INTERNATIONAL JOURNAL
OF
CONSERVATION SCIENCE

ISSN: 2067-533X Volume 17, Issue 1, 2026: 137-154 www. ijcs. ro

DOI: 10. 36868/IJCS.2026.01.09

EXPLORING INNOVATIVE METHODS FOR ASSESSING THE DEVELOPMENT POTENTIAL OF HISTORIC ARCHITECTURAL STRUCTURES: THE CASE STUDY OF SMALL MEDIEVAL CITIES IN SUBCARPATHIA

Anna Maria MARTYKA[1,*]

[1] Faculty of Civil and Environmental Engineering and Architecture - Department of Architecture and Cultural Heritage - Rzeszow University of Technology - Poznańska 2 Street, 35-084 Rzeszów - Poland

Abstract

This article presents an innovative multistage research methodology for assessing the development potential of small historic cities, with the aim of developing tools to support the protection and sustainable development of the architectural heritage. The proposed procedure involves an analysis of the historic space, and the first two stages have been tested on medieval cities in the Subcarpathian region of Poland. The first stage involves classical methods of architecture and urban planning, focusing on the history of urban development. The second stage introduces three original indicators: Morphology and Physiognomy (MPI), Sustainable Development (SDI), and Urban Integration (UII). MPI describes the spatial structure and the state of conservation of the historic urban layout. SDI takes into account economic, social, and spatial aspects and allows for a comparison of the surveyed cities in a regional context. UII assesses the degree of integration of the historic urban fabric with the contemporary spatial and functional environment. The third stage, which is an innovative element of the methodology, is based on modelling the urban fabric, digital representations of the heritage, and predicting the evolution of the urban fabric. The aim is to integrate these approaches to protect and adapt the historic fabric of small cities to contemporary needs, using advanced digital technologies for documentation and analysis. The presented research concept is in line with both the idea of the Smart City and the Regional Intelligent Specializations of the Subcarpathia, offering a comprehensive approach to the assessment and protection of the architectural heritage in small historic cities.

Keywords: *Architectural heritage; Medieval cities; Conservation; Sustainable development; Digital twins*

Introduction

Small cities of medieval origin are a valuable part of Europe's cultural heritage. In many countries, such as Italy, Spain, France, and Germany, they are treated as "*living monuments*" subject to special protection. Their value comes from both their historical urban layout and the specific social relationships that have shaped their identity over centuries. Weber [1] noted that medieval cities played an important role as universal markers of Western culture, characterized by autonomy, citizenship, and a uniform legal framework that governs political and economic life. The historic medieval spatial structure of small cities is not only a testimony to their urban character but also a key element of their identity. Wejchert [2] referred to such elements as "crystallizing components," emphasizing their role in the organization of space. Despite repetitive

* Corresponding author: amartyka@prz.edu.pl

patterns, medieval urban layouts simultaneously exhibit distinctive individual characteristics [3]. Today, small historic Polish cities face numerous challenges. Their development has been influenced by historical political changes and contemporary demographic, economic, and spatial processes. Unfortunately, the political transformation in Poland in the 1990s exacerbated problems such as depopulation, changes in the social structure, or the uncontrolled development of suburbs at the expense of historic centers. Despite numerous revitalization and renovation activities, the authenticity of these cities and their *genius loci* is slowly being lost [4].

Rational city planning requires a thorough understanding of the mechanisms that govern it. Planning decisions shaping its "*anatomy*" should have a solid foundation, not only in terms of land use but, above all, in the interpretation of the spatial processes that can be described as its "physiology." This is because a proper diagnosis of the urban structure allows for not only its effective protection but also the design of a development that preserves the integrity of the urban form and its historical identity. Zuziak defines the 'anatomy' of a city as the set of physical elements that, through their development and structural relationships, build up the urban fabric [5]. It is a heterogeneous structure within which we can distinguish nodes of urbanity and urban corridors that act as factors crystallizing space, giving it form, and facilitating the orientation of users. They build up the image of the city as a coherent whole in the minds of the inhabitants, defining its character and identity. In small cities, the market acts as the dominant urban node, often constituting the main public space with strong social, symbolic, functional, and cultural significance.

In the face of the dynamic changes that shape today's small cities, several fundamental questions are being asked about their future. This has provided the impetus for the search for effective tools to protect their specific spirit of place, heritage, and sustainable spatial planning. The analysis of these questions formed the starting point for the research undertaken and the design of innovative urban development strategies that aim to harmoniously combine historical values with the challenges of modern urban planning. The following issues were addressed at the center of these considerations:

- Sustainability: How can a balance between economic, social, and spatial aspects be achieved to prevent stagnation while protecting a city's unique cultural identity?
- Demography and space: What urban planning solutions can effectively respond to the challenges of an aging and declining population?
- Suburbanization and its consequences—How to limit uncontrolled spatial expansion leading to depopulation of centers, increased infrastructure costs, and fragmentation of the cultural and natural landscape?
- Protecting the urban landscape: What legal mechanisms and planning tools can protect historic urban silhouettes and their foreshores from inappropriate development?
- Quality of public spaces: How can public space networks be shaped to enhance the attractiveness of small cities and to improve the quality of life of their inhabitants?

The answers to these questions provide directions for further research and lay the foundation for the search for urban planning tools and strategies that will allow small cities to maintain their historical identity and adapt successfully to contemporary challenges.

Methodology, scope, and aim of the study

The architectural and urban heritage of small historic cities requires specific protection methods. The aim of this research is to develop research into the creation of an effective tool to consciously manage heritage in a way that allows it to be protected while adapting to contemporary challenges [6], [7], [8]. The development of the presented methodology was inspired by the theoretical and practical work of Zbigniew K. Zuziak [5], [9]-[13], who developed the concept of urban structure modelling, initiated in Poland by Tadeusz Zipser. Zipser emphasized the importance of modelling structure mechanisms as an important tool in spatial planning processes [14].

This article presents the author's research procedure for assessing the developmental potential of small historic cities. The proposed methodology combines a conservation approach with an adaptive approach to bridge the gap between traditional heritage conservation efforts and current urban development needs. The proposed research procedure is based on a multistage analysis of urban structures, with a particular focus on areas of high historical value. It combines classical methods of urban analysis with modern digital tools and technologies, allowing comprehensive coverage of both the tangible and intangible aspects of urban heritage. The first two stages of this method have been applied to the analysis of small medieval cities in the Subcarpathian region, allowing an empirical evaluation of the effectiveness of this toolkit in a real urban context [15]-[19]. The case study of these cities adds a practical dimension to the research by highlighting its relevance to spatial policy. This work is in line with the current challenges of urban planning and heritage conservation, combining historical source material analysis, research on the sustainability of urban structures, and the use of scientific tools to accurately assess space. The third stage involves the development of a general theoretical framework for the implementation of technology to support the needs of small historic cities. This proposal takes the form of an iterative digital model to assess architectural and urban heritage, providing a starting point for further research and development. An important element of this methodology is the digital modelling of urban structures, which can be used from the theoretical conceptualization of spatial transformation processes and their impact on the urban fabric to guide their further development and analyze possible development scenarios. In the future, its empirical verification will allow these tools to be adapted and refined.

The results of this research are of particular relevance to the spatial policy of small cities, which often face constraints due to the lack of access to expert specialized resources. Unlike large cities, the local governments of smaller centers do not have sufficient resources dedicated solely to spatial planning. Therefore, the development of innovative methods to support heritage conservation and spatial development is not only desirable but also necessary for effective urban management and planning in regions such as Subcarpathia, which is historically dominated by small cities. Furthermore, the results of this research can be an effective tool to support decision-making processes in the field of conservation and revitalization, resulting in improved quality of life for residents and increased attractiveness of small cities to investors.

Multistage research procedure in the preservation and development of small historic cities in the Subcarpathian region

First stage

The first stage is the analysis of spatial and cultural mechanisms, which consists of many of the classical methods applied to architecture and urbanism applicable to the discipline of architecture and urbanism (Table 1). The history of urban development, based on the findings of historians, archaeologists, and geographers, is important.

The theoretical frameworks of distinguished urban planners and spatial theorists, including Lynch, Wejchert, Żórawski, and Cullen [20]-[23], along with Calvino's literary notions in "Invisible Cities" [24], as a metaphorical interpretation of the city as a transient phenomenon, constitute the foundational basis of this research. Within this approach, the city is considered a work of art. This way of thinking has receded into the background of contemporary urban planning, which is still extremely important in historic cities. Therefore, the first stage of the research has a contemplative element that allows us to capture the beauty and spirit of small cities.

Queries and analyses of historical and cartographic sources have allowed a reconstruction of the evolution of urban spatial arrangements. Particular attention has been paid to medieval parcel divisions, the composition of monumental and residential buildings, and their spatial relationships. The initial phase of the urban layout and the origins of the city are presented, along with its most important conditions. This descriptive historical approach explains the processes involved in urban development [25]. The characterization of the geometry of the space and the functions of the foundations of the historic city was developed on the basis of cartographic records and the existing state, which is an entourage of the essential spatial dispositions and historical conditions and transformations made over the centuries. Relics of historic settlement elements and layouts were searched using metrological analyses to establish the measures and principles of the original layout and the composition of the city plan. The analysis was based on preserved artifacts, that is, the traces of the original parcels, the outline of the building blocks, and the character and arrangement of monumental objects that are still visible today. On the other hand, the course of the hypothetical defensive perimeter, gates, and gateways to the city in the Middle Ages was determined based on previous archaeological research (if relics of the fortifications survived), historical sources, and previous findings of researchers who were additionally confronted with the contemporary relief presented on the shaded map, developed based on data from the Digital Terrain Model (DTM) obtained from Geoportel [26].

Cartography is an important source for tracking the development of cities during the medieval period. This involves, in particular, the study of urban composition, spatial structure, transport systems, and the extent of development, as well as the recognition of the geography of the area. In the small cities studied, there were no revolutionary transformations of the original structure due to the peculiarities of slow economic development and the fact that the spatial form of a city is more permanent than its social layout [27]. Friedrich von Mieg's first survey map, made on a scale of 1:28,800, was particularly helpful. This was the first military picture of Galicia and Lodomeria taken between 1775 and 1783 (Josephinische Landesaufnahme). Used for military purposes, Mieg's map includes descriptions of road conditions, water obstacles, terrain, and forest complexes. Particular attention was paid to fortified objects, such as castles, city walls, bastion assumptions, and earth fortifications, including entrenchments from the period of the Bar Confederation. These descriptions reflect the state of defensive potential at the time when Galicia was taken over by the Austrians after the first partition of the Republic in 1772. Most of this potency was evaluated as obsolete, dating from the 18th century or earlier [28]. Later, cartographic material, much more detailed in urban terms, included cadastral maps dating from the 19th century. On them, the urban layout, which had been preserved in small cities since the Middle Ages, was already recorded in a geometrical manner, despite the spatial changes in the region that occurred in the 19th century due to the development of industry.

Another extremely important source of information on the construction of medieval cities is the layout of the original building plots, which has survived to the present day. The original layout and sometimes even individual masonry buildings, but from later periods (usually with a public function), and the remains of defensive equipment survived. The landform was slightly transformed. For this reason, field surveys are important in the first phase. These consisted of an inventory of the historical area of each small city and a confrontation with the documents and cartographic material collected. Traditional photographic documentation of urban objects and interiors was conducted, as well as the spatial layout from a drone perspective. In the process of analyzing urban space, in situ research, considering participatory observation and analysis of spatial and architectural relationships, is extremely important. Field research and cabinet analyses allow the original geometry of surveyed architectural structures to be mapped, which forms the basis for further stages of evaluation and planning for the preservation of historic cities. The first stage allowed us to conduct further research (Table 1).

Table 1. Stage 1 of the research procedure: objectives, methods, and techniques applied at this stage, as well as strategic and operational benefits of its implementation for the development of a historic small city.

MAIN OBJECTIVES
Identification of the original urban structure - hypothetical reconstruction of the geometry of the city in its original setting (medieval subdivisions, plot layout, location of market, location of residential and public buildings)
Understanding urban development and spatial and cultural heritage, including cultural and aesthetic dimensions of perception of the city
Assessment of the sustainability of the spatial structure, determining which elements of the urban layout have survived and in what way
Verification of planning and conservation documents, evaluation of the effectiveness of conservation regulations

METHODS AND TECHNIQUES	
Type of method	**Name of method/technique**
Historical and cultural methods	Queries of source materials; Study of the history of the city's development; Analysis of cartographic, iconographic and archaeological sources; Analysis of scientific, literary and cultural sources
Cartographic methods	Analysis of historical maps; Interpretation of spatial layers; Analysis of the Digital Terrain Model (DTM)
Metrology methods	Measurement and proportion analysis of urban layouts; Computer studies of the geometry of spatial layouts
Archaeological methods	Study of relics of fortifications, plot layouts, historic buildings; Confrontation with previous studies
Field research	Participatory observation; Inventory of buildings and urban interiors; Photography and drone shots
Urban image analysis	Study of spatial structure and composition; Analysis of view sequences
STRATEGIC AND OPERATIONAL BENEFITS OF IMPLEMENTATION FOR THE DEVELOPMENT OF A SMALL HISTORIC CITY	
Development area	**Benefits**
Spatial planning	Basis for updating planning regulations in a way that is compatible with heritage protection; Greater resilience to planning error
Protection of cultural heritage	Basis for register/listing of monuments; Conservation planning supported by scientific analysis
Identity and social participation	Building local identity around heritage
Crisis management and adaptation	Better understanding of the city's structure = better prepared for disasters and risks
Education and promotion	Basis for educational projects, museum exhibitions or VR

Second stage

The second step of the research procedure involved constructing the author's set of methods to evaluate space using three indicators: Morphology and Physiognomy Index (MPI), Sustainable Development Index (SDI), and Urban Integration Index (UII) (Table 2).

Morphology and physiognomy index (MPI)

Urban morphology is the science that studies the shape, structure, and functions of cities, analyzing the layout of streets, buildings, squares, and parks. It also deals with the processes of their formation and the influence of history, culture, and society on their spatial development. It aims to improve quality of life and adapt cities to changing needs [29], [30]. Urban morphology is an interdisciplinary field of research that combines the perspectives of architects, urban planners, and geographers. Its aim is to analyze and optimize urban forms in the context of urban development. Special emphasis is placed on the cultural dimension of urban space, which integrates the physical structure of the city with the functioning of the community.

In morphological studies, "*urbanity*" is defined by characteristics such as social diversity, spatial proximity, and quality of the living environment. Therefore, urban space is not a neutral entity; it is a reflection of the values, norms, and social identity that shape both its form and use [31]. Lynch and Wejchert [2], [22] emphasize the emotional importance of the structure of space for the identification of inhabitants. These researchers have linked morphology to the concept of sustainability, which can help combat environmental crises [32]. This is particularly relevant for localities experiencing socioeconomic stagnation, such as small peripheral cities with problems of depopulation and spatial degradation.

The morphology and physiognomy index was calculated according to the method presented by Szmytkie in the publication "Methods of analyzing the morphology and physiognomy of settlement units" [33]. The author analyzed, in terms of morphology and physiognomy, small cities and large villages in the Lower Silesian and Opole provinces (171 settlements). This group also includes cities located in the Middle Ages. The results obtained for the three municipalities surveyed in the Subcarpathian region were compared to those obtained by Szmytkie. The Morphology and Physiognomy Index (MPI) is a synthetic index that quantitatively characterizes the morphology of a given locality. This is dependent on the four subindices. These were the Built-up Index, Net Population Density Index, Graph Development Index, and Built-up Compactness Index.

The *Built-up Index* characterizes the type of residential development and is calculated as the number of dwellings divided by the number of residential buildings. The indicator may have a minimum value of one when there are only single-family dwellings in a given locality. A higher value indicates the presence of multifamily housing. The higher the value, the more multifamily development. To calculate the development index, data on the number of residential buildings were obtained from the city and municipal offices of the respective localities, the National Census was used, and data on the number of dwellings in relation to the statistical localities were contained in the Local Data Bank [34].

The *Net Population Density Index* illustrates the intensity of residential development in a given locality. It was calculated as the ratio of the number of inhabitants to the area of residential development. The minimum value of the indicator is found in sparsely populated settlement units, and is high where there is a high concentration of population in areas with residential functions. To calculate the indicator, data from the city and municipal offices and data from the Central Statistical Office were used. The areas occupied by residential development were calculated using QGIS.

Another subindicator is the *Graph Development Index*. Graphs were first applied in the study of transport networks by Kansky [35]. In Poland, an analysis of settlements presented in the form of graphs was conducted by Zagozdzhon [36], who developed Kansky's method. According to these theories, the spatial structure of a settlement unit can be reduced to a simplified model, expressed in the form of a graph. Graphs can then be used to aid in parametric analysis of the spatial layout of different types of settlement units. The graph development index indicates the degree of complexity of a settlement's form of development. The layout may be simple in rural areas or have a significant degree of complexity of heterogonal layouts, as found in urban areas. Physical elements of space, such as streets and built-up areas, are represented using a formalized language. A street along which buildings occur is represented as an edge, whereas a group of buildings or the top of street sections filled with buildings is represented as a node/point. The rank of each node depends on the number of edges. In addition to nodes and edges, the shape of a graph contains cycles, i.e., closed edge connections between vertices [33].

The *Built-up Compactness Index* (circularity index) describes how the layouts and elements are located around the geometric center of the city. The highest index value is achieved by cities whose layouts fill a circle. This property has been used for a long time in the history of city planning, which is why in the Middle Ages the first cities and later cities were usually given circular shapes, thus ensuring that the largest area was enclosed by the shortest possible line of fortification. The building density index takes values from 0 to 1, with a value of 1 for the circular shape. The area and perimeter of the built-up areas in the surveyed settlements were calculated using the QGIS program based on orthophotos available on Geoportal.

After calculating the above four subindices for the studied small historic cities within their current administrative boundaries, the value of the morphology and physiognomy index was calculated, which expresses the degree of urbanization of the settlement unit in the morphological aspect. High values (above 2) are found in settlements showing an urban character in morphology and physiognomy, while low values (below 1, close to zero) are found in units with a rural character [15], [33].

Sustainable Development Index (SDI)

Another analytical tool of the second stage is the Sustainable Development Index (SDI), which considers economic, social, environmental, and spatial aspects. Thanks to its application, it is possible to compare the studied cities against the entire voivodeship, which makes it possible to determine their development in a regional context [19].

Shaping sustainable development as a principle for stabilizing economic and social phenomena in the context of the natural environment creates the need to consider spatial transformation [37]. Spatial planning concerns both urban and rural environments as well as naturally valuable areas, which are characteristic features of the Subcarpathian region [38]. The quality of their development creates a direct correlation with environmental (nature and ecosystem protection), social (e.g., quality of life and integration of inhabitants), and economic (e.g., tourism) aspects. The linking of various aspects and their balance leads to a synergistic effect in the form of sustainable development [39], [40].

Sustainable development is a complex process of change within a space that involves numerous aspects and is expressed in terms of many specific characteristics. Its analysis is most often performed using synthetic indicators, which allow a set of multiple measures to be replaced by a single quantity. In this procedure, a sustainability indicator was calculated based on statistical data showing its level in five areas: economic, social, environmental, institutional, and spatial. Linking diverse aspects, particularly in the area of spatial policy. The spatial planning system, as an important instrument in shaping sustainable development, was included in the calculation of the synthetic indicator, which represents a new approach to this issue. The method used to calculate the level of sustainable development takes into account the different development conditions between municipalities and provides an opportunity to compare, analyze, and monitor the achievement of its objectives in all territorial units of the voivodeship and small cities in their background. The basis for the construction of the rankings was a set of specific indicators, which comprehensively characterize the process of adjustment of individual municipalities in the Subcarpathian region to the sustainable development paradigm [19].

The research was based on phenomena characterized by numerical data, which can testify to the implementation of sustainable development goals. Data were obtained from the Central Statistical Office [34] and selected based on an analysis of the literature on the subject. This allowed the selection of metrics characterizing the five areas. The main criteria for their selection were as follows: selection of the measure that best described the given phenomenon, variability of the measure over time, and comparability in time and space in the form of relative measures, such as percentage or number of inhabitants. In addition, the availability of data from publications from the Central Statistical Office [41] was taken into account. Unfortunately, much of this information was not available for the smallest territorial units, such as municipalities. Therefore, the final selection of indicators was dictated by the availability and uniformity of the data for all communes in the Subcarpathian region (urban, rural, and urban-rural).

Among the many procedures of the static method, the linear ordering method was chosen, which is one of the methods used in multivariate comparative analysis [42]. It ranks objects in order from best to worst. The ordering criterion is the level of the composite phenomenon, and the final result is the ranking. To apply the linear ordering method, the variables that can be stimulants and destimulants must be normalized [43]. The linear ordering of objects, that is, the creation of their ranking, should be preceded by the selection of a suitable normalizing formula. The best are those that give stable or almost stable ranges of values of the normalized variables. Norming aims to standardize diagnostic characteristics expressed in different units of measurement and varying numerical ranges.

Urban Integration Index (UII)

A novel and original element of the methodology is the urban integration index (UII), which assesses the degree of integration of the historic urban fabric with its contemporary spatial and functional environment. This index has been used by the authors for more than a dozen cities [15], [16], [17]. The index considers both physical and social aspects, allowing a detailed analysis to be divided into elementary features that describe the spatial-functional structure.

Integrating urban structures is important both at the level of new developments and at the level of conservation, revitalization, and transformation of existing historic structures. The integrity of an area means that it belongs to the urban system and establishes a relationship with the rest of the city [18]. The process of urban integration, in the context of urban planning and development, involves integrating the spatial structure of the city by building links between other areas of the urban fabric and strengthening the links that are particularly important for the revitalization of urban space. A city that effectively integrates various elements is conducive to enhancing the well-being of its inhabitants, strengthening social bonds, and achieving the principles of sustainable development [44]. This is a particularly important issue for small historic cities, where traditional, historical, and cultural aspects remain in symbiosis with the contemporary culture of spatial design. Integration of historic urban layouts with the surrounding environment is crucial, as it can adequately highlight and expose its unique character and position.

Zuziak [40], [45] states that integration is one of the most important processes initiated in a city. He understood urban integration as a purposeful and desirable action that produces a synergistic effect in response to the manifestations of the disintegration of urban structures, particularly visible in Polish cities. Unfortunately, urban development plans tend to focus on single sites and/or strategic projects with no or weak links between them, significantly limiting their potential to integrate and achieve synergies in the process. Boelens [46] emphasized the necessity of reintegrating urban structures but proposed a different point of view, from the outside to the inside, in contrast to the traditional detail-to-general approach. This is a form of acknowledgment of the drive to seek alternative and proactive methods for creating urban perspectives.

Valorization of the level of integration of the historic spatial system made use of qualitative (often appropriate in urban planning and architecture) and quantitative research apparatus (questionnaires and expert interviews). Qualitative analysis made it possible to determine the strengths and weaknesses of an area and plan a transformation process to improve its quality rationally. Qualitative assessments of the built environment play an important role not only in improving the quality of life of residents but also in improving the quality of planning and design, allowing the development of environmental knowledge and comparison between different areas.

After a literature study, research criteria were adopted to determine the level of integration, which was oriented towards the physical features and functions of the historical area under study. The level of urban integration was determined based on 7 categories: composition, architectural aesthetics, public spaces, communication, natural elements, functions, and regulations. The integration of these elements can create a coherent and harmonious environment in which both culture and modernity exist [47]. The set of criteria created systematized how to determine the level of spatial integration of all the small historic cities analyzed. The result is a matrix with partial (28 in total) and main criteria influencing the level of integration of historic systems.

The assessment of the level of urban integration was also modeled on the procedure used in the Landscape and Visual Impact Assessment (LVIA). LVIA is an informative procedure used in land use planning and environmental management to assess how a proposed development or spatial change will affect the character and appearance of the landscape and the views that are characteristic of it. LVIA is particularly relevant when a proposed development affects areas of high landscape value, such as national parks or areas of outstanding natural beauty or cultural heritage. It is a standard procedure in many countries, including the United Kingdom [48].

Questionnaires and expert interviews were used to assess the specific features, which were organized into seven thematic categories. Assessments were made using a four-level Likert scale, in which each attribute was assigned a point value ranging from 0 to 3. For each category, a partial value of urban integration was calculated as the arithmetic mean. The final level of integration, that is, the value of the Urban Integration Index (UII), is also the arithmetic mean calculated from all the detailed characteristics included in each category and can take a value from 0 to 3 points. Calculations were performed using an Excel spreadsheet. The advantage of this method is its simple calculation procedure and easy interpretation of the results, which can become an asset when involving the local community in the process of co-determining the surrounding environment.

The application of the three indicators of the second stage of the research procedure, i.e., the indicators of morphology and physiognomy, sustainable development, and urban integration, constitutes a tool that enables a multidimensional approach to the assessment of spaces of particular importance. They allow not only the diagnosis of their current state but also the identification of potential transformation directions, supporting the pursuit of their protection, sustainable development, and integration into contemporary urban structures (Table 2).

Table 2. Stage 2 of the research procedure: objectives, methods, and techniques applied at this stage, as well as strategic and operational benefits of its implementation for the development of a historic small city.

MAIN OBJECTIVES	
Diagnosis of spatial structure of settlement units - assessment of the degree of "urbanness" of a locality by analysing the level of urbanisation, compactness of buildings, logic of spatial layout and preservation of historical urban structures	
Identification of potentials and deficits - classification of localities based on their morphology and physiognomy, supporting revitalisation measures and strategies to counter depopulation	
Benchmarking, that is, comparing the urban status of the analysed locality with others of a similar nature and status	
Development of a single, comprehensive synthetic indicator to diagnose the level of sustainable development of a municipality or a city	
Assessment of territorial units in relation to each other and in relation to the province as a whole	
Monitoring change over time and integrating different aspects of development: social, economic, environmental, institutional, and spatial.	
Diagnosis of the level of integration of historic urban structures with their contemporary surroundings	
Assessment of spatial and functional coherence in the urban fabric - to what extent are heritage areas integrated into current urban life?	
Identification of areas in need of urban intervention - identification of which categories (e.g., aesthetics, accessibility, functional diversity, communication, greenery) are weakest	
Involving the local community in the assessment of the environment through a simple interpretive scale and transparency of results	
Strategic mapping for revitalisation, investment and protection measures	
RESEARCH METHODS AND TECHNIQUES	
Type of method/tool	**Name of method/technique**
Morphology and Physiognomy Index - a quantitative-qualitative research tool developed by Szmytkie to describe and analyse the spatial structure of localities, included in the author's set of procedures.	GIS analysis (QGIS, orthophotos); Topological analysis (Kansky graphs); Statistical data; spatial visualization, Geometric modelling; Spatial graph method (topology); Morphometric analysis
Sustainable Development Index - an analytical tool that combines quantitative (statistical) methods with multidimensional comparative analysis techniques	Multidimensional comparative analysis; Linear ordering method (ranking); Selection of diagnostic measures
Urban Integration Index - a synthetic, wholly proprietary tool for assessing the quality of urban space	Urban analysis; Contextual analysis; Aesthetic and compositional assessment; Interviews and field observations, Criteria matrix; Tabulation; Consultation with local specialists; Expert assessments; Mapping of historic areas
STRATEGIC AND OPERATIONAL BENEFITS OF IMPLEMENTATION FOR THE DEVELOPMENT OF A SMALL HISTORIC CITY	
Development area	**Benefits**
Spatial planning	Optimisation of spatial layouts - better design of functional, compact and socially inclusive urban structures

	Investment decision support - a tool to facilitate informed decision-making and the preparation of justifications for applications for external funding Implementing smart growth principles - reducing sprawl by analysing the compactness and functionality of urban layouts Prioritisation of spatial measures - identification of areas in need of intervention, e.g., areas with a low level of socio-spatial integration More effective revitalization - actions become more targeted, strategic and comprehensive rather than ad hoc or piecemeal Data-driven development management - identification of the municipality's strengths and weaknesses (e.g., poor environmental quality, social problems) based on measurable indicators Integrated spatial planning - the ability to combine spatial, social and environmental data in planning documents Creating development strategies - benchmarking and ranking of units support the process of applying for external funding Protecting resources and activating potential - planning that simultaneously protects nature, improves quality of life and develops tourism potential (e.g., in valuable landscape areas) Combating spatial disintegration - eliminating incoherent, unconnected development projects
Protection of cultural heritage	Identification of valuable historic layouts - the high value of the WMF indicates well-preserved urban structures, which justifies their protection and adaptive use in revitalization. Integrating heritage with contemporary challenges - protecting, displaying and activating historical resources Increase in the attractiveness of public spaces - a better-designed environment promotes a positive perception of the city by both residents and tourists
Identity and social participation	Strengthening the inhabitants' identification with the space - the urban structure shapes the sense of belonging and local identity, which is crucial in the face of the depopulation of small cities Social activation - a better understanding of local resources and problems promotes greater involvement of residents and community organizations. Simple tools, greater involvement - transparency of methods and scale of indicators facilitates participation of citizens and local authorities in co-decision-making processes Use in participation - indicators can be used in urban planning workshops, citizen budgets and public consultations

Third stage

Preserving the architectural and urban heritage of small cities requires an interdisciplinary approach that combines historical analysis, spatial modelling, and digital technologies (Table 3). Contemporary approaches to architecture and urban planning focus on sustainable development and the integration of modern urban functions while preserving cultural and historical assets. This stage of the research procedure is based on three key pillars: urban structure modelling, digital representations of heritage, and prediction of the development of urban structures.

As indicated in the Introduction, the third stage of research has not yet been the subject of the author's previous analyses, which accounts for its innovative character in the research approach presented here. Its assumptions are to become an integral element of the author's multistage research procedure for the protection and development of small historic cities. Awareness of the complexity of this issue highlights the need for further research that requires multidisciplinary cooperation. Specialists in geoinformatics and digital technologies, experts in geographic information systems (GIS) and building information modelling (BIM), and specialists in laser scanning and photogrammetry play an irreplaceable role in this process. Researchers working on virtual and augmented reality (VR/AR) solutions and digital twin specialists, whose expertise enables precise mapping and analysis of historic urban fabric, can make important contributions to the development of this concept. Collaboration between these communities will allow for comprehensive coverage of the issue and the development of innovative tools to support the preservation and adaptation of historic urban areas.

Modelling of spatial structure

Contemporary urban models draw on classical theories such as Christopher Alexander's concept of pattern language [49] and Kevin Lynch's theory of urban perception [21]. Both emphasize the importance of spatial patterns and their perceptions in shaping the urban environment. Technologies such as Geographic Information Systems (GIS) and Building Information Modelling (BIM) enable integrated analysis and visualization of urban structures, supporting planning and spatial management processes [50], [51]. Generative algorithms are also increasingly being used, allowing the automatic creation of urban development scenarios and simulation of potential changes in the spatial structure of cities [52], [53]. However, contemporary approaches to modelling the physical structure of cities rarely consider the need to adapt historical urban layouts to contemporary social and environmental challenges [54]. The importance of the City Information Model (CIM), which provides a basis for building semantically enriched models using data from public institutions, businesses, and local communities, is growing [55].

The development of an iterative urban model that considers the evolution of historic urban structures in the context of contemporary social, functional, and environmental challenges can significantly support the preservation and sustainable development of these sensitive spaces. Such a model, based on generative algorithms, would allow for the flexible adaptation of traditional urban layouts to new urban functions while respecting their cultural values and place identity. Digital tools, such as photogrammetry, laser scanning, and 3D modeling, are widely used in the documentation, protection, and reconstruction of cultural heritage [56]. They allow the creation of accurate three-dimensional representations of historic buildings, which supports both conservation efforts and the dissemination of knowledge about the past. In addition, augmented reality (AR) and virtual reality (VR) technologies have opened up new possibilities for the presentation and interpretation of historic spaces. They enable immersive and interactive experiences that enrich research, design, and educational processes and facilitate a deeper understanding of the significance of heritage for audiences outside the specialist community [57], [58].

Digital representations of heritage

A new trend in this field is dynamic digital twins (DT), virtual models of physical systems updated in real time that allow changes in the urban environment to be monitored and analyzed [55], [59], [60]. Although the use of digital twins in urban environments is still at an early stage of development, advances in technology, the availability of spatial and non-spatial data, and the global development of simulation technologies mean that increasingly complex and dynamic systems, such as cities, can be reflected using digital twin technologies [54]. To date, DT applications have focused mainly on the infrastructure of contemporary cities, neglecting the specificity of historical systems. Approaches that combine digital documentation, spatial analysis, and public participation are lacking [61]. Furthermore, the implementation of DT in small historic cities can support the monitoring of site conditions, the planning of revitalization, and the protection of cultural values.

The digital twin of the city integrates spatial (GIS, photogrammetry), technical, environmental, and sociocultural data. This requires the sophisticated integration of large amounts of data from different sources and structures. Examples from cities such as Amsterdam, Rotterdam, and Vienna demonstrate the effectiveness of combining data from geodatabases, sensors (IoT), BIM, and GIS. Updating the virtual model in line with changes in the physical world brings the digital replica of a city closer to its real-world counterpart. Sensor data, 3D BIM models, public institution databases, and geographic information systems (GIS) are only part of a wider data ecosystem, the integration of which is crucial for DT to operate effectively. Different data integration models are being developed, depending on the target use of DT to meet the needs of specific urban management scenarios. It is also necessary to consider the semantics of the data, its structure, and its storage methods [55].

Anticipating the development of architectural and urban structures

The application of DTs in small historic cities would allow for a more precise prediction of the impact of modernization, assessment of the risk of loss of historic values, and planning of urban interventions in line with heritage conservation principles [62]. With the ability to model change scenarios and monitor their impact on existing urban fabric, digital twins could become a key tool to support sustainable management of cultural spaces [62].

Predictive models based on artificial intelligence and data analysis have been used to forecast spatial changes, including the development of infrastructure and the impact of climate change [63]. What is lacking are systems that combine the analysis of historical urban trends with modern forecasting methods [64]. Current spatial development models rarely consider the impact of heritage adaptation on long-term urban transformation processes. Social variables, in particular the role of local communities in shaping the future of small cities, are also insufficiently analyzed. In response to these shortcomings, the development of a comprehensive predictive model is called for, which integrates the analysis of historical urban transformation with modern methods of artificial intelligence. This model should take into account both tangible aspects, such as historical structures, and intangible aspects, including space uses, cultural contexts, and social conditions. The aim was to simulate the long-term effects of different strategies for the protection, adaptation, and modernization of heritage in small cities (Table 3).

Table 3. Stage 3 of the research procedure: objectives, methods, and techniques applied at this stage, as well as strategic and operational benefits of its implementation for the development of a historic small city.

MAIN OBJECTIVES	
Documentation and protection of heritage - through digital mapping of objects and analysis of their technical condition	
Scenario-based regeneration planning - allowing the effects of different spatial development strategies to be tested	
Simulation of spatial transformations - assessment of the impact of functional and demographic changes on urban structure	
Strengthening local identity and community participation - using narrative AR/VR technologies and mind maps	
Optimising adaptation to climate change - through integration of environmental data and predictive models	
RESEARCH METHODS AND TECHNIQUES	
Type of method/tool	**Name of method/technique**
Heritage documentation methods	Photogrammetry and scanning; Heritage Building Information Modelling (HBIM); AR/VR immersive tools for reconstruction and education
Predictive and simulation methods	Machine learning (ML) and AI predictive models - predicting development scenarios; Digital twins as dynamic systems replicating the behaviour and evolution of physical structures
Social methods	Mapping the needs of local communities (qualitative research, interviews, mental maps); Local narratives and participatory design (story-mapping, urban ethnography); Integration of soft (social) data with hard (spatial) data
STRATEGIC AND OPERATIONAL BENEFITS OF IMPLEMENTATION FOR THE DEVELOPMENT OF A SMALL HISTORIC CITY	
Development area	**Benefits**
Spatial planning	Decision-making based on simulations and data

	Integration of social and spatial functions: the needs of the elderly, children or people with disabilities are more easily taken into account Efficient allocation of regeneration budgets through scenario optimisation
Protection of cultural heritage	Non-destructive maintenance through accurate 3D models Possibility of reconstructing monuments that cannot be physically restored Creating 'living archives' - dynamic, replenished models of heritage; Comparative documentation to track changes in the structure of buildings and, for example, their damage - allows the degradation of historic elements of the urban space to be monitored over time, which is key to their preservation Documentation of damage to buildings resulting from activities within the historic spatial system - through the use of photogrammetry and photographs, it is possible to show the exact condition of buildings before and after restoration or construction work was carried out
Identity and social participation	Strengthening resident involvement through narrative digital tools Education and inclusion - residents understand, co-create, and accept change
Crisis management and adaptation	Conservation of environmental and energy resources (e.g., optimization of thermal retrofitting of historic urban buildings) Addressing the effects of climate change - modelling runoff, air circulation, shading, etc. Development of green infrastructure (integrated natural data) Artificial intelligence for automatic surveillance of monuments - AI systems make it possible to detect activities that could lead to damage to buildings, such as vandalism, by comparing the current appearance of the façade with a recorded pattern. This makes it possible to respond immediately to threats, improving the protection of cultural heritage 3D models combined with AI for spatial analysis and threat monitoring - combined with cameras and artificial intelligence
Education and promotion	Acquisition of EU funds and research grants - innovative approach and educational dimension Possibility to export know-how to other small historic cities in the world

Conclusions

Small historic cities are currently facing the need to make informed decisions about their future. This article presents an innovative multistage research methodology for assessing the development potential of small historic cities with the aim of developing tools to support the protection and sustainable development of architectural heritage. The proposed procedure includes an analysis of historic space, and the first two stages were tested in medieval cities in the Subcarpathian region.

The first stage covers the classical methods of architecture and urbanism, focusing on the history of urban development. The second stage introduces three original indexes: Morphology and Physiognomy (MPI), Sustainable Development (SDI), and Urban Integration (UII). The MPI describes the spatial structure and the state of preservation of historic urban layouts. The SDI considers economic, social, and spatial aspects, enabling a comparison of the cities studied in a regional context. The UII assesses the degree of integration of the historic urban fabric with the contemporary spatial and functional environment. The third stage, which is a novel element of the methodology, is based on urban structure modelling, digital representations of heritage, and the prediction of the development of urban structures. It aims to integrate these approaches to protect and adapt historic structures of small cities to contemporary needs, using advanced digital technologies for documentation and analysis.

The presented research concept on protecting the architectural and urban heritage of small historic cities fits both the Smart City concept and the regional smart specifications of the Subcarpathian region. The use of modern technologies, such as GIS systems, BIM modeling, laser scanning, photogrammetry, virtual and augmented reality (VR/AR), and digital twins, enables precise documentation and analysis of the urban structure, which supports smart management of urban space. An interdisciplinary approach to the revitalization of historic areas, integrating the traditional urban fabric with modern functions, responds to the contemporary challenges of sustainable development. Furthermore, the use of artificial intelligence and the analysis of large datasets make it possible to forecast urban change and assess its impact on the preservation of the historic coherence of cities. An important aspect is the possibility of linking this topic to smart specialization in the Subcarpathian region. It is also worth highlighting the social dimension of the Smart City concept: interactive 3D models and digital twins can involve residents in planning processes, enabling them to participate in decisions about the future of their cities. Additionally, the development of green technologies, such as smart monitoring systems for historic buildings, could further strengthen the concept in the context of regional policies and smart city strategies.

The city is not a static structure but a dynamic organism in which historical urban layers intermingle with contemporary transformations, and decisions made today affect its future shape. In an approach that considers a city as a living system subject to self-regulating mechanisms, it remains crucial to extend this perspective to include cultural factors. This is because they influence not only spatial policy and administrative decisions but also the individual choices of city users and investors. Taking these interrelationships into account in the planning and heritage conservation process allows for more informed urban strategies that combine respect for the past with openness to the future needs of a city and its inhabitants.

Although the developed methodology offers a comprehensive approach to the assessment and conservation of architectural heritage in small historic cities, it requires further empirical verification, particularly in terms of digital modeling and urban structure prediction. Integration of advanced digital technologies with traditional research methods offers new opportunities for heritage management; however, multidisciplinary collaboration between experts in urban planning, historic preservation, geoinformatics, and artificial intelligence is essential for its successful implementation.

References

[1] M. Weber, *Gospodarka i społeczeństwo. Zarys socjologii rozumiejącej*. Warszawa, Poland: Wydawnictwo Naukowe PWN, 2002.

[2] K. Wejchert, *Elementy kompozycji urbanistycznej*. Warszawa, Poland: Arkady, 1984.

[3] J. Kobylarczyk and D. Kuśnierz-Krupa, *Jakość środowiska mieszkaniowego a dziedzictwo kulturowe na przykładzie wybranych miast województwa podkarpackiego*. Kraków, Poland: Politechnika Krakowska, 2018, p. 9.

[4] A. Dmytrenko, T. Kuzmenko, J. Kobylarczyk, and K. Paprzyca, "The problems of small towns in Ukraine and Poland," *Czasopismo Techniczne*, no. 10, 2019, DOI: 10.4467/2353737xct.19.103.11027.

[5] Z. Zuziak *et al.*, *Węzły i Korytarze Rozwoju Funkcji Metropolitalnych Rzeszowa*. Rzeszów, Poland: Biura Rozwoju Miasta Rzeszowa, 2019.

[6] C. Baera, A. Gruin, F. Enache, B. Bolborea, R. V. Chendes, A. Ciobanu, L. Varga, I. Sandu, O. Corbu, "Opportunities regarding the innovative conservation of the romanian vernacular urbanistic heritage," *International Journal of Conservation Science*, vol. 14, no. 3, pp. 913-936, 2023, DOI: 10.36868/IJCS.2023.03.09.

[7] Y. Ivashko, I. Buzin, I. G. Sandu, D. Kusnierz-Krupa, J. Kobylarczyk, A. Dmytrenko, L. Bednarz, "State-Of-The-Art Technologies of Imitation of Mural Painting from the Kyivan Rus and Baroque Periods in the Reconstructed St. Michael Golden-Domed Cathedral in Kyiv," *International Journal of Conservation Science*, vol. 13, no 1, pp. 147-162, 2022.

[8] R. Blazy, H. Hrehorowicz-Gaber, I.G. Sandu, A. Hrehorowicz-Nowak, "Garden Cities and Heritage of the Howard's Idea in Europe with Particular Consideration of Poland," *International Journal of Conservation Science*, vol. 13, no. 3, pp. 805-822. 2022.

[9] Z. Zuziak, "Węzły miejskości a modele przestrzenne struktur miejskich," *Budownictwo i Architektura*, 2018, pp. 107–129.

[10] Z. Zuziak, "Konstrukcje urbanistyczne miast przyszłości. Uwagi do dyskusji nad wizją rozwoju Rzeszowa," *Czasopismo Inżynierii Lądowej, Środowiska i Architektury*, vol. 64, 2017, pp. 467–485.

[11] Z. Zuziak, "Konstrukcje urbanistyczne a planowanie metropolitalne," in *Nowe idee w planowaniu rozwoju terytorialnego. Problemy obszarów metropolitalnych i wielkich miast*, E. Węcławowicz-Bilska, Ed. Kraków, Poland: Wydawnictwo Politechniki Krakowskiej, 2018, pp. 17–44.

[12] Z. Zuziak and D. Ogrodnik, *Konstrukcja urbanistyczna Krakowa. Rola śródmieścia a korytarze rozwoju – jako wskazanie do opracowania kierunków rozwoju dla sporządzanego Studium Uwarunkowań i kierunków zagospodarowania przestrzennego Miasta Krakowa*. Kraków, Poland: Biuro Planowania Przestrzennego Urzędu Miasta Krakowa, 2018.

[13] M. Gyurkovich, A. Szarata, and Z. Zuziak, *Model przestrzennej struktury Krakowa. Perspektywa planistyczna. Etap I – Założenia modelu strukturalnych zmian w zagospodarowaniu przestrzennym miasta*. Kraków, Poland: Biuro Planowania Przestrzennego Urzędu Miasta Krakowa, 2016.

[14] T. Zipser, "Powiązania transportowe jako generatory struktury przestrzennej systemu osadniczego," *Czasopismo Techniczne*, vol. 107, 2010, pp. 21–30.

[15] A. Martyka, "Development Directions of Small Historic Cities in the Subcarpathia," in *Proc. CEE 2023*, Lecture Notes in Civil Engineering, vol. 438, Z. Blikharskyy, P. Koszelnik, L. Lichołai, P. Nazarko, and D. Katunský, Eds. Cham, Switzerland: Springer, 2024, DOI: 10.1007/978-3-031-44955-0_26.

[16] A. Martyka, "A Model of Functional-Spatial Transformation of Medieval Urban Structure. The Example of Krosno in the Subcarpathia in Poland," in *Conservation of Architectural Heritage (CAH 2022)*, Advances in Science, Technology & Innovation, M. L. Germanà, N. Akagawa, A. Versaci, and N. Cavalagli, Eds. Cham, Switzerland: Springer, 2024, DOI: 10.1007/978-3-031-33222-7_31.

[17] A. Martyka, *Dziedzictwo urbanistyczne średniowiecznych małych miast Podkarpacia – morfologia, zrównoważenie, integracja*. Rzeszów, Poland: Oficyna Wydawnicza Politechniki Rzeszowskiej, 2023.

[18] A. Martyka, "Spatial integration level of housing complex with the city structure. Case of Rzeszów," *Civil and Environmental Engineering Reports*, no. 3, pp. 36–61, 2022, DOI: 10.2478/ceer-2022-0028.

[19] A. Martyka, D. Jopek, and I. Skrzypczak, "Analysis of the Sustainable Development Index in the Communes of the Podkarpackie Voivodeship: A Polish Case Study," *Sustainability*, vol. 14, 2022, DOI: 10.3390/su141610237.

[20] H. Adamczewska-Wejchert and K. Wejchert, *Małe miasta. Problemy urbanistyczne stale aktualne*. Warszawa, Poland: Wydawnictwo Arkady, 1986.

[21] G. Cullen, *Obraz miasta* (wyd. skrócone). Lublin, Poland: Ośrodek "Brama Grodzka – Teatr NN", 2011.

[22] K. Lynch, *The Image of the City*. Cambridge, MA, USA: MIT Press, 1960.

[23] J. Żórawski, *O budowie formy architektonicznej*. Warszawa, Poland: Arkady, 1962.

[24] I. Calvino, *Invisible Cities*. London, U.K.: Vintage, 1997.
[25] B. Jałowiecki, "Studia miejskie – między historia a teorią," *Studia Regionalne i Lokalne*, no. 2, pp. 26–40, 2011.
[26] Geoportal, "Spatial Information Infrastructure 2022," [Online]. Available: https://www.geoportal.gov.pl. [Accessed: Aug. 23, 2022].
[27] A. Berdecka, *Lokacje i zagospodarowanie miast królewskich w Małopolsce za Kazimierza Wielkiego, 1333–1370*. Zakład Narodowy im. Ossolińskich, 1982.
[28] W. Bukowski, B. Dybaś, and Z. Noga, *Galicja na józefińskiej mapie topograficznej 1779–1783*, vols. 3–5. Kraków, Poland: Polska Akademia Nauk; Uniwersytet Pedagogiczny, 2015.
[29] M. Hanzl, *Morphological Analysis of Urban Structures – The Cultural Approach: Case Studies of Jewish Communities in Lodz and Mazovian Voivoideships*. Łódź, Poland: Wydawnictwo Politechniki Łódzkiej, 2017.
[30] A. Kantarek, *Tkanka urbanistyczna: wybrane zagadnienia*. Kraków, Poland: Wydawnictwo Politechniki Krakowskiej, 2019.
[31] A. Wallis, *Miasto i przestrzeń*. Warszawa, Poland: PWN, 1977.
[32] P. Gauthier and G. Gilliland, "Mapping urban morphology: A classification scheme for interpreting contributions to the study of urban form," *Urban Morphology*, vol. 10, 2006.
[33] R. Szmytkie, *Metody analizy morfologii i fizjonomii jednostek osadniczych*. Wrocław, Poland: Rozprawy Naukowe Instytutu Geografii i Rozwoju Regionalnego Uniwersytetu Wrocławskiego, 2014.
[34] Statistics Poland, [Online]. Available: https://stat.gov.pl/. [Accessed: Aug. 29, 2023].
[35] K. Kansky, *Structure of Transport Networks: Relationships between Network Geometry and Regional Characteristics*, Research Papers 84. Chicago, IL, USA: Univ. of Chicago, Dept. of Geography, 1963.
[36] A. Zagożdżon, "Wykorzystanie metod i technik grafowych w analizie struktur przestrzennych," in *Metody ilościowe i modele w geografii*, Z. Chojnicki, Ed. Warszawa, Poland: Państwowe Wydawnictwo Naukowe, 1977, pp. 158–169.
[37] J. Shi, W. Miao, H. Si, T. Liu, and T. Sanchez, "Urban Vitality Evaluation and Spatial Correlation Research: A Case Study from Shanghai, China," *Land*, vol. 10, no. 11, 2021, DOI: 10.3390/land10111195.
[38] W. Gorzym-Wilkowski, "Spatial Planning as a Tool for Sustainable Development, Polish Realities," *Barometr Regionalny*, vol. 15, 2017.
[39] United Nations, "Sustainable Development Goals," 2023. [Accessed: Aug. 18, 2023].
[40] Z. Zuziak, "O synergii planu w urbanistyce," *Budownictwo i Architektura*, vol. 16, 2017, DOI: 10.24358/bud-arch_17_161_16.
[41] I. Żurek, A. Balas, A. Molenda, J. Nowicka, and E. Panasiuk, *Wskaźniki Zrównoważonego Rozwoju dla Polski*. Katowice, Poland: Główny Urząd Statystyczny, 2015.
[42] I. Skrzypczak, W. Kokoszka, D. Zientek, Y. Tang, and J. Kogut, "Landslide hazard assessment map as an element supporting spatial planning: The flysch carpathians region study," *Remote Sens.*, vol. 13, 2021, DOI: 10.3390/rs13020317.
[43] J. Dziechciarz, *Ekonometria. Metody, przykłady, zadania*. Wrocław, Poland: Wydawnictwo Akademii Ekonomicznej we Wrocławiu, 2003.
[44] UNESCO, *Recommendation on the Historic Urban Landscape*, Records of the General Conference—31st Session, vol. 1. 2011.
[45] Z. Zuziak, *O tożsamości urbanistyki*. Kraków, Poland: Wydawnictwo Politechniki Krakowskiej, 2008.
[46] L. Boelens, *The Urban Connection: An Actor-Relational Approach to Urban Planning*. Rotterdam, The Netherlands: 010 Publishers, 2009.

[47] A. Palej, *Miasta cywilizacji informacyjnej: poszukiwanie równowagi pomiędzy światem fizycznym a światem wirtualnym*. Kraków, Poland: Wydawnictwo Politechniki Krakowskiej, 2003.
[48] J. Diego, S. Bonete, and P. Chías, "VIA-7 Method: A seven perceptual parameters methodology for the assessment of visual impact caused by wind and solar facilities on the landscape in cultural heritage sites," *Renew. Sustain. Energy Rev.*, vol. 165, 2022, Article Nomber: 112528, DOI: 10.1016/j.rser.2022.112528.
[49] C. Alexander, S. Ishikawa, and M. Silverstein, *A Pattern Language: Towns, Buildings, Construction*. Oxford, U.K.: Oxford University Press, 2006.
[50] D. Kasznia, "BIM – nowe zawody," *Materiały Budowlane*, no. 1, 2017, DOI: 10.15199/33.2017.06.26.
[51] D. Kasznia, "BIM – czyli jak zażywać to lekarstwo," *Materiały Budowlane*, no. 1, 2017, DOI: 10.15199/33.2017.03.23.
[52] M. Batty, *The New Science of Cities*. Cambridge, MA, USA: MIT Press, 2017.
[53] F. Zampieri, A. Da Costa Braga, C. De Ugalde, and D. Rigatti, "The local spatial logic: Application of pedestrian model in Criciúma, Brazil," in *Proc. 10th Int. Space Syntax Symp. (SSS 2015)*, 2015.
[54] V. Lehtola *et al*., "Digital twin of a city: Review of technology serving city needs," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 114, 2022, Article Number: 102915, DOI: 10.1016/j.jag.2022.102915.
[55] I. Jeddoub, G. Nys, R. Hajji, and R. Billen, "Digital Twins for cities: Analyzing the gap between concepts and current implementations with a specific focus on data integration," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 122, 2023, Article Number: 103440, DOI: 10.1016/j.jag.2023.103440.
[56] F. Remondino and S. Campana, *3D Recording and Modelling in Archaeology and Cultural Heritage: Theory and Best Practices*. BAR Publishing, 2014, DOI: 10.30861/9781407312309.
[57] A. Addison, "Emerging trends in virtual heritage," *IEEE Multimedia*, vol. 7, 2000, DOI: 10.1109/93.848421.
[58] S. Van Nguyen, S. Le, M. Tran, and H. Tran, "Reconstruction of 3D digital heritage objects for VR and AR applications," *J. Inf. Telecommun.*, vol. 6, 2022, DOI: 10.1080/24751839.2021.2008133.
[59] S. Majumdar, V. Kandpal, and L. Anthopoulos, *Smart Cities: Innovations, Challenges and Future Perspectives*. Cham, Switzerland: Springer, 2024, DOI: 10.1007/978-3-031-59846-3.
[60] I. Yaqoob, K. Salah, L. Khan, R. Jayaraman, A. Al-Fuqaha, and M. Omar, "Digital Twins for Smart Cities: Benefits, Enabling Technologies, Applications, and Challenges," in *2023 IEEE Future Networks World Forum (FNWF)*, 2023, pp. 1–6, DOI: 10.1109/FNWF58287.2023.10520349.
[61] L. Correia, R. Santos Bartholo, A. Brufato, and E. Thomé Sanchez, "Toward a Digital Twin for Cultural Heritage," in *Advances in Tourism, Technology and Systems*, Smart Innovation, Systems and Technologies, vol. 345, J. Carvalho, A. Abreu, P. Liberato, and A. Peña, Eds. Singapore: Springer, 2023, pp. 419–430, DOI: 10.1007/978-981-99-0337-5_35.
[62] T. Penjor, S. Banihashemi, A. Hajirasouli, and H. Golzad, "Heritage building information modeling (HBIM) for heritage conservation: Framework of challenges, gaps, and existing limitations of HBIM," *Digit. Appl. Archaeol. Cult. Herit.*, vol. 35, 2024, Article Number: e00366, DOI: 10.1016/j.daach.2024.e00366.
[63] C. Pande, L. Radhadevi, and M. Satyanarayana, "Evaluation of machine learning and deep learning models for daily air quality index prediction in Delhi city, India," *Environ. Monit. Assess.*, vol. 196, 2024, Article Number: 1215, DOI: 10.1007/s10661-024-13351-1.

[64] J. Huang, S. Bibri, and P. Keel, "Generative spatial artificial intelligence for sustainable smart cities: A pioneering large flow model for urban digital twin," *Environ. Sci. Ecotechnol.*, vol. 24, 2025, Article Number: 100526, DOI: 10.1016/j.ese.2025.100526.

Received: April 24, 2025
Accepted: January 24, 2026