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METHODS AND TOOLS IN LANDSCAPE PERSISTENCE IMAGING WITH THE EXAMPLE OF A STRATIGRAPHY MODEL

Abstract: Cultural landscape stratigraphy is a concept based on geological epoch imaging. It refers to a method of interpretation of the specific arrangement and relations between cultural layers visible in the landscape. The number of layers and their age carry information about the persistence of a given landscape type and structure. For a specific site (region, landscape unit) and scale, the layers can be illustrated in a graphical notation of a coordinate system, where the vertical axis (y) represents the time intervals and the x and z axes illustrate the spatial location in Cartesian coordinates of a given landscape unit. This paper aims to present the landscape stratigraphy model, taking into account the necessary differences depending on the landscape scales. Three levels of analysis are presented. On the mesoscale (level of geographical mesoregion), the landscape stratigraphy includes the biography and schematic imaging of the area. The microscale (level of landscape units and level of landscape interior) contains three types of imaging: cartographic, spatial digital (3D), and spatial graphic drawing. These two scales differ in their imaging detail. The landscape stratigraphy model is based on analysis of both literature and cartographic sources. The stratigraphy imaging includes two steps: the analysis of historical and contemporary maps performed in GIS, and the creation of an appropriate type of imaging, using 3D modelling software, vector graphic software, and a graphic tablet. The landscape stratigraphy model can be used in landscape persistence identification, and landscape protection and forecasting. Moreover, the attractive visualisation of landscape changes can be helpful in landscape education.

Keywords: landscape stratigraphy, historic landscape imaging, landscape visualisation, landscape changes, landscape analyses, cultural landscape

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Introduction

Cultural landscapes are formed by natural and human factors. They have developed on top of natural landscapes over the past 10,000. During this time, the natural landscape has undergone dynamic changes under the influence of non-natural factors. As a dynamic system, landscape does not remain the same, therefore the remains of the old landscape carry the information necessary for understanding its structure (Birks et al., 1988), as well as the ecological, historical, and social meaning of landscapes. The temporal extent of the dominance of a given type of landscape expressed by the temporal continuity of its use, is studied as landscape persistence. Landscape persistence can be understood as the persistence of particular land cover classes measured as the percentage of the area where land use has not changed over a specified period (Affek, 2016). Many methods and sources of cartographic analysis enable an approximate assessment of the persistence of cultural landscapes (e.g. Lieskovský et al., 2014; Lieskovský & Bürgi, 2017; Sobala, 2018; Schulp et al., 2019, Żemła-Siesicka & Myga-Piątek, 2021).

Cultural landscapes can be studied using different scales (Birks et al., 1988), from a broad geographical view of the landscape as a complex system of matrix, patches, and corridors, through the landscape studied in terms of landscape units, to detailed architectural analyses of elements of landscape interiors at the micro-scale (also defined as a sub-landscape, Chmielewski et al., 2018). Different scales and approaches to the landscape require diverse research methods, including methods for presenting historical landscape changes.

Visualisation of cultural landscape changes is used to image past and, more and more often, to forecast future changes. The methods can be divided into two general groups depending on the type of visualisation: cartographic (horizontal approach to the landscape) and graphical imaging (vertical approach to the landscape). Cartographic imaging is mostly used in geographic research and urban planning. In geographical studies, landscape changes are often presented as a landscape persistence. The sources of data in this case are topographic or orthographic maps (contemporary and historical). The results are presented in the form of maps showing changes in the extent of particular landscapes (Affek, 2016; Sobala, 2018; Godziek & Szypuła, 2020) or landscape persistence isochrones (Żemła-Siesicka & Myga-Piątek, 2021). Cartographic methods of imaging landscape changes are also connected with spatial planning (Grădinaru et al., 2017; Musiaka et al., 2021).

Graphical imaging is used, among others, by landscape architects, architects, urbanists, and geographers. It includes photo imaging, digital visualisation, and 3D landscape models (before the digital era, instead of digital models, physical models were used). The source of the data are topographic or orthographic maps, digital terrain elevation data, and ground photographs, both contemporary and historical. Very detailed information about terrain and landscape elements are obtained using laser scanning. Graphical methods, including comparative analyses of photographs (e.g. Chmielewski et al., 2015), digital visualisations and 3D models, can be used for geodesign (Crumley et al., 2017), landscape forecasting (Jenkins et al., 2020), or even in archaeology for cultural heritage visual reconstruction (Houtkamp et al., 2014).

Given the different data sources, imaging methods, and objectives, it is also necessary to use different imaging tools. For cartographic analyses, GIS software brings the best solutions for enabling comprehensive analysis and creation of choropleth or landscape maps, including an attribute database. For 3D visualisation, architectural – CAD software is applied. There is also the possibility of mixing both cartographic and visualisation (models) methods in some GIS software.

Landscape stratigraphy is a model which visualises historical temporal changes of landscape. The term "landscape stratigraphy" has been applied so far in scientific works concerning the geological landscape (Buttler & Spencer, 1999; Plotnick, 2012; Pernreiter et al., 2019). However, as a method of analysis and visualisation of landscape history and space evolution, it has only just begun to develop. The theoretical outline of the concept appeared in the works of Sauer (1925) (the concept of "cultural imprints") and of Dobrowolska (1948) (landscapes of "deposited cultures"). A complete methodological study of landscape stratigraphy was developed and presented by Myga-Piątek in 2012 and expanded in 2018. The landscape stratigraphy model is based on the assumption of co-existence in the landscape space of historical-cultural layers "deposited" on the natural substrate of the environment. Analysis of the cultural overlaps of the landscape has also been used in research as a landscape biography, in historical and settlement geography (Koter, 1976; Koter & Kulsza, 1994), as well as in landscape architecture (Raszeja, 2015) and landscape archaeology (Darvill, 2006; Pouncett, 2007; Kobyliński, 2019). It also appears in the literature in the socio-symbolic approach of landscape history analysis (Schama, 1995).

The aim of this paper is to present the landscape stratigraphy model as a way to visualize historical landscape changes. The presented model takes into account the necessary differences depending on the landscape scale. Three levels of analyses are presented. On the mesoscale (level of geographical mesoregion), the landscape stratigraphy includes a schematic imaging of the area, presenting estimated rather than exact past changes. The microscale (level of landscape units and level of landscape interior) contains three types of imaging: cartographic, spatial digital (3D), and spatial graphic drawing. This article highlights the method and tools necessary to construct the landscape stratigraphy model.

Materials and methods

Study area. The presented study covers a very characteristic area of the mesoregion Częstochowa Upland (southern Poland, Fig. 1). The area covers 982.95km^2. Recent studies of Poland's physico-geographical regionalization (Solon et al., 2018) assigned the study area to a part of the macroregion of the Kraków-Częstochowa Upland. Administratively, the research area is mostly located within the Silesian Voivodship, with its southern part in the Małopolskie Voivodships. This area has a long and diverse history of evolution of the natural environment and a long history of anthropogenic land use. A characteristic feature of the Upland landscape is the limestone rocks (monadnocks) and the fortified castles built in the Middle Ages, the so-called eagles' nests. One of them is the castle in Ogrodzieniec (Podzamcze district), whose surroundings have been included in detailed studies. The ruins and the accompanying group of rocks, the so-called "rock city", are a characteristic element of the landscape (a landmark), located on the highest elevation of the Upland – Janowski Mountain (516m a.s.l.). The area on the second level of research, the landscape of the Podzamcze settlement, with agricultural fields, forests, and the castle has been presented (2.73km^2). The area of study on the third level covers the land adjacent to the castle with diverse landscapes including settlement, forest, and agriculture (fields, wastelands and pastures) (0,55km^2).

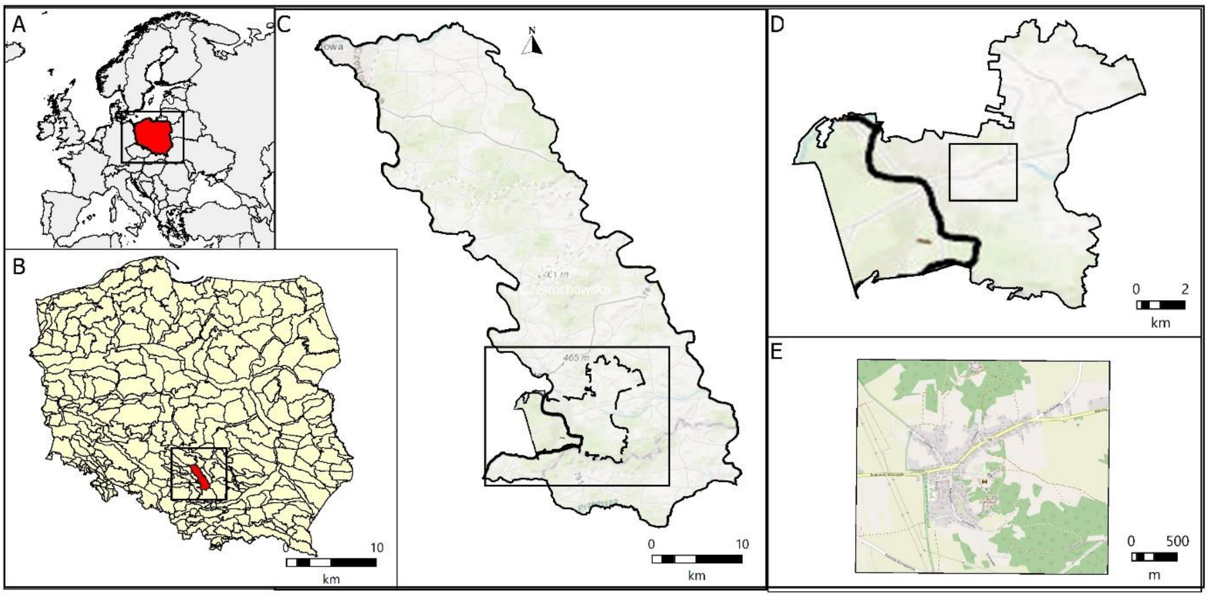


Fig. 1. Location of the study area. A – in Europe, B – Częstochowa Upland in Poland on the background of mesoregions, C – Częstochowa Upland and Ogrodzieniec municipality borders, D – Ogrodzieniec municipality and a part of the Podzamcze district, E – a part of the Podzamcze district

Source: own compilation based on topographic map and OpenStreetMap

Research levels. To present the differences in stratigraphy visualisation, three levels of research were considered. On the mesoscale, the whole area of the Częstochowa Upland mesoregion was taken into account (mesoregion understood as a unit of physical-geographical subdivision of space covering a larger area with similar environmental and landscape characteristics, Kondracki, 2002). This scale shows the landscape changes throughout history, with law imaging detail. The second and third level covers research at the microscale (in the geographic approach) in the Ogrodzieniec municipality (located on the western edge of the Częstochowa Upland). The second level includes a part of the Ogrodzieniec – Podzamcze district. The level of detail here applies to the level of landscape units (understood as a spatial unit with defined boundaries and size, determined on the basis of landscape cover, Chmielewski, 2012). The stratigraphy visualisation reaches a high level of detail of landscape changes and offers different methods of visualisation (cartographic, graphic, spatial). On the last level, one of landscape interior (understood as the basic unit of the physiognomic composition of a landscape, a fragment of space which envelops the observer, distinguished from the surrounding landscape by a recognised composition of land cover and topography Chmielewski et al., 2018), the landscape changes are considered at the level of landscape elements rather than landscape units. On this level, a spatial 3D visualisation was proposed for stratigraphy imaging (Fig. 2).

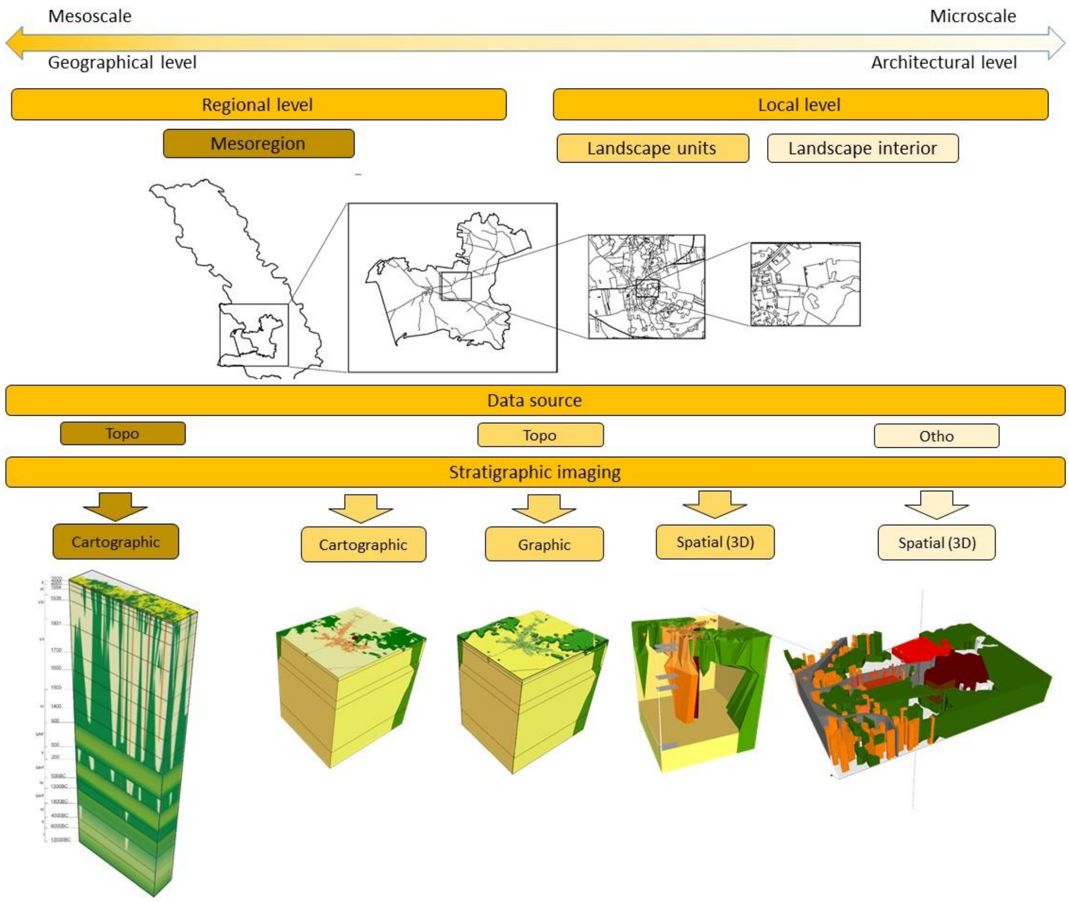
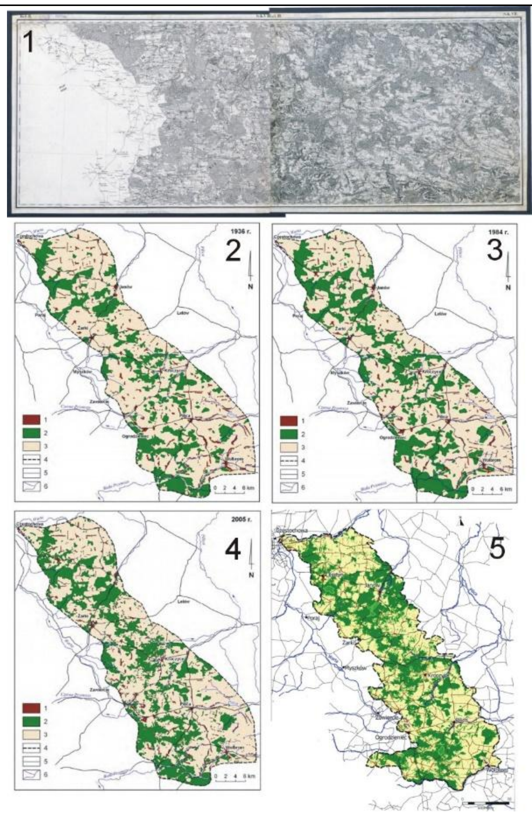
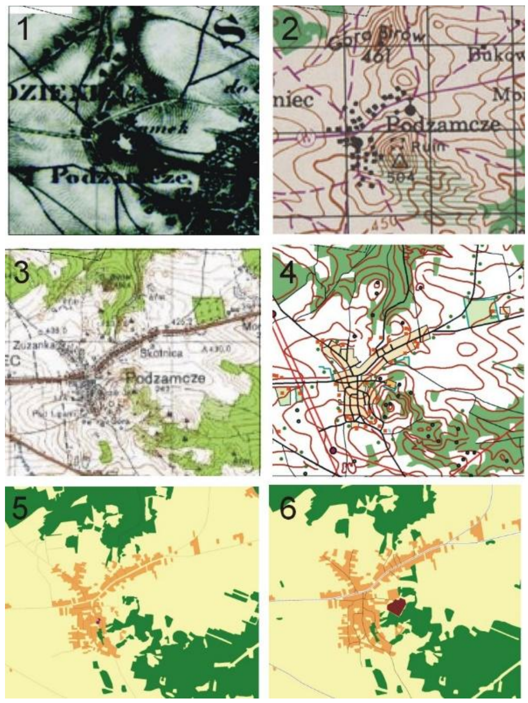
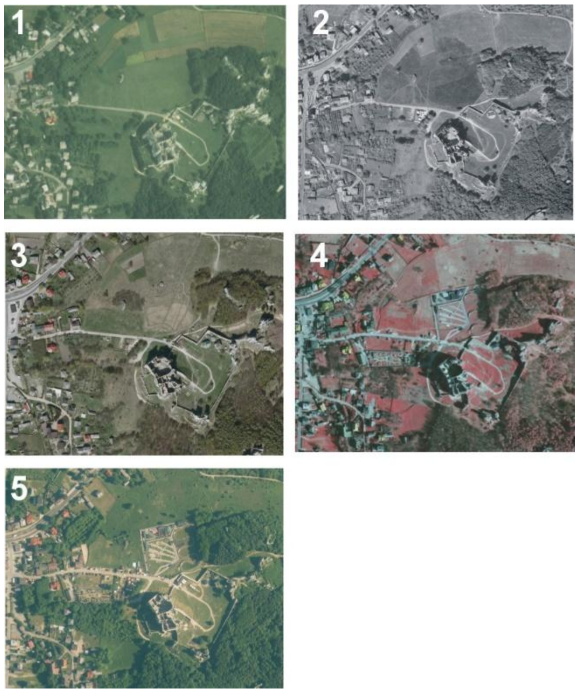


Fig. 2. Differences in imaging depending on the geographic scale of analysis
Source: own compilation

Materials. The landscape stratigraphy model is based on analysis of both literature (historical, archaeological, paleontological) and cartographic (topographic maps, orthophotomaps) sources. Different research sources were used depending on the study level. On the mesoscale, the stratigraphy model covers cartographic analyses from the last 200 years (the period available on topographic maps), but earlier changes are considered on the basis of a literature review collected as a landscape biography. On the microscale, only cartographic research was conducted. In the case of the second level, the analyses were based on topographic maps from the last 200 years, and in the case of the third, the most detailed level, the data sources available were orthophotomaps from the last 25 years. Precise information on materials is provided in Table 1.

Table 1. Materials used in the study depending on the level of the research

Level	Materials	Maps
Mesoscale – level of geographical mesoregion	Last 200 years (form 1831) – changes based on analyses of topographic maps (cartographic research), previous changes – based on landscape biography (literature research, based on Myga-Piątek, 2012), Maps: 1. Topographic map of the Kingdom of Poland, 1831 (scale 1:126 000), 2-4. Main types of land use in Częstochowa Upland in 1936, 1984, 2005 (source: Myga-Piątek, 2012), 5. Database of Topographic Object 10k (TBD 10k, 2020)	
Microscale – level of landscape units	Last 200 years (from 1831) – changes based on analyses of topographic maps (cartographic research), 1. Topographic map of the Kingdom of Poland, 1831 (scale 1:126 000), 2-3. Contemporary cartographic studies – WIG topographic map of 1944 (coordinate system 1942, scale 1:100 000) – Topographic map 1965 (coordinate system 1965, scale 1:50 000), 4-6. Database of Topographic Object 10k (V Map Level 2, 2007, 1:50 000, TBD 10k, 2014, 2020)	

Microscale – level of landscape interior	Last 25 years (from 1996) – changes based on orthophotomaps (cartographic research), Orthophotomaps: 1-5. M-34-52-C-a-3 – 1996, 2003, 2009, 2015, 2019	

Source: own study

To construct a stratigraphy model, an interdisciplinary form of research, both geographical and architectural, was conducted. Cartographic analyses and building a spatial model require the use of different software in both disciplines. For cartographic analyses, typical "geographical" GIS software (MapInfo, ArcGIS) was used. But the next step, construction of stratigraphy model/ imaging (visualisation), needs a different, architectural approach and use of cad and 3D modelling software (such as AutoCAD, SketchUp), and/or graphic (raster) software (such as SketchBook, CorelDraw). In the presented research, MapInfo Pro 17.0 software was used in cartographic analyses and for imaging SketchUp Make 2017, Autodesk Sketchbook and CorelDraw 9 were applied. For graphics, a graphic tablet was used.

Methods. Stratigraphy of a cultural landscape means a method of interpreting the specific arrangement and mutual positions of cultural layers (historical landscape structures) visible in the landscape. Each layer can be assigned chronologically. The number of layers and their age carry information about the persistence of a given type of landscape or landscape structure. For a specific area (region, landscape unit, landscape interior), they can be illustrated on a graph/schematic (Myga-Piątek, 2012; 2018), in a graphical notation of a coordinate system where the vertical axis (y) illustrates the time intervals, and the x and z axes – the spatial location of a given landscape unit in Cartesian coordinates. The model assumes that the oldest (historical) landscapes are "located" deepest and are "covered", in whole or in part, by structural elements (point, linear, strip, surface) of landscapes from later historical periods. Differentiation of landscapes may be of evolutionary or revolutionary character; continuous (laminar cultural layering) or discontinuous (extreme natural events, cultural faults, and interruption of cultural continuity – gaps). The basis for distinguishing the main types of landscapes is the gradient of anthropopression (Chmielewski et al., 2015). The second level of separating chronological "typological layers" is the genesis (absolute age/ stratigraphic position – relative age) of the landscape.

The method adopted in this paper proposes three author methods (modifications) of stratigraphic imaging: cartographic imaging, spatial digital (3D) imaging, and spatial graphic (drawing), modified according to the scale of the study. The method for constructing the profile depends on the type and scale of imaging.

Results and discussion

Mesoscale – level of geographical mesoregion. This scale of the studyexcludes a detailed stratigraphy imaging. The stratigraphy imaging on this level includes two steps. The first one is based on analysis of the literature (landscape biography) and analysis of historical and contemporary maps. The literature research of landscape changes of the Częstochowa Upland was based on the work of Myga-Piątek (2012) and included history before 1831. Myga-Piątek distinguished ten stages of landscape transformation. These analyses are reflected in the profile in low details, so the changes can only be estimated. Cartographic analyses covering the last 200 years are more accurate. This stage covered an identification of landscape types for topographic maps from 1831 and digital maps from 2020. Maps used from 1936, 1984, and 2005 have already been interpreted and the land use has already been presented (Myga-Piątek, 2012). To present a profile, the upland area was divided by two perpendicular lines – cross-sections, enabling the imaging of historical changes. In the next step, the map from each year was imposed (drawn) on the profile in CorelDraw software, marking on it the visible layers of landscape types, finally obtaining a single profile containing the whole studied time interval (Fig. 3).

The obtained model shows changes occurring mainly in the surface of forest and agricultural landscapes. The gradual reduction of forested areas and the expansion of agricultural areas were followed by a reverse trend in the 20th century. The model also shows the character of the changes, which were evolutionary rather than revolutionary.

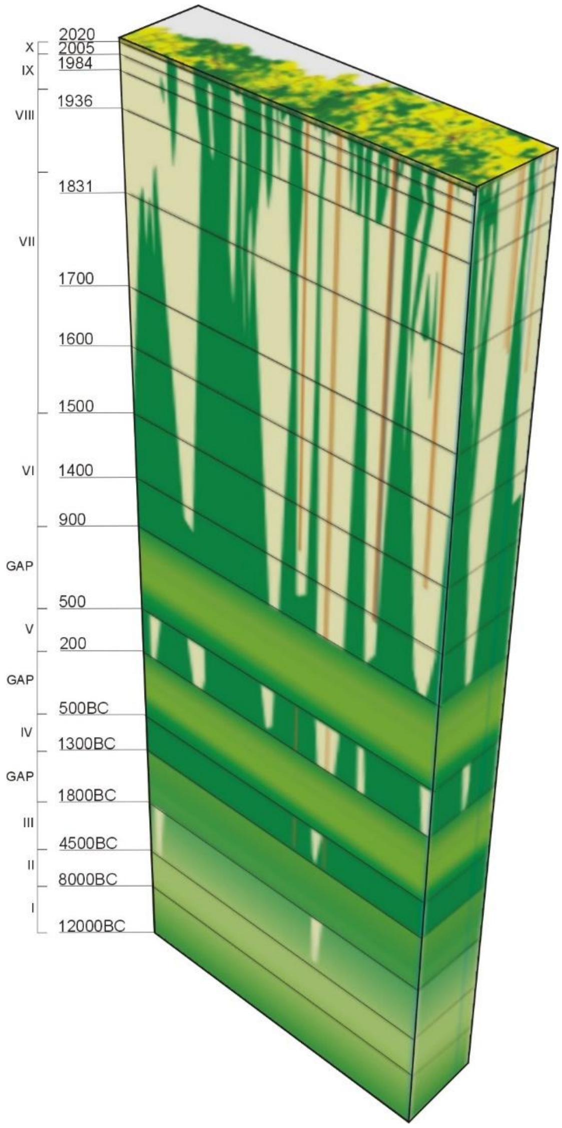


Fig.3. Częstochowa Upland stratigraphy – cartographic imaging
Source: own elaboration

Microscale – level of landscape units. The accuracy of the model on the level of landscape units is higher than on the level of mesoscale, as the research includes only the last 200 years. The analyses are based on topographic maps. The first step on this level covers identification of landscape types on available historical and contemporary maps. Maps from 1831, 1944, and 1965 required a vectorisation, and digital maps needed a classification process of landscape types. The second step was overlapping the maps and next building the imaging model. On this level, the first model – cartographic – is similar to the model of the mesoregion but was constructed using a different tool – SketchUp software. Each map was imported to the program and imposed on a prepared block of an appropriate height, depending on the duration of the studied period. On the sides of the profile (block), landscape type changes were delineated. After all the maps were overlapped, a unified model (spatial profile) was obtained (Fig. 4).

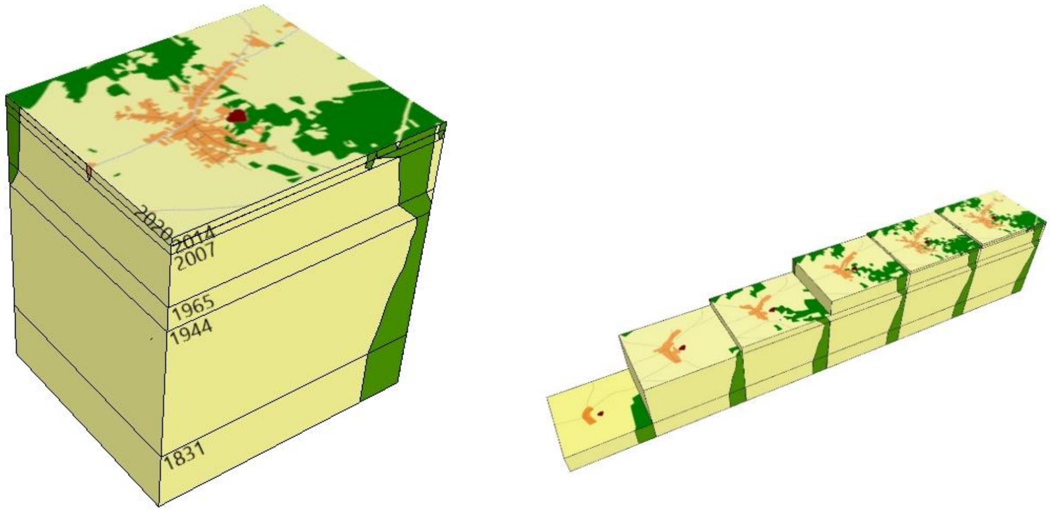


Fig. 4. Cartographic imaging – showing landscapes: agricultural (yellow), settlement (orange), forest (green), fortified (brown) and waters (blue). On the left – unified model, on the right – process of imposing particular maps on the model
Source: own elaboration

A similar procedure was followed in the case of graphic (drawing) spatial imaging. In the case of this method, a simplified visualisation of the surface was created on the basis of a map drawn by hand (using a graphics tablet, in a program dedicated to digital graphics - Autodesk SketchBook). In addition, the depiction of landscape changes on the walls of the model was performed in this software (Fig. 5). This method of imaging shows landscape type changes on the profile in a similar way to cartographic imaging but offers more detailed information on the "top" of the model. The drawing, applied instead of a map, allows landform differentiation and elements of landscape to be presented (buildings, fields, the castle).

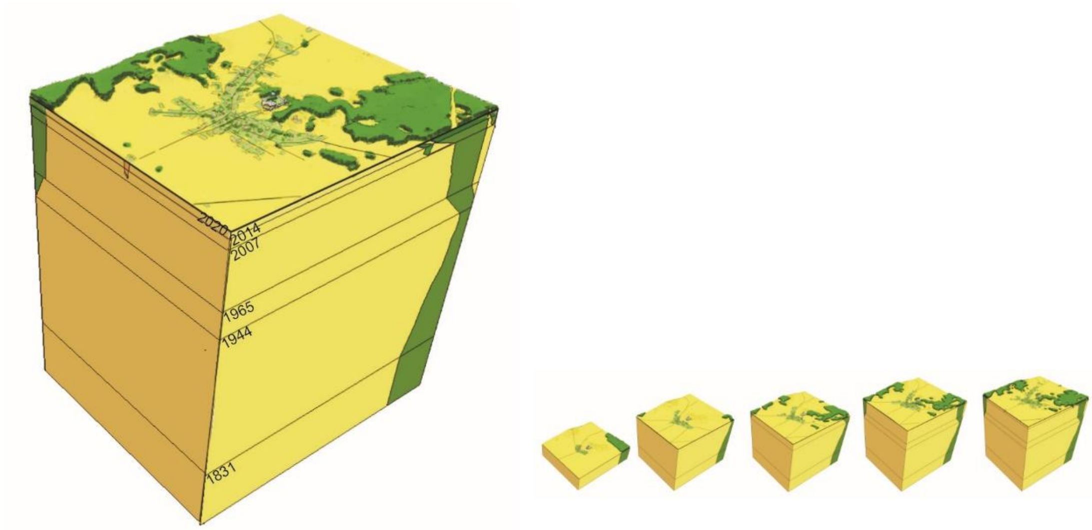


Fig. 5. Graphic imaging – showing landscapes: agricultural, settlement, forest, fortified, waters
Source: own elaboration

However, the above two methods have limitations in the form of the visibility of individual landscape types on the profile – on the walls of the profile, only the borderline landscape types are visible, while the types located "in the middle" of the area are hidden. This problem was solved by using 3D spatial imaging, which allows the changes in the profile for each landscape type to be accurately traced. In SketchUp, forest, settlement, fortified, industrial and water landscapes were generated by vertical merging of individual areas of successive years. The agricultural landscape was treated as a background and was not visualised. In this way, a spatial profile was obtained which allows unlimited insight "into the depths" of the profile, possible from different sides (Fig. 6).

This model indicates a significant increase in forest landscape. The “core” – the fortified landscape is fundamental for the changes that take place in the surroundings. The forest and settlement landscape are spreading more and more in the vicinity of the castle.

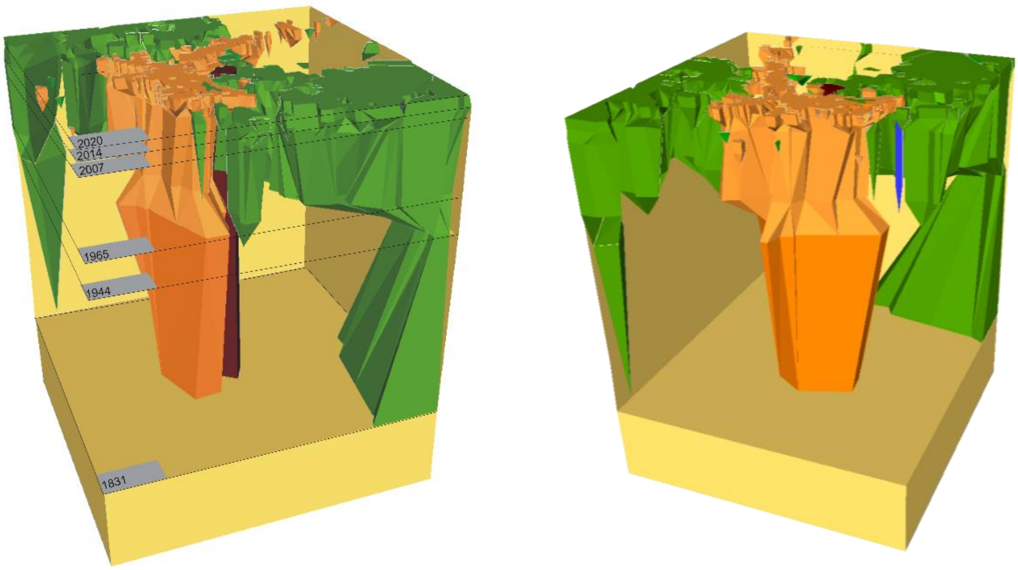


Fig. 6. 3D imaging – showing landscapes: agricultural, settlement, forest, fortified, waters. Agricultural landscape is treated as landscape background (not shown in the image to better visualise changes)
Source: own elaboration

Microscale – level of landscape interior. This level covers landscape analyses in the architectural approach conducted for landscape interior. The stratigraphy model on this level was constructed for the area in the closest vicinity to Ogrodzieniec castle. On the scale of landscape interior, the model presents the changes of particular landscape elements, instead of landscape types analysed at the levels previously described. This scale of detail required the use of other cartographic sources. Orthophotomaps available in Geoportal from 1996, 2005, 2009, 2015, and 2019 were used. To construct the profile, the interpretation of the maps required a vectorisation of distinguished elements: forests and dense woodlands, buildings, castle, temporary tourist infrastructure, and roads and squares. Vectorised maps were overlapped in SketchUp software. Each element was "pulled out" by a given height, depending on the persistence of the element.

This model, similar to a 3D model of spatial imaging on the level of landscape units, allows the changes of the particular element to be followed and gives the possibility to look at the model from different sides and distances (Fig. 7).

At this scale, the changes in the vicinity of the castle are well seen in detail. In particular, the development of tourist infrastructure and temporary facilities, is remarkable. Also, the increase in buildings and area of forest are evident.

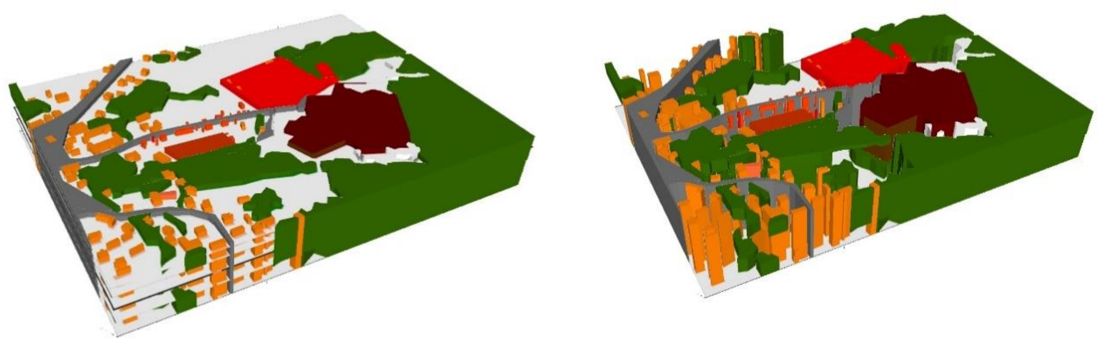


Fig. 7. 3D imaging – showing landscape elements: forest and dense woodland (green), castle (brown), buildings (orange), temporary tourist infrastructure (red), roads and squares (grey). Left – model with maps, Right – model without maps
Source: own elaboration

Conclusions

The landscape stratigraphy model presented in this paper allows landscape changes developed during the studied periods to be followed and analysed. This method can be adapted to different scales and approaches. The presented study was performed in MapInfo, CorelDraw, SketchUp, and SkechBook software, but the model can also be constructed in other GIS, CAD, and graphic software.

The greatest advantage of this method is the ability to visualise changes in the landscape over space and time. A graphical record in the form of a landscape profile allows the type of landscape transformation to be determined. It is possible to indicate whether the changes were evolutionary or revolutionary. Comparing to standard cartographic methods, the stratigraphy brings the possibility of visualisation of changes in the third, temporal dimension on one model.

Proposed models are prepared for a given landscape scale but also bring the possibility to adjust each model to another scale. The limitations are connected to the available materials. The further back in time the analysis goes, the fewer details are provided on the occurrence of landscape types and their spatial extent.

The cartographic model in the presented study was used on two levels: mesoregional and landscape units. The difference in the presented models concerns the thickness (depth) of the profile - in the case of the mesoregion, the model reaches much further back in time, thanks to the use of a landscape biography. In the case of a microscale, the problem may be the availability of literature studies concerning the small selected area.

Graphic imaging was proposed for the second level because of the limitation of the visualisation of landscape put on the top of the profile. Graphic visualisation on the mesoregion scale would be illegible. However, the authors can see the possibility of using this method of imaging on the level of landscape interior.

3D imaging is the most accurate and labour-intensive method. In this model, two variants were proposed, and both can be applied on levels two and three. They require the construction of each landscape type/element in the space. This model, however, allows the changes in any period or any landscape type to be analysed (if the model is well constructed, particular periods or types can be hidden or revealed if needed).

The landscape stratigraphy model can be useful in landscape assessment aimed at determining the persistence or past, or future changes, so can also be used in landscape forecasting. As the history of landscape is essential in landscape planning, this method can also be valuable in the procedure of landscape protection (taking into account not only the natural or cultural values, but also the persistence) and planning of built-up and forested areas, also considering past trends. It is also worth mentioning its educational functionality, as using a spatial model, landscape can be better "seen" and, therefore, understood by the society.

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