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Interactive HGIS platform union of lublin (1569): A geomatic solution for discovering the Jagiellonian heritage of the city



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ABSTRACT

Lublin in the period of the Lublin Union (1569) is an interdisciplinary research project conducted by the "Grodzka Gate - NN Theatre" Centre in Lublin as a part of the celebration of the 450th anniversary of signing the Union of Lublin Act - one of the most important historical events in 16th-century Europe, during which the Polish-Lithuanian Commonwealth was constituted. This paper aims to present the research process by which an innovative Historical GIS web platform, based on an object-orientated database design, was tested and refined. The portal uses four pillars of spatial-temporal databases (events, people, places, sources) to collect data and develop historical narratives presenting various events in the history of the city and the region. The idea behind the project was to develop an Internet portal that would acknowledge modern users with the historical event of the Union of Lublin from the perspective of the then resident of Lublin. What is known about the 16th-century Lublin? What did the city and its surroundings look like? Who lived in Lublin? Who used to visit it? What architectural elements and traces of cultural heritage have been saved to this day? The reconstruction of the 16th-century urban space was carried out using the retrogression method of 11 early plans and maps of Lublin, verified and supplemented with the latest archaeological findings, accurate architectural research (geo-radar, laser scanning) and an extensive archival query. Thanks to the Historical GIS technology, the research results have been published in the form of a universal platform (www.teatrnn.pl/unia-lubelska), with an interactive webmap of 16th-century Lublin (Google Maps API implementation) and modelling urban facilities with 3D technology (SketchUp & Unity). The designed technological solution is scalable, making it possible to search and combine individual records (e.g. person-event-address) as well as entire groups of records on higher hierarchical levels (social groups - sequences of events - multifaceted maps). The portal editing panel is dedicated to humanists (historians, journalists, sociologists, etc.) without specialist knowledge of GIS. The functions integrated with the CMS facilitate mapping the content collected in the database and embedding the narration in an adequate context of the historical space. As a result, editors preparing a thematic article have a searchable set of documents, facts, people and places at their disposal, and their task is to fill the narrative with descriptive content. This is a universal model for building deep maps and spatial narratives.

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1. Introduction

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The year 2019 marked the 450th anniversary of the founding of the Lublin Union – one of the most important moments in Polish history. The act of signing the Polish-Lithuanian Union in Lublin is an unprecedented event whose significance for 16th-century Eu-

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rope is comparable to that of the European Union today. The celebration of the 450th anniversary was accompanied by multiple cultural and educational events aimed at promoting the history and cultural heritage of Lublin during the Jagiellonian era. An attempt to reconstruct the space of the then city was one of the activities carried out by the "Grodzka Gate - NN Theatre" Centre team in cooperation with researchers from Lublin universities.

The idea of research on the historical development of the cities is at least as old as modern science. However, systematic research had not been conducted until 1955, when the International Commission for the History of Towns (ICHT) was founded in Rome (www.historiaurbium.org). The Commission stressed the great importance of archival cartographic documentation (towns plans and maps) for understanding urban growth. For the sake of better comparability, the Commission established a unified concept of the Historical Towns Atlas [7]. The latter development of computer technology created new possibilities to document architecture and present urban heritage to larger audiences [6,9,15,18]. As the technology changed, so did the expectations of recipients for whom a traditional paper map is no longer an attractive form of cognition [28]. Researchers associated with HTA have recognized the need to evaluate the objectives and assumptions defined in the last century.¹ Adapting practices and dissemination tools to the 21stcentury-realities is a necessity [7,8,26,27].

Several fairly successful attempts have been made to develop Urban Historical GIS (including HTA), based on popular web-GIS technologies. The Royal Irish Academy team developed three experimental digital HTA atlases based on ArcGIS Online.² Irish atlases present standard functionality with thematic layers represented with point objects (mostly descriptive attributes) and raster overlays. Derry-Londonderry digital atlas is the most advanced one with thematic layers in polygon geometries. The bright side of these portals is beautiful archival maps. On the other hand, key HTA maps are published in 32-bit colour depth which is suitable for print but not for digital form. Generally, these works are mostly done by historians and should use the hand of an experienced cartographer.

In Germany, Deutscher Historischer Städteatlas is undergoing a digital turn [5]. Six towns had been developed with open JavaScript library *Leaflet*.³ These atlases present a higher level of cartographic approach with a more professional design of raster overlays and vector layers. The logic of these atlases is not clear: why did archival cadastre, settlement development until the 19th century and spatial development in the 20th century had been developed as separate web maps? The interaction between these maps is not possible. The scope and design of corresponding maps for different towns are not consistent. The use of greens for presenting phases of development is misleading - according to the principle of isomorphism, green polygons evoke associations with woodland, which may not necessarily be relevant for the historical state before the area was developed. For three towns only raster overlays of the key maps are available. Digital atlases of Deutscher Historischer Städteatlas are available only in German.

In Italy, a web map of Rome (CROMA⁴) has been developed with Google Maps API [26,27]. The platform was developed on the basis of 18th-century maps and 19th century and early 20th-century cadastre. CROMA has standard geoportal functionality, with multiple spatial data services providing both raster overlays

and interactive vector layers. Access is limited for registered users, registration is free. Alternative Historical GIS of Rome had been developed by the cooperation of American universities: Oregon and Stanford. *Mapping Rome* with an Interactive Nolli Map Website 2.0 [34] gains recognition.⁵ The portal developed with Mapbox and MapTiler is a mixed interface with neat raster overlay and numerous geometrical layers (points, lines, polygons) connected with an interactive legend. The web page is designed more as a digital guide with a map as an interface for presenting historical narration.

Apart from Historical GIS associated with HTA or devoted to particular cities, two major HGIS platforms are worth mentioning: *Arcanum Maps* and *David Rumsey Map Collection*.

One of the most important projects in terms of European Historical GIS is developed by Hungarian company Arcanum. *Arcanum Maps*, more commonly known as the *Mapire*, is a vast library of georeferenced archival cartography of the Habsburg Empire, including thousands of sections of 1st, 2nd, 3rd Military survey and 19th-century cadastre. The momentum and pace of the Arcanum project may have an adverse effect on the quality of the presented data. On the project website we can read:

The accuracy of the historical maps depends on the scale on the creation method of the original map. In case of 1:2.880 scale cadastral maps from around 1850 the accuracy can reach up to 15 to $20m.^6$

Happily, this is a very prescient statement. A visual assessment of the Habsburg Empire Cadastral Maps at maps.arcanum.com reveals that the sections have been matched with greater accuracy. Based on our own experience of working with the 1:2880 scale cadastre of Galicia within the Polish HTA,⁷ achieving a georeferencing result of 1–2 m is possible.

David Rumsey Map Collection is also a key player in the Historical GIS with almost 70 thousand georeferenced maps (83% of all collected) at various scales all around the World.⁸ This was possible due to the crowdsourcing techniques⁹ and online georeferencing tool developed at David Rumsey's with MapTiler. Wrapping maps by non-qualified volunteers is not always the best but always better than none. Searching for archival maps for a specific region from the *Georeferenced Map Finder* is somewhat cumbersome, as the area is overlaid with numerous maps made at different scales, periods and for different purposes (military cartography, school cartography, maps from geographical atlases, etc.). Therefore maps of an outstanding historical value are mixed with dozens of common, insignificant ones. The web-map interface could use some simple slide bars for filtering.

All of these are developed with a classic field-based approach to database construction, with homogenous layers of points, lines and polygons. Without prejudice to the professionalism of the implementation of the presented applications (which we rate very highly), the authors are convinced that the classical field-based design of the backend has limited functionality. Adopting an objectorientated approach significantly expands the scope of interaction between objects and layers - this would be discussed closer in chapter 3. The explanation of the difference between a spatiallyorientated database system and an object-orientated approach can be found in the previous article [25].

The Internet portal devoted to the 16th-century Lublin (www. teatrnn.pl/unia-lubelska, Fig. 1) was developed with a broad range

¹ Full list of atlases deveopled under ICHT HTA programme is available at *Europäische Städteatlanten* - https://www.uni-muenster.de/Staedtegeschichte/portal/staedteatlanten/index.html

² Irish Historic Towns Atlas Digital - https://www.ria.ie/research-projects/ irish-historic-towns-atlas/ ihta-digital

³ https://www.uni-muenster.de/Staedtegeschichte/portal/Stadtkarten/index.html

⁴ https://archivio.centroricercheroma.it/default.asp?contenuto=hgis

⁵ Mapping Rome project - http://mappingrome.com/ with interesting Interactive Nolli Map - https://nolli.stanford.edu/.

⁶ https://www.arcanum.com/en/technology/historical-maps/

⁷ http://atlasmiast.umk.pl/

⁸ https://www.davidrumsey.com/view/georeferenced-maps

⁹ Similar tool called NYPL Map Wrapper has been developed at New York Publish Library. Unfortunately. this tool is being terminated https://wayback.archive-it.org/ 13216/20210520171637/http://maps.nypl.org/warper/



Fig. 1. Portal www.teatrnn.pl/unia-lubelska - the main window with thematic sections displayed.

of modern digital technology – digitization of archival documents, analyses and spatial reconstructions in GIS systems, 3D modelling and audio and video techniques. The portal is divided into modules: an interactive map of the Lublin Union, Lublin in a document, description of the city during the Union and the 16th century in general, important persons participating in the Union's *Sejm*, events connected with the Union's *Sejm*, diplomatic demarcation and historical criticism of the Union of Lublin Act, scientific studies on the Union, Lublin 450 years after the Union (book publication in PDF), video materials about the Lublin Union. Finally, the project benefits from previous works that included developing an interactive 3D model of Lublin in the 16th century (video 1) and animated models of water supply facilities in that historical period (video 2 & video 3).

2. Research aim

This paper aims to present the research process by which an innovative Historical GIS web platform, based on an objectorientated database design, was tested and refined. The portal uses four pillars of spatial-temporal databases (events, people, places, sources) to collect data and develop historical narratives presenting various events in the history of the city and the region. Referring to the latest global trends [1,2], Historical GIS is, in this case, understood broadly, not only as a tool (desktop GIS software) for collecting and analysing spatiotemporal data but above all as an interactive publication platform. The implementation was presented on the example of the Lublin in the period of the Lublin Union platform (www.teatrnn.pl/unia-lubelska). The case presented covers the full research process: from the acquisition, collection and processing of archaeological, architectural and historical data to the publication of results in the form of a publicly available web platform the Historical GIS portal using multiple media technologies - including audio, video, 3D animation and interactive mapping. The technology developed and used within the project presented may evolve into a new technological paradigm for the HTA [8] or similar projects on Urban History & Urban Heritage.

3. Methodology

The Lublin in the period of the Lublin Union was an interdisciplinary project, combining many research perspectives: archaeology, architecture, historical geography, urban geography, history, history of art as well as multiple modern technologies. The process of cartographic reconstruction of the city was based on various analyses – from written sources, archival and contemporary cartographic and iconographic materials, historical-architectural and archaeological documentation, to direct inventories and field measurements, etc. The geomatic method [22] and the Historical GIS [14,31,32] were the broadest basis for the use of such a heterogeneous set of data.

The historical geoportal of Lublin (Lublin Historical GIS -[25], https://teatrnn.pl/bazy-danych/en/) is one of the first interactive map portals in Poland that uses object-based GIS for presenting information about people, events, places and sources (documents). These four groups of records are united within a network of common relationships and references. Object-based GIS is founded on a loose relation amongst entities in the database [30,35]. Several theoretical conceptions were analysed and utilised to design the database structure, amongst others: *Three Domain Model* [36], *Object Role Modelling* [10], *Deep Mapping* [1], the separation of source and critical structure [32] and Spatial Narration [2].

The main requirements for the system design were: hierarchical organization of data sets, spatial and temporal scalability, a thematic grouping of entities, tagging with keywords and automation of calling up documentary sources for thematic articles in the CMS. T.M. Harris' [17] concept for a geospatial web framework for deep mapping and spatial storytelling served as inspiration for the design of the backend as well as the frontend functionality (Fig. 2).

The basic unit of the platform is the 'content' chart, in which one object of the chart corresponds to one of the website content. Objects of the 'content' chart are classified into categories (events, places, people, sources) and tagged with adequate text attribute 'type'. Every person and place is treated as a separate item and as such has its page and identifier, being at the same time part of a larger network of information. The same applies to source quotations and events. All these elements are then used



Fig. 2. Lublin Historical GIS (Teatrnn.pl) portal backend and frontend data flowchart, designed for publishing articles with the use of historical-geographical data stored in the four-pillar database.

for more complex narratives, such as family or organization descriptions, thematic maps or event calendars. The chart consists of obligatory elements like title entry, creation/update date, language or object ID. Simultaneously, depending on the type, an object can contain relation with other charts (authors, taxonomies, geometries, sources amongst other things from the digital library). Individual sets of separate objects relations with other objects are stored in the 'content connections' intermediary chart. It is possible to search through different categories (events, places, people, sources). The module takes into account *Soundex* usage for words with similar phonetic sounds. Advanced options allow searching:

- people in relation to certain place and/or time; searching whole families;
- places (addresses) for a particular period or all available; searching by streets, districts, towns; searching by function (e.g. church);
- events filtered by time, place or people involved. The majority of events stored in the database are related to a genealogical query. These were grouped in subsequent categories such as: birth of a person (X was born in), place of residence (X lived at), marital status (X married Y), education, occupation, death of a person;
- sources by type (e.g. civil and ecclesiastical records, eligible voter rolls, business directories, tax rolls), archive, period or content (people, places and other phrases included).

An object can possess many relations connected with location, geometrical form and time. In other words, one hypothetical object can be represented in many different time ranges, different places and by different types of geometries [25]. A crucial element of databases is the hierarchization from more general to more and more detailed notion classes [14]. Object-based databases provide for the possibility of information inheritance: properties and methods characterizing superior classes are, by assumption, attributed to inferior classes, although the latter can contain their separate combinations of properties and behaviours [30]. This speeds up the populating of the database. For example, the surname of a

particular family will automatically be assigned to all its members, but this can be changed for any particular individual [e.g., a woman's surname can be changed if she got married] [25]. The object-orientated approach is currently acknowledged as the superior method for collecting and processing data for historical studies [13,17].

Mapping certain phenomena is available from the administration panel - editors define a new map (which is a separate entity), to which they connect existing database entities (e.g. previously searched geometries or place-address markers) or define new places to be added to the map. Because of the loose hierarchical structure, some maps may be composed of other maps, e.g. a map of a town may be built from district maps, which can be built from street maps, that consist of plots surrounding certain streets, etc. Non-hierarchical relations are also allowed, therefore site editors decide which issues should be presented on the map. The main limitation of the adopted approach is the Internet network capacity and the efficiency of the user's browser. Due to the attribute inheritance function, a map containing popular objects (churches, schools, offices) will contain hundreds of places and thousands of links to people, events and sources collected in the database. To avoid server infrastructure overload, the functionality of creating new maps or editing existing ones is restricted to the registered users only [25].

4. Interdisciplinary approach

The reconstruction was preceded by deep literature study on the history of Lublin. The literature sources can be divided into two groups: valuable but general monographic studies and detailed studies on individual buildings from the 16th century. The first group include Lublin. Rozwój przestrzenny i funkcjonalny od średniowiecza do współczesności [20], Lublin. 700 lat dziejów miasta [11], Lublin: przeobrażenia urbanistyczne 1815–1939 [29] and the series Lublin. Historia dzielnic. W 700. rocznicę lokacji miasta [4]. These monographs overwhelmingly present the general depiction of the city centre in the 16th century. Only a few attempts were taken



Fig. 3. St. Nicolas Church - laser scanning point-cloud visualization (K. Janus 2019). .

to reconstruct the course of trade roads and tracts as well as river network during this period [21]. Unfortunately, the attached maps were characterized by quite a high level of generalization and did not contain a division into plots, dwellings, etc. The second group include several hundred books (e.g. *Zabytki architektury i budownictwa w Polsce*, [3]), articles and files at the WUOZ (Lublin Voivodship Monument Conservator Office) – all of them are listed on www.teatrnn.pl/unia-lubelska/literatura/. A detailed list of historic buildings and their dating can be found in above-mentioned publications, but unfortunately there was no lists for particular epochs nor cartographic synthesis.

4.1. The perspective of an architect

The analysis of available studies of the 16th-century Lublin showed that to reconstruct the map, detailed and up-to-date data on the city's historical architecture is needed. For centuries, gradual extensions, superstructures, conversions or catastrophes, formed the current outline of buildings. To establish the chronology, the nodal relations in the walls and the type of materials are used. The connection with historical data enables linking individual phases with specific historical events or periods (e.g. http://teatrnn.pl/rozwoj-przestrzenny/ cyfrowa-rekonstrukcja-kosciola-farnego-pw-sw-michala-archaniola/). Architectural research made distinguishing structure parts possible. Assignments to particular historical phases allowed to determine whether a given object could have existed during the period of the Union of Lublin and what is left of it. Thanks to the involvement of specialists-practitioners, it was possible to take into account the results of the latest research conducted in the Lublin city space - also by non-invasive methods such as thermography, ground penetrating radar (hereinafter: GPR) and laser scanning (Fig. 3, Appendix A, Appendix D).

4.2. The perspective of an archaeologist

The archaeological sources played a twofold role in the cartographic reconstruction – they confirmed and clarified the information in the historical sources and filled the gap in the historical records about the places for which there were no 16thcentury mentions. This was particularly important in the areas outside the city walls. Archaeological research allowed to develop a database of reference points, which then served as a warp for later cartographic materials. The indicated places document successive phases of the city's development, often with relics of immovable objects or movable objects of everyday use. Approximate reconstruction of the settlement area was based on the analyses of spatially dispersed archaeological data. The first group included discovered relics of cellars, foundations of houses, remnants of fortifications (Fig. 4, Appendix A, Appendix D), roads, cloaks, fragments of waterworks and related elements, as well as household appliances such as furnaces - all these made possible to determine the character of the settlement in a certain part of the town. The movable monuments consisted mainly of fragments of ceramics, less numerous were the remains of tiles and everyday objects - coins and other personal belongings (e.g. http://teatrnn.pl/places/place/ brama-krakowska/). It is worth noting that archaeological dating is relative and therefore limited only to stylistic or architectural periods, that often lasted several decades.

4.3. The perspective of a historian

Archival scripts were the main historical sources for the cartographic reconstruction of the city from the period of the Lublin Union (Fig. 5, Appendix C, Appendix D). An invaluable source of information on the city's development in the 16th century is mainly the Lublin Province vetting in 1565 and 1570, and the Szos lists (tax censuses) in 1524 and 1573, which can be found in the Archiwum Państwowe w Lublinie (State Archive in Lublin, hereinafter: APL). In these documents, one can find information about the main buildings together with information about their owners, street names and places. Determining the development and boundaries of the parish and monastic properties required a query in the sources of church provenance. Akta konsystorza lubelskiego (Acts of the Lublin Consistory) (1630–1633), Akta wizytacji archidiakonatu lubelskiego (Acts of Visitation of the Lublin Archdiocese) of 1595 and 1603 located in the archives of the Lublin Archdiocese in Lublin and the Metropolitan Curia in Krakow were used. The query covered all the most important archival collections concerning Lublin in the 16th and 17th centuries. Many of them were analysed for the first time in terms of searching for information about the historical space of the city.

It is worth noting that at the beginning of the 16th century, Lublin's space was marked by elements of the city's "layout" still characteristic of the medieval period. The distribution of plots of land largely corresponded to the location priv-



Fig. 4. The archaeological discovery of the barbican in front of the Krakow Gate (Archee 2018). Vertical and oblique photos are also available at www.teatrnn.pl/miejsca/ mapa/unia-lubelska or via Google Maps.

ilege from 1317. The town was surrounded by defensive walls, erected on the order of Casimir III the Great in the second half of the 14th century. Also the Great Royal Pond – an extensive water reservoir, southeast of Old Town Hill – was established in the 14th century (http://teatrnn.pl/leksykon/artykuly/ rekonstrukcja-sieci-rzecznej-lublina-w-xvi-wieku/).

4.4. The perspective of a geographer and a cartographer

While working on the reconstruction of Lublin's space, a rich collection of archival cartographic and iconographic materials was used ([38–51,53–57] Appendix B, Appendix D), however, it should be noted that sources significant for the reconstruction were created much later than the times of the Lublin Union. The cartographic collection of the State Archive in Lublin and other institutions related to the study of the history of Lublin include several dozen plans and maps of the entire city and several hundred plans showing selected fragments of the space, e.g. districts, streets, estates [19]. The collection of 11 large maps and several dozen smaller ones was used to reconstruct the map of Lublin in the 16th century[38–51].

The earliest cartographic document presenting Lublin in its entirety is the *Plan de la ville et fauxbourgs de Lublin*[40] by C.V. d'Örken from 1716 (https://teatrnn.pl/leksykon/artykuly/ c-d-orken-plan-de-la-ville-et-fauxbourgs-de-lublin-z-1716-roku/). The handwritten document was drawn up at a scale of about 1:3400. Its range is determined by the seventeenth-century line of the city fortification (coinciding with the course of today's Lipowa Street) to the west, and the wet valleys of *Bystrzyca* and *Czechówka* to the south, east and north. The plan was drawn up in a hurry to meet the needs of the negotiations between the representatives of August II and the representatives of the anti-Royal Tarnogród confederation. An important feature of the plan is a great simplification of the situation. Significant distortions of spatial relations disqualify the plan as a base material, which does not diminish its high informative value.

The main cartographic basis for the retrogression of Lublin's space were two maps made by S.J.N. Łęcki in the years 1780–1783. The general map (*Mappa generalna...*) was drawn up in 1780 at a scale of 1:8300 to represent the entire land of the city. The original was destroyed, however, the map is known from a manuscript copy, made by M. Billewicz[46]. Currently, this copy is stored in the *Archiwum Główne Akt Dawnych* (Main Archive of Old Files in Warsaw). The detailed map (*Mappa całego miasta...*) from 1783 was made at a scale of 1:5000. This plan shows the individual buildings, plots and contains a list of the owners of the properties within the city. The original has not been preserved either. Three copies are available in the APL and via http://lac.lublin.pl/:

- by J. Kierłowicz in 1802 (scale 1:2500, in German)[42],
- by F. Bieczyński in 1852 (scale 1:5000, in Polish)[47],
- by M. Pawlak in 1941 (scale 1:5000, in German)[48].

Individual copies differ in the technique and, to a small extent, in the rendering of the content. Scans of all three copies were analysed – the Polish copy by F. Bieczyński preserved the best quality, legibility and cartometrics (Fig. 6, Appendix B, http: //lac.lublin.pl/plany/calosci/sygn-3/).

To reconstruct the surroundings of the city also Austrian topographical maps from the period 1801–1804 were used. The handwritten maps show a consistent scale sequence: from the most detailed plan at a scale of 1:5760 ([41]by E. Renner in 1800 http://teatrnn.pl/leksykon/artykuly/plan-lublina-rennera/), through a topographic map of the city and its surroundings at 1:14,400 ([43]by J. Tretter in 1803 - http://teatrnn.pl/leksykon/artykuly/



Fig. 5. Portal www.teatrnn.pl/lublin-w-dokumencie - The "Lublin in a document" section presents digital copies of the most important archival documents concerning the Lublin Union together with a description of the source and historical criticism.



Fig. 6. Mappa całego miasta J.K. Mci Lublina z wszystkiemi ulicami, przedmieściami, jurydykami [...] roku 1783 delineowana[47], scale 1:5000, Lublin, S.J.N. Łęcki in 1783 (copy by F. Bieczyński in 1852), APL, PmL, sygn. 3, 12% of original size, (public domain, scan available via www.lac.lublin.pl/plany/calosci/sygn-3).



Fig. 7. Tipus Civitatis Lublinensis in Regio Poloniae[...], A. Hogenberg in: G. Braun, A. [53], Civitates orbis terrarum, t. 6., Cologne. Lublin's Museum S/G/271/ML, 28% of original size, public domain.

plan-lublina-trettera-1803-rok/), to a multi-sheet map at 1:28,800 – developed for the entire region of West Gallicia by surveying corps under A.M. von Heldensfeld[44] in the years 1801-44] (https: //mapire.eu/en/map/firstsurvey-west-galicien). It is worth noting, that less detailed Austrian sources reproduce the content of maps on larger scales in a generalized form. Taking the logic and ergonomics of such a procedure, one must point out that the most detailed map of E. Renner is at the same time the worst in cartometric terms. This plan is characterized by extremely large distortions of distances, angles and surfaces. As a consequence, it harms the reception of J. Tretter's[43] and A.M. Heldensfeld's[44] maps – perfectly measured and drawn in rural areas, within Lublin they lose their value. E. Renner's plan[41] – similarly to the d'Örken's[40] – only served as a source of qualitative information.

Six landscape views (veduta) from the years 1618, 1719, 1774, 1803, 1826 and ca. 1840 were also used in the reconstruction process[43,53-57]. Iconographic sources differ in the date of creation, size, the technique of construction and the way topographical details and spatial relations are presented. The oldest panorama ([53],Fig. 7) is composed of several observation points located in the south, southeast and east of the city. Pożar miasta[54] ("The city fire") in 1719 is the only one depicting Lublin from the north. The four remaining panoramas were taken from the southern or south-eastern side[43,55-57]. Processing the subjective spatial relations of the landscape into the actual dimensions of the map was a big challenge. Nevertheless, the great detail of the figures makes it possible to assess them as very valuable factual material. Many nuances were positively verified by confronting the figures with cartographic materials, historical-architectural documentation and archaeological research results. During the preparation of the map of 16th-century Lublin, many findings of previous research were reviewed [19-21][49-51].

4.5. The geomatic approach

A prerequisite for the proper evaluation of cartographic archives and for maintaining cohesion between the reconstructed map of Lublin in the period of the Lublin Union and contemporary spatial data was to unify the mathematical basis of source materials. To this end, a set of tools and methods for the calibration of early maps was used [21,23]. A contemporary set of referential data was used as a basis for the calibration of archival plans and maps of Lublin. To establish ground control points (GCPs), historical objects from the Polish Main Office of Geodesy and Cartography (www.geoportal.gov.pl) modern topographical objects database BDOT10k (building layer) were transformed into a local coordinate system and used. In ambiguous situations, other contemporary data from the geoportal of were also used, i.e.: orthophoto (WMTS service), Digital Terrain Model (pol. NMT), Digital Surface Model (pol. NMPT), the register of monuments - that is available through the geoportal of the Narodowy Instytut Dziedzictwa (National Heritage Institute, www.mapy.zabytek.gov.pl). Due to significant changes in the city and irregular distribution of archaeological sites, direct calibration of the oldest maps to contemporary spatial data has not always produced satisfactory results. To increase accuracy, a calibration string consisting of several detailed maps from intermediate periods, including the 1820s and 1920s, was used (Appendix B). The number of ground control points (GCPs) used to calibrate archival plans, the positional distortion value of RMS_1 measured before map image transformation and the accuracy value of RMS_A obtained by rubber-sheeting transformation (ArcMap "adjust" method) are listed in Appendix B.

The accuracy of historical-geographical data can be evaluated at least in three categories: geographic (location), geometric (shape) and descriptive (classification, credibility). The two first categories depend most on the materials used for the vectorization of objects. From the perspective of geodesy, collecting data from maps is regarded as secondary method [33], however in case of historical data primary methods (actual surveying) are simply not available.

Therefore, when vectorizing archival maps, three major questions must be considered: 1) If it was drawn from an archival map, what was its scale? 2) What technique was used to prepare this map - was it printed, photocopied or drawn by hand? 3) How reliable are the cartometrics - does it calibrates well, how distortions look like? Similar questions arise when considering archaeological doc-umentation [16]: 1) How was the site measured - GPR, TLS, classic excavation in a regular grid? 2) In what form were the results stored - raw numerical data, GIS layers, CAD, vector graphics, analogue maps? 3) What was the reference - official geodetic network, local points or is it unknown?

Both location and shape can be addressed with standards used by national geodesy and cartography [33]. Geographic and geometric accuracy is compared with nominal resolution [size of the smallest dots perceived by the human eye]. On the map no error below 0.1–0.2 mm is seen, therefore 0.15 mm threshold is recalculated in a particular scale and used for modern spatial data. In Poland (Dz.U. 2021 poz. 1385, Dz.U. 2021 poz. 1412) this particularly refers to minimum requirements of topographical objects databases:

- BDOT500 database referring to modern master map 1:500– 1:5000,¹⁰
- BDOT10k database referring to modern topographical map 1:10,000 and following maps at scales 1:25,000, 1:50,000 and 1:100,000.¹¹

Archival maps and plans rarely meet standards of modern spatial data, which is natural considering the technological advances in geophysics, surveying, etc. Experiences in the calibration of hundreds of maps and plans from different places and periods allowed authors to consider another threshold at 1.0 mm [23]. In Historical GIS, residual between 0.15–1.0 mm is regarded as a minor error that may be acceptable in some cases, however, residual above 1.0 mm is a major error where revision is needed. These two thresholds (0.15 mm and 1.0 mm) can be easily applied in terms of evaluation of shape and location accuracy (Appendix D).

Reconciling the above mentioned, it was decided that objects that met the requirements of urban area BDOT500 or 1:1000 master map were classified as highly accurate in terms of both location and shape (Appendix E). Objects that met the criteria of BDOT10k or 1:10,000 topographic map were classified as moderately accurate. Objects that did not meet these criteria were classified as in-accurate. A combination of ranks also occurred, e.g.: *a plan of a building was found in archives, the exact shape is known but the exact location is not.* On the other hand: *during excavations an object was found, there is no doubt that there was a building of a determined function, the exact location is known but it is not known how this building looked.*

The descriptive accuracy was evaluated with cross-verification criteria. This refers to the types of sources that confirm the existence of particular objects: modern BDOT10k database, archival 1:1000 master map, archaeological documentation, architectural supervision, earlier archival plans (detailed) and maps (generalized), historical documents and studies, descriptive sources. The extensive list of database objects with '+' and '-' is enclosed in Appendix D. According to that, objects were then assigned to one of four qualitative categories (high, moderate, low, very low)

in terms of geographic, geometric and descriptive accuracy. The percentage of objects assigned to each category is also listed in Appendix D.

The map of Lublin in the 16th century (Fig. 9 part b, [52]) was designed using GIS software (QGIS, ArcGIS), vector graphics (CorelDRAW) and raster graphics for postprocessing (Adobe Photoshop). The map was developed at a scale of 1:3000, i.e. large enough to present all situational details of the reconstructed objects, yet fitting A1 format. The scale of the map is similar to the scale of the oldest preserved maps of Lublin 1:2500–1:5000. The cartometrics and level of detail of the drawing are greater than on the early plans - the map georeference is consistent with a 1928 master map, aerial and satellite photographs and the BDOT 10k database.

The core database of the sixteenth-century reality consists of 360 objects confirmed by field research (Fig. 9 part a) and 575 uncertain objects, known from other sources. The classification criteria and types of objects categorized to each group are listed in Appendix D. The development of the spatial model (GIS database) began with "hard" data, occurring in many types of sources, giving a precise location and cross-checked with many research methods, e.g. fortifications, archaeologically documented buildings. During the study, 22% of objects were accurately located and shaped with detail of geometry corresponding to nowadays geodetic database BDOT10k and 1928 master map (1 m or better). These objects were mostly placed within the city walls.

Next, data with a high degree of reliability were introduced, occurring in several sources, but providing only an approximate location or course e.g. manors, paved roads, bridges. Almost 30% of objects were regarded as moderately shaped, with geometry detail corresponding with a 1:10,000 topographic map. Unfortunately, only half of these were located within a 10 m radius due to inaccuracy in the calibration of archival maps and plans.¹² Most 'moderately accurate' objects are placed outside the city wall: in the Downtown and Jewish quarter around the Castle.

Last, the data were supplemented with uncertain objects, inaccurate, characterized by conceptual or factual inaccuracy, like data occurring only in descriptive sources e.g. supplementary buildings, dirt routes, elements of hydrographic network (rivers and ponds) or the then terrain. Over 60% of objects were placed on the map to visualise appropriate context, especially in the then suburbs. These objects are not published in the interactive layer but on the raster image in the background.

Elements of cultural heritage were also the subject of the study – the map presents historically accurate local geographical names and thematic objects like traces of human economic activity. Pottery, coins and other archaeological findings provide indirect information about the occupations carried out by the sixteenth-century inhabitants of the town. The originally designed map legend includes 86 categories of objects, including 26 signatures related to the occurrence of cultural heritage objects and archaeological traces of a settlement.

During the reconstruction of the map content, ambiguous elements appeared, discrepancies in the interpretation of research results and heated discussions within the expert group. The most important buildings in Lublin from the period of the Union are mentioned in descriptive archival sources - such as vettings - but the content of the documents is not consistent. For example, the 1565 vetting mentions 12 manors, in 1570 there were 19 such buildings. On the other hand, only 11 manors are mentioned in the 1573 tax register. As result, only 11 manors confirmed by external information from the conservator's archives were finally marked on

¹⁰ [Pol. legal act] Rozporządzenie Ministra Rozwoju, Pracy i Technologii z dnia 23 lipca 2021 r. w sprawie bazy danych obiektów topograficznych oraz mapy zasadniczej (Dz.U. 2021 poz. 1385) https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id= WDU20210001385

¹¹ [Pol. legal act] Rozporządzenie Ministra Rozwoju, Pracy i Technologii z dnia 27 lipca 2021 r. w sprawie bazy danych obiektów topograficznych oraz bazy danych obiektów ogólnogeograficznych,a także standardowych opracowań kartograficznych (Dz.U. 2021 poz. 1412) https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20210001412

 $^{^{12}}$ The reader should note that 10 m error in the field results in just 1 mm error at 1:10,000 map [24].



Fig. 8. Royal Castle in Lublin: a) in portal www.teatrnn.pl/miejsca/miejsce/zamek; b) (re)construction project by J. Hempel [45]; c) historical reconstruction by S. Wojciechowski [50](1954); d) chronology by J. Teodorowicz-Czerepińska (1995) with additions by M. Florek [12].

the map. All in all, even the reconstruction of such well-known landmarks as the Lublin Castle (http://teatrnn.pl/lexicon/articles/ lublin-castle/) turned out problematic due to the imperfection of sources. Fig. 8 presents the differences in the outline of the Lublin Castle depicted at 1825 renovation plan by J. Hempel (Fig. 8 part b), the 1954 historical study of S. Wojciechowski (Fig. 8 part c) and the latest findings of J. Teodorowicz-Czerepińska and M. Florek (Fig. 8 part d). It is worth noting that the reconstruction of the exact course of medieval city walls was also problematic (http://teatrnn.pl/places/place/mur-miejski/). Frequent renovations of tenement houses that had absorbed some of the walls and the lack of research on some sections make the current knowledge in this area far from complete (Appendix D).

One of the most difficult tasks was to reconstruct the roadways. While in the case of main streets, archaeological discoveries have documented the remains of the road infrastructure in the form of wooden musts or cobblestones. In the case of their further sections, there are no such findings. Up to the mid-18th-century various unregulated dirt tracks were used depending on the seasons [20,21]. Due to scarce historical and archaeological information, the routes outside the main roads were adjusted to the terrain relief depicted on 18th-century maps by S. Łęcki and J. Tretter[42,43,46–48]. Reconstruction of the river network was based on detailed analyses of the course of the river channels, location of ponds and related hydrotechnical infrastructure (dams, mills, blech, paper mills) in historical periods. It was based on cartographic and iconographic material and analyses of the topography of river valleys [20,21].

The area covered with a detailed cartographic reconstruction of sixteenth-century Lublin [52] is in the form of a 4020 \times 2850 m rectangle (about 11.5 km²), that constitutes less than 8% of the current area of the city, in its very centre (http://teatrnn.pl/places/map/unia-lubelska/). At the same time, the area under analysis is more than 40 times larger than the "city within the walls" and significantly exceeds the previous scientific studies on a similar level of detail. The scope of the main map was dictated by the distribution of sixteenth-century traces of settlement identified by archaeological research and collected in the conservator's office documentation (Fig. 9 part a). Even though the Internet edition was

the main focus of the design, it was decided that the map should meet technical requirements for traditional printing. Modern GIS techniques were used to create relief shading that would credibly present the 16th-century landscape - far different from the one registered on modern numerical data. Multi-software processing technology allowed to develop high-resolution outcome with a consistent mathematical basis of the geometry, unified cartographic symbolization and balanced depth of colours (Fig. 9 part b, [52]).

5. Results & discussion

The Authors believe that the universal and versatile concept of the Historical GIS portal is the most important result of the presented study. The developed Historical GIS portal (www.teatrnn. pl/unia-lubelska) enables the organisation of data in hierarchical structures, creation of relational links within and between different categories of objects and embedding multimedia elements (photos, audio and video recordings, 3D models). In this sense, it is a publication platform, using the features of deep mapping to develop spatial narratives [1,2,17]. The historical map, containing a synthesis of knowledge about the city space in the studied period, serves as a universal cognitive model. The slide-map interface allows juxtaposing historical reconstruction with contemporary space, to compare changes and locations of preserved traces of architectural and urban heritage (Fig. 10). Based on common and generally available network technologies, it is possible to develop a modern narrative of the place. The addition of multimedia components significantly increases the visibility, attractiveness and effectiveness of the message for the mass audience (Fig. 11). Within the project digital libraries (dLibra), audio/video recordings (Youtube) and interactive 3D models (videos 1–3) were used.¹³

The concept of a relational web database described in chapter 3 partially refers to the ontological approach and object-orientated programming [30,32,35]. The core of the database is the "content"

¹³ Several of these are also available via Sketchfab (http://poligonstudio.pl/ portfolio/w-kregu-zywiolow/) or for download and play with Unity engine (http: //teatrnn.pl/rozwoj-przestrzenny/makiety-3d-lublina/).



Fig. 9. a) Lublin, 16th-century objects (buildings, fortification) confirmed with architectural & archaeological research (red) versus current buildings (grey – BDOT10k database); b) Lublin in the period of the Lublin Union – final map, scale 1:3000, 2019, Lublin, 18% of the original size[52].

table corresponding to the content of the website (Fig. 2,Fig. 12). The table objects are classified into one of four content components: events, places, people and sources. They answer basic questions of the process of interpretation of historical phenomena: What has happened? When? Where? Who took part? How do we know about this? Events, Places, People and Sources are autonomous entities, i.e. basic hierarchical units of the database. The main functions of the system include the ability to group units into larger assemblies, create a tree of hierarchical relations and inherit the characteristics of superior objects by subordinate objects. The scheme of content categories is similar to the Three Domain Model [36] and *Object-Role Modelling* [10], however, unique solutions had been applied. Therefore editors of the portal have more freedom to combine content, e.g. create loops within a given content category and build relationships that do not necessarily preserve sequences of hierarchical levels [25].

Finally, the project Lublin in the period of the Lublin Union (1569) benefited from other projects run by the 'Grodzka Gate - NN Theatre' Centre. That also included using 3D maquettes of historical buildings and facilities of Lublin that had been modelled by computer graphic artists: Krzysztof Mucha and Robert & Wojciech Miedziocha (www.poligonstudio.pl) that collaborate with the Centre since the early 2010s (Fig.11). The first virtual maquettes of Lublin in the 14th, 16th 18th and early 20th centuries were developed in 2012 (http://poligonstudio.pl/portfolio/ hang-around/). The use of CAD 3D modelling and animation at the Centre went through a major technological change, starting from SketchUp and Google Earth VRML plugin for virtual tours (Fig. 11 part a). Since Google terminated the plugin, different scenarios of how to proceed with virtual maquettes were considered. Alongside the Lublin Union project, in 2019 another project The spatial development of Lublin was also run to modernize, update and adapt historical maquettes to contemporary Internet



Fig. 10. Portal www.teatrnn.pl/miejsca/mapa/unia-lubelska - the Krakow Gate a) interactive map, b) narration of the place, c) iconography), d) satellite imaging with archaeological excavations (Google Maps).



Fig. 11. Virtual maquette Lublin in 16th century: a) 2012 edition in Google Earth; b) 2019 edition in Unity (video 1). Interactive 3D models of the old Polish municipal water supply system (SketchFab): c) rurmus – water pump (video 2); d) water tower (video 3). All models by Poligon Studio.

technology (Fig. 11 part b). Finally, historical modelling production switched to Unity cross-platform game engine (video 1, http: //teatrnn.pl/rozwoj-przestrzenny/makiety-3d-lublina/) and online VRML library SketchFab (video 2 & video 3). Models of historical buildings are developed following the Open Geospatial Consortium CityGML standard (https://www.ogc.org/standards/citygml). Most of the models refer to Level of Detail 3 (LoD 3), yet the latest projects are presented with the LoD 4 complexity (Fig. 11 part c & d, http://teatrnn.pl/rozwoj-przestrzenny/cyfrowe-rekonstrukcje/ or http://poligonstudio.pl/portfolio/w-kregu-zywiolow/). With CMS add-ons, editors can easily embed 3D objects into the narrative sections.

6. Conclusion

The project presented in the article expands the current state of research in four areas: 1) the reconstruction of city space as a scientific problem; 2) the functionality of internet maps as a universal medium for linking information about the past with the contemporary state; 3) database design as a tool for collecting, organising and sharing historical documentation to build a multifaceted knowledge base; 4) CMS design supporting the work of editors without specialist knowledge of computer techniques and GIS.

First, the interactive map *Lublin in the period of the Lublin Union* (www.teatrnn.pl/unia-lubelska) is the first project that re-



Fig. 12. Main page tiling scheme: how to navigate through the portal https://teatrnn.pl/unia-lubelska/

constructed the entire city space of that time with a detail corresponding to contemporary databases and master map ([52], Fig. 9). The cartographic reconstruction was created by compiling the results of comprehensive archaeological, architectural, historical and geographical research (chapter 4). It is, in fact, a pioneering attempt to synthesize the current state of knowledge about Lublin in the 16th century. Secondly, in functional terms, the map serves as a GUI - a graphical user interface for the spatial database of conservation documentation resources [17,25]. It is an excellent tool for further studies on the development of the then city (http://teatrnn. pl/rozwoj-przestrzenny/) and other aspects of cultural heritage research. Thirdly, relational links between places and information on documentary sources, people, and events provide an opportunity to conduct deep analyses, e.g. to determine the functions of particular parts of the city in the 16th century, its sociotopography, or to capture family ties between townsmen. Thus, the presented study meets D.J. Bodenhamer's [1,2] definition of a deep map (chapter 3). The technology developed and used within the project presented may evolve into a new technological paradigm for the HTA [8] or similar projects.

Finally, the portal editing panel is dedicated to humanists (historians, journalists, sociologists, etc.), especially people without advanced skills in computer technologies and GIS ([25], Fig. 2). The functions integrated with the CMS facilitate mapping the content collected in the database and embedding the narration in an adequate context of the historical space. As a result, editors preparing a thematic article have a searchable set of documents, facts, people, places, embedded maps and multimedia add-ons at their disposal, and their task is to fill the narrative with descriptive content (chapter 3, Fig. 10-12). The authors believe that this is a universal model for building deep maps and spatial narratives [17].

To conclude, the main objective of developing the Lublin Union portal is consistent with the logic of HTA - to develop a base of knowledge, popularise the history and multicultural heritage of European cities [8]. The case presented proves that despite technological changes and digital form, a map is still a universal carrier enabling the presentation of any historical subject in any part of the world. The use of the most popular Internet applications (Google Maps, Youtube, Sketchfab) makes the Lublin in the period of the Lublin Union portal suitable for display on mobile devices, intuitive to use - also for international users. The example of the presented portal shows the advantages of using interactive maps as a coherent, digital medium for historical narration, that may be used for HTA and similar scientific projects. The designed solution integrates the advantages of both CMS and web mapping but puts the narrative first. Multimedia elements, such as photographs of archaeological finds (e.g. coins), audio recordings or 3D reconstructions (http://teatrnn.pl/rozwoj-przestrzenny/ makiety-3d-lublina/, videos 1-3) make the story even more interesting for an unqualified audience. With thousands of hits per day [25,37], interactive tools developed have already found practical implementation in multidisciplinary research, heritage promotion, e-learning and virtual tourism.

Last but not the least, the Historical GIS of Lublin is a work in progress. The geomatic framework is constantly filled with historical data by multiple research teams. Over thirty thematic projects covering Lublin's history are actively developed (https://teatrnn.pl/places/maps), e.g.:

• core database - http://teatrnn.pl/bazy-danych/en/,

- Lublin districts (interwar period) https://teatrnn.pl/places/ map/mapa-dzielnic-lublina-dwudziestolecie-miedzywojenne/ (including 9 of 15 subsequent, detailed district maps),
- thematic map devoted to early 20th-century brickyards https: //teatrnn.pl/places/map/cegielnie-lubelskie-xx-w-do-1939/,
- thematic map devoted to former Lubliner and Holocaust survivor Ida Gliksztejn - https://teatrnn.pl/places/map/ mapa-miejsc-w-lublinie-ida-gliksztejn/.

With each new project added to the database, researchers verify their findings against existing records and deepen the web of connections between events, people, places and sources. Currently, the database consists of over 72,000 personal records, 12,000 places, 127,000 historical events and 67,000 references to archival sources - all connected in relational matrix. These numbers are constantly rising [25,37].

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Interactive 3D models by poligonstudio.pl - http: //poligonstudio.pl/portfolio/w-kregu-zywiolow/ also available online at Sketchfab - https://sketchfab.com/Materia_Miasta and https://sketchfab.com/PilotPirx.

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(including 9 of 15 subsequent, detailed district maps), thematic map devoted to early 20th-century brickyards https://teatrnn.pl/places/map/cegielnie-lubelskie-xx-w-do-1939/,

thematic map devoted to former Lubliner and Holocaust survivor Ida Gliksztejn - https://teatrnn.pl/places/map/ mapa-miejsc-w-lublinie-ida-gliksztejn/.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.culher.2021.11.001.

Appendices

Appendix A Non-invasive research used for the reconstruction of the space of 16th-century Lublin.

No.	Object	Address (modern)	Research technique	Scope of research	Previous state of research	Added value	Information used
1	The Bernardine complex of St. Paul's Church	Bernardyńska Street 5	GPR	1) The interior of St. Paul's Church,80% of the church monastery area 2) The surrounding area	1) At least 6 reconstruction phases have been determined from the end of the 15th century. >50% of the 16th-century substance has been preserved. 2) Archaeological research to date (supervision) in the surroundings of the church has indicated the possibility of a cemetery.	The geo-radar and architectural surveys carried out are currently the most advanced form of object recognition. The location of the non-existent chapels on the north side, the location of the "House under the Eagle" building and the inaccessible cellars under almost all the monastery rooms have been determined	Chronological stratification and outline of the range of St. Paul's Church for the 16th century. The portal also uses a compilation of documentation from the cemetery's archaeological supervision
2	St. Stanislaus Church (Dominican)	Złota Street 9	GPR, ther- mography	The interior of the church	at least 6 conversion phases have been defined. >50% of 16th-century substances have been preserved. Until the non-invasive prospectus, such detailed data about the crypts were not available.	A thorough stocktaking of the church was carried out, several dozen crypts from different periods were identified, the findings were confirmed during subsequent research and renovation works. Archaeological research in 2017 verified their number, distribution and parameters - there were more of them than according to the GPR.	The non-invasive inventory and research allowed to indicate the architectural transformation of the church. The location of the Dominican tower from the 14th century was confirmed. The layout of the church during the Lublin Union period (similar to the shape of the present presbytery and the main nave with the sides) was established. Non-invasive tests were confirmed by
3	St, Nicholas Church on Czwartek Hill	ks. Michał Słowikowski Street 1	GPR	The interior of the church50% of the surrounding area	At least 10 conversion phases starting from the 15th century have been determined. >50% of 16th-century substances have been preserved. In the field of archaeology, general concepts for the creation and development of the sacred building and the Czwartek Hill settlement were developed	Archaeological discoveries made it possible to verify the thickness of the burial levels of the church cemetery and the structural elements of the sacred building, located below the modern surface of the area. Thanks to non-invasive research, 4 inaccessible crypts and a number of anomalies were found under the church floor, the layout of the terrain and the shape of the hill on which the church was built were determined outside.	The original morphology of Czwartek Hill, the layout of the church and the layout of the settlement Czwartek, which in the 16th century was the northern suburb of Lublin, were opened

Appendix A (continued)

No.	Object	Address (modern)	Research technique	Scope of research	Previous state of research	Added value	Information used
4	Holy Trinity Chapel in Lublin Castle	Zamkowa Street 9	GPR	The interior of the chapel	The Holy Trinity Chapel was the subject of various research: archaeological, architectural and historical. The object has extensive descriptive documentation, but so far no transformation phases have been defined.	The archaeological recognition of the interior of the chapel is marginal, and apart from indicating the presence of a "crypt" it did not contribute much. In the tangential space - relations with the Casimir Wall were established and the simultaneous creation of the foundation party was indicated. Thanks to non-invasive research, the location of two inaccessible vaulted rooms inside the building was determined	The external outline of the chapel during the 16th century and the course of the vast majority of the Casimir castle wall (14th century) were confirmed, and the common chronology of the chapel and the castle wall was proved. An attempt was made to reconstruct the development of the Castle Hill area and the places of future research were indicated.
5	The area in front of the main entrance to the Lublin Museum in Lublin Castle	Zamkowa Street 9	GPR	Parcel no. 41, 2200 m ²	The most important source so far is the archival geotechnical research from the 1950s and 1960s, which provided the basis for the reconstruction of the original terrain morphology	The precise location of the former prison building and the possible location of the buildings of the former royal castle were determined	The probable course of the wall and buildings in the western part of the former royal castle was determined, the places of future research were indicated
6	South wall of the former royal castle with a donjon undergoing renovation works	Zamkowa Street 9	Laser scanning	100%	The most important source so far is the archival geotechnical research from the 1950s and 1960s, which provided the basis for the reconstruction of the original terrain morphology.	The exact shape and location and degree of preservation of the non-existent wall of the former royal castle was determined	Location and layout of some of the defensive objects of the royal castle during the period of the Union of Lublin was determined
7	Old Town	The area bounded by the city wall in the 14th century (so-called Casimir Walls)	Laser scanning	100%	The tradition of researching the Old Town Hill in Lublin dates back nearly 100 years. The literature of the subject includes hundreds of scientific items and thousands of pages of conservation documentation files. However, due to the lack of cartographic materials from the 16th century, this period has so far been poorly recognized.	Laser scanning made it possible to develop a precise three-dimensional model of contemporary city development. A numerical land model and a numerical land cover model have been developed, which is the basic spatial reference for data from archaeological, architectural, historical research and conservation documentation.	The connection of the DEM and the DTM with the results of archaeological and geotechnical research made it possible to clarify the original shape of the old town hill and to draw the historical layout of the parcel and communication network. Determination of the original flow directions made it possible to plot the course of the sewage system (gutters). In the reconstruction, the discovered relics of the fourteenth-century city walls and other

(continued on next page)

fortification elements were used, as well as the layout of buildings based on the preserved foundations and stone foundations.

Appendix A (continued)

No.	Object	Address (modern)	Research technique	Scope of research	Previous state of Added value research		Information used
8	The area in front of the Cracow Gate in the course of archaeological works	Łokietek Square	Laser scanning	100%	The Cracow Gate is one of the three surviving relics of the Casimir Wall in Lublin. The object has a rich conservation documentation, its dating and chronological delamination is known. Elements of the moat, bridge and curtain (barbican) have not yet been confirmed	The exact shape and location as well as the degree of preservation of the relics of the building adjacent to the foregate of the Cracow Gate (barbican) were determined. LiDAR measurements were the basis for the spatial reference of further archaeological (excavation) studies.	The location, the shape of the elements of the fortifications in front of the Cracow Gate, and the direction of the exit roads during the Union of Lublin were determined.
9	Bernardyńska Street	Bernardyńska Street	Laser scanning	100%	In the years 2000–2002, archaeological surveys were carried out, as part of which historical street surfaces were discovered.	As part of the non-invasive test, an accurate terrain height model was made. Thanks to the obtained 3D model and the results of archaeological and geotechnical works, it was possible to create a model of the original shape of the suburbs behind the Bernardines up to the city walls.	The layout of the suburban area behind the Bernardines during the Union of Lublin was determined
10	Sobieski Palace	Bernardyńska Street 13	GPR	100%	Descriptive documentation from architectural supervision and historical research. Iconography.	Chronological stratification of the building was made, and in confrontation with the descriptive and iconographic documentation, the development and transformation phases of the architectural form were established	The precise external outline of the original site during the period of the Union of Lublin was determined
11	Kościół pobry- gidkowski	Narutowicza Street 10	GPR	100% of the interior of the aisles and the presbytery	Until the time of undertaking the GPR prospectus, no research was conducted inside the church - the knowledge was based on the analysis of source records.	The presence of unknown structures was pointed out: walls under the floors, crypt, cemetery with elevated graves, which was verified during archaeological research and was one of the pillars for chronological stratification of the temple.	Chronological stratification of the object was worked out, the precise course of the external outline of the object in the 16th century was drawn. The reconstruction of the object's surroundings, monastery buildings and the range of the church cemetery was performed
12	Lubomirski Palace	Lithuanian Square 3	GPR	100% of the ground floor area	General historical descriptions and analyses	Identification of undiscovered cellars, determination of foundations and underground parts of the object. The development of chronological stratification of the building, additionally confirmed by local archaeological findings.	Deletion of the palace's body, reconstruction of the farm buildings situated before the residence. Establishing the course of the residence's defensive wall.

(continued on next page)

Appendix A (continued)

No.	Object	Address (modern)	Research technique	Scope of research	Previous state of research	Added value	Information used
13	historical Krakowskie Przedmieście (to the west of the second ground fortification line	Lithuanian Square	Magneto- resistive; GPR; laser scanning; aerial pho- tography	Not more than 50% of the total area	Until the beginning of the 21st century, there was a conviction that this part of Lublin played a marginal role in the history of the city, a lack of empirical research, conclusions based solely on historical analyses.	The magneto-resistive (archaeological- geophysical) method in Lithuanian Square was used as the first non-invasive method in Lublin - 2000. In 2015, the geo-radar surveys of the eastern part of Lithuanian Square made it possible to develop an altitudinal model of the parent rock (loess rock). In 2016, geo-radar measurements indicated the presence of relics of brick objects. Excavations have confirmed their existence and dating.	Reconstruction of the original terrain. Confirmation of the presence of traces of settlement from the 16th century and later, mentioned in conservation documentation and historical studies.
14	Modern Downtown of Lublin with adjacent areas	Streets: Krakowskie Przedmieście, Narutowicza, Chopin, Okopowa, Lipowa, Radzi- wiłłowska, Zielona, Staszica	Laser scanning	Around 1 km ² i.e. nearly 25% of the reconstructed area.	General historical recognition, basic chronology of spatial development based on cartographic materials.	DEM and DTM of high quality (LiDAR) were obtained from the resources of the Municipal centre for Surveying and Cartographic Documentation. The material was a precise spatial reference for the findings from archaeological, architectural, conservation documentation and others.	The confrontation of modern measurement data with the collected cartographic, iconographic and descriptive documentation made it possible to develop a hypothetical model of the original relief. Based on the findings of the research described in the above points, a hypothesis was developed for the layout of plots, buildings, communication network and defensive elements of the western suburbs. A model concept was presented, and the elements currently verified and others requiring further field research were distinguished.

No	Date	Scale	Original title	Author, authors	Language	Technique	Preservation condition	Scope of content	Area covered	Cartometrics	Information used
1	1649	1:240	Plan okolic Bramy Krakowskiej[39]	K. Bekiewicz	Polish	Multi- coloured manuscript	Partially destroyed (marginal), but rather legible	Detailed situation drawing, parcel geometry, prospective drawing of buildings, street	Very small 0,05 km ² in front of the Cracow Gate	High GCPs – 12 RMS_1 – 4,60 m RMS_A – 0,72 m	Approximate geometry of buildings, several street names
2	1716	1:3400	Plan de la ville et fauxbourgs de Lublin[40]	C. V. d'Orken	French	Multi- coloured manuscript	Very good	Detailed but geometric drawing of buildings, church and public utility markings, course of fortifications and fortifications, layout of roads and bridges, river network, land cover	Average 3 km ² , includes the Old Town and the Downtown within the limits of 18th-century ground fortifications	Very low, the march-plan, significant distortion of distances and angles GCPs - 29 RMS_1 - 216,75 m RMS_A - 8,73 m	Qualitative information, which requires the correct course to be established on the basis of other materials
3	Mid-18th century	-	Plan posiadłości szpitala św. Ducha	unknown	Polish and Latin	Monochromatic ink drawing (photo- copy)	Average, e mostly legible	Simplified road and river network with a prospective drawing of sacred buildings and manors, property descriptions	Small 0,6 km ² , covers the northern part of Downtown	Very low, situational sketch, significant distortion of distances and angles GCPs – 11 RMS_1 – 51,26 m RMS_A – 14, 58 m	Location of noble manors, churches and monastic estates in the northern part of Downtown
4	1780 (copied ca. 1850)	1:8300	Mappa generalna całego miasta JKMci Lublina z wszystkiemi polami, zaroślami, łąkami, jury- dykami[46]	S.J. N. Łęcki (copy by M. Billewicz)	Polish	Multi- coloured manuscript	Significantly damaged in the central part, well- preserved drawing of city sur- roundings	Detailed drawing of the situational content - the plan is a spatial extension of the map described at no. 5	Very large 150 km ² covers the entire administrative area of the city within the limits of the end of the 18th century, including all the land belonging to the city, the suburbs and the iurisdicts	Average GCPs – 91 RMS_1 – 29,17 m RMS_A – 3,90 m	The division of properties surrounding the city in the 18th century, used as a basis for retrogression
5	1783 (copied in 1852)	1:5000	Mappa całego miasta JKMci Lublina z wszystkiemi Ulicami, Przedmiesciami, Jury- dykami[47]	S.J. N. Łęcki (copy by F. Bieczyński)	Polish	manuscript	Partially destroyed (marginal), but rather legible	Detailed drawing of the situation content, geometry of free-standing buildings, built-up parcels, fortifications, forms of land use, layout of roads and bridges, river network, land division, signature and descriptive markings	Large 24 km ² covers the entire built-up area of the city from the end of the 18th century and the suburbs of Kalinowszczyzna, Piaski and Wieniawa	High GCPs - 357 RMS_1 – 13,35 m RMS_A – 0,74 m	Geometry of the situation drawing in the 18th century, used as a basis for retrogression

No	Date	Scale	Original title	Author, authors	Language	Technique	Preservation condition	Scope of content	Area covered	Cartometrics	Information used
6	1783 (copied in 1802)	1:2500	Mappa der granzen konigl. Stadt Lublin sam allen Gassen, Vorstadten, Jurisdikzio- nen[42][48]	S.J.N. Lęcki (copy by J. Kierłowicz)	German (Austrian)	manuscript	Average, mostly legible	Detailed drawing of the situational content - the plan is an enlarged drawing of the map described at no. 5, in a simplified graphic form, slight	Large 24 km ² covers the entire built-up area of the city from the end of the 18th century and the suburbs of Kalinowszczyzna, Piaski and	High GCPs – 279 RMS_1 – 17,73 m RMS_A – 1,35 m	Verification of the content of the map no. 4.
7	1800	1:5760	Afunahmsblatt der Stadt Lublin[41]	E. Renner	German (Austrian)	Multi- coloured manuscript	Very good	Seemingly detailed drawing of the situational content, geometry of buildings, marking of churches and public buildings, course of fortifications and fortifications, layout of roads and bridges, river network, land cover, signature and descriptive markings	Average 4 km ² , covers the entire built-up area of the city from the end of the 18th century and the suburbs of Kalinowszczyzna, Piaski and Wieniawa	Very low, the march-plan, significant distortion of distances and angles GCPs – 76 RMS_1 – 121,70 m RMS_A – 5,43 m	Qualitative information, which requires the correct course to be established on the basis of other materials
8	1803	1:14,400	Plan der West Galizischen Kreis Stadt Lublin nebst der umliegenden Gegend[43]	J. Tretter	German (Austrian)	Multi- coloured manuscript, high aesthetics	Very good	Detailed drawing of the situation, building geometry, marking of churches and public buildings, course of fortifications and fortifications, layout of roads and bridges, river network, land cover, signature and descriptive markings, rich relief of the terrain	Very large 72 km ² , covers the administrative area of the city within the borders of the early 19th century, and the surroundings	In the area of the city's built-up area, low, it reproduces the distortions of the map no. 7. Outside the city – average GCPs – 88 RMS_1 – 29,68 m RMS_A – 2,05 m	Topography of the area outside the urban fortification, landscape
9	1804	1:28,800	Carte von West Gallizien col. XV sect. 195[44]	unknown, (under supervision of A.M. von Heldens- feld)	German (Austrian)	Multi- coloured manuscript, high aesthetics	Very good	Detailed drawing of the situation, building geometry, marking of churches and public buildings, course of fortifications and fortifications, layout of roads and bridges, river network, land cover, signature and descriptive markings, rich relief of the terrain	Very large 223 km ² , covers the administrative area of the city within the borders of the early 19th century, and the surroundings	In the area of the city's built-up area, low, it reproduces the distortions of the map no. 7. Outside the city – average GCPs – 40 RMS_1 – 32,58 m RMS_A – 5,55 m	Topography of the area outside the urban fortification, landscape drawing

Appendix B (continued)

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ADDEMUIX D (COMUNUEU)	App	endix	В	(continued)
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No	Date	Scale	Original title	Author, authors	Language	Technique	Preservation condition	Scope of content	Area covered	Cartometrics	Information used
10	1827 (copied in 1959)	1:2250	Kopia płana goroda Lublina	W. Ziółkowski (copy by R. Jaruga)	Russian	Photocopy	Very good	Detailed drawing of buildings, parcels, road and river network, street and river names, parcel numbering	Average 6 km ² , covers the entire built-up area of the city from the first half of the 19th century, including the suburb of Piaski	Very high GCPs – 652 RMS_1 – 4, 18 m RSM A – 0,09 m	Intermediate map used to calibrate older maps, relics of urban fortifications and historical shape of buildings were confirmed
11	1928	1:1000	Plan Wielkiego Miasta Lublina	Lublin Municipal Office, De- partment of Mea- surements	Polish	Monochromati print	Very good c	Full	Large 28,5 km ²	Very high, comparable to reference data GCPs – 1231 RMS_1 – 1,98 m RMS_A < 0,01 m	Intermediate map used to calibrate older maps, preserved historical buildings from the 16th-century or older
12	2019	1:10,000 nominal 1:500 for buildings	Baza Danych Obiektów Topograficznych (BDOT10k) - database of topographical objects at scale 1:10,000	Main Office of Geodesy and Car- tography	Polish	XML vector data format	-	Full	Very large 147,5 km ²	Reference topographical data, similar to master map 1:500, inaccuracy < 0,075 m	Modern reference topographical data, preserved historical buildings from the 16th-century or older were selected
13	2019	Approx. 1:2000	Ortofotomapa standardowa (usługa WMTS) - standard ortophoto Web Map Tiled Service at geo- portal.gov.pl	Main Office of Geodesy and Car- tography	Polish	WMTS tiles, also .TIF raster data format available for download	-	Full	Very large 147,5 km ²	Reference orthorectified aerial images with pixel sampling 0,1 x 0,1 m	Modern reference image, used to verify GCPs.
14	2019	Арргох. 1:2000	Numeryczny Model Terenu (NMT) - Digital Terrain Model	Main Office of Geodesy and Car- tography	Polish	.ASCII raster data format	-	Full	Very large 147,5 km²	Reference terrain data, with pixel sampling 0,5 x 0,5 m and height accuracy +/- 0,1 m	Modern reference terrain data modified to model the 16th-century landscape
15	2019	Approx. 1:2000	Numeryczny Model Pokrycia Terenu (NMPT) - Digital Surface Model	Main Office of Geodesy and Car- tography	Polish	.ASCII raster data format	_	Full	Very large 147,5 km ²	Reference surface data, with pixel sampling 0,5 x 0,5 m and height accuracy +/- 0,1 m	Modern reference surface data used for modelling the height of preserved 16th-century buildings

GCPs - Ground Control Points, RMS_1 - total Root Mean Square Error at 1st order transformation, RMS_A - total Root Mean Square Error at composed rubber-sheeting transformation 'adjust method'.

Appendix C Archival descriptive sources used for the reconstruction of the space of 16th century Lublin.

No	Date	Original title	Author, authors	Language	Access type	No. of objects mentioned	Information used
1	1565	Lustracja województwa lubelskiego	Marcin Falęcki h. Leszczyc, Paweł Działyński h. Ogończyk, Sebastian Wielogłowski h. Starykoń	Polish and Latin	Printed edition A. Wyczański, Lustracja województwa lubelskiego 1565, Wrocław-Warszawa 1959	53	describes all royal lands in Lubelskie Voivodeship, the information includes, amongst others, property owners or tenants, approximate location of buildings, functions of buildings, street names and physiographic objects
2	1570	Lustracja miasta Lublina	unknown	Polish and Latin	manuscript in National Archive in Lublin APL: Zespół: 35/22/0 Akta miasta Lublina » Seria: 2.7 Lustracje Miasta Lublina i Województwa Lubelskiego » lednostka: 310	21	Property owners, approximate location of buildings, functions of buildings, street names and physiographic objects
3	1573	Akta miasta Lublina, księga rachunkowa – dochody i wydatki: Spis podatkowy	Unknown	Polish and Latin	Online scans, microfilm, original manuscript in National Archive in Lublin APL: Zespół: 35/22/0 Akta miasta Lublina » Seria: 2.5.1 Rejestry Dochodów, Wydatków, Podatkowe » Jednostka: 267 https: //szukajwarchiwach.pl/35/ 22/0/2.5.1/267/str/1/21/15/ d-wXodkVd2q0pPyf1TaoLg/ #tabJednostka	443	Property owners, approximate location of buildings, functions of buildings, tax level, street names and physiographic objects
4	1595	Akta wizytacji kanonicznej archidiakonatu lubelskiego	Jerzy Zamoyski, Lublin archdiacon	Latin	Manuscript in the Archives of the Cracow Cathedral Chapter (deposit in the Archives of the Metropolitan Curia in Cracow)	10	Visitation files contain a description of churches and their surroundings, as well as parts of the clergy's property in the Lublin archdiocese, amongst others, property owners, approximate location of buildings, cemeteries, gardens, land, building functions, street names and physiographic objects
5	1603	Akta wizytacji kanonicznej archidiakonatu lubelskiego	Tomasz Josicki, Lublin's official	Latin	Manuscript in the Archdiocese Archives of Lublin	10	Visitation files contain a description of churches and their surroundings, as well as parts of the clergy's property in the Lublin archdiocese, amongst others, property owners, approximate location of buildings, cemeteries, gardens, land, building functions, street names and physiographic objects
6	1633	Akta konsystorza lubelskiego	Several witnesses	Polish	Manuscript in the Archdiocese Archives of Lublin	20	Testimonies relating to land located in the northern part of the city limits. Area north of the Czechówka River, including property owners, approximate location of land

Appendix D	
Geographic, geometric and descriptive accuracy of objects used for the reconstruction of the space of 16th century Lublin.	

		Number of		Geographic accuracy		Descripive accuracy			•	Informati	on sources			
No	Object type	objects	Current status	(location precision)	Geometric accuracy (shape)	(classification)	BDOT10k	1928 master map 1:1000	Archaeological excavations and	Architectural supervision	Archival plans (1:1000 or	Archival maps (1:2500 or	Historical studies	Descriptive sources
1	Royal Castle Chanel	1	Preserved (minor changes)					•	supervision		better)	worse)		-
2	Royal Castle Tower (wieża)	. 1	Preserved (minor changes)	-				-		-				-
2	Royal Castle Tower (basste)		Preserved min	High (1m or better)	High (with precise size and shape)									
4	Royal Castle other buildings	16	Not precerved	-										
5	Royal Castle - other buildings	10	Not preserved	Modamia (10m or hattar)	Modernite (with general cize and chane)	-	-	-	Ŧ	-	Ŧ	+		- T
6	City hall	10	Processived (major changes)	Moderate (1011 of better)	would general size and shape)	-		-			-	+		- T
2	City gate (major fortification -		Preserved (migor changes)	-										
-	brama)	2	Preserved (minor changes)	High (1m or better)	High (with precise size and shape)		+	+	+	+	+	+	+	+
8	brama)	1	Not preserved				+	+	+	+	+	+	+	+
9	City gate (minor fortification - furta)	1	Preserved (major changes)				-	-	+	+	+	+	+	+
10	City gate (minor fortification - furta)	7	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)		-	-	-	-	-	+	+	+
11	Barbican (fortification)	1	Discovered with precise archaeological context				-	-	+	-	-	+	+	+
12	Tower (baszta)	1	Preserved (minor changes)	High (1m or better)	High (with precise size and shape)		+	+	+	+	+	+	+	+
13	Tower (baszta)	2	Preserved (major changes)	ringii (rini or octuar)	ringh (with preese size and shape)	High (appears in numerous descriptive and graphic	+	+	+	+	+	+	+	+
14	Tower (baszta)	2	Preserved ruin			sources)	+	+	+	+	+	+	+	+
15	Tower (baszta)	11	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)		-	-	+		-	+	+	+
16	City wall section	3	Preserved ruin				+	+	+	+	+	+	+	+
17	City wall section	5	integrated into an existing	High (Im or better)	High (with precise size and shape)		-		+	+	+	+	+	+
18	City wall section	23	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)	1	-	-	+		-	+	+	+
19	Church	4	Preserved (minor changes)			1	+	+	+	+	+	+	+	+
20	Church	2	Preserved (major changes)	High (1m or better)	High (with precise size and shape)									
21	Church	1	Preserved ruin	1			+	+	+	+	+	+	+	+
22	Synagogue	1	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)	1	-	+	+	-	+	+	+	+
23	Monastery	3 orders (total 10 buildings)	Preserved (minor changes)	High (1m or better)	High (with precise size and shape)		+	+	+	+	+	+	+	+
24	Monastery	1	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)		-	-	+	-	-	+	+	+
25	Other walls (fortified monastery or	7	Preserved ruin	High (1m or better)	High (with precise size and shape)		+	+	+	+	+	+	+	+
26	Other walls (fortified monastery or manor, etc.)	8	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)	Moderate (appears in several descriptive sources)		-	+		-	+	+	+
27	Manor	2	Preserved (minor changes)	High (1m or better)	High (with precise size and shape)	High (appears in numerous descriptive and graphic sources)	+	+	+	+	+	+	+	+
28	Manor	8	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)	Moderate (appears in several descriptive sources)	-	-	+	+	+	+	+	+
29	Brewery	1	Preserved (major changes)	High (1m or better)	High (with precise size and shape)	High (appears in numerous descriptive and graphic sources)		-	+	+	+	+	+	+
30	Brewery	3					-		+		-	+	+	+
31	Pottery workshop	1				Madama (anna 12 anna)	-	-	+		-	+	+	+
32	Foundry	1	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)	descriptive sources)	-	-	+	-	-	+	+	+
33	Public bath	1					-	-	-	-	-	+	+	+
34	Watermill	3					-		-		-	+	+	+
35	Water tower	1	Preserved (minor changes)	_			+	+	+	+	+	+	+	+
36	Remnants of water supply	2	archaeological context			High (appears in numerous	-	-	+	+	+	+	+	+
37	Townhouse	36	Preserved (minor changes)	High (1m or better)	High (with precise size and shape)	descriptive and graphic sources)	+	+	+	+	+	+	+	+
38	Townhouse	27	Preserved (major changes)				-	-	+	+	+	+	+	+
39	Brick house	15	Rebuilt differently			MILLI	-	-	+	+	+	+	+	+
40	Brick house	11	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)	descriptive sources)	-	-	-	-	-	+	+	+
41	Wooden house	3	existing buildings	High (1m or better)	High (with precise size and shape)		-	-	+	+	+	+	+	+
42	Wooden house	25	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)		-	-	-	-	-	+	+	+
43	Outbuilding	2	Rebuilt differently	High (1m or better)	High (with precise size and shape)		-		+	+	+	+	+	+
44	Outbuilding	21	Not preserved	Moderate (10m or better)	Moderate (with general size and shape)	4	-		-	-	-	+	+	+
45	remnants of cellars	6	integrated into an existing buildings				-	-	+	+	+	+	+	+
46	remnants of unknown buildings	3		High (1m or better)	High (with precise size and shape)		-	-	+	+	+	+	+	+
47	Other traces of settlement (potterv.	18	Discovered with precise archaeological context			Low (single references or		·	+	+	-	+	+	+
48	personal belongings, coins)	13	Discovered with uncertain			circumstantial evidence)	-	-	+	-	-	+	+	+
49	personal belongings)	18	archaeological context Discovered with precise	Moderate (10m or better)	Moderate (with general size and shape)		-	-	+	-	-	-	+	+
50	Cloacal pit (with pottery and coins)	2	archaeological context	High (1m or better)	High (with precise size and shape)		-	-	+	-	-	+	+	+
51	Cloacal pit (with pottery)	2	archaeological context	Moderate (10m or better)	Moderate (with general size and shape)	High (appears in numerous	-	-	+	-	-	+	+	+
52	City moat (with pottery and coins)	1	archaeological context	High (1m or better)	High (with precise size and shape)	descriptive and graphic sources)	-	-	+		-	+	+	+
53	Castle moat (with pottery)	1	Discovered with uncertain archaeological context	Moderate (10m or better)	Moderate (with general size and shape)	descriptive sources)	-	-	+	-	-	+	+	+
54	Other findings	17		High (1m or better)	High (with precise size and shape)	circumstantial evidence)	-	-	+	-	-	-	+	+
Core	data - total		1	1		360								
55	Probable settlements (suburbs)	122	Not preserved	Low (10m or worse)	Moderate (with general size and shape)	Low (registered number of houses and owners but no certain location)	-		-		-		+	+
56	Probable settlements (other)	453			Low (no information about size and shape)	Very low (general description only)	-	-	-	-	-	-	-	+
Sup	lementary objects (map only) - total					575	_						-	

Objects	Geographic acc	curacy (location)	Geometric ac	curacy (shape)	Descriptive accuracy (classification)		
	number	account	number	account	number	account	
High	211	22.6%	211	22.6%	203	21.7%	
Moderate	149	15.9%	271	29.0%	67	7.2%	
Low	575	61.5%	453	48.4%	222	23.7%	
Very low	-	0.0%		0.0%	453	48.4%	

Appendix E

Geographic and geometric evaluation of historical data referring to standards of modern spatial data in Poland.

		Reference scale							
		BDO	OT500 or n	aster maps		BDOT10k	Generalized topographic maps		
		Urban area		Rural area					
		1:500	1:1000	1:2000	1:5000	1:10,000	1:25,000	1:50,000	1:100,000
	Error threshold	Terrain a				n accuracy			
Shape	0,15 mm	0.075 m	0.15 m	0.3 m	0.75 m	1.5 m	3,75 m	7.5 m	15 m
Location	1.0 mm	0.5 m	1.0 m	2.0 m	5.0 m	10.0 m	25.0 m	50.0 m	100.0 m
Evaluation of historical data vectorization		High		Moderate			Low		Very low

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