Spatial Analysis in Military Archaeology Research, with Special Regard to the Retrospective Landscape Modelling of Zrínyi-Újvár with Geographic Information Systems

Attila Kállai

Introduction

The GIS-based analysis of geographic factors relevant to historical research, and the digital modelling of the position and environment of artefacts became widely available to the researchers of this field in the 1990s.[1] The spread of technical equipment complying with high computational and graphic resource requirements also affected professions and disciplines employing spatial analysis. Archaeology soon recognised[2] the potentials of GIS, and exploited its vast data storage, data processing and analysing, as well as diverse visualisation capacities, and also utilised algorithms and tools capable to analyse the relationships of spatial phenomena.

Geographic Information Systems (GIS) is an interdisciplinary tool and method focusing on the characteristic, determinant and essential components of space. It has contributed to the development of many professions and disciplines, and due to the synthesis of informatics and Earth sciences, it makes possible the development of new concepts and methods. It is uniquely suited for modelling space, for the complex, analytical determination of its components, as well as for developing IT systems focusing on a diverse set of tasks in collecting, managing, processing, analysing and displaying spatial data.

In the following, we are presenting the possibilities of applying the currently available GIS toolbox in archaeological research (including military archaeology) through some specific examples for application. Of the numerous ways of application, this time we highlight retrospective GIS modelling, a relatively rarely employed method, which can also be used in military archaeology with great success.

The tools of Geographic Information Systems

Collecting, analysing and displaying geographically located spatial data had already existed before the introduction of GIS. It was an activity performed at a high level, with the use of an extensive array of tools and methods. The traditional mapping methods and cartographic

1 *Connoly–Lake* 2006.
2 The first examples of practical applications appeared in the early 1990s. Ibid. 7–8.

https://doi.org/10.36250/00757_09

tools have always provided the necessary conditions for performing the tasks of spatial navigation, planning, organisation, leading and controlling by meeting the requirements of visualisation and spatial data communication, that is, functioning as a part of expert systems.

Mapping is a highly developed abstraction capability unique to the human race, the first manifestations of which are contemporary to the emergence of the early civilisations. Maps not only enabled orientation and the identification of landmarks (and still do so), but also a structured spatial thinking, or (in today's parlance) the making of spatial decisions.

In the historical development of cartographic representation, a number of significant technological milestones have led from the depictions on the Mesopotamian clay tablets to the development of modern mapping techniques. The flat representation of the Earth's curved surface, the depiction of dynamically changing phenomena, or even the mapping of the terrain can only be partially fulfilled with traditional representation techniques. Nevertheless, the toolbox of cartography, which have been refined over the centuries, have proved to be sufficient to reflect the characteristic features of the geographical space in a measurable, assessable and analysable way.

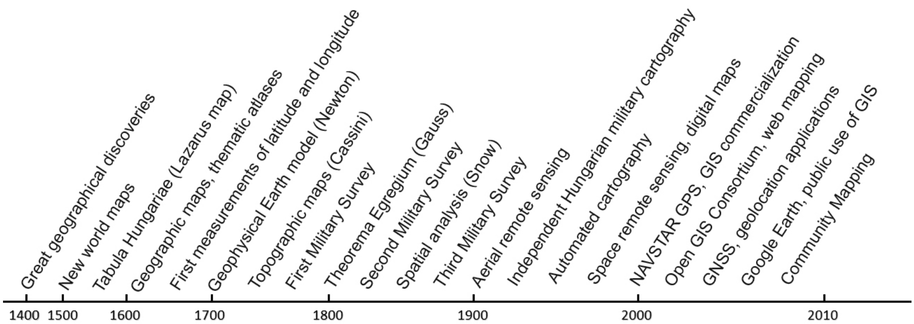

Figure 1.

Major milestones in the historical development of cartography and GIS

Source: compiled by the author

Information revolution beginning in the second half of the twentieth century transformed, or at least significantly affected all areas of fundamental human activities due to the emergence of infocommunication technologies and digitalisation, and later due to the emergence of an information sharing network. In a relatively short period of time, fundamental changes have occurred in the processing, storage and sharing of information, which have led to the birth of the information society, forming a new milestone in the development of human civilisation. The structure of this type of society is characterised by the fact that all its fundamental elements (production, economics, commerce, political organisation, public administration, communication, culture, etc.) are interwoven and determined by the importance of information, the central role of information technology, the direct and rapid access to information, and, ultimately, by a strong dependence on them.

The information revolution inherently affected the development of *cartographic communication,* too. By the last millennium, it has become evident that – because of their being a static medium for information recording – analogue, traditional paper-based maps will not be able to meet the challenges of the exponentially increasing amount of information in a dynamically changing environment in the digital era. Apparently, *digital maps* represent the solution to an advanced management of spatial data, but this concept has now a number of significantly different interpretations, depending on which expert system uses them. The digital modelling of geographic space has led to various development branches, which have gained, and still have a new, integrative meaning within a unified systems theory of GIS.

Digital terrain models[3] were the first representatives of the geographic space modelling for defensive purposes. Their raison d'être increased when manoeuvring aircraft capable of following the land surface appeared in the 1970s. Afterwards, they became more widely used in the field of studying the terrestrial radio wave propagation,[4] followed by various land relief analyses. Digital terrain models are of paramount importance in all terrain-related tasks with defensive purposes, whether they are terrain passability surveys, modelling for inundation with water, simulation exercises for destroying terrestrial targets, planning communication links, signal propagation modelling for radio-electronic combats (detection, interference), the efficiency analysis of ABC weapons, as well as studying the spread of polluting materials.

The *Digital Surface Model*[5] is a more advanced version of the terrain model, which not only represents the terrain ruggedness but also the land coverage with a good approximation. In other words, it shows the vertical dimensional properties of all relevant and permanent cultural features along with the geomorphological features. Digital surface models extend the analytical capabilities of digital terrain models by considering the real-world visibility conditions of the terrain and other obstacles to the passability of the terrain. Furthermore, they make possible the analysis of those characteristics of the terrain that affect the electromagnetic imaging in addition to the optical visibility. Digital terrain models offer a three-dimensional, realistic visualisation of the terrain by combining the data of high-resolution digital images made of the terrain and the real-world surface forms of features *(Figure 2).*

---

3 In Hungary, the abbreviation DDM is used, but in international terminology the technical term *Digital Elevation Model* (DEM) is applied. It is also worth mentioning the term *Digital Terrain Model* (DTM), as well. Its Hungarian translation ('digitális terepmodell') may be ambiguous, as the terrain ('terep') and the terrain model ('terepmodell') based on this refer to the ground surface together with the natural and cultural features on it. The difference between DTM and DEM is that the former is enhanced with the breaklines of defining terrain features (drainage divides, catchment basins, benches, inflection points and lines) that are particularly important in *Cross Country Movement* (CCM) surveys.

4 In Hungary, the Experimental Institute of the Post Office (*Posta Kísérleti Intézet,* PKI) made the first national digital terrain model in the 1970s under the name DTM-200 for designing telecommunication networks.

5 The term *Digital Surface Model* is used widely in international terminology and it is abbreviated as DSM.

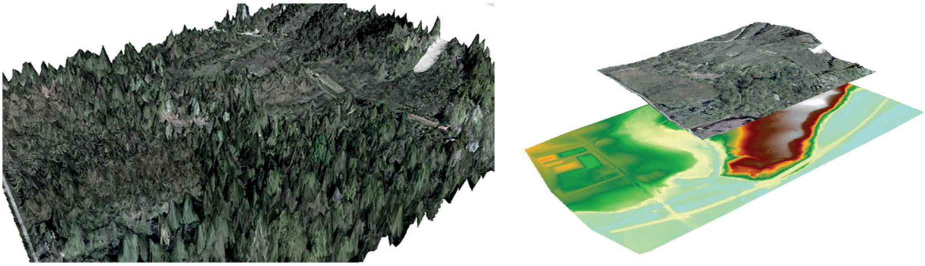

Figure 2.
Digital modelling of the same territory based on the elevation data of the real land surface and geomorphological features found in the research area of Zrínyi-Újvár
Source: compiled by the author based on the LIDAR[6] survey data collected by the Remote Sensing and Rural Development Institute of the Károly Róbert University College in 2013

One of the biggest challenges of designing digital surface models is the changeability of surface objects. In case of digital terrain models, we do not encounter such a problem because geomorphological features are the most static elements of the terrain. A significant part of the surface objects, on the other hand, undergo varying degrees of transformation over time. These changes demand the updating of digital surface models from time to time so that we could gain accurate information about the real elements of the terrain during defence uses.

High-resolution *digital images* are also significant elements of making a virtual reconstruction of the terrain. In GIS, these are *raster map datasets*[7] created with state-of-the-art remote sensing tools. In practice, remote sensing datasets normally comprise various digital aerial photographs, satellite imagery, LIDAR, SAR and other types of radar imagery. By changing the width and complexity of the imaging wavelength range (infra-, multi-, and hyperspectral imaging) hidden features of the geographic space can also be detected *(Figure 3).*

6 LIDAR stands for *Light Detection and Ranging,* which is a remote sensing method using light in the form of a pulsed laser for detection. Its operating principle is based on the fact that laser beams are concentrated and have a uniform wavelength, which is well suited for measuring ranges (that is, variable distances) between the instrument emitting the light pulses and the solid surface to be scanned and, thus, for detecting the relative differences of the height of the surface. LIDAR technology can be used effectively in the field of GIS data collection for the rapid survey of geographically rugged terrain, especially when it is covered.

7 They are the main components of digital mapping databases that capture the characteristics of the Earth's surface in a grid model structure. Concerning the geometry of the grid, raster data models with a square grid structure are the most common in GIS systems. However, tessellation grid models with other shapes also exist. A specific part of the grid element carries the characteristics of the terrain typical of that grid element. The grid structure consisting of the grid elements and the complex data make the raster dataset itself. If this dataset also comprises image data, then the grid elements are the pixels (i.e. elementary units) of the given digital raster image.

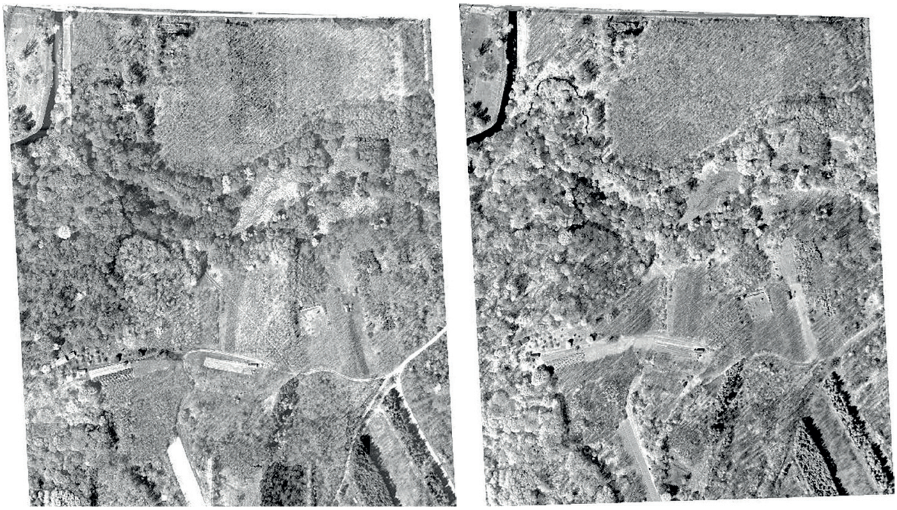

Figure 3.
The panchromatic and near-infrared (NIR) aerial images of the excavation area of Zrínyi-Újvár
Note: Infrared light is scattered less due to the humidity of the air, which makes some terrain features appear much sharper. Water surfaces are particularly easier to identify.
Source: compiled by the author based on images made by the Remote Sensing and Rural Development Institute of the Károly Róbert University College using a Leica RCD30 airborne camera with 60 megapixel resolution

Colour and multispectral satellite images with a resolution of a few metres are advantageous for general surveys of larger areas and the partial exploration of certain geographical factors. Panchromatic satellite images, according to current technical development, are capable of displaying the Earth's surface with a resolution of less than one metre, which is sufficient for the topographical investigation of geological landforms of medium and large size.[8] At the same time, in the case of archaeological research, a great emphasis is placed on studying the micro-relief of the surface. The detection of even a few centimetres of difference in height can be useful in the discovery of morphological features that are partially or wholly below the ground, if they can be observed over large distances or areas. Therefore, in case of detailed geomorphological surveys, remote sensing – and within that the LIDAR technology that is capable of exploring the micro-relief features of the terrain – can provide satisfactory conditions for data collection.

For this reason, aerial remote sensing – especially LIDAR technology that is capable of exploring the characteristics of micro-relief – provides satisfactory conditions for data collection for detailed geomorphological investigations.

8 Based on the technical data published in the first half of 2019 by the currently leading commercial remote sensing data providers (Airbus Defense and Space – www.intelligence-airbusds.com; DigitalGlobe – www.digitalglobe.com; SI Imaging Services – www.si-imaging.com; SpaceWill – en.spacewillinfo.com).

Nevertheless, satellite remote sensing has the advantage of offering relatively frequent periodicity, as a result of which multiple recordings of the same areas may be available from different times. The number of Earth observation satellites has increased in linear proportion to the cost-effectiveness of satellite technology. The current development trends of larger companies interested in producing satellite imagery point towards the possible availability of weekly or even daily updated satellite images covering the entire surface of the Earth. Keeping track of changes in geographical factors, and defining trends and processes, is a major issue in GIS – as we will see further on.

It is important to know, however, that raw data files obtained through different image capturing methods need to be subjected to complex *image processing transformations* so that they would have all the radiometric and geometric features, which make them usable for GIS purposes. Users normally get remote sensing datasets modified by image corrections in a digital georeferenced raster image format, but certainly, there is also a possibility to create traditional (paper-based) orthophotos.

The availability of the GIS data models listed above is an essential but not sufficient condition for establishing the conditions of the objective and authentic evaluation of geographical factors (whether natural, social, economic, or defensive). A comprehensive spatial analysis, taking into account all relevant geographical factors, requires a much more abstract approach of the geographical space. This can be accomplished through the process of GIS modelling, where first the theoretical, next the logical and then the physical models of geographical features must be designed. The model created in this process is a simplified, abstract representation of geographical space, which can highlight the distinctive, characteristic features of spatial processes and phenomena through the toolbox of GIS.

The construction of the theoretical model begins with defining the entity, the basic unit of mapping. This includes the geometric (size, position) and descriptive (attribute) properties of the entity, as well as its relationships and the possible classification of the same types of entities. The criteria to be met during model building include, but are not limited to, simultaneity, clarity, required level of detail, positional accuracy, compliance with reality, actuality, compatibility, as well as the management of rights.

During GIS modelling, the abstract simplification of space is also extended to spatial dimensions. While the exact positions of entities and objects in a logical model are well-defined according to the depth of the modelling, their representation entails a loss of dimension. Spatial modelling can thus produce 2-, 2 + 1-, or even 2.5-dimensional models.[9]

The use of GIS models is primarily advantageous in the exploration and analysis of the operational mechanisms of multi-factor, geographically-related, complex systems, and in studying the interactions between the components of the system. Modelling itself, however, is a lengthy and costly process, although – by speeding up complex analysis operations to a great extent and by enhancing their complexity tolerance – ready-made models could make decision-making processes more cost-effective and significantly more operational than traditional methods. The use of the conditional mode is particularly valid here, as the criteria above depend on the appropriateness of the model. Nevertheless, it is not possible to design a model that is perfect in every respect. The model itself is the result of abstraction, that is, a simplified, typified and generalised copy of reality. The suitability of the GIS model

[9] *Detrekői–Szabó* 2013.

is ultimately determined by the results of the analyses. Increasing their appropriateness is one of the key aspects in modelling.

In the light of the above, it can be said that GIS has a fairly rich toolbox to answer the questions raised in applied sciences. These questions are, obviously, related to the investigated space, and belong to five main groups of questions according to the present state of the discipline:[10]

1. Location – What is located at a particular point?
2. The state and circumstances – Where is a given thing found? Where is a given condition fulfilled?
3. Changes, trends and processes – What has changed, to what extent and due to what interactions?
2. Basic questions concerning distribution and patterns – What relationships are there between the groups of phenomena or entities with a spatially variable distribution/pattern?
3. Modelling spatial and temporal processes, which allows understanding the real causes and possible courses of the processes, and exploring their consequences.

In the context of GIS analyses, the term digital map typically does not refer to the digital copy of a traditional paper-based map, but to the graphical representation of digital cartographic databases modelling a geographical area and the digital dataset that it is based on. The main characteristics distinguishing digital maps from conventional (analogue) maps are, accordingly, as follows:

- the data of geographical space, including the reference systems used (geodetic base, elevation data, projection system, coordinate system) and the visualisation are separated, and these data are no longer included in the map
- the density of data and the level of the definition of entities are decisive rather than the scale of the map
- the top view and projection of the map are no longer essential requirements, and both the position of the viewpoint and the features of the mapping can be dynamically changed during the visualisation

In case of digital maps, the data are stored in a structured manner, typically in a digital mapping database, and the visualisation can be dynamically generated by means of querying, as well as analysis tools and methods. In contrast, conventional (analogue) maps implement the storage and representation of cartographic data on a single surface, on the material of the map itself, in a static manner. In terms of their format, digital maps can be raster, vector and hybrid. In digital cartography and GIS, their practical applicability depends on data exchange standards.

[10] *Detrekői–Szabó* 2013.

Using GIS in military archaeology

Every discipline dealing with spatial phenomena and geographical factors requires accurate and efficient solutions for managing spatial data. A basic requirement for these investigations is the capability to handle large masses of spatially-related data of diverse format obtained from various archival sources and field surveys in a common structure available for analyses. Another important aspect is the reliable archiving capability, which not only offers a higher level of data security than traditional systems of data storage and management, but also makes possible the quick querying of data, and the preparation of summaries and analyses. The state-of-the-art IT solutions used today comply with all these requirements.

The involvement of GIS tools into military archaeological research is particularly reasonable because of its numerous advantageous features. Among these, special mention must be made of the multifunctional and flexible applicability due to the digitisation of spatial data and the ability to process and manage large amounts of field data efficiently. This flexibility makes possible the performance of many complex analytical operations on spatial modelling that could not have been carried out with conventional cartographic techniques at all, or only with the help of lengthy editing and computation methods. The variation of basic parameters and environmental factors allows for more sophisticated modelling procedures than ever before.

The problem of managing a vast amount of data yielded by archaeological excavations is by no means negligible. Computer-aided processing provides lots of effective solutions for unified and convenient data recording and storage methods.[11] GIS, however, not only supports the recording of data sets yielded by archaeological excavations, but also highlighting complex inter-linkages and carrying out detailed assessments through the spatial analysis of data. The rapid development of information technology and the availability of increasingly sophisticated devices have led to the emergence of new research objectives and analytical capabilities, such as:

- a detailed and accurate spatial location of points marking the shape of features investigated during archaeological excavations
- fast recording and efficient management of the spatial data of artefacts occurring in large numbers
- marking points and lines (boundaries, directions, etc.) in the field
- calculating the volume of the extracted soil for engineering works, as well as the water-holding capacity of major depressions and catchment areas
- comprehensive survey of the relief and main features of the terrain, and, based on this, the design of a detailed terrain model
- studying visibility from one point of the area to another, the visibility of areas, the movement of surface water, the exposure of slopes, and erosive processes, based on the terrain model
- marking out areas for archaeological excavations and planning the preparation of field work

[11] *Eke–Frankovics–Kvassay* 2007.

It is no exaggeration to say that the GIS toolbox not only represents a qualitative step forward for archaeologists in the collection of primary (field) and secondary (archival) data, and in the methods of data processing and presentation, but it has also affected the way they think about geographic space. For this reason, it should be regarded as a scientific method rather than a simple technical tool.

One of the first examples of military archaeological investigation in Hungary is the GIS reconstruction of extensive fortification systems (the Árpád Line[12] in the Eastern Carpathians, and the Attila Line[13] to the east of the capital) built by the Royal Hungarian Army for defensive purposes during the Second World War. Furthermore, mention should be made of the special method for data collection[14] employed in the underwater archaeological survey of the Austrian barge that sunk at Gönyű in 1849, as well as the GIS-based investigations carried out in the region of the Szigetvár fortress *(Figure 4).* Last but not least, GIS was also used to support the excavation and reconstruction works[15] in the area of the fortress built by Miklós Zrínyi, poet and military leader, near the confluence of the Mura and Drava, which is also the main topic of the present collection of studies.

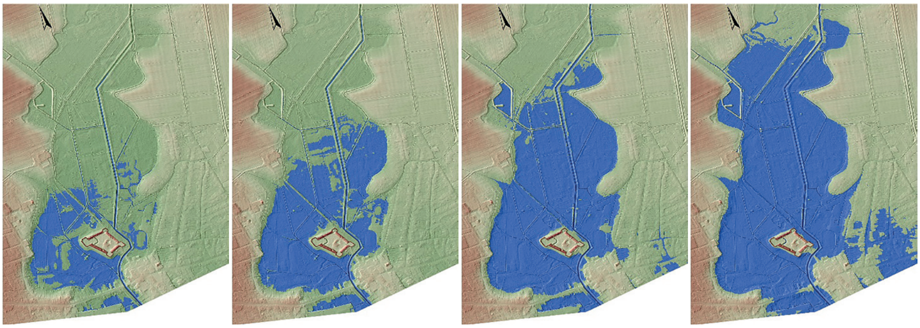

Figure 4.

Some phase images of the animation made during modelling the flooding of the area around the fortress of Szigetvár

Source: compiled by the author based on the LIDAR survey data collected by the Remote Sensing and Rural Development Institute of the Károly Róbert University College

All the components of the GIS workflow described above are present in military archaeology. These will be highlighted in the following through some specific practical examples, especially through the tools and methods used in the military archaeological investigation of Zrínyi-Újvár.

12 *Szabó* 2005.
13 *Juhász–Mihályi* 2003. 33–37.
14 *Polgár–Schmidtmayer* 2013. 167–176.
15 *Hausner–Négyesi–Padányi* 2012. 189–218.

Spatial data acquisition

Data collection for GIS purposes involves the identification of all those geographic features that may be important for modelling, the subsequent GIS analysis and the presentation of relevant geographical factors. Spatial data collection is a rather complex system of procedures, but it can be clearly divided into two main types.

The first type involves direct or *primary GIS data capture techniques,* which are used mainly when little or no initial cartographic data are available about the subject of the study (i.e. the region to be explored), and their reliability is poor due to their outdated character and the known inaccuracies in previous data collection. In such cases, it is advisable to choose such primary data collection methods or techniques that are the most relevant for all the aspects of the study.

Direct data capture techniques are normally technology intensive and, consequently, quite expensive. This way of data acquisition requires the most up-to-date technical methods. The use of inappropriate procedures can generate a significant number of unnecessary or *redundant data* that will not provide useful results during subsequent analyses. On the contrary, increasing the need of data processing capacity will reduce the operational efficiency of analytical work processes. With regard to the high costs of primary data capture techniques, it is particularly important for military archaeological investigations to formulate clear and clean-cut research hypotheses, as well as to plan and prepare the work carefully.

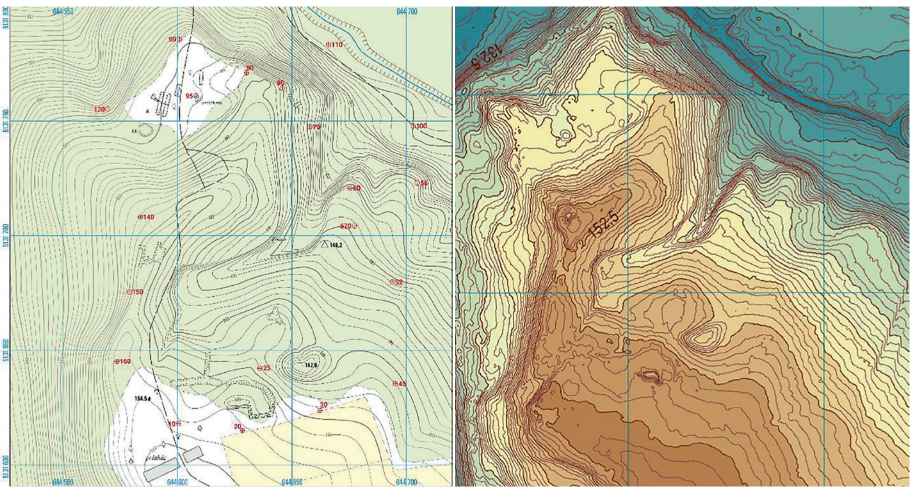

Figure 5.

The results of the excavation of Zrínyi-Újvár surveyed with traditional methods and remote sensing processes based on LIDAR technology

Source: compiled by the author

There are a wide range of primary data collection methods, the representative components of which are the geodetic survey stations, GNNS-based[16] survey methods, normal, spectral and multispectral image recorders, laser (LIDAR) and radio-wave (SAR[17]) scanning detectors, as well as mobile mapping systems. These devices can be operated with a markedly different set of conditions, operativeness and accuracy. The results obtained also differ significantly. In general, the greatest number and most diverse spatial data within a given unit of time are provided by remote sensing technologies, which can be combined or complemented, if necessary, with ground survey techniques. At the same time, we also need to take into account the significant cost implications of remote sensing devices,[18] the impact of periods and parts of the day suitable for remote sensing, and other constraining factors (for example, weather), as well as prohibitions on the use of airspace.

Indirect or *secondary GIS data capture techniques,* on the other hand, ignore the indirect collection of spatial data, which may have two main reasons. The conditions for the use of primary data collection do not exist, while an adequate number of and good quality maps and geographic data are available. Furthermore, geographical data collection has a retrospective character, that is, it studies the expression of environmental features in the past.

Secondary methods are cost-effective and can be easily automated with appropriate cartographic materials, but their accuracy and credibility depend on the quality of the source data. The correlation of cartographic solutions used in traditional map representations with the entities of theoretical GIS data model and the relations between them represents a significant problem. A typical case of this is the depiction of crossings over water. In traditional cartographic representations, the map reader can interpret the relationship between these two topographic features (watercourses and overland roads), even if they do not get the appropriate graphical expression (bridge, tunnel, ferry, shallow, etc.). By contrast, a GIS database creates a logical connection between two entities suitable for subsequent analysis (and in this way another entity to which attribute data can be assigned) if the database topology comprises this connection. A simple vector graphic conversion of traditional linear map representations, the result of which is aptly called a spaghetti model, is thus unsuitable to serve as a basis for complex GIS analyses.

The fulfilment of spatial data requirements of military archaeological investigations normally begins with indirect GIS data capture methods, whereby the available archival data are selected and then digitised. The raw materials used are mainly contemporary maps or other map-like depictions and sketches, which must be handled with appropriate source criticism. In case of large-scale cartographic representations, no projection corrections

16 *Global Navigation Satellite System* (GNSS) is a collective term applied to all positioning systems based on artificial satellites.

17 *Synthetic Aperture Radar* (SAR) imaging is a radio detection and ranging technique measuring the relative position of the radar device and the surface (e.g. the Earth's surface). In the case of SAR-based radio remote sensing, the image of the observed part of the terrain is made up of signals collected by multiple sensors or by one sensor that is in motion.

18 Digital devices suitable for taking aerial photographs for mapping purposes cost a nine-digit sum, while the LIDAR detection devices cost an eight-digit sum in Hungarian forints. Furthermore, the flying hours and the surveys of a few hectares cost seven-digit sums. In contrast with ground survey procedures, however, they are able to collect data quickly, which are suitable for various analyses.

were applied until the eighteenth century. Consequently, the maps show varying degrees of geometric distortion. These are not evenly distributed in the map content, and in some cases even the adjacent map sections do not match exactly *(Figure 6).*

At these times, it was a common practice in military engineering to depict the sites of clashes and battles in a clinogonal (cavalier) or military perspective – especially when they took place at fortifications. If this was done according to the rules of axonometric projection representation, the planar projection transformation of the depictions can be carried out during secondary data acquisition. However, most of the manuscript map sketches did not closely follow these rules, and they did even attempt to show the fortresses with a correct shape. The obvious reason for this was that not all imagery was based on a preliminary survey, so the sketchers relied on oral information and their own imagination when drawing the map sketch.

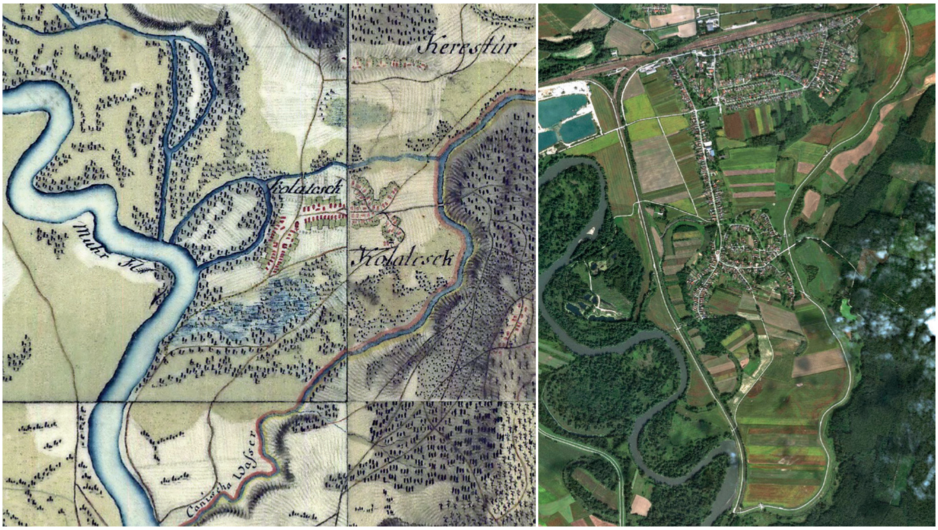

Figure 6.

A detail of four adjacent map sheets (IV-16, IV-17, V-22 and V-23) of the First Military Survey from 1784 compared to the satellite image of the same area

Note: It is characteristic of the cartographic works of the First Military Survey that the map sheets were fit to one another without any projection system or geodetic calculations, which resulted in major errors in the adjustment of the map content. These errors are rectified graphically, which along with changes of the terrain, makes the georeferencing of the base material difficult.

Source: compiled by the author based on the Első Katonai Felmérés – Magyar Királyság [First Military Survey – Hungarian Kingdom] (DVD-ROM, Arcanum, 30 September 2004), as well as satellite image (ArcGIS Basemap Online)

Data processing and analysis

Military archaeological investigations typically begin with secondary GIS data acquisition, during which all available archival and state data are processed with an appropriate level of source criticism. Various military engineering and other sketches of Zrínyi-Újvár have been found in the archives. Due to the short-lived existence of the fortress (1661–1664), relatively few authentic engineering images have remained about it. Of these, the sketch found in the legacy of Count Pál Esterházy (1635–1713) seemed to be the most suitable material in terms of its elaboration and detail *(Figure 7).*

Due to the structural features of the fortress, the brittleness of the building materials used, the total destruction of the fortress after its seizure, the subsequent agricultural cultivation, as well as the earthmoving works connected to the fortification system erected on this site in the 1950s, there was little hope that the walls of the fortress would be found. Consequently, during the excavation of the fortress the indirect methods of battlefield investigation came to the fore. In this, we determined the position of the key points of the defensive walls by identifying the traces of the siege instead of that of the fortress itself.[19]

One of the most important tasks of data processing arising during secondary GIS data capture is *georeferencing,* that is, placing the digitised spatial representations in the appropriate reference system. In each case, the GIS database defines the geometrical characteristics of landscape features (their shape points and extension) according to a known spatial reference system based on mathematical rules. Nevertheless, the currently widely known and standard geometric reference systems were not available in all ages. Therefore, going backwards in time, more and more geometric irregularities can be encountered during data processing. The solution to eliminate irregular geometric distortions, besides source criticism mentioned above, is offered by the unique transformation procedures that often require lengthy processing.

For a detailed study of the terrain, neither the military nor the civilian topographic maps of the largest available scale (1:25,000 and 1:10,000, respectively) were adequate. Due to their relatively small scale and outdated data content, these raw materials could therefore only be used to overview the area. Data from a topo-geodetic survey conducted from 2006 to 2009 served as a basis for the detailed modelling of the fortress and its foreground. The reliability of the data was strongly affected by the circumstances of the survey, such as the highly fragmented character and land coverage of the surveyed area, the repeated one-week long field surveys in summer, as well as the involvement of students of military cartography as part of their summer apprenticeship. Against this background, the size of the area surveyed from the 35 small base points set up in the field was already over five hectares by 2009.

[19] *Négyesi* 2013 and *Hausner–Négyesi–Padányi* 2012. 189–218.

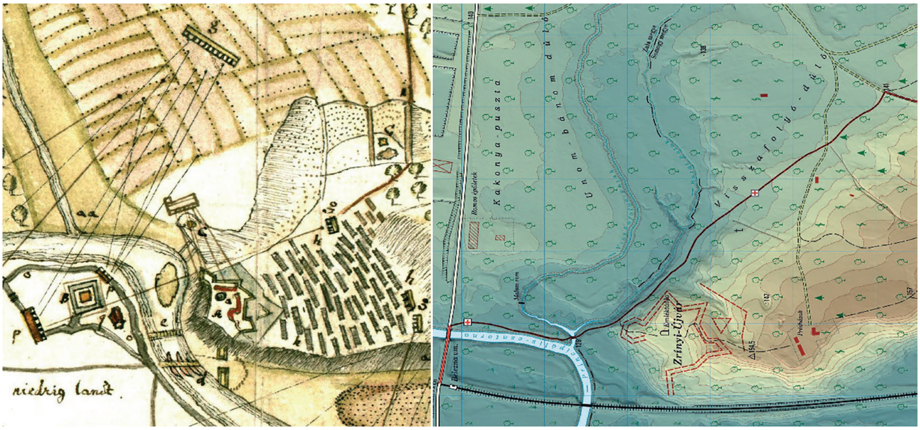

Figure 7.

Detail from the sketch depicting the 1664 siege of Zrínyi-Újvár and the map made in 2014 on the basis of direct field survey of the same area

Source: sketch by Master M. I. O. (?) from the legacy of Count Pál Esterházy (1635–1713), MNL OL T. 2. XXXII. 1064, as well as compiled by the author

However, further ground survey of the area did not seem to be reasonable. It became increasingly evident that the errors in measuring the elevation, which were significantly greater than errors in horizontal measurements, could no longer be effectively eliminated by methods used until then. In order to survey the terrain uniformly and with minimal distortion, a more accurate method had to be found.

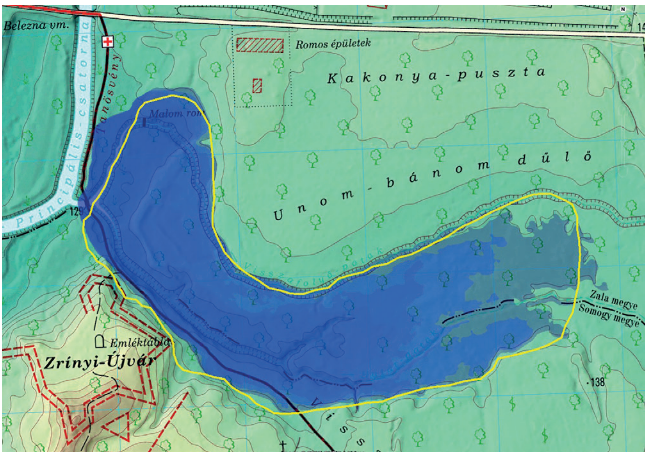

Figure 8.

Investigation of the extent of the flooded area defending the fortress from the north-east

Note: The yellow line is the hypothetical boundary based on archival data, while the size of the blue patch is the result of terrain modelling

Source: compiled by the author

In 2013, it was possible to employ LIDAR technology in the archaeological investigation of Zrínyi-Újvár supported with GIS methods. Not only did laser scanning of the area result in a more reliable and accurate data set of the terrain, but it also made possible to carry out detailed field modelling tasks that we had not done before or with insufficient reliability. Of these, special mention must be made about the investigation of the extent of the lake to the north and north-east of the fortress the water level of which was artificially raised before the siege. As a result of this, we gained a reliable picture of the size of the flooded area and the possible location of the Ottoman siege bases *(Figure 8).* A similar research was made about the firing efficiency of the guns of the Ottoman troops arriving from the south-east during the siege of the fortress.

The potentials of retrospective modelling in military archaeology

The modelling potentials of GIS cover not only the spatial relationships of the real world, but also time that is defined as the fourth dimension. Changes in geographical factors and the trends and processes that can be deducted from them are at the focus of archaeological research. Granting special attention to time in GIS modelling has many advantages. As an attribute connected to spatial data, it provides information on whether the data are still relevant or outdated. It also makes possible the identification of topological anomalies by making the content correctness of spatial databases of adjacent and overlapping territories with different time reference verifiable. Furthermore, it renders the dynamic changes and processes occurring in space and time clearly detectable, assessable and analysable.

The most common applications of GIS analyses considering time factors are the *predictive* or inferential analyses. The predictive analytical method is based on the premise that – in terms of their geographical position – the distribution of spatial data from the past is not even, but not even random, but determined by relevant geographical factors. As such, is suitable to define the distribution or the probability of the occurrence of events based on conclusions and predictions concerning possible future patterns.

During the predictive modelling of spatial events, there are fundamentally two methods to determine the probability of the occurrence of a certain element. If the qualitative characteristics describing a given element – which are compatible with the exact parameters of the geographical space (slope, exposure, coverage, soil type, etc.) – are available, the distribution pattern of this element can be determined (predicted). This is the so-called *deductive modelling* process whereby basically subjective quality evaluations are emphasised. Consequently, the professional relevance of the analyses is of paramount importance for drawing the right conclusions. In contrast to the deductive modelling process, *inductive modelling* is a method of examining the spatial relationship of the occurrences of certain elements in the past and geographic factors, which can be traced back to empirical facts. In the case of this method, predictive modelling is based on conclusions drawn from statistical regularities instead of subjective assessment by an expert.[20]

[20] *Beauvais–Keinath et al.* 2006. www.uwyo.edu/wyndd/_files/docs/reports/wynddreports/u06bea02wyus.pdf (Accessed: 19 December 2018.)

Both methods make possible for us to draw predicting conclusions from past data. However, this is not always the goal. In the archaeological application of GIS, we try to open up perspectives in the inverse of the time scale, that is, to reconstruct past events and the environment. The purpose of retrospective GIS modelling is to detect inevitable changes in the geographical environment compared to an assumed starting point, and to analyse its interactions with other factors under investigation.

The input data of retrospective modelling (qualitative and quantitative features of the finds, their spatial distribution and interrelationships), as well as the characteristics of the geographical environment make it possible to employ fundamentally deductive and inductive modelling methods, similarly to predictive modelling methods.

In the field of retrospective modelling, the greatest challenge is inherently exploring changes in the geographical environment. In the case of Zrínyi-Újvár, due to the explosion of the fortress by the Ottomans on 7 July 1664, and the subsequent destruction lasting three days, the ground surface of the fortress and its surroundings transformed significantly. The surface changed further due to soil erosion caused by rainfall (and to a lesser extent by wind), which mainly affected the ground surface uncovered by vegetation, and that was exacerbated by the relief (e.g. steep slopes).

The area surrounding the Mura–Drava confluence is one of the rainiest regions in Hungary. Its amount of precipitation is normally above the national average. Of course, we do not have reliable data concerning the precipitation conditions existing centuries ago, but it is reasonable to assume that soil erosion was – at least initially – a determining factor in shaping the landscape. It was only the intensive cultivation of vineyards in the area that could bring an end to this erosion, which – according to the testimony of the 1784 map sheet of the First Military Survey – was already carried out on the hill stretching from the projection of the demolished palisade towards south-east, along the Mura, as long as Látóhegy (‘Watching Hill’) belonging to Zákány. Maps from later periods also show signs of viticulture, which has preserved the terrain features of the ground surface to some extent. A major decrease in the cultivation of the area was brought about by the new frontiers of the country stipulated by the Treaty of Trianon, which was further lessened by the establishment of the frontier defence system after World War II. The vineyards were gradually replaced by a naturally-developing forest. Afterwards, the ground surface did not change considerably.

The walls of the palisade fortress, as well as the remains of its inner and outer structures were investigated by several methods (trench excavations, geoelectric soil resistivity and ground penetrating radar surveying), while taking into account the position of finds connected to the final battle shown on planimetric maps and relative to the surface level. The results of the LIDAR survey revealing the detailed geomorphological map of the landscape helped us connect distant pieces of the puzzle.

Summary

The development of information technology over the past two decades has also had an impact on military archaeology. Due to this development, researchers need to cope with much more detailed and diverse sets of data. Information technology offers full-fledged procedures for the processing of these data. In terms of spatial analysis, geographic

information systems provide effective support from data collection and management to building a model environment and performing complex evaluations, simulations.

Extensive technical support is now available for designing one or more possible variations of landscape image, tailored to a given period or even a specific time. Retrospective modelling tools necessary for the virtual development and transformation of the terrain, vegetation, and hydrographic features of the investigated area provide immense help for the reconstruction of past conditions from current data. Due to the necessary geographical, geomorphological, and topographical data, these can create an environment close to reality for the reconstruction of certain features or events.