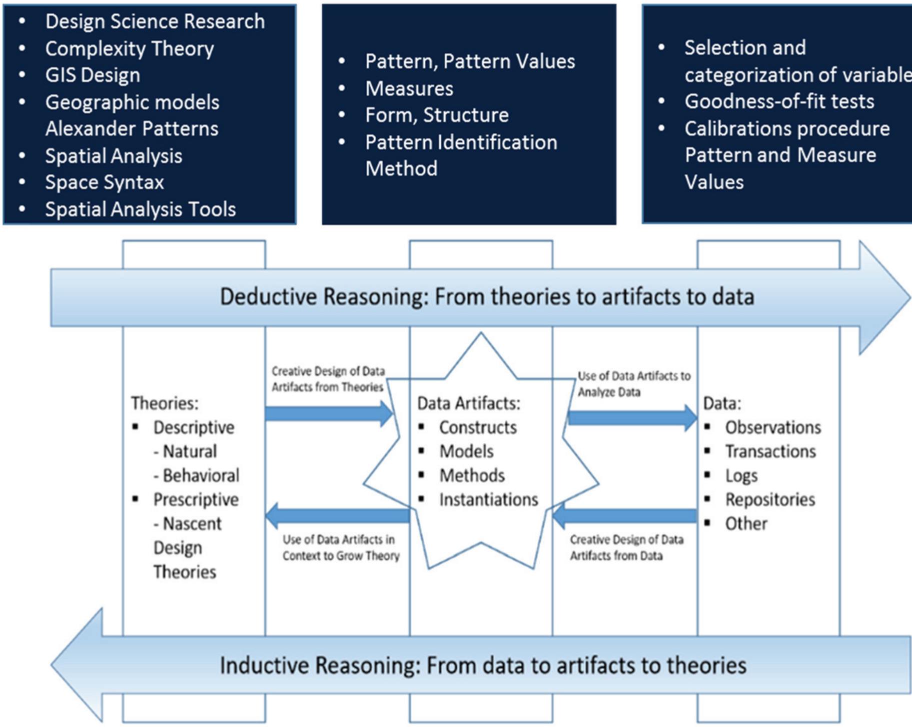


Figure 4 SPDIAM data artefacts in Data Science Reasoning (modified from [Hevner and Chatterjee 2010])

3.3. SPDIAM Requirements

The background analysis of this research indicated the fundamental SPDIAM requirements and highlighted the features that should be incorporated into the methodology while trying to contribute additional value to the already existing spatial analysis tools [Germanaitė *et al*. 2020]. SPDIAM has to [Germanaitė *et al*. 2020]:

- provide the structural and hierarchical description of SP by using spatial (geometrical, topological, visibility and perception, complexity) and non-spatial properties and allow the user to describe new SPs, SP identification methods and measures;
- use the automated SP identification method based on the user-defined rules and measures;
- use the complex and normalised measures based on the whole spatial network information for comparing the spatial entities of different sizes;
- use the statistical indicators;
- analyse: 1) the structure of the spatial entity at the macro and micro level; 2) the weighing available options and the relevance of the proposed SPD

solutions; 3) the possible impact on different urban sustainability dimensions and the spatial capital;

- analyse several SPs per one spatial entity data set and compare SPs visually;
- identify SP not only for the present spatial entity structure but also predict how the spatial entity structure will transform in the future while using the same spatial entity data set;
- be configurable and expandable.

3.4. SPDIAM Tools

In this section, the list of the selected tools used for the development, testing, and evaluation of SPDIAM is described. The choice of the tools was determined by the problem-solving directions described in Section 3.1. SPDIAM problem decomposition can be divided into 3 groups based on the input data they operate: 1) tools that work with the spatial map or vector data (*ESRI ArcGIS* tools family); 2) tools that work with a different type of graphs data (*DepthMapX*); c) tools that work with computational data (*IBM SPSS Statistics*). It is highly important to mention that SPDIAM as a methodology can be used with different tools as well, for example, the *ESRI ArcGIS* family tools can be replaced with open source software, such as *QGIS* [QGIS 2022], *DepthMapX* can be replaced with other tools that calculate Space syntax measures, or, even the measures themselves can be replaced with other method measures, and no changes for the methodology are needed in this case. Still, the condition remains that the new tools or selected measures have to let us effectively define and describe spatial entity attributes and calculate them.

ESRI ArcGIS. It offers the capabilities for applying location-based analytics to the very diverse spatial data business practices, and, by using contextual tools, to visualise and analyse spatial data [ESRI 2022]. In this research, *ESRI ArcMap* was used for: a) the spatial data preparation routine (detailed information is presented in Section 4.7. SPDIAM Spatial Data Preparation Routine); b) visual presentation of SP and metapatterns (the figures are used in this research, especially in Section 5.1.3. Identify and Present Solution Phase Experiment); c) the identified SP evaluation: the calculations and the presentation of SP and statistics data correlation (detailed information is presented in Section 6.1. SP and Statistics Data Correlation).

As the spatial data preparation routine consisted of the preparation of the vector map and the verification as well as correction of the vector map geometrical errors, these steps were executed by using the already existing features of ESRI ArcGIS and QGIS. The automation of the repetitive tasks of the spatial data preparation routine were performed by *ESRI ModelBuilder* as it addresses a fundamental problem of GIS: the vast number of the possible transformations and operations that can be performed on geographic data and the complexity in practice of many analysis sequences [Goodchild 2015]; and it enables users to develop custom processing models for the workflow and to include scripts within the models [Mihai and Marian 2016]. The users can create their own tools with *ModelBuilder*, and those tools can be used in Python scripting and other models; consequently, *ModelBuilder*, along with scripting, is a way to integrate *ArcGIS* with other applications [ESRI 2019c]. The prepared streets network's geometrical and connectivity correctness was checked by using *Axwoman 6.3* [Axwoman 2019], *Space Syntax Toolkit* for *QGIS 0.2.1* [Gil *et al*. 2015], and *ESRI ArcGIS Data Reviewer 10.3* [ESRI 2019a].

DepthMapX. It is the main tool [Varoudis 2014] used by the Space syntax community that can calculate a mixture of the classic graph-theory metrics, metrics borrowed from the urban-scale Space syntax theories, and some VGA-specific metrics describing the local spatial properties [Koutsolampros *et al*. 2019]. The detailed *DepthMapX* description can be found in Section 2.5.5. Space Syntax Software and Tools. In this research, *DepthMapX* was used for the creation of the spatial structures (segment map, convex map, visual graph) and for the calculation of Space syntax measures (the detailed description is presented in the following Sections: 5.1.3. Identify and Present Solution Phase Experiment; 5.2.2. Spatial Metapattern Description, Identification Experiment; 5.3.2. Spatial Pattern Identification Based on Metapattern).

IBM SPSS Statistics. It is a statistical software platform [IBM 2021b] that offers a robust set of features which let us extract actionable insights from the data. In this research, *IBM SPSS Statistics* was used for the complex calculations [IBM 2021a] of the cluster analysis on the spatial metapatterns and their measures. The purpose of this procedure was to identify relatively homogeneous groups of cases based on the selected characteristics, and, based on the obtained results, to select the most representative measure values for SP identification. A more detailed explanation of the use of these tools is presented in Section 5.3.2. Spatial Pattern Identification Based on Metapattern.

3.5. Summary

In this chapter, the essential assumptions for SPDIAM development were made. First, the problem area of SPDIAM was discussed, and the solutions with the appropriate concepts were chosen in such a manner that SPDIAM could support the computerised and automated SP identification solution in CSS. The insight was made that the standard analytical CSS problems which can be solved by SP have a spatial, functional, and structural background. Each solution has to be stated in such way that it gives the essential field of relationships needed to solve the problem, but in a very general and abstract way so that the analyst can solve the problem by adapting it to his/her personal preferences as well as the local conditions [Alexander 1977]. In CSS, the effectiveness of the developed methodology is the extent to which it can lead to efficient modes of analysis that will contribute to problem-solving in these contexts. For it, we have to aggregate the properties, measures, and indicators describing CSS into abstract logical entities, thus creating IT artefacts necessary for solving the tasks of SPD analysis.

The main phases of the SPDIAM development process (based on [Wilson 2008; Hevner and Chatterjee 2010]) were defined: the system of interest (or CSS) definition, theory development for the system of interest, deployment of the appropriate methods to operationalise the theory, and the creation of IT artefacts.

The background analysis of this research indicated the fundamental SPDIAM requirements and highlighted the features that should be incorporated into the methodology while trying to contribute additional value to the already existing spatial analysis tools [Germanaitė *et al*. 2020]. SPDIAM should provide the structural and hierarchical description of SP by using spatial and non-spatial properties and let the user describe new SPs, SP identification methods and measures. Also, SPDIAM should use the automated SP identification method based on the user-defined rules and measures.

The choice of the tools was determined by SPDIAM problem decomposition, and these tools can be divided into 3 groups based on the input data they operate: 1) tools that work with the spatial map or vector data (*ESRI ArcGIS* tools family); 2) tools that work with a different type of graphs data (*DepthMapX*); c) tools that work with computational data (*IBM SPSS Statistics*). SPDIAM as a methodology can be used with different tools as well, for example, the *ESRI ArcGIS* family tools can be replaced by open source software, such as *QGIS* [QGIS 2022]. Still, the condition remains that new tools or selected measures have to let us effectively define and describe the spatial entity attributes and calculate them.

4. SPDIAM DEVELOPMENT

4.1. Spatial Pattern Definition Model

This section aims to explain the general SP definition model of SPDIAM that is used for the SP identification algorithm and undertakes to let us identify SP in the vector data of the spatial entities. In the scope of this research, this SP model shall be used to describe and identify SP in the experiments described in Section 5. SPDIAM experiments.

The general assumption of SPDIAM is that there is SP formed by the already existing distribution of variables across space; out of these distributions, certain aggregate quantities (densities and accessibilities) can be calculated which form part of the basis for ongoing decisions that will generate changes in CSS as a whole [Samson *et al*. 2014, Wilson 2000]. SP is a recurring form of a complex physical entity that has a spatial structure and can be presented as geometrical or topological primitives in a map [Marshall and Gong 2009; Germanaitė *et al*. 2020]. A *structure* is a set composed of relations between its elements [Langlois 2011]. SP could be approached on the basis of the theory of urban capitals by Lars Marcus [Marcus 2007] as the four capitals (spatial, economic, ecological, social) are forming the functional background of a city and interact constantly. The spatial capital is formed by spatial configurations that can significantly affect economic, social, and ecological processes. Therefore, Marcus's spatial capital approach could be seen as an expansion and an additional explanation to the idea of the pattern language by Alexander, and it makes a background for SP modelling and analysis. Space syntax as a mathematical graph-based model is used for SP modelling so that to catch the spatial capital, but the appropriate selection of the different syntactic measures and indicators could be related to different types of capitals (economic, social, etc.).

The main concepts of the general model to address the CSS problem that needs an analytical approach are presented in Fig. 5. There are already existing SPs in CSS, and these SPs can be described by the measures. Each and every CSS can have different capitals that can be expressed in terms of the spatial configuration which is the basis for the spatial capital. Spatial configuration can be defined by different spatial characteristics; therefore, the spatial configuration consists of SP that is constituted of different measures. [Germanaitė *et al*. 2022]

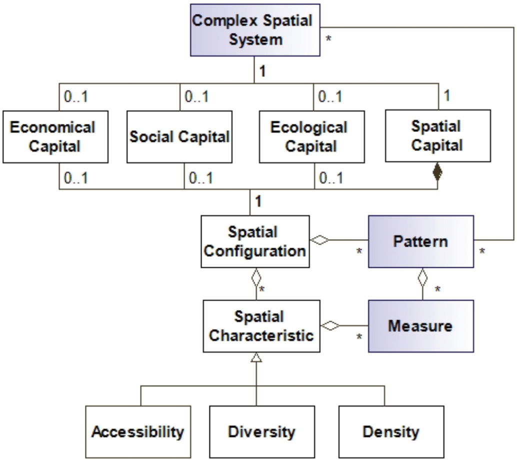


Figure 5 General model of SPDIAM concepts to address CSS problem that needs analytical approach [Germanaitė *et al*. 2022]

Each and every SP as a spatial feature can be defined as consisting of the different kinds of attributes (as described in Section 2.2.4.) as presented in Fig. 6 [Germanaitė *et al*. 2022].

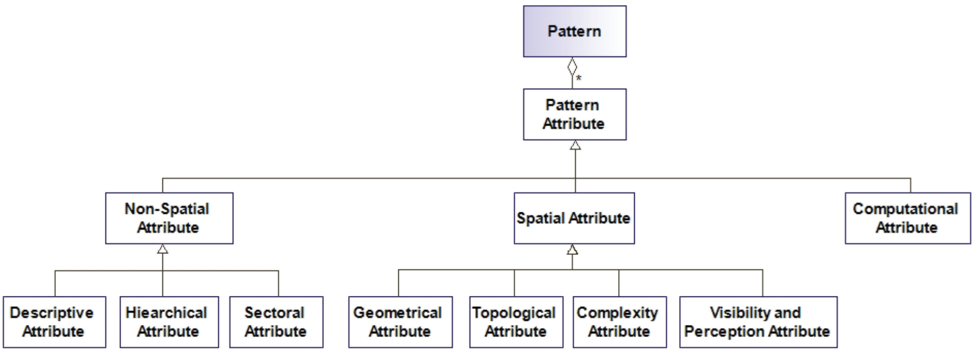


Figure 6 Types of SP attribute [Germanaitė *et al*. 2022]

The elaborated model of SP is presented in Fig. 7, and it features some significant changes. First, the class *PAttribute* for non-spatial SP attributes is created. It defines descriptive SP attributes (any descriptive SP characteristic, such as the origin or scientific justification of SP, etc.), hierarchical SP attributes (such as *Configuration*), sectoral SP attributes (such as *Dimension* (spatial, economic, social or environmental) or SP *Context* (region, city, district, site)). Class *Pattern* has its attributes, such as SP *Name*, *Description,* and *Type* (SP or metapattern). The algorithm for specific SP identification relies on the selected identification method (like Space syntax) (class *PatternMethod*). The algorithm is described as a sequence of calculated spatial forms that step-after-step identifies SP. Hence, for SP spatial attributes, two classes *Form* and *FAttribute* are created. The class *FAttribute* defines SP geometrical attributes (area, perimeter, part size), topological attributes (zone count, part count), visibility and perception SP attributes (visibility, distance), and complexity SP attributes (fractal dimension, lucinarity). Each SP consists of SP values (class *PatternValue*) that let us identify the specific SP. For example, SP City Layout can have the following values: co-centric, linear, sector, and so on. Each SP value consists of computational SP attributes (class *PatternValueMeasure*). By using instances of this class, the real values of the measures that define SP value are kept. The SP identification algorithm compares the return value of the specific SP identification method with the measures that define the SP value [Germanaitė *et al*. 2022].

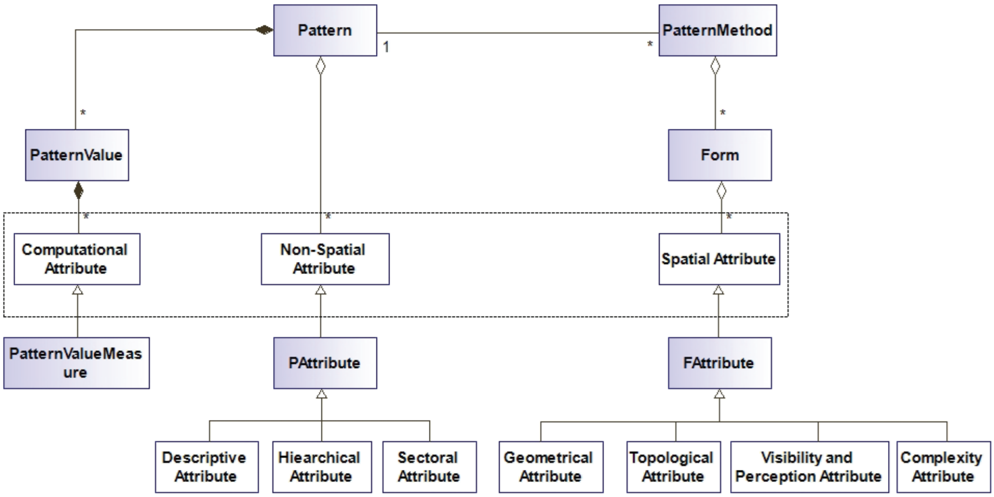


Figure 7 General SP definition model [Germanaitė *et al*. 2022]

The detailed idea of the SP composition of metapatterns was presented in [Germanaitė *et al*. 2018]. SPs can be constructed of metapatterns, and the *Configuration* attribute (instance of class *PAttribute*) is responsible for this construction. In Fig. 8 below, we present 6 spatial metapattern values that are used in the spatial metapattern description and identification experiment described in Section 5.2. These basic spatial metapattern values depict 6 basic geometrical and topological forms that repeat themselves in real-world SPs in different proportions [Germanaitė *et al*. 2022].

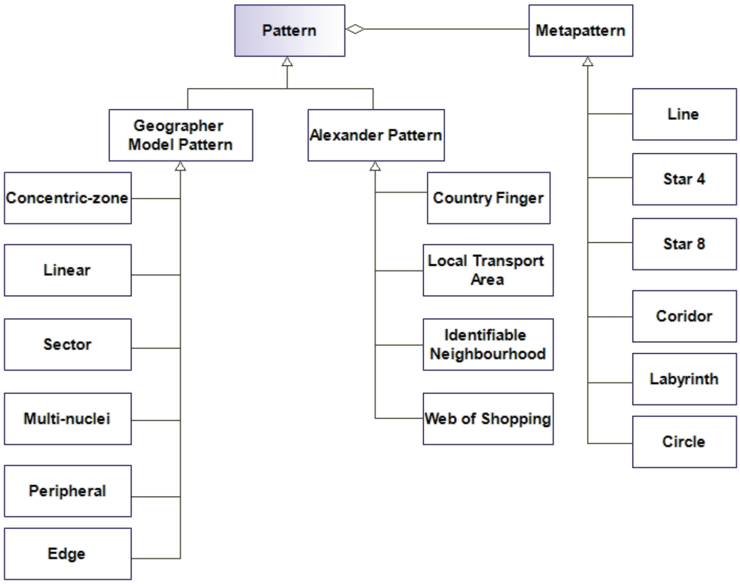


Figure 8 Basic spatial metapattern [Germanaitė et al. 2022]

In Fig. 9, we present the final SP and metapatterns model (UML class diagram) which forms the basis of the static description of SPDIAM. [Germanaitė *et al*. 2022]

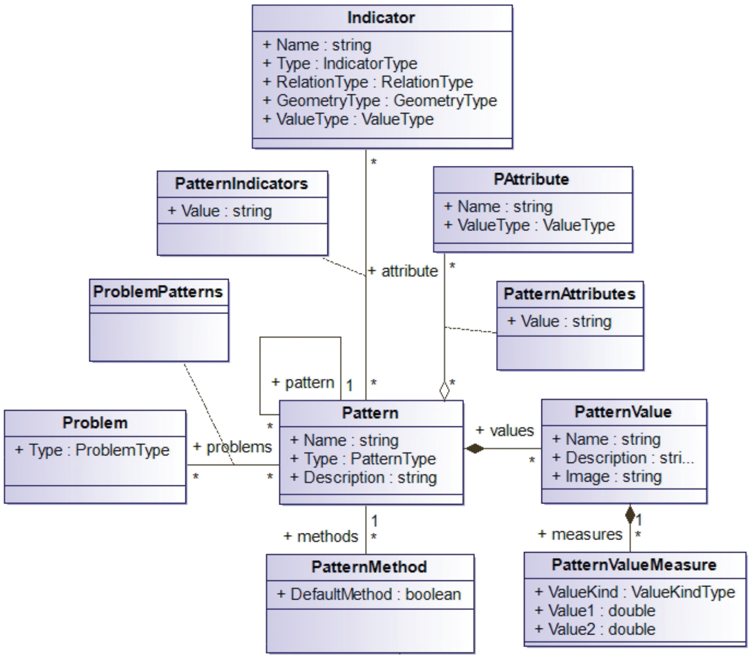


Figure 9 General SP and metapattern model [Germanaitė *et al*. 2022]

4.2. Spatial Pattern Identification Algorithm

The algorithm presented in this section is the SP identification algorithm used in SPDIAM (phase *SP Identification and Evaluation*) [Germanaitė *et al*. 2020]. First, the area of SP is constructed by using Space syntax angular segment analysis measures with a certain percentage of maximum values, intersecting them with a grid (the size of the cell is 200x200), and then SP is formed, identified, and evaluated.

Spatial metapattern identification aims to detect the working basic metapattern values that can later be used to identify the geographer's and Alexander's patterns and to apply them in CSS analysis in other domains. This algorithm further analyses the form of SP and uses a new Space syntax structure – *Visuality Graph* – together with the new VGA measures to describe and identify the form of SP. The steps of the SP identification algorithm (presented in Fig. 10) include: 1) selection of the SP economical, ecological, or social orientation (PAttribute.Name = 'Dimension'); 2) selection of the proper measures to describe *PatternValue* (class *Measure*); 3) tessellation [Huisman and By 2009] of the CSS area to the grid and the assignment of the calculated syntactic values of the measures to grid cells (classes *Structure* and *Form*); 4) construction of the SP area by taking 30% of the highest value grid cells (classes *Structure* and *Form*); 5) identification of SP by using VGA and the relation to geographer's and Alexander's pattern typologies (classes *PatternValue* and *PatternValueMeasure*); 6) evaluation of SP by using open data indicators (class *Indicator*). As for the spatial metapattern, the algorithm is much simpler, and it contains only 2 steps (Fig. 11): 1) construction of the spatial metapattern area; 2) identification of the spatial metapattern by using VGA measures [Germanaitė *et al*. 2022].

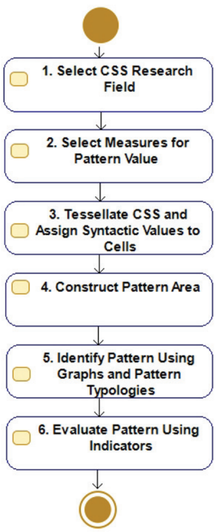


Figure 10 Algorithm of SP identification (simplified) [Germanaitė *et al*. 2022]

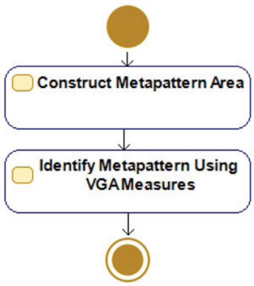


Figure 11 Algorithm of spatial metapattern identification (simplified) [Germanaitė *et al*. 2022]

4.3. SPDIAM Description

Each of the SPDIAM problems and solutions presented in Table 5 (Section 3.1.) reflects the elements of the developed methodology, based on which, a unified solution is formed. The following section presents this solution while outlining the principles of its creation and using the following logical groups:

Spatial Entity (CSS) -> Set of Structures -> Set of Structure Elements;
Pattern -> Set of Pattern Values -> Set of Pattern Value Measures;
Pattern Method –> Set of Operations -> Set of Forms -> Set of Measures.

SPDIAM (as presented in Fig. 12) consists of the concepts, based on which, SPDIAM static and dynamic views are created. The SPDIAM static view is the SPDIAM conceptual data model that lets us describe, identify, and apply SP. The SPDIAM dynamic view presents the SPDIAM application process and consists of 3 phases: SP description, SP identification, and SP application. In Fig. 12, the relationships between the concepts show the simplified logical connections in each SPDIAM phase. In the *SP Description* phase, SP is connected with the problem and some thematically related indicators and can have some values. In the *SP Identification* phase, the SP identification method is connected with the possible operations. Each operation is defined by the measures. The measure can be calculated for the element of the spatial structure. In the *SP Application* phase, the spatial structure should be filled with the spatial data of CSS, the indicators should be filled with the indicators layer data, and then (after SP identification) the objectives of CSS can be set.

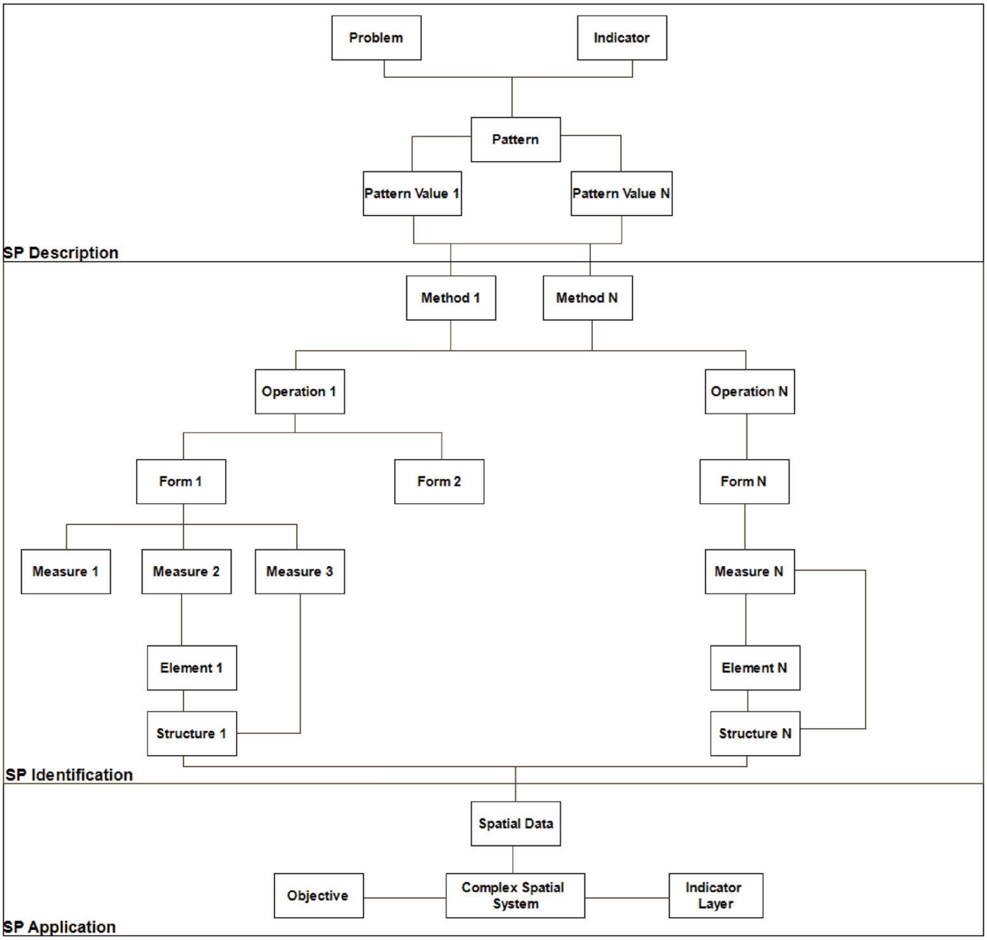


Figure 12 SPDIAM concept

4.4. SPDIAM Static View

SPDIAM is a structural, ruled-based SP recognition method that provides SP structural description by using spatial metapatterns and morphological relationships, and which uses Space syntax topology and visibility analysis to identify the SP of road network by using GIS. The static view of SPADIAM is defined by the UML Class diagram (Fig. 13) which contains two principal SPDIAM concepts: the *PatternMethod* class which defines the specific *Pattern* class identification methods, and the *Analysis* class which defines the user-created instance of the *SpatialEntity* class analysis. Once the SP identification method has been described, the process of SP identification can be defined. This process uses two main classes – *Form* (it defines different SP forms emerging in the SP identification process) and *Structure* (it defines spatial structures of the *Form* class and is based on the *SpatialEntity* class spatial data). Also, the measures that will be used to estimate the features of the SP form, structure, and its elements are defined by the *MeasureTarget* class. Both instances of the *Form* and *Structure* class can be reused for other SP by using the same method; consequently, it makes the SP description process simpler in the future [Germanaitė *et al*. 2020].

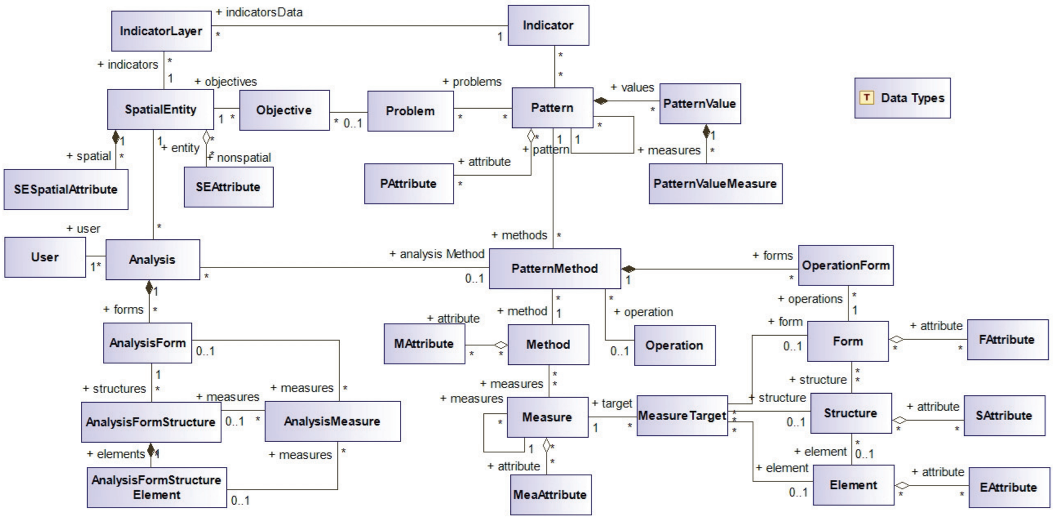


Figure 13 SPDIAM conceptual data model

The conceptual model of the SP description and identification model is based on the concepts from Table 5 (Section 3.1.) and presented in Figure 21. It consists of 5 main parts that are dedicated to describing SP, SP method, SP method steps, spatial entity (or CSS), and spatial entity analysis.

The main classes of SP are presented in Fig. 14 and described in Table 5.

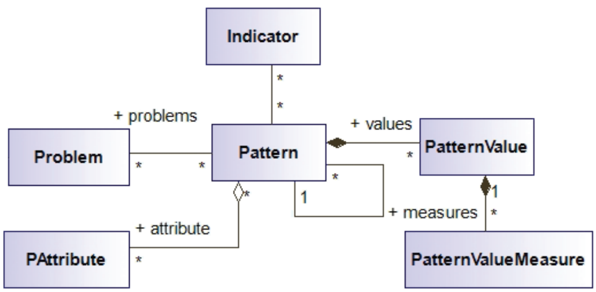


Figure 14 Main classes defining SP

Table 5 Main classes defining SP

Class - Description	Class Attribute	Associated Class	Used Data Types
Pattern – describes SP	**Pattern** + Name : string + Type : PatternType + Description : string		**PatternType** + Name : string + Type : PatternTypeName **PatternTypeName** Metapattern Pattern
PAttribute – describes SP attributes	**PAttribute** + Name : string + ValueType : ValueType	**PatternAttributes** + Value : string	
PatternValue – describes SP values	**PatternValue** + Name : string + Description : string + Image : string		
PatternValueMeasure – describes measures and their values that define SP values	**PatternValueMeasure** + ValueKind : ValueKindType + Value1 : double + Value2 : double		
Indicator – describes statistical indicators that can be used to evaluate SP	**Indicator** + Name : string + Type : IndicatorType + RelationType : RelationType + GeometryType : GeometryType + ValueType : ValueType	**PatternIndicators** + Value : string	**IndicatorType** + Name : string + Type : IndicatorTypeName **IndicatorTypeName** Demography Land Use Transport Urban Form Pollution Resources **RelationType** + Name : string + Type : RelationTypeName **RelationTypeName** Intersect
Problem – describes a problem that SP solves	**Problem** + Name : string + Type : ProblemType	**ProblemPatterns**	**ProblemType** + Name : string + Type : ProblemTypeName **ProblemTypeName** Urban Development

The main classes of the SP method are presented in Fig. 15 and described in Table 6.

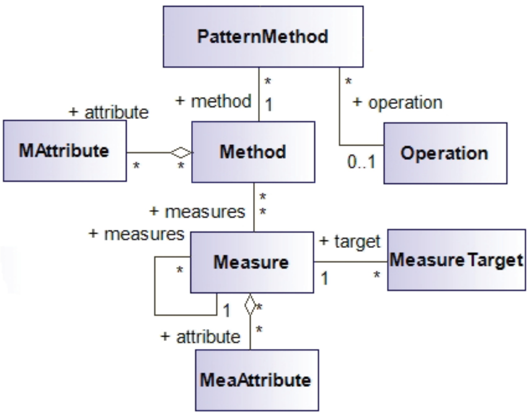


Figure 15 Main classes defining SP method

Table 6 Main classes defining SP method

Class - Description	Class Attribute	Associated Class	Used Data Types
PatternMethod – describes specific SP method and operation	**PatternMethod** + DefaultMethod : boolean		
Method – describes SP identification method	**Method** + Name : string + Type : MethodType + Description : string		**MethodType** + Name : string + Type : MethodTypeName **MethodTypeName** Space Syntax
MAttribute – describes method attributes	**MAttribute** + Name : string + ValueType : ValueType	**MethodAttributes** + Value : string	**ValueType** + Name : string + Type : ValueTypeName **ValueTypeName** Integer Double String Enumeration Boolean
Operation – defines SP method operation	**Operation** + Type : OperationTypeName + DefaultOperation : boolean		**OperationType** + Name : string + Type : OperationTypeName **OperationTypeName** Identification Transformation Evaluation
Measure – describes measures that are used for SP, Form, Structure, or Structure Element calculations; can have composite measures	**Measure** + Name : string + Description : string	**MethodMeasures**	
MeaAttribute – describes measure attributes	**MeaAttribute** + Name : string + ValueType : ValueType	**MeasureAttributes** + Value : string	**ValueType** + Name : string + Type : ValueTypeName **ValueTypeName** Integer Double String Enumeration Boolean
MeasureTarget – describes an entity that a measure can define	**MeasureTarget** + Value : string		

The main classes of the SP method steps are presented in Fig. 16 and described in Table 7.

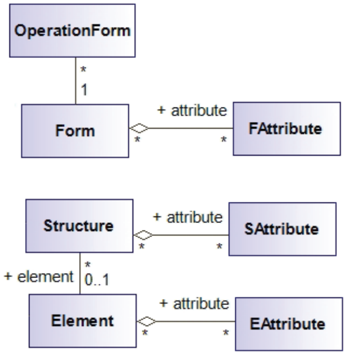


Figure 16 Main classes defining SP method's steps

Table 7 Main classes defining SP method's steps

Class - Description	Class Attribute	Associated Class	Used Data Types
OperationForm – describes the specific form used for the operation	**OperationForm** + OperationForm : boolean + PatternVisualizationForm : boolean + FormOrder : integer		
Form – describes forms of the spatial entity that can be identified in the spatial structure	**Form** + Name : string + Type : FormType + FormVisualization : FormVisualizationType		**FormType** + Name : string + Type : FormTypeName **FormTypeName** Abstract Form Spatial Network Spatial Grid Segment Network Area Zone Center Zone Center Configuration Center Layout Future Center Layout Basic Metapattern **FormVisualizationType** + Name : string + Type : FormVisualizationTypeName **FormVisualizationTypeName** Point Polyline Polygon Grid
FAttribute – describes form attributes	**FAttribute** + Name : string + ValueType : ValueType	**FormAttributes** + Value : string	**ValueType** + Name : string + Type : ValueTypeName **ValueTypeName** Integer Double String Enumeration Boolean
Structure – describes a structure to which the spatial data of a spatial entity can be transformed	**Structure** + Name : string + Type : StructureType + Description : string		**StructureType** + Name : string + Type : StructureTypeName **StructureTypeName** Spatial Network Segment Graph Convex Graph Grid Visual Graph

SAttribute – describes spatial structure attributes	**SAttribute** + Name : string + ValueType : ValueType	**StructureAttributes** + Value : string	**ValueType** + Name : string + Type : ValueTypeName **ValueTypeName** Integer Double String Enumeration Boolean
Element – describes an element which is a constituent part of a spatial structure	**Element** + Name : string + Type : ElementType + GeometryType : GeometryType		**ElementType** + Name : string + Type : ElementTypeName **ElementTypeName** Segment Graph Segment Grid Cell Convex Graph Segment Visual Graph Node **GeometryType** + Name : string + Type : GeometryTypeName + ValueType : ValueTypeName **GeometryTypeName** Point Polyline Polygon
EAttribute – describes element attributes	**EAttribute** + Name : string + ValueType : ValueType	**ElementAttributes** + Value : string	**ValueType** + Name : string + Type : ValueTypeName **ValueTypeName** Integer Double String Enumeration Boolean

The main classes of a spatial entity (CSS) are presented in Fig. 17 and described in Table 8.

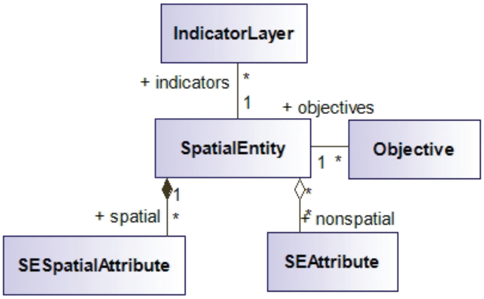
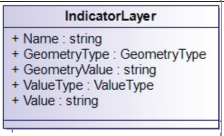
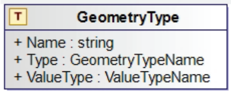
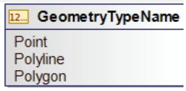
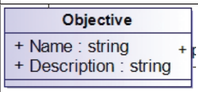


Figure 17 Main classes defining spatial entity (CSS)

Table 8 Main classes defining CSS

Class - Description	Class Attribute	Associated Class	Used Data Types
SpatialEntity – describes a spatial object, e.g., region, city, district, or building	**SpatialEntity** + Name : string + Type : SpatialEntityType		**SpatialEntityType** + Name : string + Type : SpatialEntityTypeName + Size : string **SpatialEntity TypeName** Region City District Site
SEAttribute – describes spatial entity attributes that could be used for identified SP application	**SEAttribute** + Name : string + ValueType : ValueType	**SpatialEntityAttributes** + Value : string	**ValueType** + Name : string + Type : ValueTypeName **ValueTypeName** Integer Double String Enumeration Boolean
SESpatialAttribut e – describes spatial data of the	**SESpatialAttribute** + GeometryType : GeometryType + GeometryValue : string		**GeometryType** + Name : string + Type : GeometryTypeName + ValueType : ValueTypeName **GeometryTypeName** Point Polyline Polygon

spatial entity			
IndicatorLayer – describes statistical indicator data that can be used to evaluate SP			 
Objective – describes objectives that can be set to the spatial entity			

The main classes of spatial entity (CSS) analysis are presented in Fig. 18 and described in Table 9.

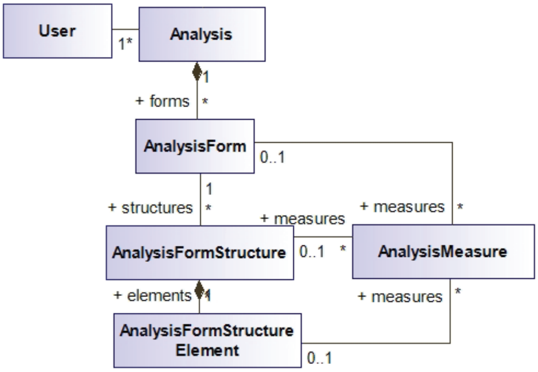
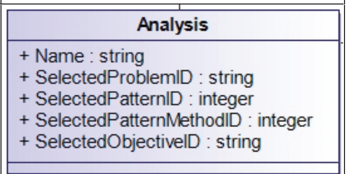
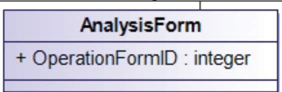
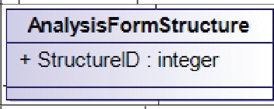
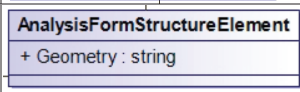
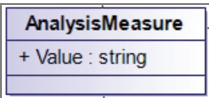
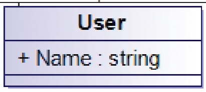


Figure 18 Main classes defining spatial entity (CSS) analysis

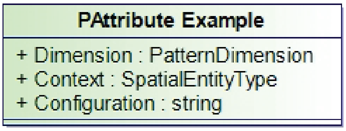
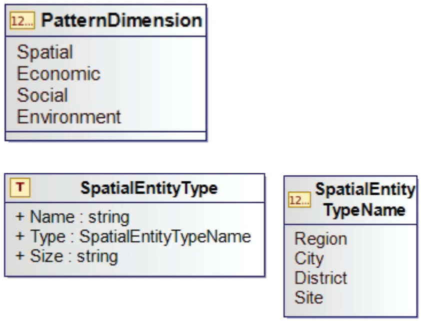
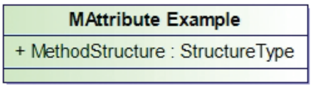
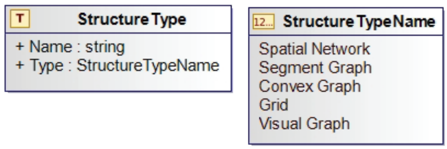
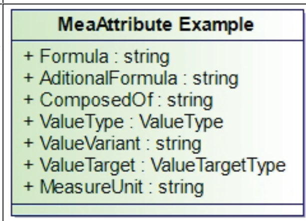
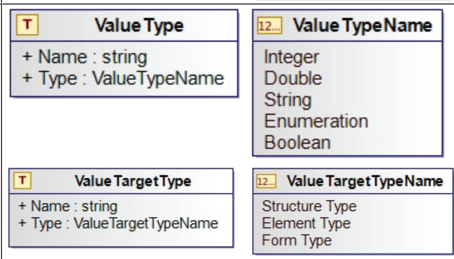
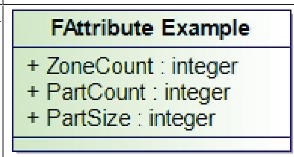
Table 9 Main classes defining spatial entity (CSS) analysis

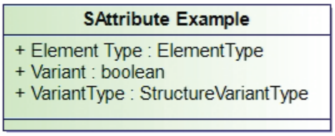
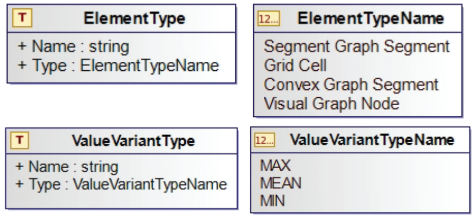
Class - Description	Class Attribute
Analysis – describes user-performed spatial entity analysis	
AnalysisForm – describes analysis forms	
AnalysisFormStructure – describes analysis form structure	
AnalysisFormStructureElement – describes analysis form structure element	

<table>
<tr><td>AnalysisMeasure – describes analysis measure values</td><td></td></tr>
<tr><td>User – describes SPDIAM user</td><td></td></tr>
</table>

The completed SPDIAM logical data model is presented in Annex 1. SPDIAM specification can be extended based on the newly defined SP properties, and an UML Class diagram can be appended with new attributes and operations based on the table from the previous step. In Table 10, there are some examples of the instances of the attributes that were used in the experiments in Chapter 5.

Table 10 Some examples of the instances of attributes

<table>
<tr><th>Class – Description</th><th>Class Attribute</th><th>Used Data Types</th></tr>
<tr><td>PAttribute – pattern attributes</td><td></td><td></td></tr>
<tr><td>MAttribute – method attributes</td><td></td><td></td></tr>
<tr><td>MeaAttribute – measure attributes</td><td></td><td></td></tr>
<tr><td>FAttribute – form attributes</td><td></td><td></td></tr>
</table>

SAttribute – structure attributes		

4.5. SPDIAM Dynamic View

SPDIAM consists of 6 phases dedicated to defining the problem, designing, analysing, presenting, evaluating, and applying a solution or SP (see Fig. 19). It should be noted that the result of the solution evaluation in the Evaluation phase depends on the UPD practitioner who uses SPDIAM, but the solution itself (the identified SP value) is based on the calculated scientifically based Space syntax measures; thus it can be compared to the alternative solutions [Germanaitė *et al.* 2020].

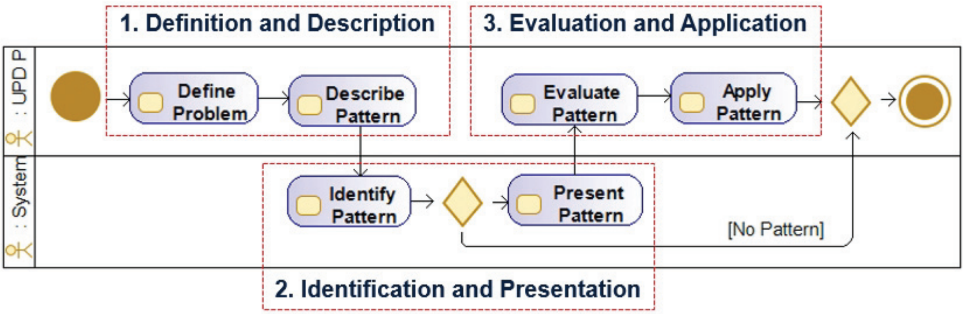


Figure 19 Dynamic view of SPDIAM

In the Definition phase (Fig. 20), the UPD practitioner defines the problem that can be understood as a grouping entity for SP that also lets us link the identified SP with the appropriate indicators in a further phase of SP Application. In the Description phase (see Fig. 20), the UPD practitioner creates a solution (an instance of the *Pattern* class), links it to the problem, and chooses the method that shall be used for SP identification in the Analysis phase. Then, the operation for the method should be selected: the *Pattern Identification* operation identifies the already present SPs of the Spatial Entity, and the *Pattern Transformation* operation identifies the future changes of the SPs of the Spatial Entity. For each method, operation, and SP, the set of the *Form* class instances with the corresponding instances of the *Structure* and *MeasureTarget* classes should be created. The Description phase is ended by creating instances of the *PatternValue* class and adding these values to the instances of the *PatternValueMeasure* class that shall be used to identify SP.

In the Analysis phase (see Fig. 21), the instance of the *SpatialEntity* class is created based on the Spatial Entity spatial data, and it can have both spatial and non-spatial attributes. A UPD practitioner can select the problem, the SP to solve this problem (or leave it to all possible SPs to be detected in the spatial entity data), the method that will be used to detect that SP (or use the default method for each SP), and the operation. After this step, SP identification begins, and it depends on the selected method. The Space syntax method workflow to identify the City Layout SP consists of creating different instances of the Analysis Form Structure class (segment graph, grid, and convex graph) and calculating the values for the instances of the *AnalysisMeasure* class. The final instance of *AnalysisForm* class, defined as the Operation Form, contains the measures that can be compared to the *PatternValueMeasure* whose instance values were set in the previous Design phase. In the Presentation phase, if SPs were identified, the system draws SPs and presents them to the UPD practitioner in the form that can later be discussed with other users.

In the Evaluation and Application phases (see Fig. 23), the UPD practitioner can visually evaluate the identified SPs and select the indicators to intersect with SP. In the Application phase, the UPD practitioner can make the observations and set objectives that address the problem, as selected in the Definition phase, with the objective to memorise the results of SP analysis or to use them in future work [Germanaitė *et al*. 2020].

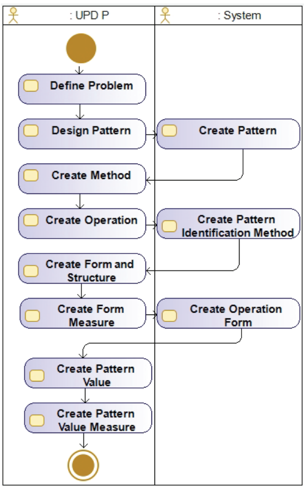


Figure 20 SPDIAM Definition and Description phase

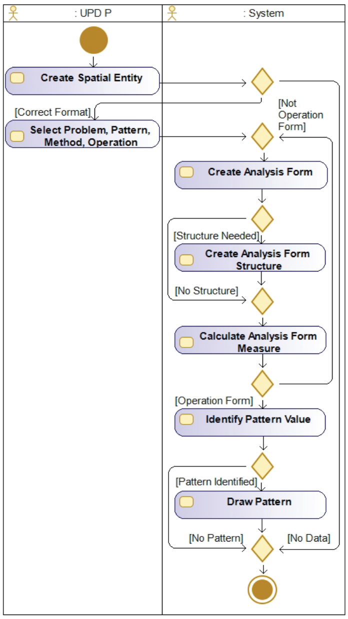


Figure 21 SPDIAM Identification and Presentation phase

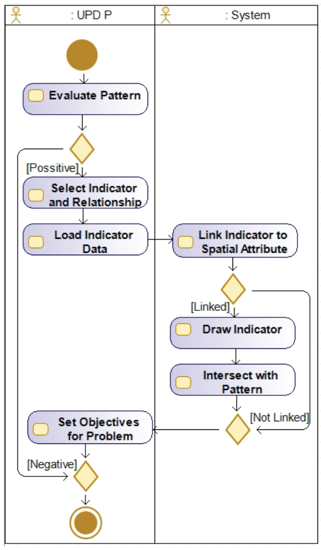


Figure 22 SPDIAM Evaluation and Application phase

In Figs. 23–25, a new SP, its values and measures, the SP identification method, and its steps creation algorithm using the forms and structures are presented.

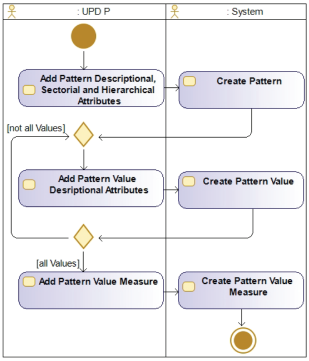


Figure 23 Algorithm of SP creation

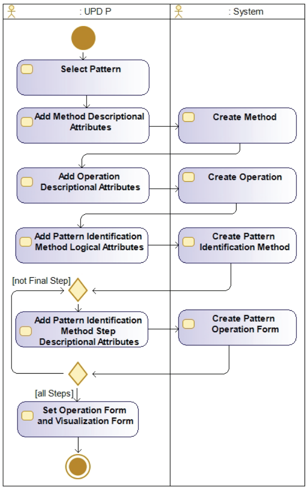


Figure 24 Algorithm of SP identification method creation

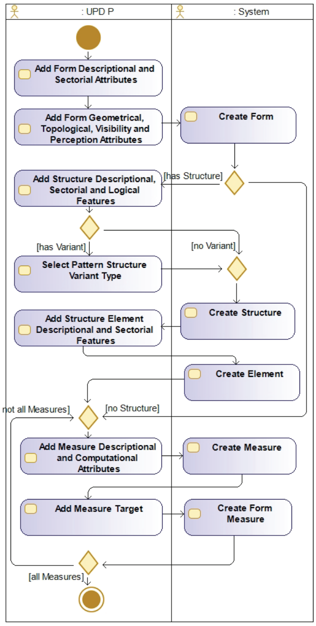


Figure 25 Algorithm of SP method step creation

Cases of SPDIAM use were grouped by the SPDIAM phases, presented in Fig. 26 and described in Table 11. First of all, the UPD practitioner wants to define the problem that has to be solved by using SP, then define the SP and the method how to identify it. Then, s/he has to describe and create the model of CSS, and, after that, the SP identification can be done. The UPD practitioner has to be able to evaluate the identified SP, and then to apply it (e.g., set the objectives for the CSS planning and development tasks).

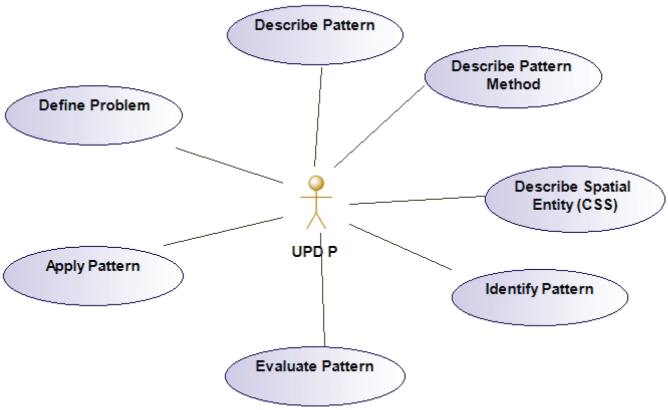


Figure 26 SPDIAM use cases

Table 11 SPDIAM use cases grouped by SPDIAM phases

	Use Case	UPD Practitioner	System
	Phase 1: Definition and Description		
1.	Define Problem	- wants to define a problem	- creates the problem's definition - assigns SP to the problem
2.	Describe Pattern	- wants to describe SP	- creates SP - creates an SP attribute - creates SP value - creates an SP value measure - creates a new SP indicator
3.	Describe Pattern Method	- wants to describe an SP identification method	- creates an SP method - creates a method - creates a method attribute - creates an operation - creates a measure - creates a measure attribute - creates a measure target
		- wants to describe an SP identification method step	- creates an operation form - creates a form - creates a form attribute - creates a structure - creates a structure attribute - creates a structure element - creates a structure element attribute
4.	Describe Spatial Entity (CSS)	- wants to describe a spatial entity	- creates a spatial entity - creates a spatial entity attribute - creates spatial entity spatial attribute - loads spatial entity spatial data
	Phase 2: Identification and Presentation		
5.	Identify Pattern	- wants to identify SP	- creates analysis - assigns analysis to a user - creates analysis forms - creates analysis structures - creates analysis structures elements - calculates analysis measures values - compares analysis measures values to SP value measures - draws an operation form
	Phase 3: Evaluation and Application		
6.	Evaluate Pattern	- wants to evaluate SP	- loads a statistical indicator data layer
7.	Apply Pattern	- wants to apply SP to a spatial entity	- creates a new objective for the spatial entity

4.6. SPDIAM Spatial Data Preparation Routine

The SPDIAM spatial data preparation routine must be created while taking into account that a partial-comprehensive model of CSS must be developed as it was defined in Section 3.1. SPDIAM Problem Decomposition. The partial-comprehensive model of CSS defines that such a model is not made up of all possible CSS data (as CSS is too large), but only based on the part of the data that is specifically important for the calculations. For example, if a CSS is a city, then only the data for the city street network is taken for the analysis, and not the pedestrian or bike paths. Also, the SPDIAM spatial data preparation routine depends on the method that has been selected for SP analysis. The Space syntax method requires a vector data model as the spatial network is formed of the road network layer. The various input spatial data sets can be gathered from the publicly available sources that make SPDIAM easy to customise for personal data needs. Some well-known examples of geodata sources include *OpenStreetMap* data sets [Geofabrik 2019], official government data sets [Geoportal LT 2019; Geoportal PL 2019], and free data sets [DIVA-GIS 2019]. In some cases, SP identification requires the administrative, geographic, or urban boundaries that will be used for the definition of the spatial entity area.

The Spatial data preparation routine consists of two steps: 1) the preparation of the vector map which shall later be transformed into the segment graph that will be operated by the Space syntax method; 2) verification and correction of the vector map geometrical errors. These steps can be executed by using the already existing features of *ESRI ArcGIS*, *QGIS*, or other *GIS* software. The tasks of the spatial data preparation routine can be performed by *ESRI ModelBuilder*. The repetitive tasks include: 1) clipping spatial entity area from the road network layer by using the appropriate boundaries; 2) simplifying road lines and rationally reducing the total count of nodes in the graph so that to avoid the distortion in calculations due to an excessive number of nodes; 3) dissolving road lines; 4) splitting road intersections into individual segments and deleting coincident line segments; 5) checking the geometrical connectivity of the road network and correcting errors. For error verification, the in-build *GIS* features, *GIS* extensions, or stand-alone applications can be used [Jiang 2015; ESRI 2019a; Gil *et al*. 2015].

The input data sets and formats for the *ArcMap ModelBuilder GIS* model could be chosen from the publicly available sources. Some well-known examples of geodata sources include *OpenStreetMap data sets*, such as www.geofabrik.de [Geofabrik 2019]. *Geofabrik* offers region extracts of *OpenStreetMap* data in the *OpenStreetMap* raw data formats and selected features as shape files [Geofabrik 2019]. For graph processing (e.g., routing or reachability analysis with such software as *Network Analyst*), they also offer special routable shape files which only include the road network [Geofabrik 2019]. For these, *OpenStreetMap* data is pre-processed by splitting each road at each junction, so that the resulting shape files contain only road segments, and the pre-processing step is slightly different for automobile, bicycle, or pedestrian routing [Geofabrik 2019]. *Official data sets*, e.g., www.geoportal.lt [Geoportal LT 2019] or www.geoportal.gov.pl [Geoportal PL 2019], are prepared by government institutions or local authorities. It offers various geographic data search and download services that could be used for spatial data analysis. Some of the *free data sets*, such as DIVA-GIS http://www.diva-gis.org/ [DIVA-GIS 2019], come together with the free computer program for mapping and geographic data analysis, and they also provide free spatial data for the entire world that can be used in *DIVA-GIS* or other programs [DIVA-GIS 2019].

The next step is to prepare the administrative boundaries of the research area, though these boundaries could be drawn by hand and saved as an *.SHP file in *ESRI ArcMap*. There are relatively many official data sources, such as [Geoportal LT 2019] or www.gugik.gov.pl [Gugik 2019], from where these administrative boundaries can be downloaded. Non-official data sources, e.g., [DIVA-GIS 2019], as mentioned above, also contain administrative boundaries. The use of the boundaries depends on the research, and there is also a possibility not to use any boundaries at all and simply look for SP in the whole spatial data set.

The spatial data of the particular area (region, city, district, or site) should contain data for the roads (or streets) and should be in the *SHAPE* format. The same applies to administrative (or any other necessary) boundaries, and they also should be saved in the *SHAPE* format. The final result of selecting the input data sets for the *ArcMap ModelBuilder GIS* model should be 2 *.SHP files, one with the roads layer, and the other one with the boundaries layer. An example of the main *.SHP file of the city road network is presented in Fig. 27; each line describes a shape with its vertices.

gis_osm_roads_free_1

FID	Shape	osm_id	code	fclass	name	ref	oneway	maxspeed	layer	bridge	tunnel
0	Polyline	3412414	5121	unclassified	Salomėjos Nėries g.		B	50	0	F	F
1	Polyline	4853620	5115	tertiary	Žvejų g.		B	50	0	F	F
2	Polyline	4853621	5114	secondary	Vilniaus g.		B	50	0	F	F
3	Polyline	4853622	5122	residential	Vinco Kudirkos a.		B	0	0	F	F
4	Polyline	4853624	5114	secondary	Gedimino pr.		B	30	0	F	F
5	Polyline	4853639	5153	footway			B	0	0	F	F
6	Polyline	4853642	5114	secondary	Šventaragio g.	A3;A15;101	B	40	0	F	F
7	Polyline	4853643	5153	footway			B	0	0	F	F
8	Polyline	4856229	5122	residential	Totorių g.		F	40	0	F	F
9	Polyline	4869653	5114	secondary	Felikso Vaitkaus g.		F	40	0	F	F
10	Polyline	4869655	5122	residential	Pelesos g.		B	0	0	F	F
11	Polyline	4869656	5113	primary	Liepkalnio g.	A3;A15	B	50	0	F	F
12	Polyline	4869753	5113	primary	Pylimo g.		F	50	0	F	F
13	Polyline	4870008	5153	footway			B	0	0	F	F
14	Polyline	4870048	5153	footway			B	0	0	F	F
15	Polyline	4870067	5122	residential	A. Mickevičiaus g.		B	40	1	T	F
16	Polyline	4870069	5114	secondary	J. Jasinskio g.		F	0	0	F	F
17	Polyline	4870096	5113	primary	Saltoniškių žiedas		B	50	0	F	F
18	Polyline	4870109	5112	trunk	Geležinio Vilko g.	A2;A14	F	60	1	T	F
19	Polyline	4870120	5152	cycleway	Baltasis tiltas		B	0	1	T	F
20	Polyline	4870121	5113	primary			B	50	0	F	F
21	Polyline	4870204	5123	living_street	Žygimanto Liauksmino g.		F	20	0	F	F
22	Polyline	4870206	5122	residential	Totorių g.		B	40	0	F	F
23	Polyline	4870213	5121	unclassified	Vokiečių g.		B	20	0	F	F
24	Polyline	4870214	5121	unclassified	Vokiečių g.		F	20	0	F	F
25	Polyline	4870216	5152	cycleway			B	0	0	F	F
26	Polyline	4870300	5123	living_street	Aušros Vartų g.		B	0	0	F	F
27	Polyline	4870309	5123	living_street	Šv. Jono g.		F	20	0	F	F
28	Polyline	4870310	5123	living_street	Švarco g.		F	20	0	F	F
29	Polyline	4870839	5124	pedestrian	A. Vienuolio g.		B	0	0	F	F
30	Polyline	4870916	5132	trunk_link		A4;A16	F	40	0	F	F
31	Polyline	4870955	5111	motorway		A1	F	120	0	F	F
32	Polyline	4871038	5112	trunk	Geležinio Vilko g.	A1;A4;A16	F	60	-1	F	T

Figure 27 Input (*.SHP) file of city road network

The spatial data preparation for the spatial pattern analysis contains two steps: first, the vector map should be transformed into the network that could be operated by the Space syntax logic and methods, and, secondly, the topological errors verification and correction should be done. The data preparation routine could be executed by using the already existing features of *ESRI ArcMap*, *QGIS*, or other *GIS* software. For the error checking and correcting part, the in-built *GIS* features, *GIS* extensions or stand-alone applications that could detect and correct geometrical and topological errors could be applied. As the spatial data preparation tasks contain repetitive steps, additionally, an executable *GIS* model could be created by using the *ESRI ArcMap* tool *ModelBuilder*. The purpose of the particular *GIS* model described below is to automate the repetitive tasks of the workflow that is needed to prepare spatial data for the Space syntax based SP identification. The main spatial data preparing tasks include cutting off the urban area from the streets layer of the *GIS* shape file by using administrative boundaries or other selection criteria that is/are suitable for the particular situation, such as the logical city boundaries; simplifying street lines, and making short single lines into long straight street axial lines that a) conform to the visibility lines b) rationally reduce the total count of nodes (vertices) in the graph and avoid the distortion in calculations due to an excessive number of nodes; merge (or dissolve) street lines; split street intersections into individual segments and delete coincident line segments; check the already prepared streets network's geometrical, topological and connectivity correctness and correct the errors (orphan or island lines); export the streets data layer to the CAD (*.DXF) format.

The prepared streets network's geometrical and connectivity correctness should be checked, and some of the existing tools, specifically, both *ESRI ArcGIS* and *QGIS*, shall be discussed below. *Axwoman 6.3* was developed by using *Microsoft C#* and *ESRI*'s *ArcObjects*, and it is an extension for *ESRI ArcGIS 10* which supports the Space syntax analysis based on both axial lines and natural streets [Axwoman 2019]. *Axwoman 6.3* provides a tool for checking the existence of any isolated lines.

Space Syntax Toolkit is a *QGIS* plug-in for spatial network and statistical analysis, and it provides a front-end for the *DepthmapX* software within *QGIS*, thereby offering Space syntax analysis workflows in a *GIS* environment [Gil *et al*. 2015]. It is primarily aimed at supporting the Space syntax methodology, and enhancing it with the GIS data, analysis, and visualisation features [Gil *et al*. 2015].

ESRI ArcGIS Data Reviewer offers many checks which allow to perform geometric and attribute validation as well as to ensure data integrity [ESRI 2019a]. Database *Validation : Network Connectivity Rules* check returns geometries for the features that violate the geometric network connectivity rules [ESRI 2019a]. Table 12 is a simple comparison between different tools, and *Axwoman 6.3* is the best choice for the isolated lines search and selection as it allows not only to find orphans and islands in one search, but also helps to remove them easily.

Table 12 Comparison of spatial data geometrical and connectivity correctness tools

Tool	GIS version	License	Used Functions	Comment
Axwoman 6.3 [Axwoman 2019]	*ESRI ArcMap 10.3*	Free	Get Isolated Lines	Finds isolated lines (orphans and islands)
Space *Syntax Toolkit* for *QGIS 0.2.1* [Gil *et al*. 2015]	*QGIS 2.18*	Free	Graph Analysis	Finds isolated lines (orphans and islands), but the deletion is difficult
Data Reviewer 10.3	*ESRI*	Paid	Database Validation	Finds orphans

[ESRI 2019a]	*ArcGIS* (*10.5*)		checks : Network Connectivity Rules	

The GIS model was built by using the standard features of *ESRI ArcMap*, and then the streets network's geometrical and connectivity correctness was checked by using *ESRI ArcGIS* (*10.5*) extension *Data Reviewer* [ESRI 2019a]. The goal of the *GIS* model execution was to test the spatial data preparation and error checking procedure and to prepare the initial spatial data for Space syntax network analysis that should identify SPs. The main used features were: *ArcMap* feature Clip (Analysis); *ArcMap* feature Simplify Line (Cartography) using Simplification Tolerance 3–5 m; *ArcMap* feature Merge (Data Management) or Dissolve (Data Management); *ArcMap* feature Feature To Line (Data Management) with YX Tolerance 1 m); *ESRI ArcGIS* extension Data Reviewer [ESRI 2019a]; *ArcMap* feature Export to CAD (Conversion)). The created *ArcMap ModelBuilder GIS* model is shown in Figs. 28–30, and it contains 3 main steps: preparing street lines for Space syntax segment analysis in roads with the *.SHP file; checking the streets network's geometrical, topological, and connectivity correctness by using *ESRI ArcGIS* extension *Data Reviewer*; removing false data from the streets network and exporting spatial data to the *.DXF file for further Space syntax analysis.

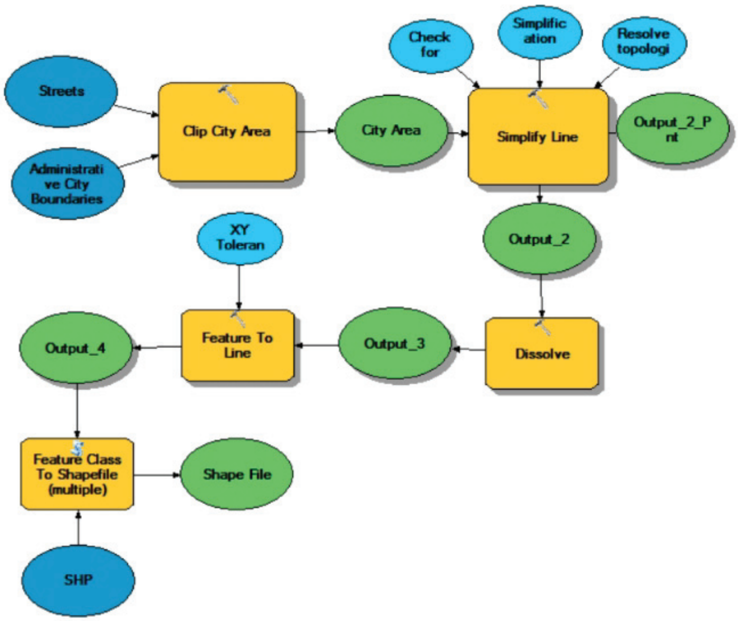


Figure 28 Preparing street lines for Space syntax segment analysis (*ESRI ModelBuilder*)

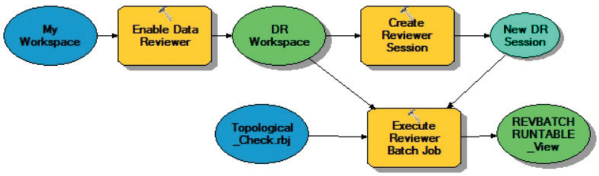


Figure 29 Checking streets network's geometrical and connectivity correctness (*ESRI ModelBuilder*)

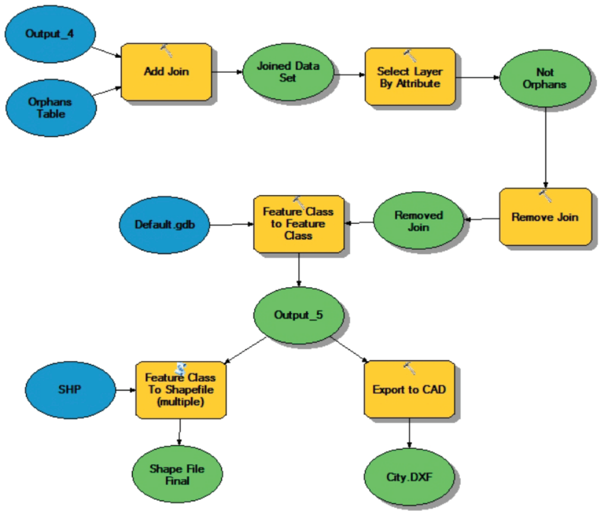


Figure 30 Removing false data from streets network and exporting spatial data to CAD (*ESRI ModelBuilder*)

The preparation of the spatial data input for Space syntax spatial network analysis should consist of the following steps.

1. The spatial data should be in the vector format, the *.SHP file.
2. The spatial data should contain streets or roads data.
3. The spatial data should contain only roads data, e.g., bike and pedestrian paths (but not pedestrian streets) should be removed from the selected vector data. It can be done by selecting roads data by attributes. For example, in the *OpenStreetMap* data, it can be done by selecting the attribute FCLASS (*ArcMap* feature *Select By Attributes*):

"FCLASS" not in ('bridleway', 'cycleway', 'footway', 'path', 'service', 'steps', 'track', 'track_grade1', 'track_grade2', 'track_grade3', 'track_grade4', 'track_grade5', 'unknown')

and leaving all the data for 'living street', 'motorway', 'motorway link', 'living street', 'primary', 'primary link', 'residential', 'secondary', 'secondary link', ‘tertiary’, ‘tertiary link’, ‘trunk’, ‘trunk link’, ‘unclassified’, ‘pedestrian’. Such a selection can be modified depending on the goal of the pattern research, but the huge sets of the unessential data will extend spatial data preparation and pattern calculation time.

4. The spatial data set should be saved in a local coordinate system to avoid data distortions. A local (or projected) coordinate system is based on a spheroid geographic coordinate system, and it uses linear units of measure for coordinates. The local coordinate system of the region could be identified by using a website like https://projest.io/ns/ [Projest 2017] which provides a simple application programming interface (API) for finding map projections appropriate for a particular area [Projestion 2019]. The process of detecting the local coordination system is presented in Fig. 31.

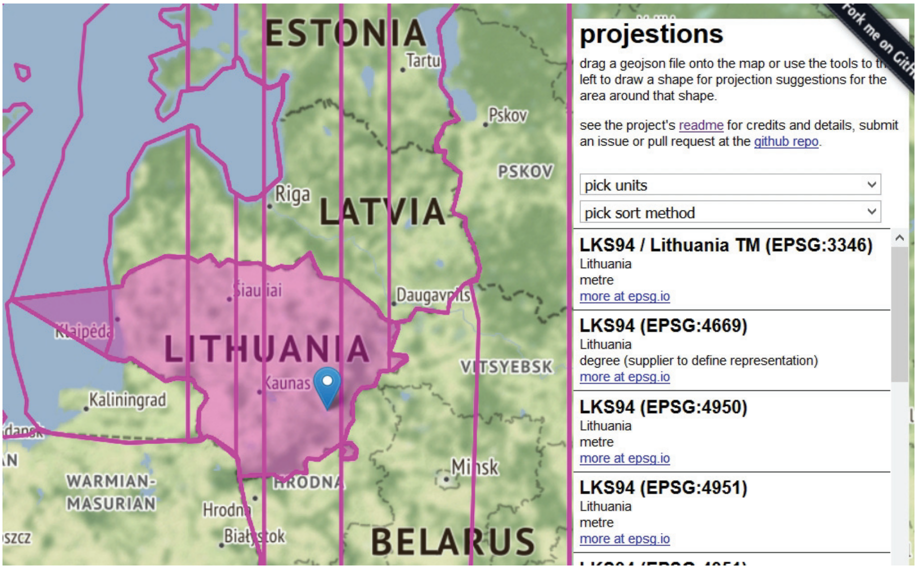


Figure 31 Detecting local coordination system [Projest 2017]

5. The research has proven that multilevel intersections in the roads layer could be safely ignored. The experiment was conducted by selecting multilevel intersections (ArcMap feature *Select By Attributes*) and merging intersection lines for making actual roads (ArcMap feature *Merge (Data Management*). Table 13 shows that merging intersection lines for making actual roads did not change the values of *Normalised Angular Choice* significantly (if we round up to two decimals, the numbers would be the same).

Table 13 Comparison of networks based on multilevel intersections data (NAIN – Normalised Angular Integration, NACH – Normalised Angular Choice)*

	Vilnius streets network without merging multilevel intersection lines					
Indicator	**NAIN n**	**NAIN 5000**	**NAIN 1500**	**NACH n**	**NACH 5000**	**NACH 1500**
MEAN	0.549	0.7	0.89	0.908	0.991	1.067
MAX	0.826	1.241	4.547	1.449	1.465	1.656
	Vilnius streets network after merging multilevel intersection lines					
	NAIN n	**NAIN 5000**	**NAIN 1500**	**NACH n**	**NACH 5000**	**NACH 1500**
MEAN	0.500	0.666	0.874	0.908	0.992	1.068
MAX	0.777	1.225	4.452	1.452	1.448	1.656

* Detailed description of Space syntax measures and formulas is presented in Table 15

6. The roads that are made up of two separate road lines, for example, with a green grass line between them, could be merged for more accurate calculation results, if such attributes exist in our spatial data, or this can be ignored (Fig. 32 and 33).

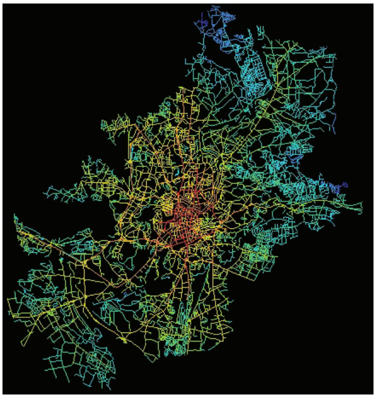


Figure 32 Vilnius streets network without merging multilevel intersection lines (*DepthmapX*)

Figure 33 Vilnius streets network after merging multilevel intersection lines (*DepthmapX*)

The completed preparation of the spatial data for the SP identification routine implementation is presented in Fig. 34.

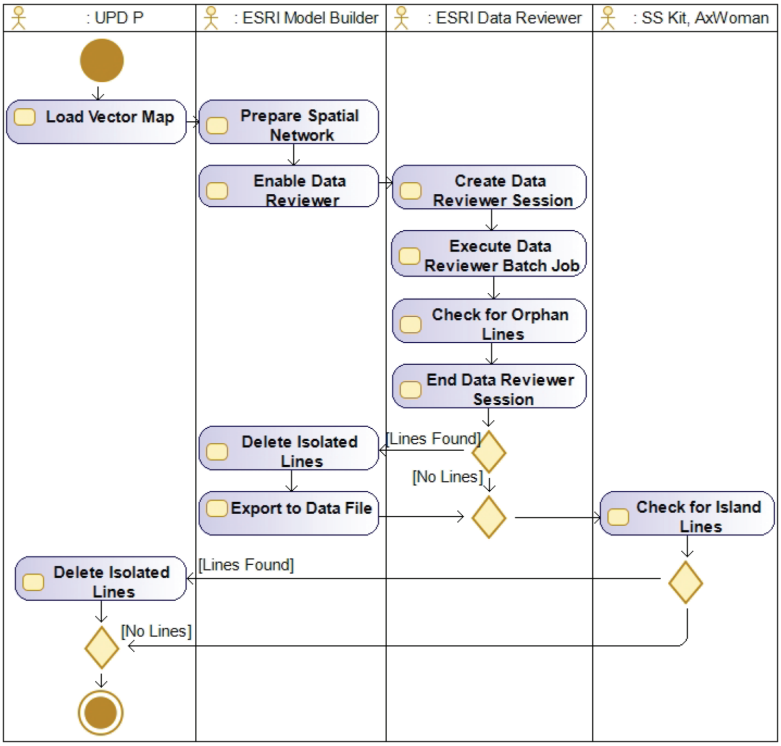


Figure 34 Preparation of the spatial data for SP identification routine implementation

4.7. Summary

In this section, the general SP definition model of SPDIAM that is used for the SP identification algorithm and which lets us identify SP in the vector data of the spatial entities has been explained. This SP model shall be used to describe and identify SP in the experiments described in Section 5. SPDIAM Experiments.

The general assumption of SPDIAM is that there is an SP formed by the existing distribution of variables across space, and, out of these distributions, certain aggregate quantities (densities and accessibilities) can be calculated which form part of the basis for ongoing decisions that will generate changes in CSS as a whole [Samson *et al*. 2014; Wilson 2000]. SP is a recurring form of a complex physical entity that has a spatial structure and can be presented as geometrical or topological primitives in a map [Marshall and Gong 2009; Germanaitė *et al*. 2020] and can be approached on the basis of the theory of urban capitals by Lars Marcus [Marcus 2007]. Every SP as the feature can be defined as consisting of different kinds of attributes: non-spatial, spatial, and computational. SP can be constructed of metapatterns; 6 spatial metapattern values were presented that depict 6 basic geometrical and topological forms that repeat themselves in the real-world SP in different proportions [Germanaitė *et al*. 2022]. As a result, the final SP and metapatterns model as a UML class diagram which forms the basis of the static description of SPDIAM has been created.

The presented SP identification algorithm used in SPDIAM constructs the area of SP by using Space syntax angular segment analysis measures with a certain percentage of maximum values, and then intersects them with a grid (the size of the cell 200x200); after that, SP is formed, identified, and evaluated. Spatial metapattern identification aims to detect the working basic metapattern values that can later be used to identify the geographer's and Alexander's patterns and to apply them in CSS analysis in other domains. This algorithm further analyses the form of SP and uses a new Space syntax structure – *Visuality Graph* – together with the new VGA measures to describe and identify the form of SP.

The SPDIAM description consists of the concepts, based on which, SPDIAM static and dynamic views in the form of UML diagrams are created. The SPDIAM static view is an SPDIAM conceptual data model which lets us describe, identify, and apply SP. The SPDIAM dynamic view presents the SPDIAM application process and consists of 3 phases: SP description, SP identification, and SP application.

The developed SPDIAM spatial data preparation routine lets us create a partial-comprehensive model of CSS because such a model is not made up of all possible CSS data (due to the fact that CSS is too large), but it is only made of the part of the data that is important for the calculations. The Spatial data preparation routine consists of two steps: 1) preparation of the vector map which shall later be transformed into the segment graph that will be operated by the Space syntax method; 2) verification and correction of the vector map geometrical errors. These steps can be executed by using the already existing features of *ESRI ArcGIS*, *QGIS*, or other *GIS* software. The automated tasks of the spatial data preparation routine were performed by *ESRI ModelBuilder*. The input data sets and formats for the *ArcMap ModelBuilder GIS* model could be chosen from the publicly available sources. The input data sets used in the experiments were taken from *OpenStreetMap* data sets, such as www.geofabrik.de [Geofabrik 2019].

As a result, SPDIAM is positioned as a structural, ruled-based SP recognition method that provides SP structural description by using spatial metapatterns and morphological relationships and which uses Space syntax topology and visibility analysis to identify the SP of a road network by using GIS.

5. SPDIAM EXPERIMENT

5.1. Case Study 1: SPDIAM Application

5.1.1. Input Spatial Data Preparation Experiment

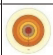
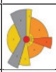
For the spatial data preparation routine experiment, 12 North American, European, and African cities were selected in terms of a different scale, continents, layouts, and historical circumstances reflecting the potential diversity of SP: Baltimore (USA), Chicago (USA), Gdańsk (Poland), Helsinki (Finland), Ibadan (Nigeria), Kaunas (Lithuania), Klaipėda (Lithuania), Nice (France), Vilnius (Lithuania), Stockholm (Sweden), Bucharest (Romania), Ottawa (Canada). Also, two different types of spatial data sets were chosen: the government-provided spatial data sets [Geoportal LT 2019] and the *OpenStreetMaps* data sets [Geofabrik 2019]. The *ESRI ModelBuilder GIS* model was created to test the described spatial data preparation routine and to prepare spatial data for the SP identification. The *GIS* model was executed on the road networks of the selected cities, and spatial data was prepared for the transformation to the segment graph. The prepared road network's geometrical correctness was tested by using *ESRI ArcGIS Data Reviewer*, Space syntax *Kit for QGIS*, and *Axwoman* [Jiang 2015; Germanaitė *et al*. 2020].

The executed experiment of the spatial data preparation routine revealed several issues. First, the spatial data should contain only roads data, e.g., bike and pedestrian paths (but not pedestrian streets) should be removed from the data. Road network data selection can be modified depending on the goal of the SP analysis, but the huge sets of inessential spatial data will extend the time of the spatial data preparation and SP calculation. Secondly, the local coordinate system of the spatial entity should be used to avoid data distortions; the proper coordinate system can be identified by using online tools [Projest 2017]. Thirdly, the data of multilevel intersections in the road network could be safely ignored, as it does not significantly change the values of the Space syntax measures [Germanaitė *et al*. 2020].

5.1.2. Define Problem and Describe Solution Phase Experiment

For the SPDIAM experiment, the general SPD problem *urban development* was selected to illustrate the idea of SP. When looking for the solutions to this problem, the classic concepts which are known as the concentric-zone, sector, multiple-nuclei, and linear urban development forms are commonly mentioned [Major 2018]. Based on them, the SP named *City Layout* was created together with the values it can acquire: Concentric-zone, Linear, Sector, and Multi-nuclei. The instances of UML classes and explanatory attributes used to describe the City Layout SP and its values are presented in Table 14. The Pattern Configuration attribute contains the information of what metapatterns and patterns the City Layout SP consists, and later it can be used to build new SPs based on the previously defined metapatterns and patterns [Germanaitė *et al*. 2020].

Table 14 City Layout SP

***Instance_name* : Pattern**	***Instance_name*: Pattern Value**		**Pattern Type : Pattern Attribute**	**Pattern Group : Pattern Attribute**	**Pattern Configuration : Pattern Attribute**	**Pattern Context : Pattern Attribute**	**Pattern Dimension : Pattern Attribute**
Attribute_name							
Name	Name	Image	Value	Value	Value	Value	Value
Attribute_value							
'Center'	'Center'	●	'Metapattern'	'Center'	NULL	NULL	NULL
'Core–periphery'	'Core–periphery'		'Pattern'	'Abstract'	'Center, Periphery'	NULL	NULL
'City Layout'	'Concentric-zone'		'Pattern'	'Layout'	'Center, Core–periphery'	'City, Regional, District'	'Economic, Social'
	'Linear'						
	'Sector'						
	'Multi-nuclei'						

For the City Layout SP identification, the Space syntax method was defined by the Method class, and the used Space syntax measures were defined by the Measure class as presented in Table 15. Apart from the standard Space syntax measures, two new measures based on the Space syntax theory CENTER and URBAN COMPACTNESS INDEX (UCI) were suggested and tested in the SPDIAM experiment; also, standard Space syntax measures NAIN and NACH measures were suggested to be used in a new way so that to detect the probable change of the identified City Layout SP value in the future [Germanaitė *et al*. 2020].

Table 15 Space syntax measures for City Layout SP identification

***Instance_name* : Measure**			
Attribute_name			
Name	Formula	Component	Description
Attribute_value			
'r'; 'k'; 'm'	'INPUT'	NULL	'Radius in meters'; 'Radius-from in meters'; 'Radius-to in meters'
'c'; 'n_y'; 'cn_y'	'MAP VARIABLE'	NULL; 'r x'; 'c, x'	'Grid cell'; 'Segment in radius r from node x'; 'Segment in grid cell x'
'd_{xy}'; 'Σ_y'; 'Σ_{yz}' 'Σ_{zy}'; 'g_{yz}'	'MAP VARIABLE'	'x, y'; 'x, y'; 'x, y, z'; 'x, y, z'; 'x, y, z'	'Distance from node x to node y'; 'Sum of the distances from x to y'; 'Sum of all shortest trips from y to z through x'; 'Sum of all shortest trips from z to y through x'; 'Count of shortest trips between y and z through x'
'NC'	'Σ_r n_y'	'r, n_y'	Node Count at radius r'
'Cell NC'	'Σ_c cn_y'	'c, cn_y'	Node Count in grid cell c'
'MR r'	'Σ_r d_{xy}'	'r, d_{xy}'	'Length of the reachable street length within radius'
'ATD'	'Σ_y MIN d_{xy}'	'MIN d_{xy}'	'Angular Total Depth of node x'
'AIN'	'NC^2 / ATD'	'NC, ATD'	'Angular Integration'

'CENTER'	'AIN * MR 1500'	'AIN, MR 1500'	'Center positioning'
'MEAN CENTER GRID CELL'	'Σ_c MEAN CENTER / Cell NC'	'c, MEAN CENTER, Cell NC'	'Mean CENTER value of the segments in grid cell'
'ACH'	'$\Sigma_y \Sigma_z g_{yz}$'	'y, z, g_{yz}'	'Angular Choice'
'NAIN'	'NC^1.2/ ATD'	'NC'	'Normalised Angular Integration'
'NACH'	'log (ACH + 1) / log (ATD + 3) '	'ACH, ATD'	'Normalised Angular Choice'
'UCI'	'(MIN ATD Line – MIN ATD Circle) / (MIN ATD Line – MIN ATD Structure)'	'MIN ATD Line, MIN ATD Structure, MIN ATD Circle'	'Urban Compactness Index'

In Table 16, instances of the *Form* and *Structure* classes with the corresponding instances of the *MeasureTarget* class are presented together with the instances of the Operation class, which illustrates that SPDIAM enables to reuse same Form, Structure, and Measure for both SP identification and transformation operations [Germanaitė *et al*. 2020]. It is important to note that the class *Form* instances described in Table 16 must be created in the same order as they are listed, and this order is defined by the SP identification method, as it was described in Section 4.5. SPDIAM Dynamic View.

Table 16 Forms and structures for City Layout SP operations

Instance_name **: Form**	***Instance_name*** **: Structure**		***Instance_name*** **: MeasureTarget**	***Instance_name*** **: Operation**
Attribute_name				
Name	Type	Variant	Name	Type
Attribute_value				
'Spatial Network'	'Spatial Network'	'Structure'	NULL	'Pattern Identification', 'Pattern Transformation'
'Segment Network'	'Segment Graph'	'Structure'	'CENTER'	
'Area'	'Grid'	'Structure'	'MEAN CENTER GRID CELL'	'Pattern Identification'
'Zone'	'Grid'	'Structure'	'ZONE COUNT', 'ELEMENT ZONE'	
'Center Zone'	'Grid'	'Structure'	'ELEMENT ZONE'	
'Center Configuration'	'Convex Graph'	'Structure' 'Line', 'Circle'	'PART COUNT', 'PART SIZE', MIN ATD'	
'Center Layout'	'Grid'	'Structure'	'UCI'	
'Future Center Layout'	'Segment Graph'	'Structure'	'NAIN', 'NACH'	'Pattern Transformation'

5.1.3. Identify and Present Solution Phase Experiment

The SP City Layout identification experiment was conducted on the prepared 12 cities road network data by using *ESRI ArcMap* (*10.3*) and *DepthmapX* (*0.6.0.*). The prepared road network was converted to a segment graph, and the CENTER measure was calculated by using *DepthmapX*. Then, the graph map from *DepthmapX* was imported to *ESRI ArcMap*, the grid was created by using *ESRI ArcMap*, and the MEAN CENTER GRID CELL measure was calculated. Based on the MEAN CENTER GRID CELL values, the area of the spatial entity was classified into 3 zones (which is a minimum number for the classification) by the *Jenks' Natural Breaks* algorithm [Jenks 1977]. The grid zone with the highest centre values was chosen as a presentation of the City Layout SP and imported back to *DepthmapX*. Here, the convex graph was created, and its segments were linked with the closest accessible neighbourhood nodes; after that, the ATD measure was calculated for three variants of the *Structure* class instance: the structure (e.g., the real structure of the spatial entity), the line, and the circle. Then, the UCI measure was calculated, and, based on its value, the Pattern Value for the City Layout SP was identified. After that, the calculated Space syntax measures were displayed on the map by using *ESRI ArcMap* to present the instances of the *AnalysisFormStructure* class. In Fig. 35, all five instances of the *AnalysesFormStructure* class together with the initial set of raw data for Kaunas City are presented to illustrate how the form and structure (listed in Table 16) of a spatial entity evolves through the SP City Layout identification experiment [Germanaitė *et al*. 2020].

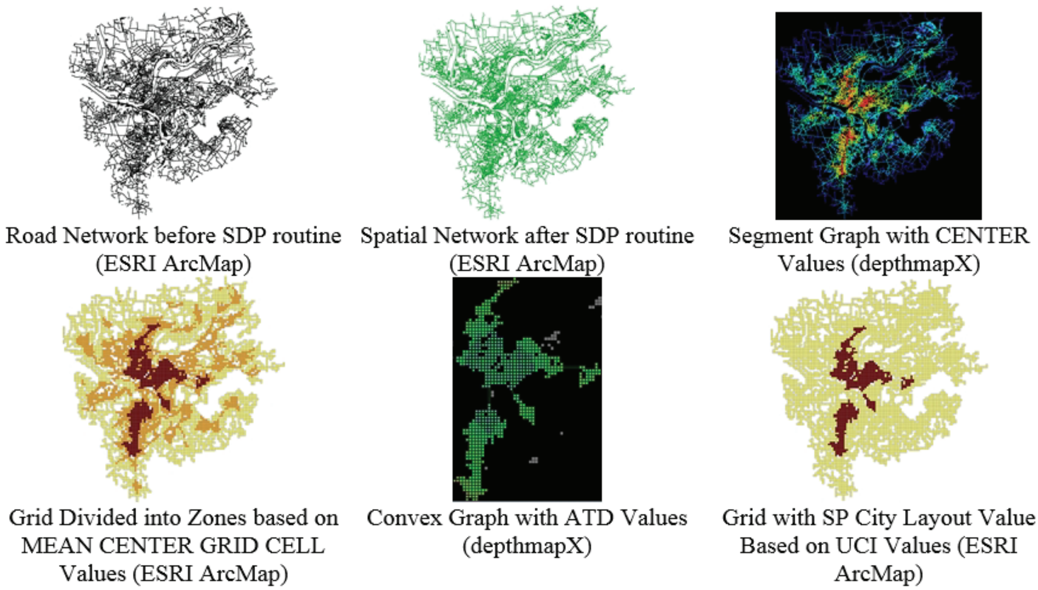


Figure 35 Instances of Analysis Form Structure class of Kaunas City spatial entity

The structure images in Fig. 35 have been created by using different software tools (*ESRI ArcMap*, *DepthMapX*), and they show the ranges of the measures (indicated under each image) calculated in the different structure for the same spatial entity.

The numerical results of the SPDIAM experiment are presented in Table 17. The combination of the UCI measure and PART COUNT values identifies the SP Pattern Value: 1) UCI values 0.9–0.95 show the maximum scattered form of the centre which consists of 0–1 separate parts, thus, the Pattern Value is Linear

(Klaipėda); 2) UCI values 0.9–0.95 and several parts show that the parts are of a similar size, spaced apart, and likely due to the lack of a clear hierarchical centre, thus the Pattern Value is Multi-nuclei (Gdańsk and Helsinki); 3) UCI values 0.951–0.979 show that either one part is in a non-compact form (like Nice), or else there are several parts, but one part is significantly dominant (such as in the case of Ibadan, Kaunas, or Ottawa), thus the Pattern Value is Sector; 4) UCI values 0.98–1.0 show that one part is compact (Baltimore, Vilnius) or dominant, and several satellite parts can be small and non-competing as local hubs (Chicago), thus the Pattern Value is Concentric-zone [Germanaitė *et al*. 2020].

Table 17 Ranges of City Layout SP measures and experimentally obtained values

Instance_name **: PatternValue**	***Instance_name*** **: Measure**	***Instance_name*** **: PatenValueMeasure**		***Instance_name*** **: SpatialEntity**	***Instance_name*** **: AnalysisMeasure**
Attribute_name					
Name	Name	Value Range Bottom	Value Range Top	Name	Measure Value
Attribute_value					
'Concentric- zone'	'UCI'	0.98	1	'Baltimore'	0.995
				'Bucharest'	0.986
				'Vilnius'	0.984
				'Chicago'	0.981
	'PART COUNT'	NULL	NULL	'Baltimore'	0
				'Bucharest'	2
				'Vilnius'	0
				'Chicago'	5
'Sector'	'UCI'	0.951	0.979	'Ibadan'	0.976
				'Nice'	0.974
				'Ottawa'	0.966
				'Kaunas'	0.959
	'PART COUNT'	NULL	NULL	'Ibadan'	2
				'Nice'	0
				'Ottawa'	8
				'Kaunas'	3
'Multi-nuclei'	'UCI'	0.9	0.95	'Gdansk'	0.923
				'Helsinki'	0.920
	PART COUNT	2	NULL	'Gdansk'	2
				'Helsinki'	2
'Linear'	'UCI'	0.9	0.95	'Klaipeda'	0.904
				'Stockholm'	0.904
	PART COUNT	0	1	'Klaipeda'	0
				'Stockholm'	1

The visual representation of the City Layout SP in USA, European, and African cities are presented in Fig. 35. The spatial forms of spatial entities are presented by a colour scheme in which the brown area presents identified SP (Form.Name = 'Center Layout'), and the yellow area presents the rest of the city area that was used in the experiment ((Form.Name = 'Area'). The picture of Ottawa SP differs from the other pictures due to the differences in the size of the pictures (the map of Ottawa is larger than the maps of other cities).

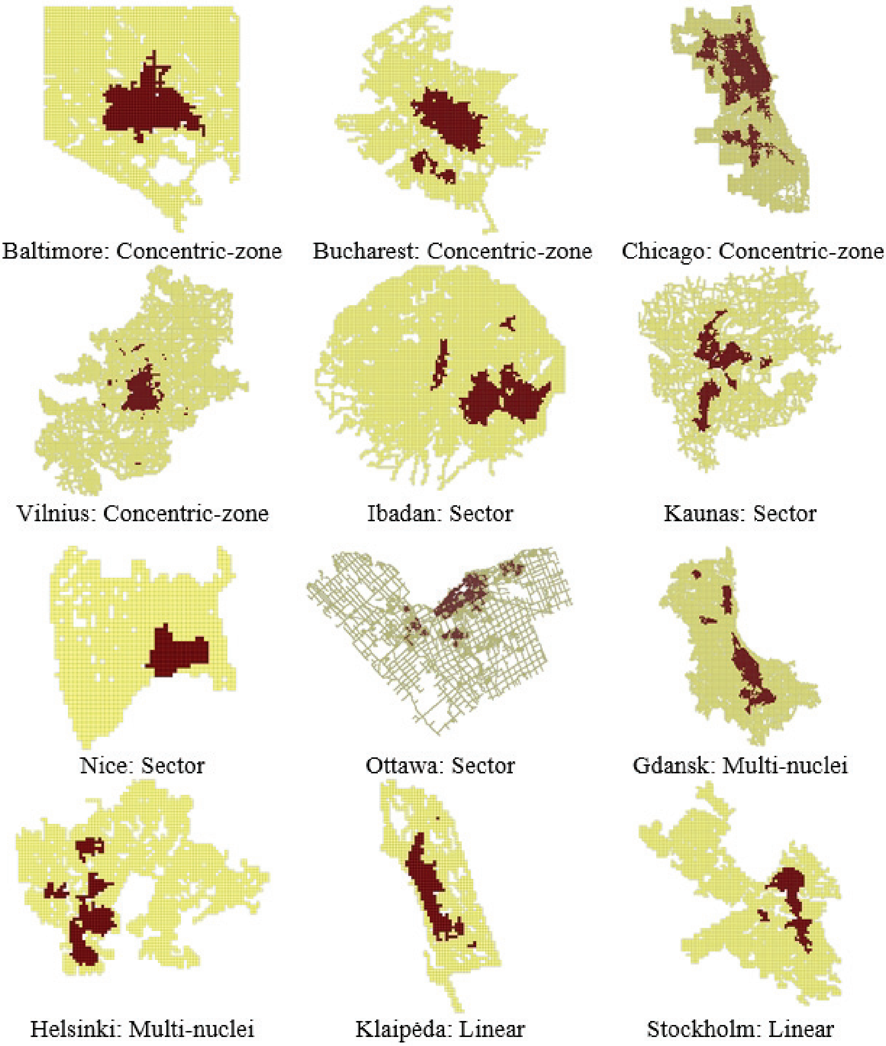


Figure 36 City Layout SP in USA, European and African cities (*ESRI ArcMap*) [Germanaitė *et al*. 2020]

5.1.4. Evaluate and Apply Solution Phase Experiment

In the Evaluation phase, the obtained City Layout SP values for the 12 cities were visually evaluated by a UPD practitioner. The first and most important insight that can be drawn from the City Layout SP identification experiment is that SPDIAM can be used for the automated SP identification as the detected City Layout SP values match the empirically observed urban models in the selected cities, for example, Chicago is known as a Concentric Zones city, Gdańsk is a Linear city, etc. Secondly, some improvements to the City Layout SP can be done by detailing the difference between measures that would help to highlight trends in city layouts. Thirdly, it is possible to transform the UCI measure scale and meaningfully use all values from 0 to 1, and the composition of SPDIAM allows doing it as it supports the level of flexibility [Germanaitė *et al*. 2020].

In the Application phase, the identified City Layout SP was used for the objectives set that can help to solve the previously defined urban development problem and to get the urban development insights. Sector City Layout SP, ATD measure values were intersected with the Kaunas City street network and statistical data of the commercial entities (Figs. 37 and 38), and it can be seen that it shows definite correlation; at some places, SP and indicators data does not match, and this contrariety should be kept in mind when planning the placement of the new infrastructure and defining the already existing economic and social attraction of the areas of city centre together with its desired directions for expanding. As the Spatial Layout SP value for Kaunas is the Sector, the objectives for Kaunas SPD should be directed towards increasing the accessibility and integration of city spaces, and the City Layout SP can help to emphasise it. The experiment of the SP Application phase proved that economic, social, and environmental indicators can be used not only to get insights about the SPD domain, but also to verify the identified SPs. From the technical perspective for the best precision spatial entity and indicators, spatial data has to be of the same type [Germanaitė *et al*. 2020].

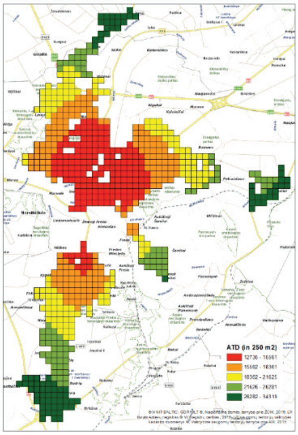


Figure 37 City Layout SP of Kaunas with ATD Values (*ESRI ArcMap*)

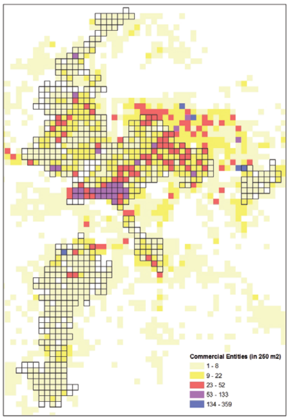


Figure 38 City Layout SP of Kaunas with statistical commercial entities data (*ESRI ArcMap*)

In Fig. 37, the SP of Kaunas also shows the ATD measure values represented by a colour scheme using the ranges from the shortest paths (shown in red) to the longest paths (shown in dark green). In Fig. 38, the SP of Kaunas is intersected with the statistical data of the commercial entities: the purple colour shows the areas of the maximum density of the commercial entities, whereas the yellow colour shows the minimum density. In both cases the decision can be made regarding these insights as to how the city infrastructure should be improved based on the length of the paths and the density of the points of interest.

The experiment results confirm that SPDIAM is appropriate to describe SPs and identify them automatically; the use of the normalised measures enables SP comparison with each other and reduces the degree of subjectivity; SPDIAM no longer relies on the statistical information, but forms SP by the complex modelling of a city, and then associates territories with SP; SPDIAM indicates a possible direction of CSS SP changes in the future and can be used for the evaluation of SPD plans of urban areas [Germanaitė *et al*. 2020].

5.2. Case Study 2: General Spatial Pattern and Metapattern Model Application

5.2.1. Input Data Preparation Experiment

The SPDIAM spatial data preparation routine depends on the method that is selected for SP identification. The Space syntax method requires a vector data model as the spatial network is formed of the roads network layer. The spatial data preparation routine was described above in Section 4.7. and previously in [Germanaitė *et al*. 2020], but, for the spatial metapattern identification, this routine is somewhat different as we do not need the data of actual spatial entities (cities or regions). Instead, the 6 spatial entities for 6 metapattern values were drawn in *Autodesk Autocad 2017* and saved as *.DXF files as the ideal forms for testing spatial measures. The first spatial entity (Circle) consisted of 778 squares, and then the other entities had to fit in the same area of the drawing. The following geometrical structures of spatial entities were prepared: Line, Star4, Star8, Sectoral, Labyrinth, Circle. These primary spatial structures in the *.DXF format were transformed to *Visuality Graph* by using *DepthmapX* (*0.5.0.*), and each square of the spatial structure became a cell in the *Visuality Graph* (Figs. 39 and 40). The vertices of the *Visuality Graph* were connected if they could be seen from each other without obstruction. As a result, 6 *Visuality Graphs* were prepared as the input data for the experiment.

Such ideal spatial structures present an idealised situation and help to analyse simple geometric forms of SP. Such structures have to be essential (most common) and elementary (the simplest transformation of the selected form). Should the need arise, the library of spatial metapatterns and their values can always be supplemented with the new members; we merely have to use the same area of the drawing so that the calculated measure values would be in the same range.

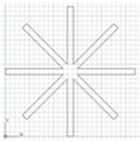


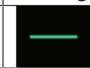
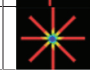
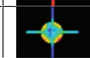
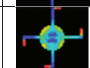
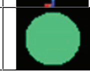
Figure 39 Idealised spatial entity *Star8* (*Autocad* drawing, *Autodesk Autocad*)

Figure 40 Spatial structure of *Star8* (*Visuality Graph*, *DepthmapX*)

5.2.2. Spatial Metapattern Description and Identification Experiment

For the experiment, the basic spatial metapattern and its values were described by using the instances of UML classes and the explanatory attributes of the general SP and metapattern model from Chapter 3 as presented in Table 18.

Table 18 Description of basic spatial metapattern

***Instance_name* : Pattern**	***Instance_name*: PatternValue**		**Type : PAttribute**	**Configuration : PAttribute**
Name	Name	Image	Value	Value
'Basic Metapattern'	'Line'		'Metapattern'	NULL
	'Star4'		'Metapattern'	NULL
	'Star8'		'Metapattern'	NULL
	'Sector'		'Metapattern'	NULL
	'Labyrinth'		'Metapattern'	NULL
	'Circle'		'Metapattern'	NULL

The structures of the basic geometrical metapattern values were drawn and analysed with the objective to select working VGA measures and test if they can be used for the identification of real SPs. VGA measures (Table 19) were selected by using the following rules: 1) evaluating them by the meaning: what the measure defines or shows on the map; 2) taking those measures that can hypothetically define the shape of the visual field, e.g., the geometrical form of the selected spatial area which is used for SP identification (class *Form*); 3) testing measures in the VGA spatial metapattern description and identification experiment (as described in the present Section); and, finally, 4) evaluating the values of the measures and deciding which measures can be used to define the physical and the functional form of the spatial metapattern value and which of them can be normalised for later use.

Table 19 VGA measures for basic spatial metapattern values identification (some measures are taken from [Koutsolampros *et al*. 2019])

Instance_name **: Measure**			
Name	Formula	Component	Description
'k'	'MAP VARIABLE'	NULL	'number of cells in system'
'd_{xy}'	'MAP VARIABLE'	NULL	'distance from cell x to y'
'v'; 'N'	'MAP VARIABLE'	NULL	'cell of the grid'; 'neighbourhood'
'e'; 'E'	'MAP VARIABLE'	NULL	'pair of mutually visible cells'; 'edge'
'g'; 'c'	'MAP VARIABLE'	NULL	'generating point'; 'center of gravity of polygon'
'A'; 'Π'	'MAP VARIABLE'	NULL	'isovist area'; 'isovist perimeter'
'TD'	'$\sum_y MIN\ d_{xy}$'	'd_{xy}'	'total depth of system'
'Visual Mean Depth (VMD)'	'$\frac{TD}{(k-1)}$'	'TD, k'	'average number of visual steps to reach every other cell in the system'
'RA'	'$\frac{2*VMD}{k-2}$'	'MD, k'	'relative asymmetry'
'D'	'$\frac{2(k(log_2(k+2)/3)-1))}{(k-1)(k-2)}$'	'k'	'idealised diamond system'
'RRA'	'$\frac{RA}{D}$'	'RA, D'	real relative asymmetry
'Point First Moment'	'$\sum_{v_j \in N\ (v_i)} d(v_i, v_j)$'	'v, N, d'	'isovist potential to spin around'
'Through Vision'	(found in *DepthmapX*)	'e, E'	'amount of visibility lines that pass through location'
'Isovist Compactness'	'$\frac{4\pi A}{\Pi^2}$'	'A, Π'	'measure of isovist shape that is invariant to its area'
'Drift Magnitude'	'$\sqrt{c_x - g_x{}^2 + (c_y - g_y)^2}$'	'g, c'	'vector from generating point to the centre of polygon gravity'
'Isovist Occlusivity'	(found in *DepthmapX*)	-	'parts of isovist perimeter'
'Visual Integration'	'$\frac{1}{RRA_D}$'	'RRA'	'amount transitions needed from graph segment to reach all segments'

The basic metapattern identification used the Space syntax method that was defined by the class *Method* and the VGA measures in use were defined by the class *Measure* as presented in Table 20. Also, the instances of the classes *Form* and *Structure* with the corresponding instances of the class *FormMeasure* were described. For the structure with the attribute Structure.Type = 'Visuality Graph', the VGA measures from Table 21 were used to identify the values of the basic spatial metapattern values.

Table 20 Forms and structures for spatial metapattern

***Instance_name* : Form**	***Instance_name* : Structure**		***Instance_name* : FormMeasure**
Name	Type	Variant	Description
'Spatial Grid'	'Grid'	'Structure'	NULL
'Basic Metapattern'	'Visuality Graph'	'Structure'	'Point First Moment', 'Through Vision', ' Isovist Compactness', 'Drift Magnitude', ''Isovist Occlusivity', 'Visual Integration', 'Visual Mean Depth'

Then, the calculation of VGA measures for each basic metapattern value was made by using *DepthmapX*, and the calculated VGA measures were normalised by dividing their values by the number of the cells of the Visuality Graph. The results of the calculation and the visual presentation of the different measures are presented in Table 21 and in Fig. 41.

Table 21 Basic metapattern value measures (MIN, MEAN, MAX) and their normalisation (N)

Line	**Line N**	**Star4**	**Star4 N**	**Star8**	**Star8 N**	**Sector**	**Sector N**	**Labyrinth**	**Labyrinth N**	**Circle**	**Circle N**
Point First Moment											
203295	2258.833	179093	1092.030	203804	627.089	383969	1126.009	5325	13.976	1632530	2098.367
270703	3007.811	247634	1509.963	278051	855.541	501121	1469.563	453064	1189.144	2216860	2849.434
396615	4406.833	356901	2176.225	727968	2239.901	658816	1932.012	658816	1729.176	2773020	3564.293
Through Vision											
0	0	0	0	0	0	0	0	0	0	8	0.010
1278	14.2	1154	7.036	970	2.984	2145	6.290	1937	5.083	6424	8.257
1980	22	3452	21.048	6648	20.455	6954	20.392	7023	18.433	21804	28.025
Isovist Compactness											
0.126	0.126	0.059	0.059	0.039	0.039	0.086	0.086	0.07	0.07	0.997	0.997
0.126	0.126	0.132	0.132	0.121	0.121	0.246	0.246	0.24	0.24	0.997	0.997
0.126	0.126	0.136	0.136	0.134	0.134	0.505	0.505	0.543	0.543	0.997	0.997
Drift Magnitude											
7	0.077	20	0.121	19	0.058	17	0.049	22	0.056	39	0.050
2258	25.088	2164	13.195	2261	6.956	1792	5.255	1637	4.186	2098	2.696
4409	48.988	4196	25.585	4201	12.926	4325	12.683	3982	10.451	3153	4.052

Line	Line N	Star 4	Star4 N	Star 8	Star8 N	Sector	Sector N	Labyrinth	Labyrinth N	Circle	Circle N
Isovist Occlusivity											
0	0	0	0	0	0	282	0.826	400	1.049	0	0
0	0	952	5.804	2923	8.993	7516	22.041	8870	23.280	0	0
0	0	8034	48.987	18833	57.947	19733	57.868	20675	52.877	0	0
Visual Integration											
no value	no value	9.83	9.83	7.88	7.88	8.62	8.62	3.64	3.64	no value	no value
no value	no value	10.36	10.36	8.6	8.6	33.61	33.61	16.54	16.54	no value	no value
no value	no value	39.33	39.33	42.63	42.63	248.91	248.91	50.6	50.6	no value	no value
Visual Mean Depth											
1	0.011	1	0.006	1	0.003	1	0.002	1.102	0.002	1	0.001
1	0.011	1.461	0.008	1.689	0.005	1.279	0.003	1.534	0.004	1	0.001
1	0.011	1.491	0.009	1.735	0.005	1.619	0.004	2.653	0.006	1	0.001

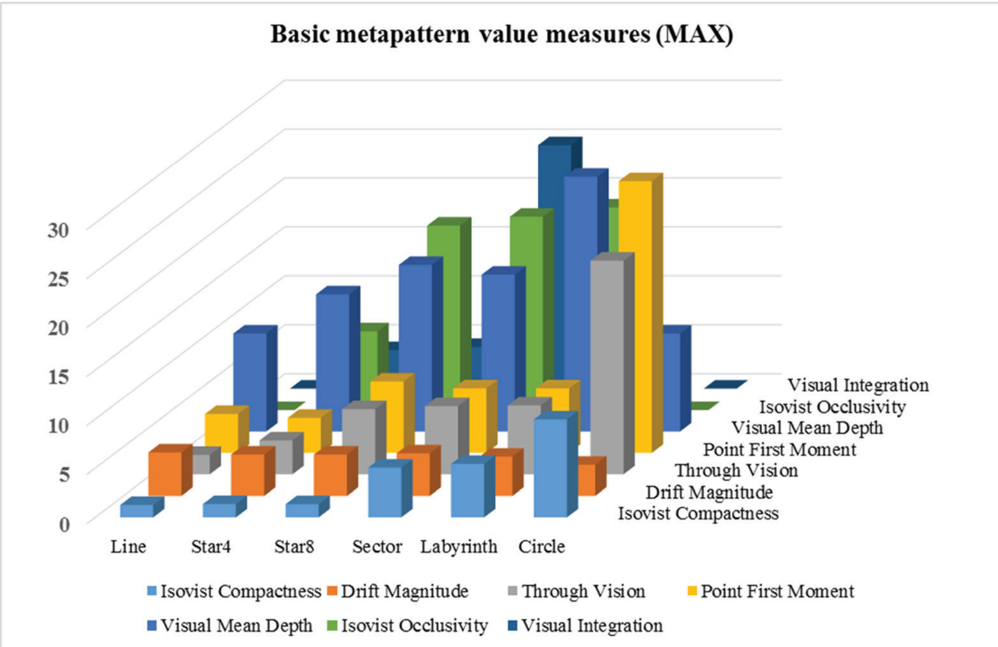
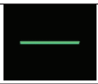
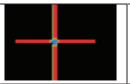
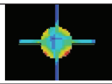
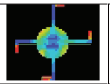


Figure 41 Basic metapattern value measures (MAX)

The visual presentation of the basic metapattern values is presented in Table 22.

Table 22 Basic metapattern values (*DepthmapX*)

Line	**Star4**	**Star8**	**Sector**	**Labyrinth**	**Circle**
Number of Cells					
90	164	325	341	381	778
Image					
					

5.2.3. Experiment Results Evaluation

The main results of the conducted spatial metapattern identification experiment are as follows: 1) The *Isovist Compactness* measure is the most suitable for SP identification as its values show certain clear ranges for different spatial metapattern values (the measure value approaching 0 shows Line, and the value approaching 1 shows the Circle metapattern value). The MAX and MEAN values of *Isovist Compactness* can be used potentially as the additional values for more precise SP description; 2) The *Drift Magnitude* measure works fairly well and can be used to identify the degree of compositional axiality. The bigger value of the *Drift Magnitude* measure is found in more prolonged spatial metapattern values; 3) only two measures – *Isovist Compactness* and *Visual Integration* – can be considered as normalised, thus allowing us to compare SPs of different sizes; 4) *Visual Mean Depth* as the measure based on the topological distance can be used not normalised, and its higher MAX or MEAN values show a more Labyrinth-like spatial metapattern structure; 5) other measures do not demonstrate clear relations between the pattern form and their values.

The main conclusion of the experiment is that the general SP and metapatterns model and IT artefacts presented in this thesis can be used to describe and identify spatial metapatterns in the spatial vector data of CSS while taking into account CSS analysis problems.

5.3. Case Study 3: Spatial Pattern Identification Using Metapattern

5.3.1. Input Spatial Data Preparation Experiment

For the spatial data preparation routine experiment, the data of 12 North American, European, and African cities (Baltimore (USA), Chicago (USA), Gdańsk (Poland), Helsinki (Finland), Ibadan (Nigeria), Kaunas (Lithuania), Klaipėda (Lithuania), Nice (France), Vilnius (Lithuania), Stockholm (Sweden), Bucharest (Romania), Ottawa (Canada)) was prepared as described in Sections 4.7. and 5.1.1. and used as described.

Then, these primary spatial structures in the *.DXF format were imported into *DepthmapX* (*0.5.0.*), the *Grid* property was set to 200x200 (as the same grid size was used in all experiments), and a separate map (a *.GRAPH file) for each independent part of the city was created. The independent part is defined by the rule that it is not connected in any of the other parts of the city. Then, each map was transformed to the *Visuality Graph* by using *DepthmapX* (*0.5.0.*) specifically as it was described in Section 5.2.1. As a result, 41 *Visuality Graphs* were prepared for the separate parts of 12 cities as the input data for the experiment.

5.3.2. Spatial Pattern Identification Based on Metapattern

Step 1: Spatial metapatterns and their values preparation

First, we selected 6 basic spatial metapatterns and their value measures calculated in Case study 2 (see Section 5.2.). Then, we performed the cluster analysis on these 6 basic spatial metapatterns and their measures by selecting *K-Means Cluster Analysis* [IBM 2021a], and also by using the *IBM SPSS Statistics* [IBM 2021b] tool. The goal of this step was to create 6 clusters of 3 Space syntax measures and their values, and to use a combination of these measure values with the objective to identify SPs by using metapatterns.

The K-Means cluster analysis procedure attempts to identify relatively homogeneous groups of cases based on the selected characteristics while using an algorithm which requires specifying the number of clusters [IBM 2021a]. While these statistics are opportunistic (the procedure tries to form groups that *do* differ), the relative size of the statistics provides information about each variable's contribution to the separation of the groups [IBM 2021a]. The variables should be quantitative at the interval or ratio level [IBM 2021a]. The results of the K-Means cluster analysis are presented in Table 23. As the MAX values of each measure showed the best result (e.g., the biggest difference in clusters), only the MAX values were used further.

Table 23 Spatial metapattern results of K-Means cluster analysis

Meta-pattern	Isovist Compactness			Drift Magnitude			Mean Depth			Cluster
	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	
Line	0.126	0.126	0.126	0.077	25.088	48.988	1.000	1.000	1.000	**1**
Labyrinth	0.070	0.240	0.543	0.056	4.186	10.451	1.102	1.534	2.653	**2**
Star4	0.059	0.132	0.136	0.121	13.195	25.585	1.000	1.461	1.491	**3**
Star8	0.039	0.121	0.134	0.058	6.956	12.926	1.000	1.689	1.735	**4**
Sector	0.086	0.246	0.505	0.049	5.255	12.683	1.000	1.279	1.619	**5**
Circle	0.997	0.997	0.997	0.050	2.696	4.052	1.000	1.000	1.000	**6**

The visualisation of the K-Means cluster analysis results based on the measure data from Table 23 is presented in Fig. 42. The *Drift Magnitude* measure values were divided by 10 in order to equalise the ranges of the values of different measures. This illustration shows us how the selected measures differ depending on the spatial metapattern value.

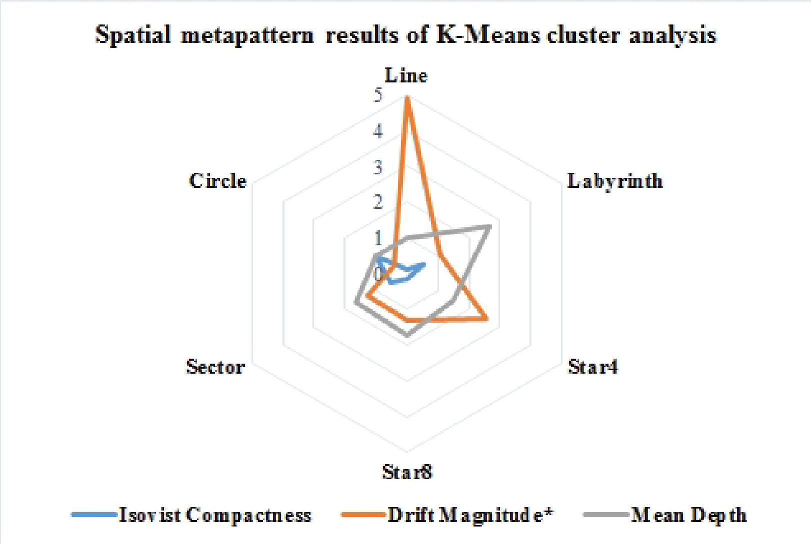


Figure 42 Visualisation of K-Means cluster analysis results (*Drift Magnitude values were divided by 10 in order to equalise the ranges of values)

2 step: Spatial metapattern assignment to city parts

First, the *visibility graph analysis* was performed by using *DepthmapX* to calculate the *Isovist Properties* and *Calculate visibility relationships* (by using options *Include global measures* and *Radius = n*) and to get MAX measure values on the 41 *Visuality Graphs* of the parts of 12 cities. The selected Space syntax measures after Case study 2 (see Section 5.2.) experiment was: *Isovist Compactness*, *Drift Magnitude,* and *Mean Depth*. The calculated values are presented in Table 24.

Then K-Means Cluster Analysis was performed on the parts of 12 cities and their measures by using the *IBM SPSS Statistics* [IBM 2021b] tool. The parts of the cities were clustered in 6 clusters, and each of them had an assigned metapattern from the previous step.

Table 24 Spatial entities parts results of K-Means cluster analysis

City Part	Isovist Compactness (MAX)	Drift Magnitude (MAX)	Mean Depth (MAX)	Cluster
Ottawa 6	0.423	22.887	2.111	**2**
Kaunas 2	0.438	21.165	2.000	**2**
Ottawa 8	0.486	20.962	3.100	**2**
Chicago 2	0.493	20.052	2.196	**2**
Gdańsk 4	0.556	24.023	1.430	**2**

City Part	Isovist Compactness (MAX)	Drift Magnitude (MAX)	Mean Depth (MAX)	Cluster
Ibadan 3	0.574	21.939	2.780	**2**
Ottawa 4	0.607	19.852	1.920	**2**
Bucharest 2	0.653	23.690	2.622	**2**
Gdańsk 2	0.716	18.285	1.860	**2**
Vilnius	0.513	8.409	3.614	**3**
Bucharest 3	0.516	6.993	2.206	**3**
Ottawa 5	0.568	9.739	3.961	**3**
Ottawa 1	0.585	7.556	4.526	**3**
Helsinki 3	0.607	6.348	4.241	**3**
Chicago 5	0.629	6.016	3.272	**3**
Baltimore 1	0.644	7.081	2.810	**3**
Ottawa 11	0.644	8.270	3.683	**3**
Chicago 7	0.453	27.494	2.187	**4**
Chicago 4	0.473	25.233	2.257	**4**
Gdańsk 3	0.540	24.571	1.600	**4**
Helsinki 2	0.573	30.280	2.578	**4**
Stockholm 2	0.574	25.695	1.590	**4**
Chicago 6	0.574	27.932	2.724	**4**
Ottawa 7	0.595	28.417	2.064	**4**
Kaunas 3	0.646	28.856	1.979	**4**
Chicago 1	0.669	31.904	2.458	**4**
Kaunas 4	0.472	11.207	2.553	**5**
Ottawa 9	0.489	13.996	2.700	**5**
Ibadan 2	0.492	17.032	3.220	**5**
Ottawa 2	0.494	12.334	3.818	**5**
Ottawa 10	0.573	15.924	2.084	**5**
Nice	0.580	13.514	1.740	**5**
Helsinki 1	0.590	15.618	2.578	**5**
Klaipėda	0.684	14.691	2.822	**5**
Stockholm 1	0.689	11.753	3.240	**5**
Bucharest 1	0.692	13.753	3.409	**5**
Ibadan 1	0.519	4.325	2.810	**6**
Kaunas 1	0.545	4.807	3.671	**6**
Gdańsk 1	0.59	5.044	4.110	**6**
Ottawa 3	0.635	3.478	4.838	**6**
Chicago 3	0.757	2.532	5.887	**6**

3 step: SP identification based on spatial metapattern

First, each city part with an assigned spatial metapattern value was defined by using additional measures: PART SIZE and PART COUNT (the same measures were used in Case Study 2 (see Section 5.2.) and PART DOMINATION – a new measure which expresses the percentage dominance of the specific part size comparing to the entire city. Then, the biggest part is taken, and its identified metapattern is evaluated and assigned an SP by using the simple rules listed in Table 25.

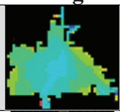
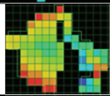
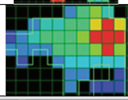
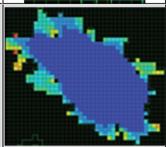
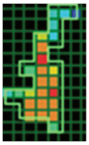
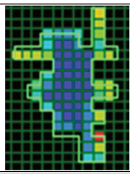
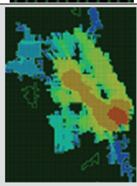
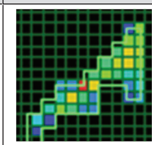
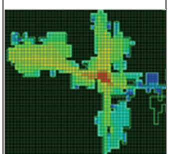
Table 25 Metapattern and SP relation

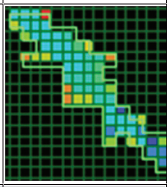
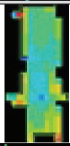
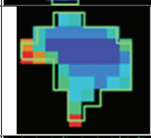
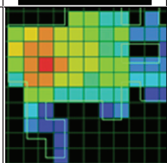
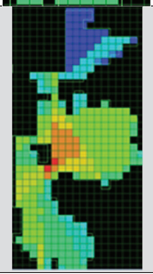
Metapattern	**Spatial Pattern**
Line	Linear
Labyrinth	Multi-Nuclei
Star4	Star
Star8	Star
Sector	Sector
Circle	Concentric Zone

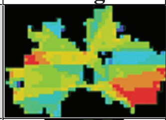
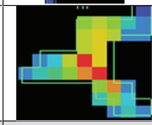
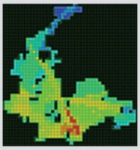
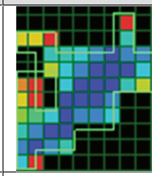
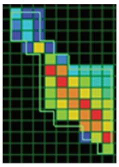
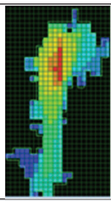
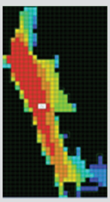
The final result of the spatial entities SP identification is presented in Table 26. For example, Baltimore has only one part (Part Count = 1). In such a case, the size of the part (Part Size) and the domination of the part (Part Domination) is not important. The visibility graph of Baltimore is presented in the Image column. By using this visibility graph, 3 measures are calculated, and then, based on the values of these measures, the cluster is assigned (see Table 24); consequently, Cluster = 3. Then, the value of the entire city spatial metapattern is assigned by using the method described in Section 5.2.2. Table 23, therefore, the result is Metapattern = Star4. As a spatial metapattern, *Star4* refers to SP *Star* (see Table 25); *Star* is identified as SP for Baltimore.

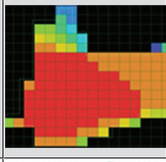
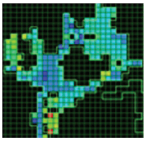
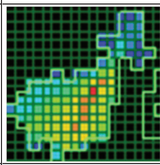
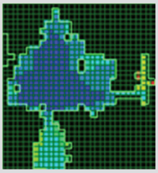
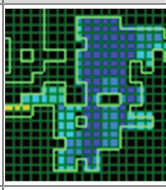
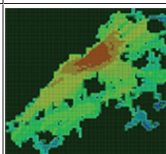
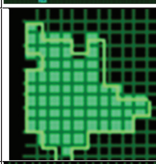
The same logic applies to the cities with more than one structural part, e.g., Bucharest. As Bucharest 3 is the biggest part of all Bucharest parts (Part Size = 644) and the most dominant part of the city (Part Domination = 87%), the whole process described above is repeated for Bucharest 3, and, as the result, metapattern *Star4* is identified. This leads to the decision that the SP of Bucharest is also *Star*. Such decisions can be automated by using the SPDIAM data model.

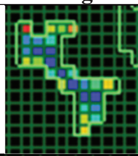
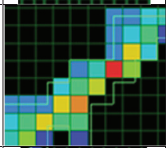
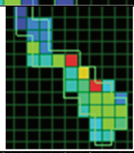
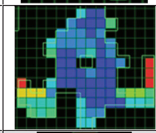
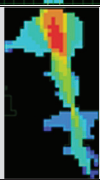
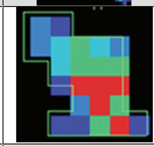
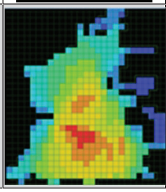
Table 26 Spatial entities SP identification (the grey rows show the dominant part of the spatial entity whose metapattern was used to identify SP)

Spatial entity parts	Cluster	Metapattern	Image	Part Size	Part Count	Part Domination (%)	Pattern (Operation = Identification)
Baltimore	3	Star4		699	1	100	**Star**
Bucharest 1	5	Sector		84	3		
Bucharest 2	2	Labyrinth		46	3		
Bucharest 3	3	Star4		644	3	87	**Star**
Chicago 1	4	Star8		25	7		
Chicago 2	2	Labyrinth		67	7		
Chicago 3	6	Circle		3137	7	78	**Concentric Zone**
Chicago 4	4	Star8		36	7		
Chicago 5	3	Star4		687	7		

Spatial entity parts	Cluster	Metapattern	Image	Part Size	Part Count	Part Domi-nation (%)	Pattern (Operation = Identification)
Chicago 6	4	Star8		30	7		
Chicago 7	4	Star8		65	7		
Gdańsk 1	6	Circle		896	4	77	**Concentric Zone**
Gdańsk 2	2	Labyrinth		161	4		
Gdańsk 3	4	Star8		63	4		
Gdańsk 4	2	Labyrinth		43	4		
Helsinki 1	5	Sector		65	3		
Helsinki 2	4	Star8		33	3		
Helsinki 3	3	Star4		316	3	76	**Star**

Spatial entity parts	Cluster	Metapattern	Image	Part Size	Part Count	Part Domination (%)	Pattern (Operation = Identification)
Ibadan 1	6	Circle		857	3	85	**Concentric Zone**
Ibadan 2	5	Sector		122	3		
Ibadan 3	2	Sector		33	3		
Kaunas 1	6	Circle		662	4	61	**Concentric Zone**
Kaunas 2	2	Labyrinth		50	4		
Kaunas 3	4	Star8		50	4		
Kaunas 4	5	Sector		321	4		
Klaipėda	5	Sector		333	1	100	**Sector**

Spatial entity parts	Cluster	Metapattern	Image	Part Size	Part Count	Part Domination (%)	Pattern (Operation = Identification)
Nice	5	Sector		155	1	100	**Sector**
Ottawa 1	3	Star4		212	11		
Ottawa 10	5	Sector		144	11		
Ottawa 11	3	Star4		2560	11	67	**Star**
Ottawa 2	5	Sector		64	11		
Ottawa 3	6	Circle		184	11		
Ottawa 4	2	Labyrinth		28	11		
Ottawa 5	3	Star4		32	11		

Spatial entity parts	Cluster	Metapattern	Image	Part Size	Part Count	Part Domination (%)	Pattern (Operation = Identification)
Ottawa 6	2	Labyrinth		31	11		
Ottawa 7	4	Star8		81	11		
Ottawa 8	2	Labyrinth		107	11		
Ottawa 9	5	Sector		342	11		
Stockholm 1	5	Sector		349	2	73	**Sector**
Stockholm 2	4	Star8		23	2		
Vilnius	3	Star4		450	1	100	**Star**

5.3.3. Experiment Results Evaluation

The results of the experiment show that SP identification can be calculated by using spatial metapatterns that are based on the clustering analysis of 3 Space syntax measures MAX values (*Isovist Compactness*, *Drift Magnitude*, and *Mean Depth*). After that, by using 3 map-defined measures (PART SIZE, PART COUNT, PART DOMINATION) and simple rules, the evaluation of the identified spatial metapattern can be made, and an automated decision can be taken which SP must be selected as the SP value.

This solution is suitable for those spatial entities (or CSSs) that have a high percentage of the central part. However, a simple refinement of SPDIAM and the proposed algorithm can be made, given that if a spatial entity does not have one larger part, then its SP must be evaluated in terms of the fact that the spatial entity can be multi-nuclei.

5.4. Summary

In this chapter, 3 case studies presenting the SPDIAM experimental application were conducted. Case study 1 was dedicated to the SPDIAM application, its goal was to consistently reproduce each SPDIAM phase by using the presented methodology, examples and spatial data preparation requirements, and to identify SP in 12 North American, European and African cities. As a result, 4 different SP (*Concentric-zone, Linear, Sector, Multi-nuclei*) were identified in these cities. The experiment results confirm that SPDIAM is appropriate to describe SPs and to identify them automatically; the use of the normalised measures enables SP comparison with each other and reduces the degree of subjectivity; SPDIAM no longer relies on the statistical information, but forms SP by the complex modelling of a city, and then associates territories with SP; SPDIAM indicates a possible direction of the CSS SP changes in the future and can be used for the evaluation of SPD plans of urban areas [Germanaitė *et al*. 2020].

Case study 2 was dedicated to the general SP and metapattern model developed along with the SPDIAM application. It also contained the input data preparation experiment. As a result, 6 basic spatial metapatterns (*Line*, *Star4*, *Star8*, *Sector*, *Labyrinth*, *Circle*) were identified. The main results of the conducted spatial metapattern identification experiment show that 3 VGA measures (Isovist Compactness, Drift Magnitude, Mean Depth) are suitable for SP identification as their values show certain clear ranges for different spatial metapattern values (a measure value approaching to 0 shows *Line*, and a value approaching 1 represents the *Circle* metapattern value), and that the general SP and the metapatterns model as well as the IT artefacts presented in this thesis can be used to describe and identify spatial metapatterns in the spatial vector data of CSS while taking into account CSS analysis problems [Germanaitė *et al*. 2022].

Case study 3 was dedicated to SP identification by using the metapatterns identified in Case Study 2. It also included an input data preparation experiment. Then, three steps of the experiment were conducted: 1) spatial metapatterns and their values preparation; 2) spatial metapattern assignment to city parts (e.g., parts of CSS); 3) calculation of SP identification based on the spatial metapattern. As a result, 4 SP (*Linear*, *Star*, *Sector*, *Concentric Zone*) were identified in the data of the 12 cities. The results of the experiment show that CSS SP can be calculated by using the evaluation of the identified spatial metapattern, map-defined measures, and simple rules, and that an automated decision can be taken whose SP value must be selected. This solution is suitable for those spatial entities (or CSSs) that are denoted by a high percentage of the central part. However, a simple refinement of SPDIAM and the proposed algorithm can be made, given that if a spatial entity does not have one larger part, then its SP value must be evaluated in terms of the fact that the spatial entity can be multi-nuclei.

The SPDIAM developed in these experiments allowed us to automatically use quantifiable CSS measures and thus identify SP and spatial metapatterns as well as perform assessment of CSS, thus improving the capabilities of quantitative CSS analysis. Such an approach has so far not been applied to the description and automated SP identification in CSS.

The developed specification, the data model, and the spatial input data preparation procedure allowed us to define descriptive, categorising, hierarchical, computational, and spatial properties of SP, SP identification methods, and CSS. The created IT artefacts can be used for spatial IS development by using *GIS* technologies to solve spatial analysis problems in CSS.

6. SPDIAM APPLICATION

6.1. Territorial Planning Process

In this section, the practical SPDIAM application use case shall be illustrated in the field of urban planning and design. *Territorial planning* is a process carried out in compliance with the requirements of the laws as well as their implementation-related legal acts which regulate sustainable territorial development and include the establishment of land use priorities, measures of environmental protection, public health, heritage protection and other measures, the creation of residential areas and manufacturing, engineering and social infrastructure systems, and which create conditions for the regulation of employment and development of activities of the resident population as well as the reconciliation of public and private interests [Register of Legal Acts 2020]. When establishing the planning objectives for a specific territory, it is necessary to take account of the public needs, the landscape, and the biodiversity of the planned territory, its geographical location, geological conditions, the already existing urban, engineering, transport and agricultural systems, the interests and rights of managers and users of land and other immovable property and any third parties, as well as the architectural, environmental, public health, nature protection and heritage protection requirements and state and public security and defence needs [Register of Legal Acts 2020]. Therefore, spatial planning objectives are usually defined and set forth by stakeholders as well as the UPD practitioner(s) and public.

The *objectives of territorial planning* are highly complex, and they consist of many different dimensions that are very hard to evaluate and combine, especially in the computerised manner. The examples of territorial planning objectives are [Register of Legal Acts 2020]:

1) to facilitate sustainable territorial development of the state, the implementation of consistent functional and spatial integration policy, territorial cohesion, comprehensive solutions to social, economic and environmental challenges;

2) to establish guidelines for the development and implementation of residential areas' engineering and social infrastructure and other areas of social and economic activities important to the state and to envisage territories required for development;

3) to facilitate rational use and restoration of the state's natural, subsoil and energy resources;

4) to provide for the preservation, targeted use and knowledge of the state's unique natural and cultural landscape, natural and immovable cultural heritage and for the formation of the nature frame necessary for the ecological balance;

5) to create a healthy, safe and sustainable living environment and complete living conditions in residential areas;

6) to facilitate private investment which creates social and economic well-being and living conditions of the appropriate quality;

7) to balance the interests of natural and legal persons or groups thereof, municipalities and the state regarding the use of a territory and conditions for developing activities therein;

8) to facilitate rational use of land and promotion of agricultural activities.

The *comprehensive plan of the territory of the state* must be prepared in compliance with the directions of spatial development of the territory of the state and the *functional priorities* of the use of territories established by the Government [Register of Legal Acts 2020]. SP can help to find such functional priorities, for example, Space syntax measures are already being used for Lithuania's comprehensive plan (the walkability and accessibility measures).

Complex territorial planning shall mean territorial planning for the establishment of spatial development directions and priorities of use and protection of territories [Register of Legal Acts 2020]. Complex territorial planning details the comprehensive plans and decides on many issues, such as to where the international railway must pass through the state and so on. The *objects of special territorial planning* shall be territories characterised by functional commonality: 1) territories intended for agriculture, forestry, use of subsoil resources and earth cavities or other activity; 2) systems of the engineering infrastructure or parts thereof; 3) the system of protected areas and parts thereof, sites of immovable cultural heritage and protection zones, complex objects of immovable cultural heritage and protection zones. The *levels* of territorial planning shall be: 1) state – the entire territory of the state or parts thereof are planned; 2) municipal – territories characterised by administrative (municipal) or functional commonality are planned; 3) local – parts of the territory of a municipality are planned: cities (or parts thereof), towns (or parts thereof), villages and steadings [Register of Legal Acts 2020].

In Table 27, the comprehensive, complex, municipal-level and local-level comprehensive and special territorial planning is described by defining the tasks and provisions which each of these planning disciplines must combine and evaluate. As SP can show the mixed functional zones along with their multi-functionality, and reveal the most ecologically important zones that should not be reduced, where to establish parks, and so on, it can be used to define the provisions for the use of a territory.

Table 27 Territorial planning tasks and provisions of the use of territory [Register of Legal Acts 2020]

Comprehensive planning	Complex territorial planning	Municipal-level and local-level comprehensive planning	Special territorial planning
Tasks:			
1) to detail solutions of the comprehensive plan of the territory of the state; 2) to establish guidelines for the	1) to establish guidelines for the implementation of spatial development of the territory of the state, the spatial structure of	1) to form the directions of functional and spatial development of a territory consistent with the level of planning; 2) to optimise the urban	1) to facilitate rational use of land, forests, subsoil resources and earth cavities; 2) to develop the

Comprehensive planning	Complex territorial planning	Municipal-level and local-level comprehensive planning	Special territorial planning
implementation of territorial development policy of the state in separate parts of the territory of the state, the spatial structures of these territories and elements thereof; 3) to establish mandatory provisions for the use of the part of the territory of the state; 4) to detail the state urban structure provided for in the comprehensive plan of the territory of the state, engineering and social infrastructure systems and recreational and other territorial structures; 5) to detail the principles of rational use of agricultural land, forests, subsoil and other natural resources and maintaining the ecological balance, the formation of the nature frame and the system of protected areas, preservation of landscape, natural and immovable cultural heritage; 6) to detail the layout of objects of projects of importance to the state.	the territory of the state and elements thereof; 2) to establish mandatory provisions for the use of the territory of the state; 3) to optimise the state urban structure, engineering and social infrastructure systems and recreational and other territorial structures; 4) to establish principles for the rational use of agricultural land, forests, subsoil and other natural resources and maintaining the ecological balance, the formation of the nature frame and preservation of natural and immovable cultural heritage and valuable landscape by optimising the system of protected areas; 5) to envisage objects of projects of importance to the state.	structure of the planned territory, its social and engineering infrastructure; 3) to provide for measures for rational preservation and use of subsoil resources, agricultural land, forests and other natural resources, the use of the nature frame and ecologically sound land, the formation of territorial structure, preservation of natural and immovable cultural heritage, landscape and biodiversity; 4) to detail solutions of respective documents of higher-level complex territorial planning.	systems of the transport infrastructure, engineering and utility networks and energy as well as other engineering infrastructure necessary for public needs and to envisage territories required for the development; 3) to envisage measures for the protection of the landscape, nature and biodiversity; 4) to establish heritage protection requirements for the protection of immovable cultural heritage and development of activities at sites of immovable cultural heritage, complex objects of immovable cultural heritage and protection zones thereof and the boundaries of the territories.
Provisions for the use of a territory:			
1) the directions of spatial development and functional zoning of the use of the territory of the state; 2) the system of residential areas – the system of urban centres of the territory of the state and their	1) functional zoning of the use of the part of the territory of the state; 2) the system of residential areas – the system of urban centres of the part of the territory of the state and their functional links,	1) functional zoning of the territory (residential, city centre, industrial and infrastructure facilities, reactive, other); 2) the system of residential areas of the territory – the system of municipal urban centres	Specific tasks of special territorial planning shall be established by the organiser of planning in compliance with the laws of the state.

Comprehensive planning	Complex territorial planning	Municipal-level and local-level comprehensive planning	Special territorial planning
functional links, the prospect of development of urban centres; 3) the formation of the nature frame of European and national importance; 4) the system of state parks, strict state reserves and state reserves, the system of state protected sites and sites of cultural heritage of national significance and the system of territories of complex objects of cultural heritage and protection zones thereof; 5) development of main roads of state importance and other transport infrastructure and energy facilities of national importance; 6) development of the structure of state importance for tourism, recreation and resorts; 7) layout of objects of projects of importance to the state.	the prospect of development of regional urban centres; 3) parts of the nature frame of regional importance, the European ecological network *Natura 2000*; 4) the system of state parks, strict state reserves and state reserves, the system of state protected sites and sites of cultural heritage of national significance and regional significance and the system of territories of complex objects of cultural heritage and protection zones thereof; 5) comprehensive development of national roads and other itemised transport infrastructure of state importance and energy facilities of national importance; 6) the layout of objects of projects of importance to the state.	and their functional links, development possibilities of the municipal urban centres and priority development directions of urbanised territories; 3) protection requirements for protected areas and landscape; 4) the system of nature frame, supplemented by the nature frame of local importance comprising an ecological network and separate green areas; 5) requirements for the protection of immovable cultural heritage of local significance and development of activities in its territories and protection zones thereof; 6) development principles of the engineering and social infrastructure (or its layout requirements), engineering communications corridors; 7) territories intended for objects the layout whereof in a planned territory depends on the impact of their activities on the environment and public health; 8) identification of urbanised territories and territories under urbanisation and not under urbanisation (or indication of development directions of urbanised territories), establishing territories	

Comprehensive planning	Complex territorial planning	Municipal-level and local-level comprehensive planning	Special territorial planning
		for priority development and possible scale of development and priority and other possible activities; 9) mandatory requirements for the layout of retail facilities (in the territory of a city), specifying the maximum possible total area of a single retail facility in separate parts of the planned territory; 10) cities and parts thereof, towns and parts thereof and other territories for which it is necessary to prepare local-level comprehensive plans at a scale of 1:2,000–10,000; 11) territories to be reserved for objects of importance to a municipality; 12) reservoirs of subsoil resources; 13) territories of objects of projects of importance to the state.	

6.2. Other Cases to Illustrate Spatial Pattern Application

When taking into account the comprehensive plan scale, the planned territory, its value and the respective planning tasks, the organiser of planning shall indicate that *additional legislation-based mandatory provisions relating to protection of the environment, landscape, natural and immovable cultural heritage, urbanism, architecture, development of the engineering and social infrastructure or other mandatory provisions* shall be established in the comprehensive plan [Register of Legal Acts 2020]. SPDIAM can be used in any of these fields: we can use the same steps to describe, identify and apply different types of SP in various application fields. Only the principle how we collect the input data that make up SP can differ, but the whole procedure is the same as described in SPDIAM. For example, the polygons of the whole city can be taken, and, by using *GIS* functions, the average distances between the buildings can be calculated and then automatically evaluated so that to select the best place for the street culture objects or places.

Some use cases to illustrate the application of SP are:

a) Development of the *dynamic plan* (e.g., the plan based on simulation in real or conditional time or in compressed time (e.g., Space syntax-based)) for the simulation of the possible development of the city (for example, the possible development of Kaunas City district Žemieji Šančiai). As the dynamic plan changes (e.g., the street network is changed by a UPD practitioner), the area covered by SP also changes based on the simulation results.

b) Development of the *digital twin* – a digital city model that reflects the real city and allows us to observe or model the real process of the urban form.

c) Development of the *memory (heritage) map* (people, important historical sites and places, heritage protection, culturally important data), *sociotopic (acceptable) map* (methodology for the detailed use of public spaces), *acupuncture (measured as points) map* (better understanding for Space syntax maps), *general vision map* (quick presentation of the current and desired situations and their comparison) and be able to predict urban changes after possible street network or urban infrastructure changes, better understand the current situation with the help of SP, or to provide better understanding of the current situation and analysis of the possible changes.

d) Decision-making on the land use functions.

e) Development of the *City Country Fingers* [Alexander 1977] map and definition of the framework of the urban structure (city vs. nature).

f) Development of the ecological, biological SP for making nature frame analysis on the grounds of the ecologically or biologically important data.

g) Development of the *Street Culture* [Mumford 1938] map and ability to select the priority locations for the street culture objects and places.

6.3. Spatial Pattern Application Process in Territorial Planning

In this chapter, the process of the territorial planning as an example of SP application shall be discussed. Since the proposed method of SP identification allows us to talk about its prognostic potential, SPDIAM is generally suitable for both the analysis of SP and the evaluation of the possible alternatives, as well as the evaluation of the effectiveness of the selected final solution. The territorial planning cycle is presented in Fig. 43; it contains 7 steps, and the grey blocks indicate the steps that can be done by using SPDIAM. All steps are described in detail in Table 28.

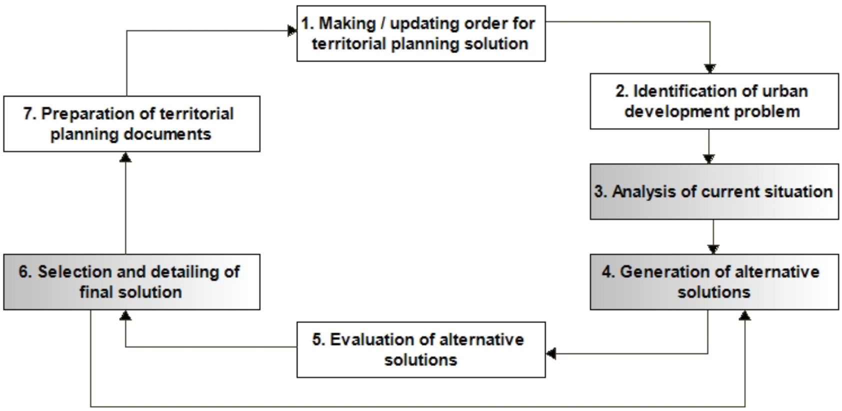


Figure 43 Territorial planning cycle

The main roles participating in the territorial planning are: *Stakeholder (developer, investor)* – defines a person who has an interest or concern in something, especially a business; 2) *UPD practitioner* – can be seen as a moderator of all stakeholders' interests; 3) *System* – computerises (and in some cases – automates) the steps of SPDIAM; *Public* – one or more natural and/or legal persons, their associations, organisations or groups; *Territorial Planning Specialist* – **a** specialist involved in the territorial planning process and the preparation of territorial planning documents. Given that the SP identification method is suitable for a variety of stakeholders, the SP application procedure in the territorial planning cycle is presented in Table 28.

Table 28 SP application in the territorial planning cycle

Step description (*Role*)	**Step Example**
1. Making/updating order for the territorial planning solution (*Stakeholder*)	
The order can be taken from the feasibility study, text description, identification of priority urban development areas and so on.	*Order for the territorial planning solution:* to define possible priorities for the development of Kaunas City territory.
2. Identification of the urban development problem (U*PD practitioner*)	
The problem is the mismatch between the needs of the stakeholders, and it is based on the urban development vision/needs and analysis results. In computer science, it can be seen as the variety of problems, like spatial accessibility, density or diversity problems, that can be found in the spatial or statistic data of the area. The problem identification step brings together information from the stakeholders, developers, investors, and so on as different layers of data indicators or statistics. In the next steps, SP helps to better understand the causes of problems or at least the extent to which the spatial structure of SP contributes to the problem. For problem identification, the tools such as *Sustainability Compass* [Bureau Urbanisme 2014] for analysing and orienting urban scale projects can be used.	*Urban development problem for Kaunas City territory:* the priority areas are identified based on the analysis of the current situation, modelling the accessibility of various services, people, and so on. There are 4 zones in Kaunas: a) the historical core that merely needs to be preserved; b) Žaliakalnis district which is a good example for other areas; c) areas in which there is an urgent need to invest in and manage the infrastructure as it is poor, but there is a large population in those areas (for example, Vilijampolė and Paneris districts marked in blue in Fig. 44); d) areas in which the attractiveness for the

Step description (*Role*)	Step Example
Problem example: there is a large population in the area, but the location of the infrastructure (kindergartens, public transport stops, shops, commercial facilities, recreational areas) does not correlate with the location of the population. *Research method example:* feasibility study, e.g., economic evaluation. *Other examples:* 1) *Vision*: Kaunas as a university city. *Research method:* a survey why students choose Kaunas as a university city. *Objectives*: make more attractions for the students in Kaunas. 2) *Vision*: Šilainiai (a district of Kaunas) as a place for the young families. *Research method*: a survey why young families choose Šilainiai to cater for the young family needs. *Objectives*: develop more attractions for the young families in Kaunas. 3) *Vision*: a small business district. *Research method*: a survey of what investments small business needs. *Objectives*: provide more small business attractions in Kaunas.	population needs has to be increased due to the relatively good infrastructure (all the green areas in Fig. 44, as well as the districts of Aleksotas and Palemonas, whose change has been reflected in the alternative solutions). Therefore, there is a need to develop the c) and d) territories.

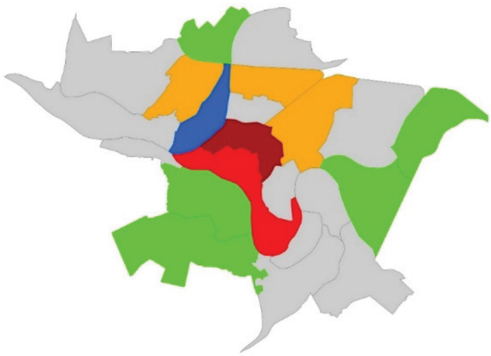
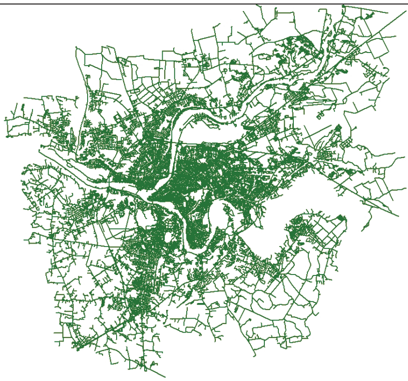
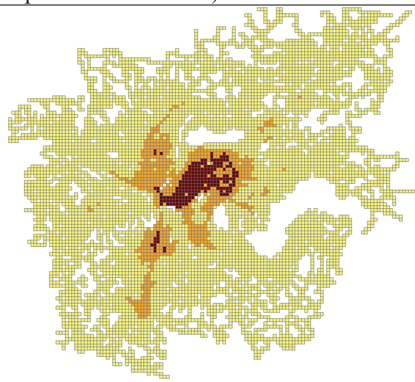
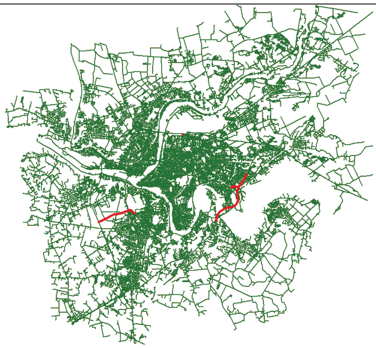
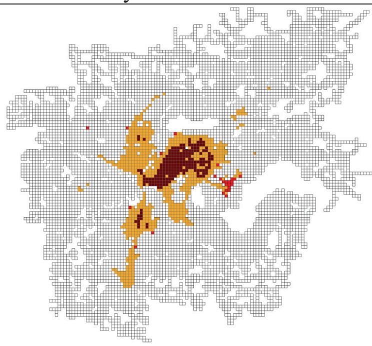
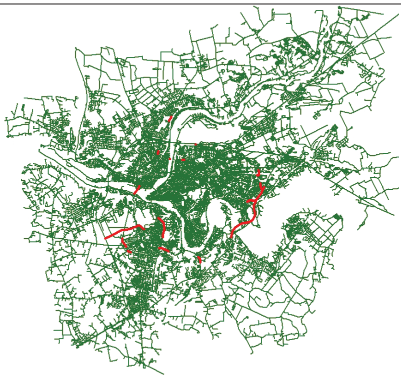
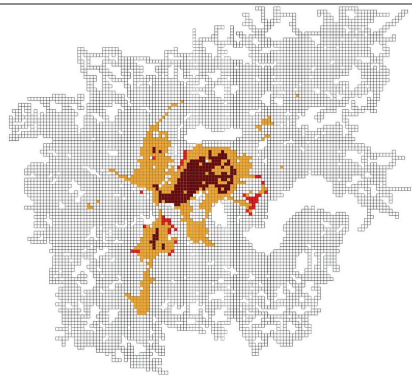


Figure 44 Kaunas social infrastructure areas and their development [KTU ASI 2022]

3. Analysis of current situation (*System, UPD practitioner*)	
Spatial entity (site) analysis: • selection of the relevant SP; • selection of quantitative SP measures; • input data collection and modelling; • SP identification (an automated step); • SP evaluation; • summary of results, etc. First, the analysis of the current situation on the basis of SP is conducted. Secondly, the additional spatial or statistical data is used to evaluate the situation in the territory covered by SP. This analysis not only collects statistical information, but also creates a simulation model whose effectiveness is checked, e.g., by calculating correlations between SP and the additional data, or by using other methods of statistical analysis.	For the analysis of the current situation, the presently existing street network of Kaunas City was used as presented in Fig. 45. After SP identification (Figure 46), the conclusion was made that Aleksotas and Vilijampolė districts are not as active in Kaunas *City Layout* SP as they should be. Therefore, Kaunas *City Layout* SP should expand into these areas. In Fig. 46, the dark brown colour depicts the centre of Kaunas, the lighter brown colour depicts the other areas which are most connected and most easily accessible to the city centre, and the yellow colour indicates the entire city territory used for SP identification.

<table>
<tr><th>Step description (Role)</th><th>Step Example</th></tr>
<tr><td>Additional data examples: population, points of interest, commercial entities, building data.</td><td>Kaunas City Layout SP evaluation shows that SP in Kaunas correlates with the statistical data and can be used in further analysis (SP evaluation process is explained in Table 29).</td></tr>
<tr><td>
Figure 45 Current street network of Kaunas used for SP identification (ESRI ArcMap)</td><td>
Figure 46 Kaunas City Layout SP (current situation) (ESRI ArcMap)</td></tr>
<tr><td colspan="2">4. Generation of alternative solutions (System, UPD practitioner)</td></tr>
<tr><td>Alternatives are generated by modifying the input data. Then SP allow us to assess the impact of the alternative solutions and becomes an argument when discussing their suitability.</td><td>First alternative Kaunas City Layout SP.
The urbanists of Kaunas City Municipality suggested additional streets, bridges, etc. for Kaunas territorial development that are marked in the Comprehensive Plan and have their own development priorities. For the first alternative SP identification, the input data – the street network – contained the additional streets that have priority ‘1’ in the Comprehensive Plan. These additional hypothetical streets that do not exist in the current Kaunas City street network are marked in the red colour in Fig. 47, and SP changes are marked in the red square in Fig. 48.
Second alternative Kaunas City Layout SP.
The input data – the street network – is composed of the same additional streets that have priority ‘1’ and also the streets with priority levels ‘2’ and ‘3’ in the Comprehensive Plan. Therefore, the expected SP change should be bigger. All additional streets are marked in the red colour in Fig. 48, and SP changes are marked in the red square in Fig. 49.
Comparison of the alternative solutions.
The implementation of the first priority streets does not radically change the situation in Kaunas. They slightly improve</td></tr>
</table>

Step description (*Role*)	Step Example
	the situation in the Palemonas area, which is acceptable in the context of the Comprehensive Plan proposals. The implementation of all three priority streets changes SP slightly more: it would develop Palemonas, Aleksotas and even slightly Eiguliai districts, and this is in line with the strategy proposed in the Comprehensive Plan. In essence, these streets proposed in the Comprehensive Plan are more evolutionary timid steps, and, for more significant changes, for example, Kėdainiai Bridge should rise to Šilainiai and above Marvelė districts, as the proposed location of the bridge will not help to reduce the load on the Kaunas City centre.
 **Figure 47** First alternative street network of Kaunas used for SP identification (*ESRI ArcMap*)	 **Figure 48** First alternative Kaunas *City Layout* SP
 **Figure 49** Second alternative street network of Kaunas used for SP identification (*ESRI ArcMap*)	 **Figure 50** Second alternative Kaunas *City Layout* SP
5. Evaluation of alternative solutions *(Society, Stakeholder)*	
• Express opinion (*Society*). • Evaluate alternative solutions (*Stakeholder*).	• Public opinions recorded in the protocol. • Discussions recorded in the protocol.

Step description (*Role*)	Step Example
6. Selection and detailing of the final solution *(System, UPD practitioner, Stakeholder)*	
Once the alternative has been selected and detailed, SP can continue to be used to model and predict the impact of the detailed decision on changes in SP and thus on the functioning of the city. The choice of the solution lies with the stakeholders. The *indicators* that help to make this selection can be: a) *demand management*, such as regulation of a given sector, which may affect the demand; b) *system efficiency*, including possible gains that come, for instance, from technology adoption; c) *capacity expansion changes*, which actually involves physically altering infrastructure assets. *Example of an indicator that affects the selection*: these are the places accessible on foot or by public transport or on foot, by car and by public transport. If the result is not satisfactory, the UPD practitioner can go back to step 3 and choose another alternative.	The second alternative is more in line with the priorities set out in the Comprehensive plan, thus slightly improving the situation in Palemonas and Aleksotas districts. The choice of such an alternative shows that the new Comprehensive Plan would require the more significant solutions that would also change the situation in Vilijampolė district.
7. Preparation of the territorial planning documents *(Territorial Planning Specialist)* • *Comprehensive plan drawings:* • the main drawing (defines the hierarchy of the elements of the city spatial structure and the principles of development, indicates the boundaries of the functional areas for which specific requirements for the use of the territory have been established); • drawings and diagrams of the components of the comprehensive plan (detail the hierarchy of individual elements of the city's functional systems, the principles of development, and indication of the site use requirements for specific areas set out in the individual topics of the comprehensive plan). • *Spatial planning document solutions.* • *Various spatial planning norms* (such norms exist not only in urban planning, but also in other fields): • building intensity; • building density; • type of construction; • building volume index. • *Current situation analysis documents*. • *Documents of territorial planning documents changes.*	The final result can be used for the preparation of the Comprehensive Plan of Kaunas city municipality territory. The exemplary Comprehensive Map of Kaunas is presented in Fig. 51.

Step description (*Role*)	Step Example

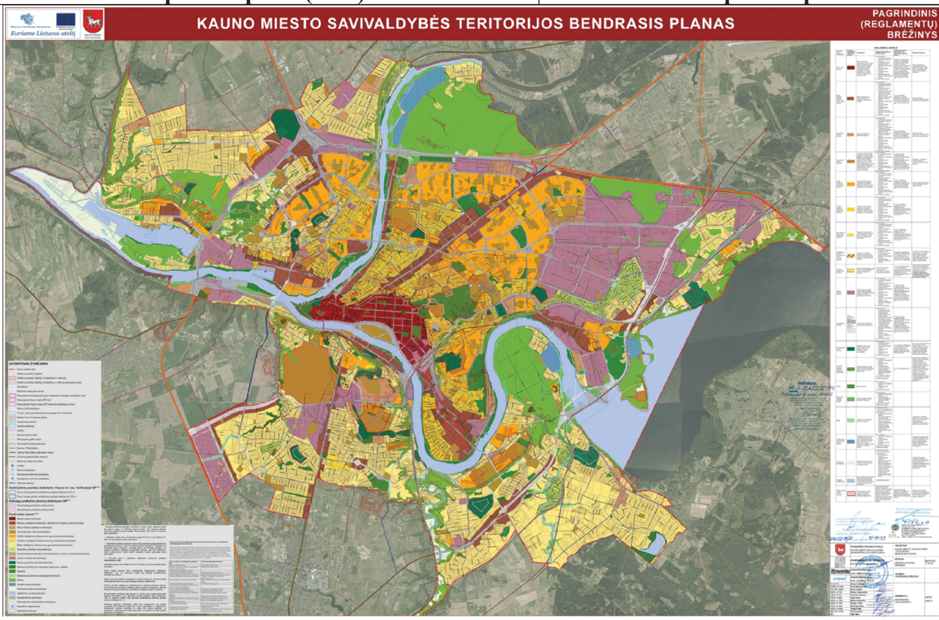


Figure 51 Comprehensive plan of Kaunas City Municipality territory for 2013–2023: main drawing [Kaunas City Municipal administration 2019]

6.4. Summary

In this section, a case of the practical SPDIAM application use was illustrated in the field of the urban planning and design. Territorial planning is a process carried out in compliance with the requirements of the laws and their implementing legal acts which aim at sustainable territorial development [Register of Legal Acts 2020]. When establishing the planning objectives for a specific territory, it is necessary to take account of the public needs, the landscape and biodiversity of the planned territory, its geographical location, geological conditions, the already existing urban, engineering, transport and agricultural systems, the interests and rights of the managers and users of land and other immovable property and the third parties, as well as the architectural, environmental, public health, nature protection and heritage protection requirements, and the state and public security and defence needs [Register of Legal Acts 2020]. Therefore, spatial planning objectives are usually defined and set by stakeholders as well as the UPD practitioner and public.

The comprehensive, complex, municipal-level and local-level comprehensive and special territorial planning defines the tasks and provisions which each of these planning disciplines must combine and evaluate. SP can be used to define the provisions for the use of a territory because SP can show the mixed functional zones, the multi-functionality, and reveal the most ecologically important zones that should not be reduced, where to establish parks, etc. SPDIAM can help to detect additional legislation-based mandatory provisions relating to the protection of the environment, landscape, natural and immovable cultural heritage, urbanism, architecture, development of the engineering and social infrastructure, or other mandatory provisions. We can use the same SPDIAM steps to describe, identify and apply the different types of SP in various fields of application, and only the principle as to how we collect the input data that make up SP may differ.

Some other cases of use intended to illustrate the application of SP are: development of the dynamic plan, digital twin, memory (heritage) map, sociotopic (acceptable) map, acupuncture (measured as points) map, general vision map, decision-making on the land use functions, etc.

For the illustration of SPDIAM application, the territorial planning cycle containing 7 steps has been created. SPDIAM was used in 3 of these steps: analysis of the current situation; generation of alternative solutions; selection and detailing of the final solutions. In the other 4 steps (making an order for the territorial planning solution; identification of the urban development problem; evaluation of alternative solutions; preparation of territorial planning documents), SPDIAM was not used because these steps mostly depend on the human factor, i.e., the decisions are taken and the documents in each of these steps are drafted by many different stakeholders and professionals in the manual way by using many different software tools. Of course, in each of these steps, for some parts (such as SP identification in the identification of the urban development problem step), SPDIAM can be used as well.

For the illustration, the territorial planning order was intended to define the possible priorities for the development of Kaunas City territory. The problem was formulated as a need to develop the areas of Kaunas City in which: 1) there is an urgent need to invest in and manage infrastructure as there is a large population in those areas (Vilijampolė and Paneris districts); 2) in which the attractiveness for the population needs have to be increased due to the relatively good infrastructure (Aleksotas and Palemonas districts).

For the analysis of the current situation, SPDIAM with the already existing street network of Kaunas City was used, and, after SP identification, the conclusion was drawn that Aleksotas and Vilijampolė districts are not as active in the Kaunas City Layout SP as they should be. Therefore, Kaunas City Layout SP should expand into these areas. Then, by using SPDIAM, two alternative data sets of the street network of Kaunas City with some additional changes (additional streets, bridges and etc.) suggested by the urbanists of Kaunas City Municipality were used, and two alternative Kaunas City Layout SPs were identified.

The comparison of the alternative solutions regarding Kaunas City Layout SP made by a UPD practitioner shows that the implementation of the first priority streets does not radically change the situation in Kaunas City. They slightly improve the situation in the Palemonas area, which is acceptable in the context of the Comprehensive Plan proposals. The implementation of all priority streets changes SP somewhat more: it would develop Palemonas, Aleksotas, and even slightly Eiguliai districts, and this is in line with the strategy proposed in the Comprehensive

Plan. In essence, the streets proposed in the Comprehensive Plan are more evolutionary timid steps, and, for more significant changes, for example, Kėdainiai Bridge should rise to Šilainiai and above Marvelė districts, as the proposed location of the bridge will not help to reduce the load on Kaunas City centre.

The final decision was that the second alternative is more in line with the priorities set out in the Comprehensive Plan, as slight improvement of the situation in the Palemonas and Aleksotas districts was demonstrated. The choice of such an alternative shows that the new Comprehensive Plan would require more significant solutions that would also change the situation in Vilijampolė district. The second alternative can be detailed, and the final result can be used for the preparation of the Comprehensive Plan of Kaunas City Municipality territory.

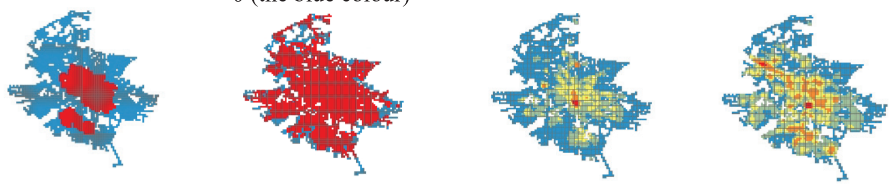
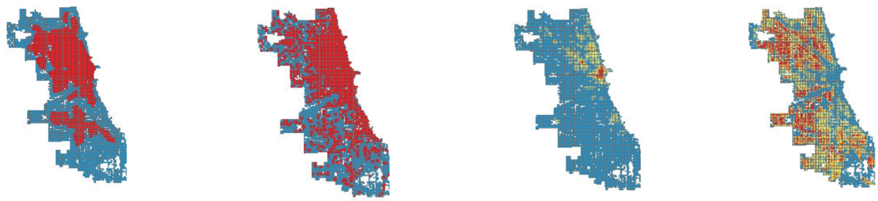
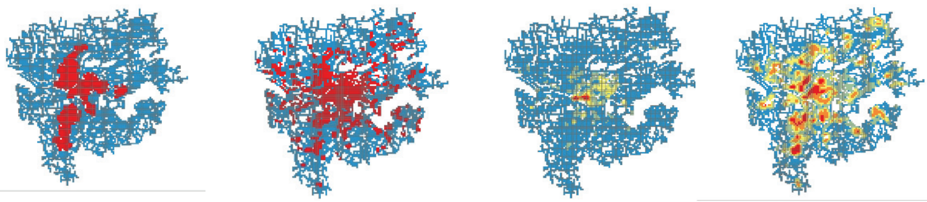
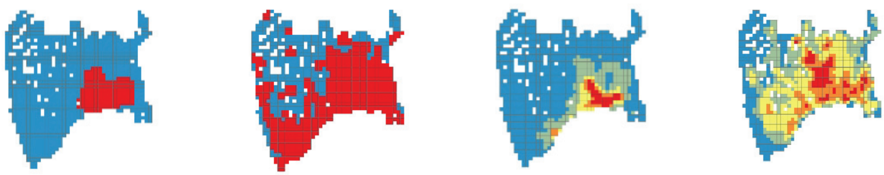
Such knowledge of SP and metapatterns allows spatial planning and design professionals to standardise the proposed urban planning solutions, to model different alternatives, and to assess the impact on the urban or other complex spatial structure development based on computable measures. Based on SP, urban development solutions can be compared with each other, thus gaining additional insights into the causes and factors associated with the functioning of a CSS. Also, the SP approach combines the spatial dimension with the social, cultural and economic dimensions, and these interactions allow spatial planning and design professionals to interpret the urban spatial structure as the spatial capital which interacts with the social, economic, and ecological capitals.

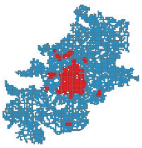
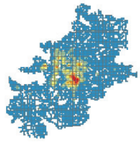
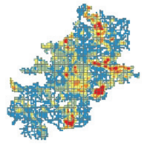
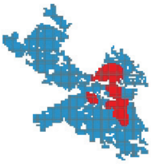
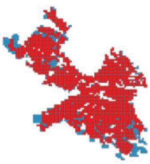
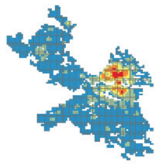
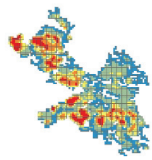
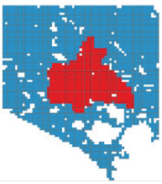
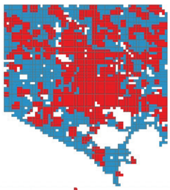
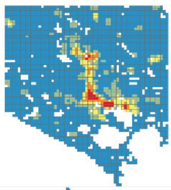
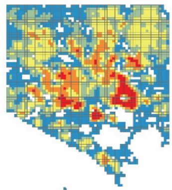
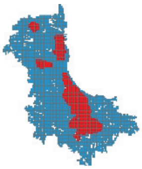
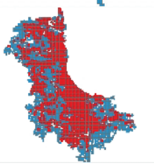
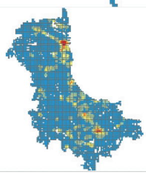
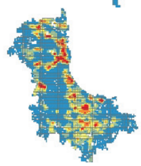
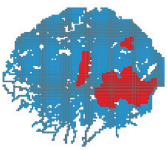
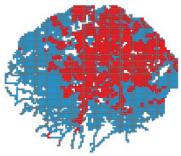
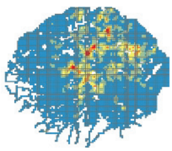
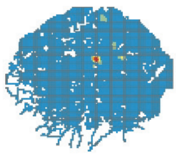
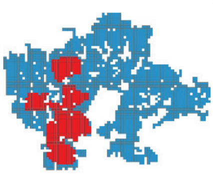
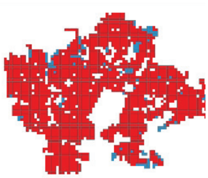
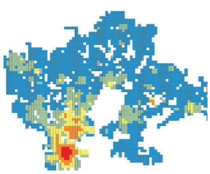
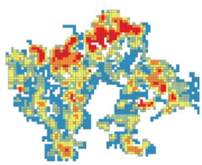
7. SPDIAM EVALUATION

7.1. Spatial Pattern and Statistics Data Correlation

In order to check whether the identified SPs reflect the real processes in urban structures, SP was compared to the points of interest (POIS) open data which represents the various objects of attraction of human activities, and which can be related to human flows, etc. It is expected that the identified SPs should correspond to the allocation of POIS, and the results of the correlation are presented in Table 29.

Table 29 SP and points of interest (POIS) correlation

	Identified SP (red colour presents SP)	**POIS presence** (if at least one POI is in the cell, the value = 1 (the red colour), if there is no POIS, the value = 0 (the blue colour)	**Number of POIS inside a cell within 200 metre distance around it** (the red colour presents higher numerical values)	**Buildings density** (the red colour presents higher numerical values)
Bucharest				
Chicago				
Kaunas				
Klaipėda				
Nice				

	Identified SP (red colour presents SP)	**POIS presence** (if at least one POI is in the cell, the value = 1 (the red colour), if there is no POIS, the value = 0 (the blue colour)	**Number of POIS inside a cell within 200 metre distance around it** (the red colour presents higher numerical values)	**Buildings density** (the red colour presents higher numerical values)
Ottawa				
Vilnius				
Stockholm				
Baltimore				
Gdańsk				
Ibadan				
Helsinki				

In Table 30, all the cities were compared by using the size of the entire city area, the size of the area occupied by SP, and the size of the SP area compared to the entire city area. Based on such comparison, various conclusions can be drawn about the location, proportions, and possible scenarios of the urban development in the city centre and periphery.

Table 30 City and SP size ratio

City	**Area of city** (number of cells)	**Area of SP** (number of cells)	**Part of SP territory**
Baltimore	3127	613	0.196
Stockholm	2736	388	0.141
Gdańsk	5950	1168	0.196
Ibadan	6216	946	0.152
Chicago	8982	3709	0.412
Bucharest	3039	731	0.240
Kaunas	6083	1050	0.172
Klaipėda	1106	370	0.334
Nice	1044	145	0.138
Ottawa	18135	3538	0.195
Vilnius	5550	628	0.113
Helsinki	2235	455	0.203

For all cities, several statistical indicators were calculated, such as Kramer's association coefficient, Pearson's correlation coefficient, and Spearman rank correlation, between SP and POIS and the building density data. Then, the correlation significance was verified by calculating the approximate significance and the *Sig (2-tailed)* p-value. SP correlation results are summarised in Table 31 and show a medium-to-close (from 0.3 to 0.5) relationship between the identified SP and the statistics, and all correlations are at the 0.01 significance level, which means that there is only 1% probability that they are random.

Table 31 SP correlation results and significance of results

City	Kramer's association coefficient between the allocation of SP and POIS location*	Pearson's correlation between SP and density of POIS*	Pearson's correlation between SP and buildings density*	Spearman rank correlation between SP and density of POIS*	Spearman rank correlation between SP and building density*
	Approximate significance	**Sig (2-tailed)**	**Sig (2-tailed)**	**Sig (2-tailed)**	**Sig (2-tailed)**
Baltimore	0.307	0.375	0.465	0.411	0.398
	0.01	0.01	0.01	0.01	0.01
Stockholm	0.155	0.616	-0.09	0.461	-0.012
	0.01	0.01	0.01	0.01	0,515
Gdańsk	0.383	0.393	0.508	0.527	0.504

	0.01	0.01	0.01	0.01	0.01
Ibadan	0.095	0.102	0.06	0.099	0.02
	0.01	0.01	0.01	0.01	0,123
Chicago	0.351	0.273	0.242	0.411	0.26
	0.01	0.01	0.01	0.01	0.01
Bucharest	0.242	0.449	0.477	0.514	0.515
	0.01	0.01	0.01	0.01	0.01
Kaunas	0.38	0.377	0.578	0.436	0.497
	0.01	0.01	0.01	0.01	0.01
Klaipėda	0.529	0.41	0.435	0.617	0.485
	0.01	0.01	0.01	0.01	0.01
Nice	0.319	0.716	0.553	0.581	0.491
	0.01	0.01	0.01	0.01	0.01
Ottava	0.629	0.452	0.707	0.707	0.591
	0.01	0.01	0.01	0.01	0.01
Vilnius	0.354	0.484	0.194	0.476	0.244
	0.01	0.01	0.01	0.01	0.01
Helsinki	0.104	0.466	0.063	0.421	0.083
	0.01	0.01	0.003	0.01	0.01

*Main landmarks from online *GIS* but unknown source for Ibadan

If we look at the relative part of POIS in SP while considering its relative size, then we can see that, in all cases in SP, the concentration of POIS is higher. The association coefficient which evaluates the presence of at least one POIS and SP allocation demonstrates a moderate association in Baltimore and Gdańsk. A strong Pearson's correlation between the density of POIS and the identified SP is found in Baltimore, Stockholm, and Gdańsk.

The data of Stockholm shows a negative correlation, as, due to the natural conditions (Stockholm is located in an archipelago), the urban structure adapts to the nature and cannot follow the laws of brevity or straightforwardness that normally affect the formation of the urban structure.

The weak correlation in Ibadan could be explained by the following:

- lack of reliable data (it was taken not from geofabrik.de based on the open street map, but from the unidentified source in the online *GIS* platform);
- a relatively low number of POIS in relation to the territory of both the city and SP;
- peculiarities of the city-by-itself.

The urban structure of Ibadan is compared with the other three cities participated in the experiment (see Table 32)by using the normalised angular choice and integration values. The big NACH max values show a continuous and clearly expressed network of the main roads; the high mean value shows the continuous background of the street networks in terms of logistics. The NAIN max high values show the presence of a clearly expressed city centre based on its reachability; the mean values say the same things about the local centres and the integrated network of local centres.

Table 32 NACH and NAIN values

	Ibadan		Baltimore		Stockholm		Gdansk	
	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
NAIN	0.481	0.777	1.176	1.843	0.551	0.857	0.748	1.130
NACH	0.796	1.489	0.973	1.582	0.831	1.494	0.813	1.553

In the case of Ibadan, the NACH mean values are the lowest, thus proving the most disintegrated background of the street among all the investigated cities. The NAIN max and mean values are very low in Ibadan, thus allowing us to conclude that there is not a big difference in the reachability between various places at the global (the entire city) and local (neighbourhood) levels. It thus allows us to determine a fragmented urban structure. In this case, low correlations between the identified SP and POIS reflect the currently existing situation.

As an additional illustration of identified Kaunas City SP and statistical data correlation Kaunas City SP was intersected with statistical business enterprise data using *ESRI ArcMap*, and the correlation results are presented in Fig. 37.

The conclusions stemming from the SP and statistics data correlation results are as follows:

1) The correlation results show the connection between SP and the statistical data of POIS and building density, and the correlation statistical reliability values (*Approximate significance* and *Sig (2-tailed*) indicate that the results are statistically significant. In such cases as Ibadan, Stockholm, and Helsinki, the explanation is logical: there is a lack of data (Ibadan), the archipelago influences and determines the even distribution (Stockholm), the city is located on island-peninsulas, so the geographical situation largely determines the urban structure (Helsinki), but the evaluation of SP depends on the UPD practitioner's estimation (as it was defined in SPDIAM phase 3).

2) It should also be noted that, when evaluating a city, there are many indefinite random factors: long reaction times to change, inertia, political decisions that may override the organic structure, and so on – therefore, it can be said that the correlations can be weaker as well.

3) Another important note is that this SP verification is based on an independent statistics data set (not only POIS, but also actual data of mobile operators, human movement, car traffic, etc.) that are *NOT* used to identify SP.

4) For the correlation, the not-so-accurate open data [Geofabrik 2019] was used, but the direction (i.e., the general trend) is still shown to be correct.

7.2. Comparison of SPDIAM and Other Methods

There are many qualitative (morphological and morphographic descriptions) and quantitative (artificial neural networks, linear/logistic regression, decision trees) methods to identify SP [Marshall and Gong 2009; Germanaitė *et al*. 2018; Musa 2016]. In this section, we shall discuss only the quantitative methods that meet two conditions: 1) they can be used to analyse CSS; 2) they can be used to identify SP. Therefore, such analysis methods as data mining or the game theory are not presently considered.

The method of comparison of SPDIAM and the other methods is the *qualitative descriptive method* [Hevner and Chatterjee 2010]. For now, there is no single specifically defined SP identification method; thus, UPD practitioners tend to identify SP visually, based on observations and/or statistical data, and only some of the SP identification methods are using the bottom-up modelling principle.

In this section and in Table 33, the features of the most common SP identification methods are compared, from which, the conclusion can be made that SPDIAM is making a step forward from the previously known SP identification methods. Such aspects of implementation as the source code, the type of the agent based on its interaction behaviour, the coding language or API for the model development/integrated development environment, the compiler/operating system (OS)/implementation platform [Abar 2017] have not been compared yet, as there are currently too many different options that can be applied to each method, thus the implementation method alone does not bring enough added value to the method.

Table 33 Methods used to analyse CSS

Criteria	**Agent-Based Modelling**	**Cellular Automata**	**Fractal Analysis**	**Space Syntax**	**SPDIAM**
Modelling					
Method is suitable for [Abar 2017]: • Designing • Modelling • Simulation	Yes	Yes	Yes	Yes	Yes
Scientific basis of the method [Xuecao 2016]	Economics, sociology	Self-organisation	Self-organisation	Movement economy, pervasive centrality, network configuration	Movement economy, pervasive centrality, network configuration
Modelling complex system [Abar 2017]: • Multiscale • Connectivit y • Self-organisation	Yes	Yes	Yes	Yes	Yes

Criteria	**Agent-Based Modelling**	**Cellular Automata**	**Fractal Analysis**	**Space Syntax**	**SPDIAM**
• Multi-element					
Adopting a bottom-up approach [Abar 2017]	Yes	Yes	Yes	Yes	Yes
Model structure [Waddell 2002] [Xuecao 2016] [Space Syntax 2021]	Zone, Grid	Grid	Fractal image	Network, Grid, Convex Graph, Visual Graph	Network, Grid, Convex Graph, Visual Graph
Model structure unit [Xuecao 2016] [Space Syntax 2021]	Agent	Grid Cell	Fractal form	Segment	Segment
Analysed feature [Cheng 2003]	Focus on human actions	Focus on landscapes and transitions	Focus on the complexity of the fractal form	Physical structure and its relations to the economic, social, and environment structures	Physical structure and its relations to the economic, social, and environment structures
Modelling mechanisms [Xuecao 2016]	Process-driven	Process-driven	Process-driven	Data-driven	Data-driven
Logic in action [Abar 2017] [Cheng 2003] [Xuecao 2016]	Agents interaction rules	Cellular automata elements interaction rules	Mathematical description of fractal complexity	Network rules	Network rules
Temporal contexts [Xuecao 2016] [Waddell 2002]	Ongoing	Ongoing	Ongoing	Compressed in time	Compressed in time
Input data requirement [Musa 2017] [Cheng 2003] [Xuecao 2016] [Germanaitė et al. 2020]	Landsat TM and ET M images, DEM, GDP and Census, remote sensing imagery detailed datasets	Landsat TM, remote sensing imagery general datasets	Urban land use maps extracted from orthophotos, Google Earth and Hellenic Cadastre, remote sensing imagery	Vector maps	Vector maps
Model development effort [Abar	Different models for different	Different models for different cases	Different models for different cases	One model for all cases	One model for all cases

Criteria	Agent-Based Modelling	Cellular Automata	Fractal Analysis	Space Syntax	SPDIAM
2017]	cases (e.g., movement to work and leisure)	(e.g., movement to work and leisure)			
Implementation					
Tool [Abar 2017]	Large family of tools	Medium family of tools	Small family of tools	Small family of tools	-
Linkage with GIS [Cheng 2003]	Yes	Yes	No	Yes	Yes
Visualisation [Abar 2017]	Yes	Yes	Yes	Yes	Yes
Measures and parameters [Musa 2017] [Germanaitė *et al*. 2020]	Urban growth indicators: land use change agents (resident, developer, and government), land use types, land use densities, population size, development history, access to public transport, access to green space, proximity to shops, and noise levels	Urban growth indicators: proximities to roads, expressways, railways, and town centres, as well as land use types and topography	Urban growth indicators: development history, distance from the central business district, proximity to urban functionaries, neighbourhood quality, and land use types	Spatial measures and parameters combined with the functional characteristics	Spatial measures and parameters combined with the functional characteristics, statistical indicators
Application					
Application domain [Abar 2017] [Musa 2017] [Space Syntax 2021] [Cheng 2003] [Xuecao 2016]	Modelling and simulation of land use and land cover dynamics used to model population dynamics, socio-economic activities	Large-scale urban simulation, for representing infrastructure, land use	Urban growth prediction planned and designed spatial objects such as urban forms and transportation networks	Architecture and urban planning	SPD

Criteria	Agent-Based Modelling	Cellular Automata	Fractal Analysis	Space Syntax	SPDIAM
Application scale [Xuecao 2016] [Cheng 2003]	Limited scaling: much larger scale, such as household and family, local	Smaller-scale such as the city level or regional level	Various scaling allows us to see the peculiarities between different scales	Different scaling possibilities	Different scaling possibilities
Public platform of comparison [Xuecao 2016]	No	No	No	Yes	Yes
Scenario-based analysis (present and future use cases) [Xuecao 2016]	Yes (but not by using the same model)	Yes (but not by using the same model)	Yes (but not by using the same model)	Yes (by using the same model)	Yes (by using the same model)
Summary					
Strength [Germanaitė 2020] [Musa 2017]	• based on the bottom-up modelling principle; • conforms to the complex nature of the city; • models and predicts self-organisation SP; [Germanaitė 2020] • models the feedback between people and their physical environment; • their integration with other models makes it possible to explore the trajectories of urban growth and	• based on the bottom-up modelling principle; • conforms to the complex nature of the city; - models and predicts self-organisation SP; [Germanaitė 2020] • can yield a complete phenomenon by setting up simple rules in a space; • indicates socio-economic development and environmental changes; • can perform better in explaining the urbanisation mechanism of an area when	• based on the examining aspects of urban morphology; • associated with the functional features of the city; • uses multi-hierarchy; [Germanaitė 2020] • distinguishes irregularity or roughness in an area; • provides room for comparing the morphology of cities as they identify different forms of cities as well as urban wards and types of peri-urban built-up patterns;	• based on the bottom-up modelling principle; • conforms to the complex nature of the city; • models and predicts self-organisation SP; • can cover the whole city due to the links that are modelled between the road segments; • procedurally calculations are simple and use GIS street network compared to Agent-Based Modelling and Cellular Automata (need to model agent	• shares all advantages of the methods described above; • allows SP comparisons when using the normalised Space syntax values thus further reducing the subjectivity of the method; • no longer relies on the statistical information; • forms SP based on complex model of CSS; • associates the shape of the territory with the with geographer's models using the bottom-up up modelling principle;

Criteria	Agent-Based Modelling	Cellular Automata	Fractal Analysis	Space Syntax	SPDIAM
	potential impacts of exogenous intercity fundamental interactions on future urban growth; [Musa 2017] • good for representing spatial entities or actors having relatively complex properties or behaviours; • easy way to capture the interactive properties of many natural and human systems and complex system behaviour that emerges from this interaction; • ideal for exploring the implications of non-linearity in system behaviour; • useful for examining the relationship between the micro-level behaviour and macro outcomes [Cheng 2003]	integrated with knowledge-driven models; • flexible, straightforward, and dynamic when compared with some other models as they are mainly concerned with changing spatial patterns over a given period; • provides platforms for performing complex computations with the help of local information only; • dynamic and compatible with remotely sensed data and *GIS* [Musa 2017]	• useful in identifying different forms of cities and urban growth; • can be used for measuring the similarity between the real and simulated SP created by other models, e.g., *Cellular Automata* [Musa 2017]	behaviour, create rules, etc.) [Germanaitė 2020]	• indicates the possible directions of CSS SP changes in the future, [Germanaitė 2020]

Criteria	Agent-Based Modelling	Cellular Automata	Fractal Analysis	Space Syntax	SPDIAM
Limitations [Germanaitė 2020] [Musa 2017]	• difficult to associate with Alexander's patterns and geographer's models; [Germanaitė 2020] • limitations due to variable outcomes resulting from the definition of arbitrary initial conditions and behavioural rules of the agent's growth [Musa 2017]	• difficult to associate with Alexander's patterns and geographer's models; [Germanaitė 2020] • solely depend on spatial data; • applying in a densely built-up area remains a challenging issue [Musa 2017]	• complete elucidation of the Euclidean form; • difficult to associate with Alexander's patterns and geographer's models; [Germanaitė 2020] • results of fractal analyses depend on the maps representing the surfaces used to determine the fractal dimension; • same value of a fractal dimension may represent different forms or structures, which may result in difficulty in interpreting the fractal measures of the spatial complexity of urban spatial patterns; [Musa 2017] • limited in urban process modelling as the temporal dimension is not incorporated in modelling; [Cheng 2003] • differences	- difficult to associate with Alexander's patterns and geographer's models [Germanaitė 2020]	- requires practical experiments to acquire the values of SP for SP identification [Germanaitė 2020]

Criteria	Agent-Based Modelling	Cellular Automata	Fractal Analysis	Space Syntax	SPDIAM
			in measurements based on the resolution and other factors; • lacks a clear method of analysis: standardised methods and interpretation [McAdams 2010]		

Fractal analysis is based on the examination of the urban morphology aspects that can be associated with the functional features of the city. Also, it uses multi-hierarchy in order to define the urban morphology aspects related to the functional properties and the potential of the city. However, this method completely elucidates the Euclidean form, and it is difficult to associate with Alexander's patterns and geographer's models.

The main advantage of the cellular automata, agent-based modelling, and Space syntax methods is that they are all based on the bottom-up modelling principle which conforms to the complex nature of the city. These methods can be used to model and predict a self-organising SP. Additionally, Space syntax can also cover the whole city due to the links that are modelled between the road segments. On the other hand, it is difficult to associate the cellular automata, agent-based, and Space syntax models with Alexander's patterns or geographer's models.

SPDIAM shares all the advantages of the methods described above and can be used to compare different SPs by using the normalised Space syntax values, thus further reducing the subjectivity of the method. SPDIAM no longer relies on statistical information and forms SPs based on the complex model of CSS. SPDIAM can be used to associate the shape of the territory with the geographer's models by using the bottom-up modelling principle. SPDIAM indicates a possible direction of the CSS SP changes in the future. The restriction of this method is that SPDIAM requires practical experiments to acquire the values of SP for SP identification.

In Table 34, the quantitative comparison of the methods used to analyse CSS is presented. The comparison is conducted according to the newly introduced SPDIAM data model characteristics (attributes and algorithms that the SPDIAM data model allows to implement). The plus sign in a Table 34 cell means that the method which is being compared either possesses that characteristic, or can easily acquire it. However, only those characteristics that are marked both with the plus sign and the grey colour are included in the final quantitative evaluation of the methods. This means that the characteristic is newly proposed, is significant, and it is intended specifically for the implementation of the SP description and identification. The minus sign in a Table 34 cell means that the implementation of the characteristic may be complex, it may require additional research and work, so it can be said at this time that the comparative method does not work with it. Therefore, SPDIAM offers 9 important data model characteristics relevant to CSS analysis which allow the methodology to be expanded in the future to include other SP identification methods that do not currently possess these characteristics.

Table 34 Quantitative comparison of methods used to analyse CSS according to the SPDIAM data model

Data model characteristics	Agent-based modelling	Cellular automata	Fractal analysis	Space syntax	SPDIAM	SPDIAM data model class
Non-spatial SP attributes:						
Descriptive, hierarchical, sectoral	-	-	-	-	+	*Pattern, PAttribute*
Spatial SP attributes:						
Geometrical	-	-	-	+	+	*FAttribute*
Topological	+	+	+	+	+	
Visibility and perception	+	+	-	+	+	
Complexity	+	+	+	+	+	
Computational SP attributes:						
Computational	-	-	-	-	+	*PatternValue, PatternValueMeasure*
Non-spatial CSS attributes:						
Descriptive, hierarchical, sectoral	+	+	+	+	+	*SpatialEntity, SEAttribute*
Spatial CSS attributes:						
Metric	+	-	-	+	+	*SESpatialAttribute*
Topological	+	+	+	+	+	
Different structures	-	-	-	+	+	*Structure, Element*
Indicator	+	-	-	-	+	*Indicator, IndicatorLayer*
Computational CSS attributes:						
Different forms	-	-	-	-	+	*Form*
CSS function evaluation	-	-	-	-	+	*PatternValue, PatternValueMeasure*
Algorithms:						
Algorithm for present SP identification method	-	-	-	-	+	*PatternMethod*
Algorithm for future SP identification	-	-	-	-	+	*Operation, OperationForm*
Different methods for SP	-	-	-	-	+	*Method*

Data model characteristics	Agent-based modelling	Cellular automata	Fractal analysis	Space syntax	SPDIAM	SPDIAM data model class
identification						
Automated SP identification	-	-	-	-	+	*PatternValue, PatternValueMeasure*
Qualitative SP identification based on quantitative measures	-	-	-	-	+	
Characteristics (total):	**0 (7)**	**0 (5)**	**0 (4)**	**1 (8)**	**18 (9)**	

7.3. Comparison of SPDIAM and Other Tools

The analysis of the spatial network analysis tools [Cardiff University 2019; City Form Lab 2016; ESRI 2019b; Gerlt 2018; Space Syntax Laboratory 2018; Urban Design Studies Unit 2012; Varoudis 2014] by comparing the features, the provided measures and the techniques of the network vertices mapping reveal that SPDIAM also offers improvements to the quantitative and qualitative characteristics of the already existing tools of spatial network analysis. The analysed spatial network analysis tools operate with the basic measures of centrality, thus the aggregated and complex measures that would allow us to combine the basic measures and to define new ones would improve the characteristics of the spatial network analysis tools. Even though the *QGIS Space Syntax Toolkit* (using *DepthmapX*) already works with normalised measures, it is not widely used yet; the method that would use normalised measures in spatial network analysis calculations would enable the comparison of the spatial entities of different sizes and between their elements. The *ESRI ArcGIS Network* analyst focuses on the analysis of the individual networks vertices rather than the whole network; most spatial network analysis tools use the whole network information, but do not use the normalised measures; the method that could offer both will also inherently improve the characteristics of the currently existing spatial network analysis tools. The analysed spatial network analysis tools do not offer capabilities for the user to describe SP, SP identification methods, and measures; this can be seen as the main quantitative and qualitative improvement to the family of the spatial network analysis tools.

After the analysis of some of the network analysis tools (complete analysis can be found in Table 35; by comparing them in terms of their features, provided measures, and the techniques of mapping of the network vertices, it can be seen that some improvements could be done to the quantitative and qualitative characteristics of the network's analysis:

1) all the network analysis tools listed in Table 35 operate only with the simple measures of centrality (Integration, Choice, etc.). SPDIAM offers already tested complex measures which let us combine the primary measures (quantitative and qualitative improvement).

2) only the *QGIS Space Syntax Toolkit* (using *DepthmapX*) already works with the normalised measures (Integration, Choice, etc.), and *DepthmapX* allows us to write the normalised measure's formulas, but it is not extensively used yet. Our method offers the use of normalised measures in calculations, that and would enable the "comparison of cities of different sizes, and their parts and elements" (which is thus qualitative improvement).

3) the *ArcGIS* Network analyst (ESRI) focuses only on the analysis of the individual network's vertices rather than the entire network. Most of the other network analysis tools use the whole network's information, but they do not use normalised measures. Our method offers to use Space syntax analysis and to get the benefit of the whole network's information (qualitative improvement) along with the normalised measures outlined in point 2.

4) Space syntax based SP can be linked to various categories of information and distinguished on its basis (by supplementing Space syntax indicators with other indicators); also, A Space syntax based SP can be easily compared with other SPS (e.g., population density, economic typology of activities, etc.); thus, the addition of SP would improve the versatility of the spatial network analysis tools.

Table 35 Comparison of different network analysis tools

Compatibility Requirements	**Description**	**Features**	**Measures**	**Mapping of Graph Vertices**	**License**
Spatial Design Network Analysis [Sustainable Places Research Institute]					
- *AutoCAD* (*2010* or above) - *ArcGIS* (*10.1* or above) - *QGIS* (*2.13* or above)	It standardises the link-node format (using continuous space algorithm), unifies the disciplines of spatial network analysis and transport modelling. It allows a wide range of inputs and decision support tools	- measures spatial networks; - runs transport models; - uses a variety of spatial formats; - uses the network node (street segment) and link (crossroad) as the base unit of analysis, ensuring compatibility with common data standards; - uses angular, metric, and	Accessibility within the radius (2D and 3D): - Closeness - Improved accessibility measures - Network gravity model Flows/Betweenness for radius (2D and 3D) Network density within the radius (2D and 3D): - Link count - Junction count - Total connectivity - Total length - Total angular cost - Total weight Severance (2D and 3D): - Total/mean geodesic length - Total crow flight distance - Mean geodesic diversion ratio Efficiency (2D only):	Segment and segment group between intersections	Free and commercial license

Compatibility Requirements	Description	Features	Measures	Mapping of Graph Vertices	License
		custom analyses; - treats network links as continuous to ensure accuracy; - customises the locality of analysis; - uses custom link weighting and costing; - supports multi-core CPUs; - Python API	- Convex hull area - Convex hull perimeter - Convex hull maximum radius - Bearing of maximum radius - Hull shape index Two-phase (generation/assignment) model (2D and 3D): - Two-phase betweenness - Two-phase destinations weigh		
Urban Network Analysis Toolbox [City Form Lab 2016; City Form Lab 2018]					
- *ArcGIS 10* with *ArcGIS* Network Analyst Extension - *Rhino3D*	It is built for easy scaling. It is suited for small-scale, detailed network analysis of dense urban areas and sparser large-scale regional networks	- uses geometry and topology in the input networks and metric or topological distance; - network nodes are crossroads and buildings, links – street segments; - buildings can be weighted according to their characteristics	Five types of graph analysis measures on spatial networks: - Reach - Gravity - Betweenness - Closeness - Straightness. Redundancy Tools additionally calculate: - Redundancy Index - Redundant Paths - Wayfinding Index	Intersection	Free and open-source plugin-in built on top of the *GIS* platform
Multiple Centrality Assessment [Urban Design Studies Unit 2012]					
- *GIS* environment	It uses simple mathematics to analyse networks of spaces represented in a *GIS* environment to illustrate the spatial qualities of	- network nodes are crossroads, and links are street segments; - measures different types of centrality; - outputs the	Four types of centrality: - Closeness - Betweenness - Straightness - Local Closeness	Intersection	-

Compatibility Requirements	Description	Features	Measures	Mapping of Graph Vertices	License
	urban systems including streets, squares, and buildings. The results are presented as maps whose scale and level of detail can be varied to meet different requirements	results graphically			
			DepthmapX [Tasos Varoudis 2014]		
- *Windows* - *MacOSX*	*DepthmapX* performs a set of spatial network analyses designed to understand social processes within the built environment. It works at a variety of scales. The aim is to produce a map of open space elements, connect them via some relationship and perform graph analysis of the network to derive variables that may have social or experiential significance	- network nodes can be axial lines, street segments, convex spaces, and links can be crossroads, turns, visibility lines, etc.; - to derive an ‘axial map’ of a layout; - axial maps may be broken into segment maps; - may be analysed by using a variety of techniques, such as road distance, or segment steps; - covers two separate models for spatial analysis: Space syntax and agent	- Angular Step Depth - Angular Mean Depth - Angular Node Count - Angular Total Depth - Angular Connectivity - Segment Length - etc.	Segment	Free and open-source (GPLv3 license)

Compatibility Requirements	Description	Features	Measures	Mapping of Graph Vertices	License
***QGIS* Space Syntax Toolkit** [Space Syntax Laboratory and Space Syntax Limited 2018]					
- *QGIS* (**2.14** or above) with *DepthmapXnet 0.35*	It offers SS analysis workflows in a *GIS* environment. It provides a front-end for the *DepthmapX* software within *QGIS* for seamless spatial network analysis. It includes tools for urban data management and analysis, namely, land use, entrances, frontages, pedestrian movement, road centre lines, and service areas. [Space Syntax Laboratory 2018]	- network nodes are street segments, and links are crossroads; - provides a front-end for the *DepthmapX* software within *QGIS*; - supports Space syntax analysis workflows in a GIS environment; - supports the verification and analysis of the spatial network model; - supports the visual and statistical exploration of the analysis results; - provides a quick analysis of individual quantitative attributes [Space Syntax Laboratory and Space Syntax Limited 2018]	- geometric and topological integrity of each layer - analysis of individual quantitative attributes	Segment	GNU General Public License v3.0
***ArcGIS* Network analyst** [ESRI 2020]					
- *ArcGIS Pro* - *ArcMap 10.3+*	It is network-based spatial analysis tool for solving complex routing problems. It	- network nodes are crossroads, and links are street segments; - optimised	'Best route' by network's cost: - fastest route - shortest route - travel time - distance (metres) - turn-by-turn maps	Intersection	Network Analyst license

Compatibility Requirements	Description	Features	Measures	Mapping of Graph Vertices	License
	uses a configurable transportation network data model allowing organisations to represent their unique network requirements, plan routes for the entire fleet, calculate drive-times, locate facilities and solve other network-related problems	routes; - finds the closest facilities; - solves multi-vehicle routing problems; - performs location allocation; - generates service areas; - creates origin-destination matrices	- time-dependent analysis - closest facility - accessibility - origin-destination cost matrix - vehicle routing problem - location-allocation		
Centrality Analysis Tools (*ESRI*) [Gerlt 2018; Gerlt 2019]					
- ArcGIS Pro 2.1 with *NetworkX* Python library [Hagberg *et al*. 2008]	There are currently no centrality tools in *ArcGIS* [Gerlt 2018], thus this tool wraps some of the graph theory centrality functionality (contained in the *NetworkX* Python library) in geoprocessing tools, thus enabling the use of these functions in *ArcGIS* geoprocessing workflows [Gerlt 2019]	- different network nodes and links can be selected; - enables calculation of various centrality measures on a graph or a network; - the graph is represented by a polyline feature class representing the edges of the graph with fields containing identifiers for starting and ending nodes; - contains the cost to traverse along with the edge	- Betweenness - Closeness - Current Flow Betweenness - Current Flow Closeness - Eigenvector - Katz [Gerlt 2018]	Segment Intersection	Free plugin-in built on top of the *GIS* platform

Compatibility Requirements	Description	Features	Measures	Mapping of Graph Vertices	License
		feature; - common costs include the travel time and distance [Gerlt 2019]			
Confeego [Gil *et al*. 2007]					
- *MapInfo 7.8* or above - *Windows*	A suite of tools to understand and harness the effects of spatial configuration in urban systems or complex buildings developed by Space syntax	- imports and exports drawings and data in a wide variety of vector and raster file formats; - combines information from multiple sources as it has a common geo-referenced basis - draws and processes complex geometries and topologies - analyses multiple layers of information both statistically and visually - performs spatial queries for the exploration of topological relationships - uses very large data sets for analysis of urban areas - converts geo-referenced	- connectivity, integration, and control - point depth - street metrics - block metrics - VGA isovists - real isovists	Segment Intersection	Free for academic use

Compatibility Requirements	Description	Features	Measures	Mapping of Graph Vertices	License
		information for use in other platforms - defines a flexible workflow combining creatively the different tools			

7.4. SPDIAM Reusability, Expandability, Flexibility and Complexity

Whatever and whichever technique we choose for modelling complex self-organising systems, we find ourselves up against several methodological problems that have not yet been fully resolved [White *et al*. 2015]. There are four main features of the general SP and metapattern model that can help to solve CSS problems (as described in Chapter 3): 1) *reusability*: SP and metapatterns can be reused for creating new SPs, also, new spatial metapatterns can arise based on the already existing metapatterns; 2) *expandability*: after the practical SP and metapatterns experiment, by virtue of knowing the ranges of the measure values, we can describe the whole new set of SP and metapatterns and cover many different geographical models, urban and spatial phenomena and problems (we can thus apply SPDIAM to other structured environmental phenomena, e.g., with the objective to identify natural phenomena (natural analysis), to evaluate the layout of buildings, etc.) while using the general SP model and the same principles (the UML class model and algorithms); 3) *flexibility*: the already existing SPs, metapatterns and algorithms can be improved by using some other measures or other SP values together with the different spatial forms and structures to refine spatial problems better if some new insights arise while working with SPDIAM; 4) *complexity*: the SPDIAM algorithm lets us use the different spatial and topological structures (such as Grid, Segment, Convex and Visuality Graph) for the same SP, while benefiting from the strengths of each structure. The other methods of spatial analysis described in [Germanaitė *et al*. 2020] when using them as stand-alone methods lack these features and need a lot of further work and additional IT artefacts to be employed in the framework of the aim of our research.

Cellular automata, agent-based modelling, fractal analysis, and Space syntax can all be used for creating simulation models, but the difference is that cellular automata, agent-based modelling, and fractal analysis show how the process is spreading over time, whereas Space syntax shows the whole process as compressed into the one moment of time, and also this highlights the potential of that process – this is the most valuable property of this method. Another important feature is that SPDIAM lets us use different models of spatial entity to follow CSS development over time and to predict changes that can happen in the future (based on [Al Sayed *et al*. 2009]). SPDIAM allows the users to create their SP, their measures along with interpretations of measure values. Also, SPDIAM can be used to describe other environmental phenomena with a structure, e.g., to identify natural phenomena (natural analysis), to evaluate a building's interior, etc. [Germanaitė *et al*. 2022].

7.5. Summary

SPDIAM was evaluated by using 3 different methods:

1) SP and statistics data correlation delivered the main conclusion that the correlation results show a medium-to-close (from 0.3 to 0.5) relationship between the identified SPs, and the statistics and all correlations are at the 0.01 significance level, which means that there is only 1% probability that they are random. In some cases (specifically, Ibadan, Stockholm, and Helsinki) additional estimation by a UPD practitioner is needed (as it was defined in SPDIAM phase 3).

2) SPDIAM and other methods describing CSS and identifying SP comparison use the qualitative descriptive method [Hevner and Chatterjee 2010]. SPDIAM shares all advantages of the methods described in Section 7.2. and can be used to compare different SPs by using the normalised Space syntax values and thus further reducing the subjectivity of the method. SPDIAM no longer relies on statistical information, and it forms SP based on the complex model of CSS. SPDIAM can be used to associate the shape of the territory with the geographer's models while using the bottom-up modelling principle [Germanaitė *et al*. 2020]. Also, the methodology offers 9 important data model characteristics relevant to CSS analysis which allow the methodology to be expanded in the future to include other SP identification methods which do not currently feature these characteristics.

3) Comparison of SPDIAM and other spatial network analysis tools. The analysis of spatial network analysis tools by comparing their features provided measures, and the techniques of network vertices mapping revealed that SPDIAM also offers improvements to the quantitative and qualitative characteristics of the already existing tools of spatial network analysis. The most significant feature is that Space syntax based SP can be linked to various information and be distinguished on its basis (by supplementing Space syntax indicators with other indicators); also, Space syntax-based SPs can be easily compared with other SPs (e.g., population density, economic typology of activities, etc.); thus, the addition of an SP would show the versatility of the proposed model which is thus greater than the versatility of any other model.

There are four main features of SPDIAM that can help to solve CSS problems: 1) *reusability*: SP and metapatterns can be reused for creating new SPs and metapatterns; 2) *expandability*: after the practical experiment, by virtue of knowing the ranges of the measure values, we can describe the whole new set of SP and metapatterns and cover many different geographical models, urban and spatial phenomena and problems using the general SP model and the same principles; 3) *flexibility*: the already existing SP, metapatterns, and algorithms can be improved by using other measures or other SP values together with the different spatial forms and structures to refine spatial problems better if the new insights arise while working with SPDIAM; 4) *complexity*: the SPDIAM algorithm lets us use the different spatial and topological structures for the same SP, thereby benefiting from the strengths of each structure.

8. CONCLUSIONS

1. After reviewing the methods of spatial analysis, it was concluded that analytical mathematical methods alone are not sufficient for CSS analysis. While there are many ways to describe and identify SPs, some SPs can currently only be detected by empirical research. It is evident that there is a lack of opportunities for spatial quantitative analysis.

2. The developed methodology allows us to automatically (by using quantifiable and scientifically based CSS measures) identify SPs and perform an assessment of CSS, thus improving the capabilities of quantitative CSS analysis. Such an approach has never been applied to the description and automated SP identification in CSS before. The obtained results were verified by calculating the correlation between the identified SP and the statistics which yielded results from 0.3 to 0.5 (significance 0.01) and showed a medium-to-close relationship between the identified SP and the statistics.

3. The developed specification, the data model and the spatial input data preparation procedure allow us to define descriptive, categorising, hierarchical, computational and spatial properties of SP, SP identification methods and CSS. The created IT artefacts can be used for spatial IS development using GIS technologies serving the objective to solve spatial analysis problems in CSS. Also, the methodology offers 9 important data model characteristics relevant to CSS analysis which allow the methodology to be expanded in the future so that to include other SP identification methods which do not currently feature these characteristics.

4. During the research, 3 experiments were conducted to test the developed methodology. By using the specification and data model, the values of 5 SP and 7 metapatterns were described, which were then automatically identified (according to user-described rules) in the data of 12 world cities and 6 abstract spatial structures while using two different methods (convex and visual graph analysis). The results of the experiments were evaluated by a domain expert and by calculating the correlations; consequently, it can be stated that the developed methodology is suitable for the implementation of its tasks.

REFERENCES

1. [Abar 2017] Abar, Sameera & Theodoropoulos, Georgios & Lemarinier, Pierre & O'Hare, Gregory. (2017). Agent Based Modelling and Simulation tools: A review of the state-of-art software. Computer Science Review. 24. 10.1016/j.cosrev.2017.03.001
2. [Ahmed et al. 2014] Ahmed B., Hasan R., Maniruzzaman K. M.: Urban Morphological Change Analysis of Dhaka City, Bangladesh, Using Space Syntax. ISPRS International Journal of Geo-Information, vol. 3, pp. 1412-1444 (2014) doi:10.3390/ijgi3041412.
3. [Al Sayed et al. 2009] K. Al Sayed, A. Turner, S. Hanna, "Cities as emergent models: the morphological logic of Manhattan and Barcelona", Proceedings of the 7^{th} International Space Syntax Symposium, Stockholm, Sweden, 2009.
4. [Alexander 1977] C. Alexander, A Pattern Language. New York, USA: Oxford University Press, 1977, pp. 10-13.
5. [Alexander 1979] C. Alexander, The Timeless Way of Building. New York, USA: Oxford University Press, 1979, pp. 82-93.
6. [Akkelies and Yamu 2018] Akkelies, N., Yamu, C.: Space Syntax: a method to measure urban space related to social, economic and cognitive factors; The Virtual and The Real in Planning and Urban Design: Perspectives, practices and applications, Routledge: Oxon, UK / New York, USA (2018), 136–150.
7. [Asht and Dass 2012] Asht, S., Dass, R.: Pattern recognition techniques: a review; International Journal of Computer Science and Telecommunications, 3, 8, (2012), 25-29.
8. [Axwoman 2015] Axwoman 6.3 Extension for ArcGIS 10.2. User's Guide. http://giscience.hig.se/binjiang/Axwoman/Axwoman63_manual.pdf Last accessed: 2019-01-15.
9. [Ballis et al. 2008] D. Ballis, A. Baruzzo, M. Comini, A Rule-based Method to Match Software Patterns Against UML Models, Electronic Notes in Theoretical Computer Science, Volume 219, 2008, Pages 51-66, DOI: 10.1016/j.entcs.2008.10.034.
10. [Batty 1994] M. Batty and M. Longley, Fractal Cities - A Geometry of Form and Function. London, UK: Academic Press, 1994, pp. 5.
11. [Billen and Zlatanova 2003] Billen R., Zlatanova S.: 3D spatial relationships model: a useful concept for 3D cadastre?. Computers, Environment and Urban Systems, vol. 27, pp. 411-425 (2003). doi: 10.1016/S0198-9715(02)00040-6.
12. [Bölen and Kaya 2017] Bölen, F., Kaya, H.: Urban DNA: morphogenetic analysis of urban pattern; Iconarp International J. of Architecture and Planning, 5, 10-41, 2017.
13. [Borgatti and EÍerett 1999] Borgatti S. P., EÍerett M. G.: Models of core/periphery structures. Social Networks, vol. 21 pp. 375–395 (1999) doi: 10.1016/S0378-8733(99)00019-2.
14. [Bureau Urbanisme 2014] BUUR, "The Sustainability Compass - a tool for analysing and orienting urban scale projects", 2014. Available: http://sustainabilitycompass.eu/theory/.
15. [Campagna 2005] Campagna M.: GIS for Sustainable Development. CRC Press (2005).
16. [City Form Lab 2016] City Form Lab (Massachusetts Institute of Technology): Urban Network Analysis Toolbox for ArcGIS, http://cityform.mit.edu/projects/urban-network-analysis, 2016. Last accessed: 2021-01-06.
17. [City Form Lab 2018] City Form Lab (Massachusetts Institute of Technology): Urban Network Analysis toolbox for Rhino3D, http://cityform.gsd.harvard.edu/projects/una-rhino-toolbox, 2018. Last accessed: 2021-01-06.

18. [Charalambous and Mavridou 2012] Charalambous N., Mavridou M.: (2012) Space Syntax: Spatial Integration Accessibility and Angular Segment Analysis by Metric Distance (ASAMeD), in Angela Hull, Cecília Silva and Luca Bertolini (Eds.) Accessibility Instruments for Planning Practice. COST Office, pp. 57-62.
19. [Cheng 2003] Jianquan Cheng, Ian MASSER, Henk OTTENS. "Understanding Urban Growth System: Theories and Methods." (2003).
20. [Crucitti et al. 2005] Crucitti, Paolo; Latora, Vito; Porta, Sergio. Centrality Measures in Spatial Networks of Urban Streets. Vol. 73, no. 3 Pt 2, 2005, p. 036125.
21. [Curtin 2007] Curtin, Kevin. (2007). Network Analysis in Geographic Information Science: Review, Assessment, and Projections. Cartography and Geographic Information Science. 34. 103-111. 10.1559/152304007781002163.
22. [Dale et al. 2002] Dale M. R. T., Dixon P., Fortin M., Legendre P., Myers D. E., Rosenberg M. S.: Conceptual and mathematical relationships among methods for spatial analysis. Ecography, vol. 25, pp. 558-577 (2002). doi: 10.1034/j.1600-0587.2002.250506.x.
23. [Depthmap 2018] Depthmap 4 - A Researcher's Handbook, http://www.vr.ucl.ac.uk/depthmap/depthmap4.pdf, last accessed 2018/04/21.
24. [Dimililer and Akyuz 2018] Raif Dimililer, Ugurcan Akyuz. Towards a Multi-Disciplinary Approach in Urban Design Education: Art and Software (Depthmap) Use in Urban Design of Public Spaces. EURASIA Journal of Mathematics, Science and Technology Education. 2018 14(4):1325-1335. 2018. DOI: 10.29333/ejmste/81521.
25. [DIVA-GIS 2019] DIVA-GIS, (2019), http://www.diva-gis.org.
26. [Dutt et al. 2012] Dutt, V., Chaudhry, V., Khan, I.: Pattern recognition: an overview; American Journal of Intelligent Systems, 2, 1, (2012), 23-27.
27. [ESRI 2019a] ESRI: Checks in Data Reviewer; (2019), http://desktop.arcgis.com/en/arcmap/latest/extensions/data-reviewer/checks-in-data-reviewer.htm.
28. [ESRI 2019b] ESRI: ArcGIS Network Analyst; (2019) https://www.esri.com/en-us/arcgis/products/arcgis-network-analyst/overview.
29. [ESRI 2019c] What is ModelBuilder? http://desktop.arcgis.com/en/arcmap/10.3/analyze/modelbuilder/what-is-modelbuilder.htm Last accessed: 2019-01-15.
30. [ESRI 2020] ESRI: ArcGIS Network Analyst, https://www.esri.com/en-us/arcgis/products/arcgis-network-analyst/overview, 2020. Last accessed: 2021-01-06.
31. [ESRI 2022] About ArcGIS. Overwiew. https://www.esri.com/en-us/arcgis/about-arcgis/overview. 2022. Last accessed: 2022-01-18.
32. [Fonseca et al. 2002] Fonseca, F., Egenhofer, M., Agouris, P., and Câmara, G. Using Ontologies for Integrated Geographic Information Systems. Transactions in GIS, Volume 6, Issue3, p. 231-257. 2002. https://doi.org/10.1111/1467-9671.00109.
33. [Furtado et al. 2019] Furtado B. A., Fuentes M. A., Tessone C. J.: (2019). Policy Modeling and Applications: State-of-the-Art and Perspectives. Complexity. 2019. 1-11. 10.1155/2019/5041681.
34. [Gamma et al. 1996] Gamma, E.; Helm, R.; Johnson, R.; Vlissides, J., Design Patterns, Addison-Wesley Publishing Company 1996.
35. [Geofabrik 2019] Geofabrik, (2019), https://www.geofabrik.de.
36. [Geoportal LT 2019] Lietuvos erdvinės informacijos portalas, (2019), https://www.geoportal.lt.
37. [Geoportal PL 2019] Geoportal, (2019), https://www.geoportal.gov.pl.

38. [Gerlt 2018] Gerlt B.: Centrality Analysis Toolbox, https://community.esri.com/groups/applications-prototype-lab/blog/2018/05/14/centrality-analysis-toolbox, 2018. Last accessed: 2021-01-06.
39. [Gerlt 2019] Gerlt B.: Centrality Analysis Tools, https://www.arcgis.com/home/item.html?id=06a6f1a2e2fe4cda9c1196ab8c7f7408, 2019. Last accessed: 2021-01-06.
40. [Germanaitė et al. 2018] I. E. Germanaitė, R. Butleris, K. Zaleckis, “How to Describe Basic Urban Pattern in Geographic Information Systems”, Communications in Computer and Information Science, Springer, vol. 920, pp.153-163, August 2018. DOI: 10.1007/978-3-319-99972-2_12.
41. [Germanaitė et al. 2020] I. E. Germanaitė, K. Zaleckis, R. Butleris, K. Jarmalavičienė, “Case Study of Spatial Pattern Description, Identification and Application Methodology”, J.UCS Journal of Universal Computer Science, vol. 26, no. 6, pp. 649-670, June 2020.
42. [Germanaitė et al. 2022] I. E. Germanaitė, K. Zaleckis, R. Butleris, A. Lopata, “General Spatial Pattern and Meta-Pattern Model for Problems That Need Analytical Approach in Complex Spatial Systems”. Applied Sciences. 2022; 12(1):302. https://doi.org/10.3390/app12010302.
43. [Getis and Paelinck 2004] Getis, A., Paelinck, J.: An analytical description of spatial patterns; L’Espace géographique, 33, 1, (2004).
44. [Gil et al. 2007] Gil, Jorge & Stutz, Chris & Chiaradia, Alain. (2007). Confeego: Tool Set for Spatial Configuration Studies. 6th International Space Syntax Symposium: 2007. https://www.researchgate.net/publication/258242070_Confeego_Tool_Set_for_Spatial_Configuration_Studies Last accessed: 2021-07-09.
45. [Gil et al. 2015] Gil, Jorge & Varoudis, Tasos & Karimi, Kayvan & Penn, Alan. (2015). The Space Syntax Toolkit: integrating depthmapX and exploratory spatial analysis workflows in QGIS. 10th International Space Syntax Symposium, At University College London, London, UK.
46. [Goodchild 2015] Goodchild, M.F.: GIS and modeling overview; GIS, Spatial Analysis, and Modeling. Redlands, CA: ESRI Press, (2005), 1–18.
47. [Gugik 2019] Gugik.gov.pl. http://www.gugik.gov.pl/pzgik/dane-bez-oplat/dane-z-panstwowego-rejestru-granic-i-powierzchni-jednostek-podzialow-terytorialnych-kraju-prg Last accessed: 2019-01-15.
48. [IBM 2021a] K-Means Cluster Analysis (2021), https://www.ibm.com/docs/en/spss-statistics/24.0.0?topic=option-means-cluster-analysis.
49. [IBM 2021b] IBM SPSS Statistics (2021), https://www.ibm.com/products/spss-statistics.
50. [Hagberg et al. 2008] A Hagberg, D Schult, P Swart: Exploring Network Structure, Dynamics, and Function using NetworkX in Proceedings of the 7th Python in Science conference (SciPy 2008), G Varoquaux, T Vaught, J Millman (Eds.), pp. 11-15.
51. [Hevner and Chatterjee 2010] A. Hevner and S. Chatterjee, Design Research in Information Systems: Theory and Practice. New York, USA: Springer, 2010, pp. 3, 6, 11, 24-25, 49.
52. [Hevner et al. 2004] Hevner, Alan & R, Alan & March, Salvatore & T, Salvatore & Park, & Park, Jinsoo & Ram, & Sudha,. (2004). Design Science in Information Systems Research. Management Information Systems Quarterly. 28. 75-.
53. [Hill et al. 2014] Hill, A.V., De Paep, M., Van Reeth, J.: Accounting for Urban Scale Sustainability; Towards Integrated Urban Modelling, Lyon, (2014), http://sustainabilitycompass.eu/resources/#documents.

54. [Hillier 2009] Hillier, B.: (2009) Spatial sustainability in cities: organic patterns and sustainable forms. In: Koch, D. and Marcus, L. and Steen, J., (eds.) Proceedings of the 7th International Space Syntax Symposium. (pp. p. 1). Royal Institute of Technology (KTH): Stockholm, Sweden.
55. [Hillier et al. 2010] Hillier, B & Turner, A & Yang, Tao & Park, H.-T. (2010). Metric and Topo-Geometric Properties of Urban Street Networks: Some Convergences, Divergences and New Results. The Journal of Space Syntax. Volume: 1, Issue: 2. Pages: 258-279. 2010. ISSN: 2044-7507.
56. [Hillier et al. 2012] Hillier, B., Yang, T., Turner, A.: Normalising least angle choice in Depthmap and how it opens up new perspectives on the global and local analysis of city space; Journal of Space Syntax, 3, (2012), 155-193.
57. [Holt et al. 2016] Holt, J.; Perry, S.; Brownsword, M., Foundations of model-based systems engineering. From patterns to models, Institution of Engineering and Technology 2016.
58. [Huisman and By 2009] Huisman O., By R. A.: Principles of Geographic Information Systems. The International Institute for Geo-Information Science and Earth Observation. Enschede, The Netherlands (2009).
59. [Jenks 1977] Jenks, George F. "Optimal data classification for choropleth maps. Occasional Paper No. 2", Department of Geography, University of Kansas (1977).
60. [Jiang 2009] Bin Jiang. Street Hierarchies: a Minority of Streets Account for a Majority of Traffic Flow. International Journal of Geographical Information Science, vol. 23, no. 8, 2009, pp. 1033–1049.
61. [Jiang 2015] Jiang, B.: Axwoman 6.3: An ArcGIS extension for urban morphological analysis, University of Gävle, Sweden, (2015), http://giscience.hig.se/binjiang/Axwoman.
62. [Jiang and Claramunt 1999] B. Jiang and Ch. Claramunt, "A Comparison Study on Space Syntax as a Computer Model of Space", August 1999. Available: https://www.researchgate.net/publication/2466998_A_Comparison_Study_on_Space_Syntax_as_a_Computer_Model_of_Space.
63. [Jiang et al. 1999] B. Jiang, C. Claramunt, M. Batty. Geometric accessibility and geographic information: extending desktop GIS to space syntax. Computers, Environment and Urban Systems. Volume 23, Issue 2, p. 127-146. 1999. DOI: https://doi.org/10.1016/S0198-9715(99)00017-4
64. [Jiang et al. 2000] Jiang B., Claramunt C., Klarqvist B.: An Integration of Space Syntax into GIS for Modelling Urban Spaces. International Journal of Applied Earth Observation and Geoinformation, vol. 2, pp. 161-171 (2000). doi: 10.1016/S0303-2434(00)85010-2.
65. [Jguirim 2014] I. Jguirim, D. Brosset, Ch. Claramunt, "Functional and Structural Analysis of an Urban Space Extended from Space Syntax", GIScience, August 2014. Available: https://www.researchgate.net/publication/265521103_Functional_and_Structural_Analysis_of_an_Urban_Space_Extended_from_Space_Syntax.
66. [Kaunas City Municipal administration 2019] Kaunas City Municipal administration. Comprehensive plan of Kaunas city municipality territory for 2013-2023. 2019. Available: http://www.kaunas.lt/urbanistika/bendrasis-planavimas/kauno-miesto-savivaldybes-teritorijos-bendrasis-planas-2013-2023-m/.
67. [Koutsolampros et al. 2019] Koutsolampros P., Sailer K., Varoudis T., Haslem R.: Dissecting Visibility Graph Analysis: The metrics and their role in understanding workplace human behaviour. Proceedings of the 12th Space Syntax Symposium, 2019.

68. [KTU ASI 2022] Kaunas University of Technology Institute of Architecture and Construction. Projektas „Kauno miesto teritorijos bendrojo plano koregavimas“. Darbo dalis: “Teritorijos vystymo galimybių nustatymas”, 2022.
69. [Kyu and Ban 2011] Sang Kyu, Jeong Yong Un Ban. Computational algorithms to evaluate design solutions using Space Syntax. Computer-Aided Design, Volume 43, Issue 6, p. 664-676. 2011. https://doi.org/10.1016/j.cad.2011.02.011
70. [Langlois 2011] P. Langlois. Simulation of Complex Systems in GIS, Hoboken, USA: John Wiley & Sons Inc., 2011, pp. 1-6.
71. [Liu and Jiang 2010] Liu, Xintao & Jiang, Bin. (2010). Defining and Generating Axial Lines from Street Center Lines for Better Understanding of Urban Morphologies. International Journal of Geographical Information Science. 26. 1521-1532. DOI: 10.1080/13658816.2011.643800.
72. [Major 2018] Major M. D.: The Syntax of City Space: American Urban Grids. Routledge, London (2018).
73. [Marcus 2007] Marcus, L.: Spatial capital and how to measure it: an outline of an analytical theory of the social performativity of urban form; (2007), https://www.researchgate.net/publication/277821851_Spatial_capital_and_how_to_measure_it_An_outline_of_an_analytical_theory_of_the_social_performativity_of_urban_form.
74. [Marshall and Gong 2009] Marshall T., Gong Y.: WP4 Deliverable Report: Urban Pattern Specification. Bartlett School of Planning, University College London (2009) http://www.suburbansolutions.ac.uk/documents/WP4DeliverableReportNov2009.pdf
75. [Matijošaitienė et al. 2013] Matijošaitienė I., Zaleckis K., Stankevičė I.: Sustainable City – A City without Crime. Architecture and Urban Planning, vol. 7, pp. 59-64 (2013) doi: 10.7250/aup.2013.007.
76. [McAdams 2010] Michael A. McAdams: Applying GIS and Fractal Analysis to the Study of the Urban Morpholgy in Istanbul, 2010, Available: http://web.deu.edu.tr/geomed2010/2007/Cravins.pdf.
77. [Mesev 2005] Mesev, V.: Identification and characterisation of urban building patterns using IKONOS imagery and point-based postal data; Computers, Environment and Urban Systems, 29, 5, (2005), 541-557.
78. [Mihai and Marian 2016] Mihai, G., Marian, D.: Visual tools for Software Development in GIS applications; Romanian Journal of Human - Computer Interaction, 9, 1, (2016), 71-85.
79. [Mumford 1938] Mumford, Lewis. 1938. The culture of cities. New York: Harcourt, Brace and Co.
80. [Murat et al. 2016] Oruc, Murat, et al. “Detecting Design Patterns in Object-Oriented Design Models by Using a Graph Mining Approach.” 2016 4th International Conference in Software Engineering Research and Innovation (CONISOFT), 2016, pp. 115–121.
81. [Musa 2017] S. I. Musa, M. Hashim, M. N. Reba, “A review of geospatial-based urban growth models and modelling initiatives”, Geocarto International, vol. 32, no. 8, pp. 813-833, July 2017. DOI: 10.1080/10106049.2016.1213891.
82. [Nes and Yamu 2021] A. van Nes, C. Yamu, “Space Syntax Applied in Urban Practice”, Introduction to Space Syntax in Urban Studies, Springer, 2021, pp. 213-237. DOI: 10.1007/978-3-030-59140-3_7.
83. [Nija and Olson 2006] Nija Shi, R, and Olsson. “Reverse Engineering of Design Patterns from Java Source Code.” 21st IEEE/ACM International Conference on Automated Software Engineering (ASE'06), 2006, pp. 123–134.

84. [O’Sullivan 2014] O’Sullivan, D.: Spatial network analysis. Handbook of regional science; Springer-Verlag Berlin Heidelberg, (2014).
85. [Pinet 2012] F. Pinet, “Entity-relationship and object-oriented formalisms for modeling spatial environmental data”, Environmental Modelling & Software, vol. 33, pp. 80-91, July 2012. DOI: 10.1016/j.envsoft.2012.01.008.
86. [Prathibha 2014] Prathibha, B. S.: Geographic Information Systems as an Integrating Technology: Overview, Concepts, and Definitions; International Journal on Recent and Innovation Trends in Computing and Communication vol. 2, issue 10, pp. 3024-3027, 2014.
87. [Projest 2017] Projest, (2017), https://projest.io/ns.
88. [Projestion 2019] Projestion. https://github.com/ebrelsford/projestions#projestions Last accessed: 2019-01-15.
89. [QGIS 2022] QGIS. https://qgis.org. Last accessed: 2022-01-18.
90. [Rati 2004] Ratti, Carlo. (2004). Space Syntax: Some Inconsistencies. Environment and Planning B: Planning and Design. 31. 487-499. DOI: 10.1068/b3019.
91. [Register of Legal Acts 2020] Register of Legal Acts: Law on Territorial Planning of the Republic of Lithuania; https://www.e-tar.lt/portal/lt/legalAct/TAR.26B563184529/asr, 2020.
92. [Samson et al. 2014] G. L. Samson, L. Joun, A. Sh. Ajibola, “Mining Complex Spatial Patterns: Issues and Techniques”, Journal of Information & Knowledge Management, vol. 13, no. 2, June 2014. DOI: 10.1142/S0219649214500191.
93. [Sevtsuk and Mekonnen 2012] Andres Sevtsuk, Michael Mekonnen. Urban network analysis. A new toolbox for ArcGIS. Revue internationale de géomatique, Volume 22(2), p. 287-305. 2012. DOI: 10.3166/rig.22.287-305.
94. [Seyed et al. 2015] Seyed, B., Miller, E., Ming, Z.: Spatial pattern recognition of the structure of urban land uses useful for transportation and land use modelling; International Conference on Transportation Information and Safety (ICTIS), Wuhan, (2015), 258-263.
95. [Shekhar et al. 2011] Shekhar, S., Evans, M. R., Kang, M. J., Mohan, P.: Identifying patterns in spatial information: a survey of methods; Wiley Interdisc. Rew. Data Mining and Knowledge Discovery, 1, (2011), 193-214.
96. [Soller et al. 2006] Soller, David & Berg, Thomas. (2006). The U.S. National Geologic Map Database Project: Overview & Progress. DOI: 10.1007/1-4020-3551-9_23.
97. [Space Syntax 2021] Space Syntax, http://www.spacesyntax.com Last accessed: 2021-06-15.
98. [Space Syntax Laboratory 2018] Space Syntax Laboratory (Bartlett, University College London): QgisSpaceSyntaxToolkit, https://github.com/SpaceGroupUCL/qgisSpaceSyntaxToolkit, 2018. Last accessed: 2021-01-06.
99. [Space Syntax Laboratory and Space Syntax Limited 2018] Space Syntax Laboratory (Bartlett, University College London), Space Syntax Limited: Qgis Space Syntax Toolkit, http://otp.spacesyntax.net/software-and-manuals/space-syntax-toolkit-2/, 2018. Last accessed: 2021-01-06.
100. [Space Syntax Limited 2018] Space Syntax Limited: Space Syntax OpenMapping project; (2018), https://spacesyntax.com/openmapping.
101. [Subba and Eswara 2011] Subba Rao, M., Eswara, B.: Comparative analysis of pattern recognition methods: an overview; Indian Journal of Computer Science and Engineering (IJCSE), 2, 3, (2011), 385-390.
102. [Cardiff University 2019] Sustainable Places Research Institute (Cardiff University): sDNA Software, https://www.cardiff.ac.uk/sdna/software/software/ Last accessed: 2021-01-06.

103. [Stoianov and Şora 2010] A. Stoianov and I. Şora, Detecting patterns and antipatterns in software using Prolog rules, 2010 International Joint Conference on Computational Cybernetics and Technical Informatics, Timisoara, 2010, pp. 253-258. doi: 10.1109/ICCCYB.2010.5491288.
104. [Torrens 2000] Torrens, P. M.: How land-use-transportation models work; Centre for Advanced Spatial Analysis Working Papers, London, UK, (2000).
105. [Uchiyama et al. 2014] Uchiyama, S. , Kubo, A. , Washizaki, H. and Fukazawa, Y. (2014) Detecting Design Patterns in Object-Oriented Program Source Code by Using Metrics and Machine Learning. Journal of Software Engineering and Applications, 7, 983-998. doi: 10.4236/jsea.2014.712086.
106. [Uitemark et al. 2020] Uitermark H.T., van Oosterom P.J.M., Mars N.J.I., Molenaar M. (1999) Ontology-Based Geographic Data Set Integration. Spatio-Temporal Database Management. Lecture Notes in Computer Science, vol 1678, p. 60-78. Springer, Berlin, Heidelberg. https://doi.org/10.1007/3-540-48344-6_4.
107. [Urban Design Studies Unit 2012] Urban Design Studies Unit (University of Strathclyde): MCA (Multiple Centrality Assessment), http://www.udsu-strath.com/msc-urban-design/mca-multiple-centrality-assessment/, 2012. Last accessed: 2021-01-06.
108. [Varoudis 2014] T. Varoudis, "Multi-Platform Spatial Network Analysis Software", 2014. Available: https://varoudis.github.io/depthmapX/.
109. [Villaverde et al. 2013] Villaverde A. B., Jiménez-Hornero F. J., Gutiérrez De Ravé E.: Multifractal analysis of axial maps applied to the study of urban morphology. Computers, Environment and Urban Systems, vol. 38, p. 1-10 (2013) doi: 10.1016/j.compenvurbsys.2012.11.001
110. [Volk 1995] T. Volk, Metapatterns. New York, USA: Columbia University Press, 1995, pp. 1, 51.
111. [Volk 2017] Volk T. Metapatterns of Nature, Mind, and Culture. Advanced Honors Seminar Spring 2017 AHSEM-UA.154 / ENVST-UA.254. 2017.
112. [Volk and Bloom 2007a] Volk T., Bloom J. W. The Use of Metapatterns for Research into Complex Systems of Teaching, Learning, and Schooling. Part I: Metapatterns in Nature and Culture. Complicity: An International Journal of Complexity and Education. Volume 4 (2007), Number 1, pp. 25–43.
113. [Volk and Bloom 2007b] Bloom J. W., Volk T. The Use of Metapatterns for Research into Complex Systems of Teaching, Learning, and Schooling. Part II: Applications. Complicity: An International Journal of Complexity and Education. Volume 4 (2007), Number 1, pp. 45–68.
114. [Tang et al. 1996] A. Y. Tang, T. M. Adams, E. L. Usery, "A Spatial Data Model Design for Feature-Based Geographical Information Systems", International Journal of Geographical Information Systems, vol. 10, no. 5, p. 643-659, July 1996. DOI: 10.1080/026937996137927.
115. [Tavana et al. 2016] Madjid Tavana, Weiru Liu, Paul Elmore, Frederick E. Petry, Brian S. Bourgeois, A practical taxonomy of methods and literature for managing uncertain spatial data in geographic information systems. Measurement, Volume 81, 2016, Pages 123-162. DOI: 10.1016/j.measurement.2015.12.007.
116. [Turner 2001] Alasdair Turner. Depthmap: A program to perform visibility graph analysis. In: Third International Space Syntax Symposium, Georgia Technological Institute. 2001.

117. [Turner 2007] Turner, A., 2007, From axial to road-centre lines: A new representation for Space Syntax and a new model of route choice for transport network analysis. Environment and Planning B 34(3):539–555 DOI:10.1068/b32067.
118. [Waddell 2002] Waddell, Paul. (2002). UrbanSim: Modeling Urban Development for Land Use, Transportation and Environmental Planning. Journal of the American Planning Association. 68. 297-314. 10.1080/01944360208976274
119. [Wahyudi 2015] Wahyudi A., Liu Y.: Spatial Dynamic Models for Inclusive Cities: a Brief Concept of Cellular Automata (CA) and Agent-Based Model (ABM). Jurnal Perencanaan Wilayah dan Kota, vol. 26, pp. 54-70 (2015) doi: 10.5614/jpwk.2015.26.1.6
120. [Widaningrum et al. 2017] Widaningrum D. L., Surjandari I., Arymurthy A. M.: Spatial data utilization for location pattern analysis. Procedia Computer Science, vol. 124, pp. 69-76 (2017) doi: 10.1016/j.procs.2017.12.131
121. [Williams and Wentz 2008] Atwood Williams, E., Wentz, E.: Pattern analysis based on type, orientation, size, and shape; Geographical Analysis, 40, 2, (2008), 97 - 122.
122. [Wilson 2008] A. G. Wilson, Complex Spatial Systems: The Modelling Foundations of Urban and Regional Analysis. Harlow, England: Prentice Hall, 2008, pp. 1-4, 6-8, 14,18, 23-25, 96-97.
123. [White et al. 2015] R. White, G. Engelen, I. Uljee, Modeling Cities and Regions as Complex Systems. From Theory to Planning Applications. Cambridge, USA: The MIT Press, 2015, pp. 1, 21-23, 32, 129.
124. [Xiaoqian et al. 2010] W. Xiaoqian, G. Weimin, L. Jia, "Application of spatial database technology of GIS to morphological research on architectural heritage", International Conference on Computer Application and System Modeling, pp. V15-502-V15-506, October 2010. DOI: 10.1109/ICCASM.2010.5622535
125. [Xuecao 2016] Xuecao, Li & Gong, Peng. (2016). Urban growth models: progress and perspective. Science Bulletin. 61. 10.1007/s11434-016-1111-1
126. [Yamu et al. 2021] C. Yamu, A. van Nes, C. Garau, "Bill Hillier's Legacy: Space Syntax—A Synopsis of Basic Concepts, Measures, and Empirical Application", Sustainability, 2021, 13, 3394. DOI: 10.3390/su13063394.
127. [Yang et al. 2010] Yang, B., Luan, X., Li, Q.: An adaptive method for identifying the spatial patterns in road networks; Computers, Environment and Urban Systems, 34, 1, (2010), 40-48.
128. [Yan et al. 2019] Yan, X., Ai, T., Yang, M., Yin, H.: A graph convolutional neural network for classification of building patterns using spatial vector data; ISPRS Journal of Photogrammetry and Remote Sensing, 150, (2019), 259–273.
129. [Yigitcanlar and Dur 2010] Yigitcanlar, T., Dur, F.: Developing a sustainability assessment model: the sustainable infrastructure, land-use, environment and transport model; Sustainability, 2, (2010), 321-340.
130. [Yoshida and Omae 2005] Yoshida, H., Omae, M.: An approach for analysis of urban morphology: methods to derive morphological properties of city blocks by using an urban landscape model and their interpretations; Computers, Environment and Urban Systems, 29, 2, (2005), 223-247.
131. [Zaleckis et al. 2020]K. Zaleckis, B. Tranavičiūtė, T. Grunskis, I. Gražulevičiūtė-Villeniškė, J. Vitkuvienė, J. Sinkienė, H. A. Doğan and K. Zaleckis, "5 Transformations of the Network on Public Spaces and its Relations to Spatial Social Content", Modernization of Public Spaces in Lithuanian Cities, Sciendo, 2020, pp. 295-392. DOI: 10.1515/9788395793875-006.

LIST OF PUBLICATIONS OF INDRAJA E. GERMANAITĖ ON DISSERTATION THEME

Articles in Journals referenced in the *Web of Science* database

1. **Germanaitė I.E.**, Zaleckis K., Butleris R., Jarmalavičienė K. Case Study of Spatial Pattern Description, Identification and Application Methodology. In: Choraś M., D'Antonio S., Keller J., Kozik R. (eds.) Journal of Universal Computer Science (J.UCS) Special Issue Pattern Recognition and Artificial Intelligence – current challenges, novel solutions and emerging applications, vol. 26, issue 6, pp. 649-670, 2020.
2. **Germanaitė I.E.**, Zaleckis K., Butleris R., Lopata A., "General Spatial Pattern and Meta-Pattern Model for Problems That Need Analytical Approach in Complex Spatial Systems". Applied Sciences. 2022; 12(1):302. https://doi.org/10.3390/app12010302.

Articles in Journals referenced in other reviewed scientific publications [proceedings]

1. **Germanaitė I.E.**, Butleris R., Zaleckis K. (2018) How to Describe Basic Urban Pattern in Geographic Information Systems. In: Damaševičius R., Vasiljevienė G. (eds.) Information and Software Technologies. ICIST 2018. Communications in Computer and Information Science, vol. 920. pp.153-163. Springer, Cham. DOI: 10.1007/978-3-319-99972-2_12.
2. **Germanaitė I.E.**, Butleris R. (2017) How to define interface patterns in model-based system engineering. In: Damaševičius R., Napoli Ch., Tramontana E., Woźniak M. (eds.) Proceedings of the International Conference for Young Researchers in Informatics, Mathematics and Engineering, vol. 1852, pp. 54-58, 2017.

1 ANNEX. SPDIAM Logical Data Model

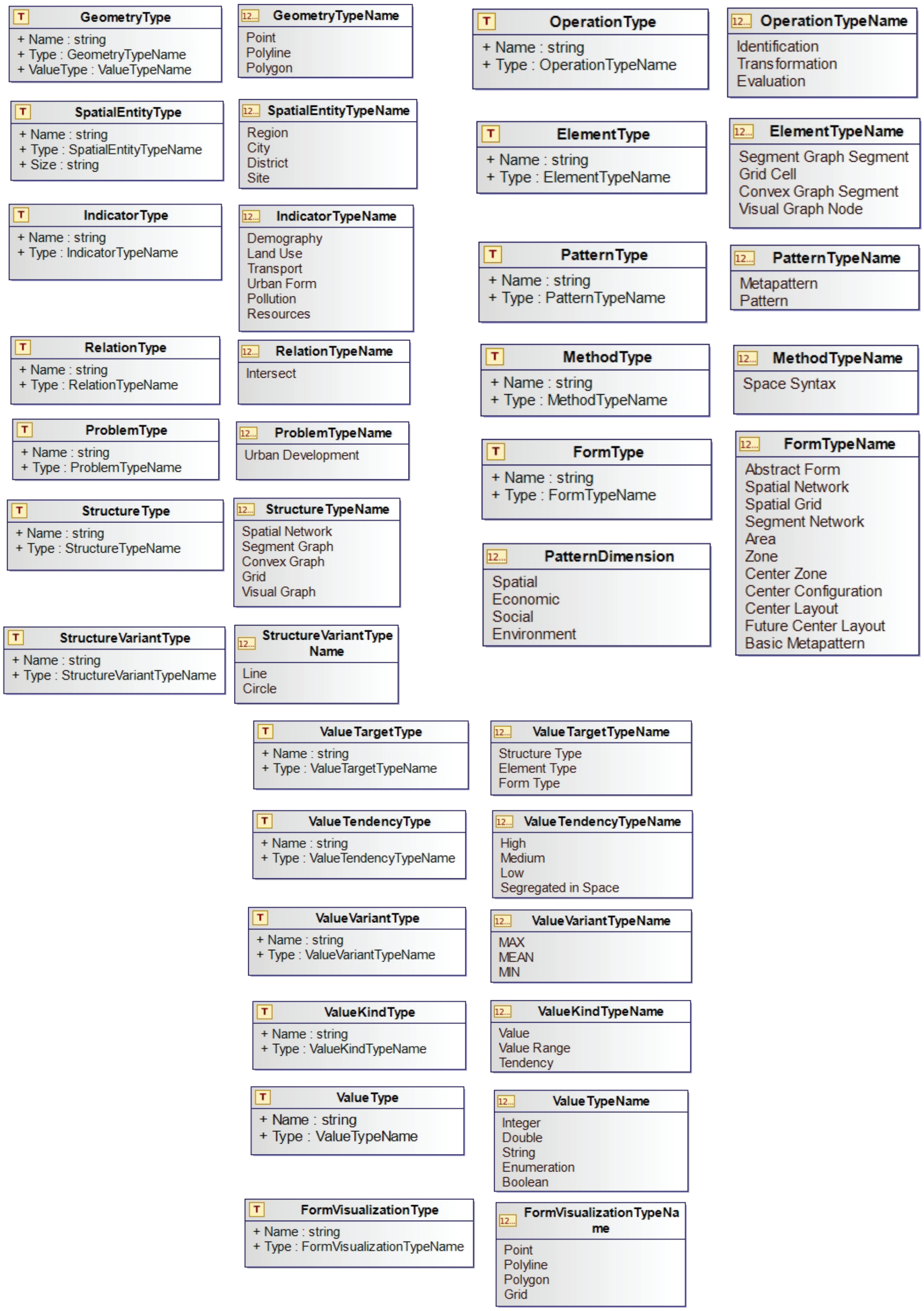


Figure 1 Data types

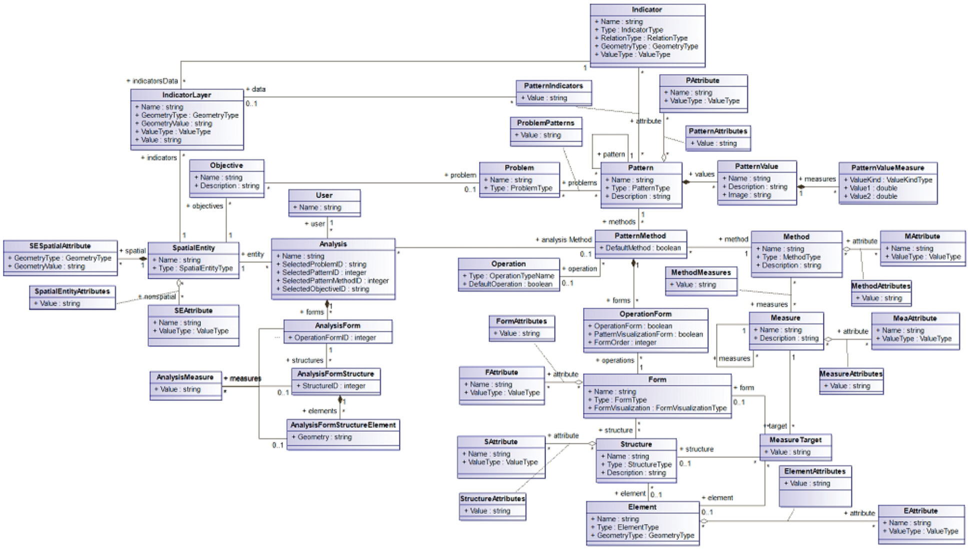


Figure 2 Logical data model

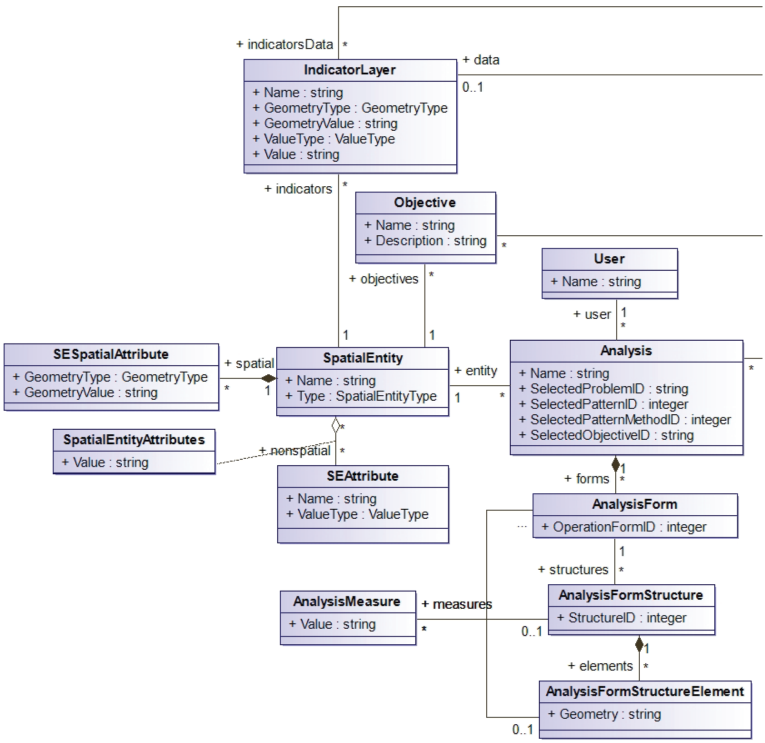


Figure 3 Data model: upper left part (zoomed in)

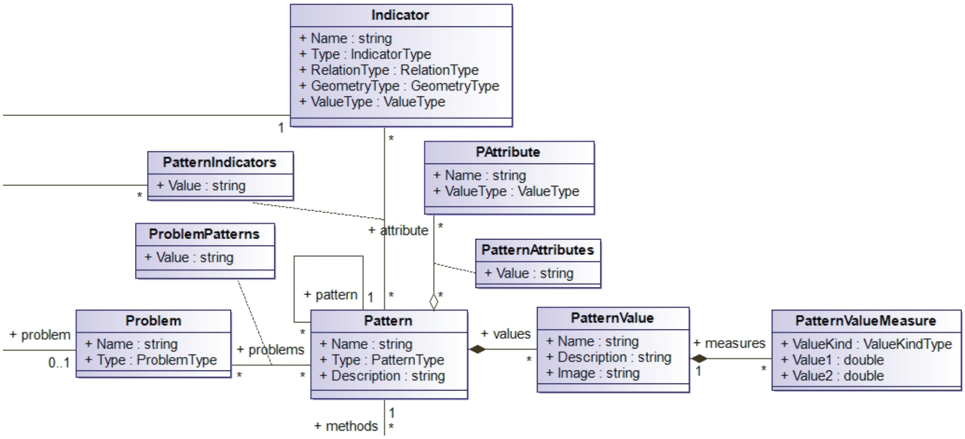


Figure 4 Data model: upper right part (zoomed in)

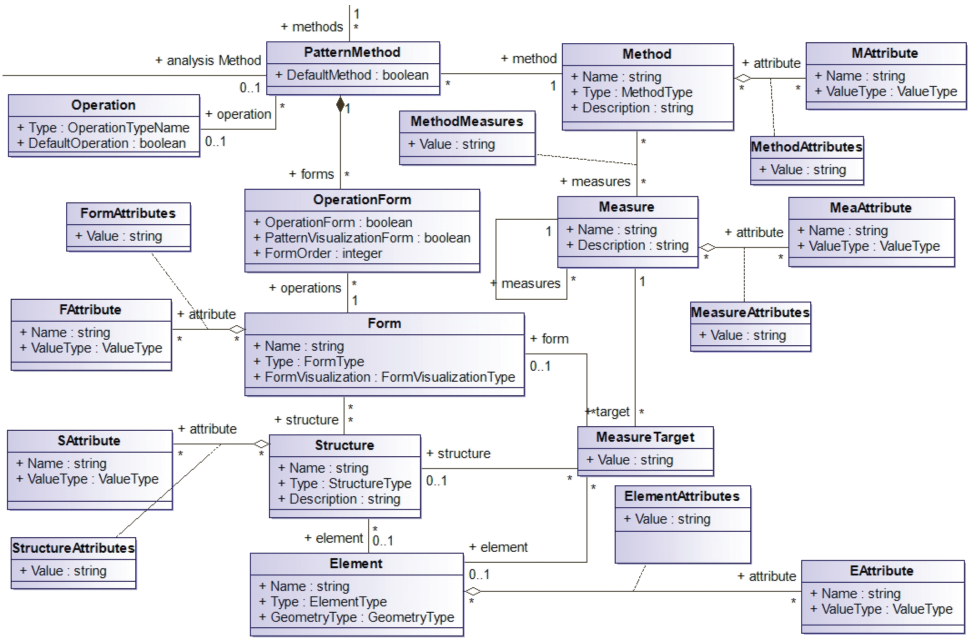


Figure 5 Data model: lower right part (zoomed in)

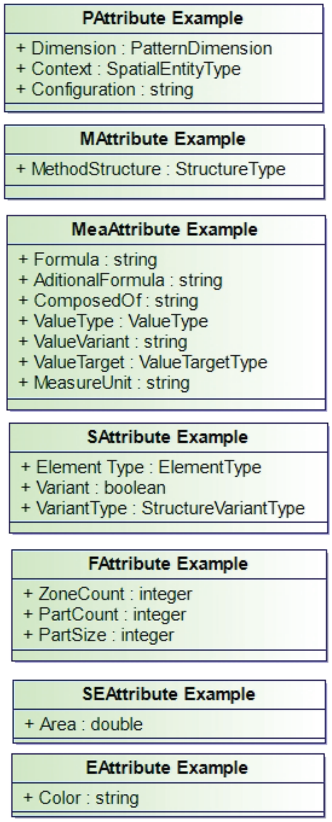


Figure 6 Examples of some classes attributes

SL 344. 2022-07-20, 20,75 leidyb. apsk. l. Tiražas 14 egz. Užsakymas 138.
Išleido Kauno technologijos universitetas, K. Donelaičio g. 73, 44249 Kaunas
Spausdino leidyklos „Technologija“ spaustuvė, Studentų g. 54, 51424 Kaunas