3D GIS REKONSTRUKCIJA MADŽARSKEGA JUŽNEGA OBRAMBNEGA SISTEMA

3D GIS RECONSTRUCTION OF HUNGARIAN SOUTHERN DEFENCE LINE

Attila Juhász, Árpád Balogh

UDK: 004.414.23:659.2:91(439)
Klasifikacija prispevka po COBISS.SI: 1.04
Prispelo: 12. 3. 2024
Sprejeto: 3. 6. 2024

DOI: 10.15292/geodetski-vestnik.2024.02.211-222
PROFESSIONAL ARTICLE
Received: 12. 3. 2024
Accepted: 3. 6. 2024

SI | EN

IZVLEČEK

Tehnologije daljinskega zaznavanja in GIS so postale učinkoviti pripomočki za rekonstrukcijo objektov in dogodkov vojaške zgodovine. V naši raziskavi smo uporabili lasersko skeniranje v povezavi z zgodovinskimi podatki za podrobno rekonstrukcijo značilnega dela madžarskega južnega obrambnega sistema. Ohranjeni objekti sistema so dobro dokumentirani in v dobrem stanju, vendar pa nekdanje vojaške karte zagotavljajo le približne položaje in smeri sovražnikovega ognja. Danes objekte prekriva gosta vegetacija, zaradi česar je dostop do njih otežen, za pridobivanje podatkov o njih smo tako uporabili združene podatke zračnega in terestričnega laserskega skeniranja. Postopek 3D rekonstrukcije obrambne linije je imel dva glavna cilja. Prvič, primerjati rekonstruirane objekte in njihove prvotne načrte na podlagi 3D CAD modelov, pridobljenih iz terenskih podatkov. Drugič, izboljšati nekdanje vojaške taktične karte, vključno s položaji in usmeritvami objektov, z vključitvijo 3D modelov v digitalni model terena območja, pridobljen iz podatkov zračnega skeniranja. Posledično so bile primerjane dimenzije in stanje objektov, obrambna struktura, predstavljena na nekdanjih taktičnih kartah, pa je bila izboljšana. S predstavljeno metodologijo bi lahko rekonstruirali celotno utrjeno linijo, kar bi lahko uporabljali za zgodovinske, izobraževalne, arhitekturne in turistične namene.

ABSTRACT

Remote sensing technologies and GIS have become everyday practice in military historical reconstruction. Our research employed laser scanning survey in conjunction with historical data to execute a detailed reconstruction of a common part of the Hungarian Southern Defence System. The system's remaining objects are well documented and in good condition. However, the previous maps only provide approximate positions and fire directions. Currently, the objects are covered by extremely dense vegetation, making surveying particularly difficult. To overcome these challenges, both airborne and terrestrial laser scanning data collected and integrated. The 3D reconstruction of the defensive line had two major objectives. Firstly, to compare the reconstructed objects and their original plans based on 3D CAD models derived from in-field data. Secondly, to improve the historical military tactical maps, including object positions and orientations by the integration of 3D models into the digital terrain model from airborne scanning data. Finaly, the dimensions and the condition of the objects were analysed, and the defensive structure appearing on historical tactical maps was improved based on the surveyed data. The described methodology has the potential to reconstruct the entire fortified line, which could have archaeological, educational, architectural and tourism applications.

KLJUČNE BESEDE

vojaška zgodovina, 3D rekonstrukcija objektov, združevanje podatkov laserskega skeniranja, 3D analize

KEY WORDS

military, 3D object reconstruction, LiDAR data integration, 3D analysis

1 INTRODUCTION

The investigation of military events and objects of the 20th century is still a widly studied topic around the world. Many publications are focusing on detecting (George et al., 2019), reconstructing (Jucha W et al., 2021) or reusing (Luke, 2020) of these fortifications. A considerable number of studies have been published about World Wars and the Cold War, even in Hungary (Juhász and Neuberger, 2018; Balatoni, 2021). Precise and engineering maps and visualizations of the studied sites and events are essential parts of these publications. Geoinformatics and remote sensing technologies provide solutions for reconstructing military historical objects and events (Kobiałka, 2017; Christopher et al., 2013). Regarding data sources, the archive data such as maps, aerial photographs, written and image documentation are the most important ones for this type of reconstruction (Juhász, 2005); recent remotely sensed data can also efficiently support the process. A complex military historical reconstruction procedure typically involves three parts: environmental reconstruction, object reconstruction and event reconstruction (Juhász, 2014). All these phases can also be analysed in GIS environment. The topography of the surrounding environment greatly influences the location of fortifications, complementary objects, and the direction of the military movements (Bruscino, 2020), therefore topography mapping and analysis has high priority in the reconstruction process. Military operations and defence planning also involve three levels: strategic, operational, and tactical levels (Boukhtouta et al., 2004); the reconstruction process should follow this structure. It is necessary to investigate and reconstruct the detailed environmental elements, especially the terrain of the selected period and area. At strategic level, this involves a broad and low scale examination of the elevation data to gain an overview of the entire selected battlefield (Butkiewicz et al., 2008). Additionally, it is often necessary to study the micro-terrain to resolve the tactical level of the particular military operation. Locating the precise position and orientation of the military objects, identifying previously demolished or even destroyed objects and finally, discovering environmental phenomena in connection with fortification objects are typical reconstruction tasks (Clermont et al., 2019). The study of local micro-terrain differences can often provide the solution. Like in any other part of geosciences, in GIS based military reconstructions the 2D visualization and analysis is no longer sufficient. Currently, 3D presentation and analysis of fortresses, defensive systems or other fortification elements are necessary and expected (Kowalski et al., 2023). Available data sources enable creating and analysing 3D models of the terrain and the objects more efficiently than ever before (Masiero et al., 2019).

Previous publications on GIS or CAD based reconstructions were only published methods at a given scale. In this current paper, we present a multi-scale approach that integrates CAD and GIS-based reconstructions. A part of fortified area of Hungarian Southern Defence System was investigated extensively using a detailed reconstruction and multiscale analysis. Dimensions, position, and orientation, together with the recent condition of the military objects were investigated in large scale. As a result, a precise and comprehensive picture of the defence system's operation was obtained in the study area. The analysis was carried out in two different scales enabling the integration of precise 3D CAD models into an airborne laser scanning (ALS) based digital terrain model.

2 MATERIALS AND RECONSTRUCTION METHOD

2.1 The study area

Following World War II and at the beginning of the Cold War era, the Hungarian and Soviet leadership aimed to strengthen the region along the common border with the former Yugoslavia. The Hungarian

Southern Defence System was constructed over years at an enormous cost, equivalent to a quarter of the annual GDP at the time. The planned total length of the fortification was more than 600 km, and its width was more than 10 km. It was intended to include 7687 fire positions for tanks, assault guns, artillery, mortars, and machine guns, as well as 2000 fighting positions and observation posts, and 2469 shelters. Additionally, it would have included also 964 reinforced concrete machine-gun domes, 219 artillery strongholds, and 4158 kilometres of fire trenches. Furthermore, more than 120 tank shelters were planned along the 600-kilometre border line. In 1955, 40% of the fortification was completed, however, due to the political changes, further construction was suspended (Suba et al., 2010).

Based on accessible archive documentation, available ALS data and field survey options, our study area was selected near the settlement of Majs (Figure 1 A and Figure 3), located 3 km from the border line. At least four different typical fortification objects can be found in this area, according to the written and military map documentation.

2.2 The data sources

Due to its time in which it was built and its function, the investigated fortification was well documented. The previous military maps and the building detailed plans of the fortification are still available today. These archive data and publications were crucial to our research. The following list describes the used archive sources, images shown in Figures 1 and 2:

- Archive military tactical maps, which show the approximate planned locations and orientation of the military objects (Figure 1 / A) (Suba et al., 2010)
- Archive aerial photographs (Figure 1 / B) (fentrol.hu)
- Detailed archive floor plans of the fortification elements such as bunkers, shelters, and fire positions (Figure 2) from the Collection of type fortifications and their camouflage (1951)
- Military historical publications (Suba et al., 2010)

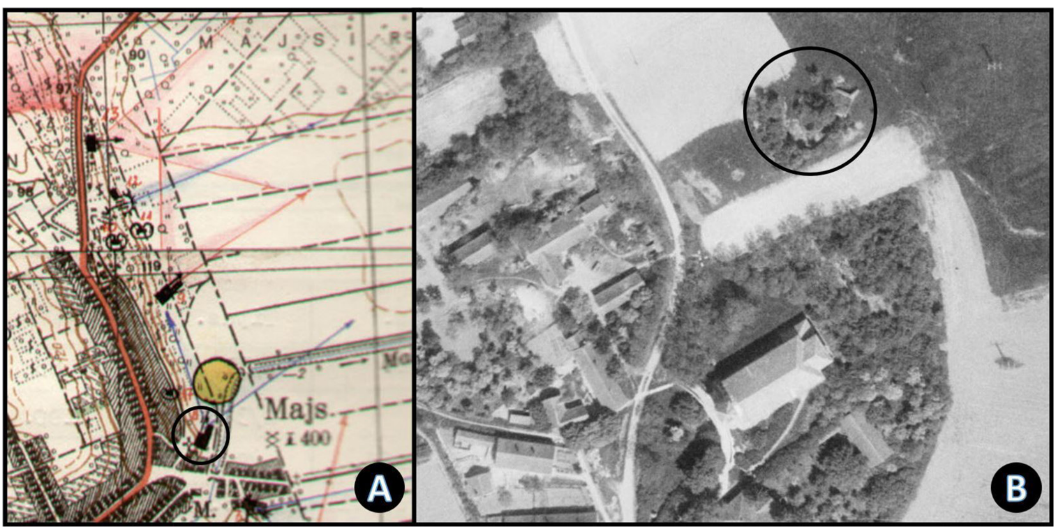

Figure 1: A: The fortification objects (positions and fire directions) on the archive tactical map, (Suba et al. 2010); B: Type A/20 artillery position (circled) on archive aerial photograph from 1979 (fentrol.hu).

These data sources were used for analysing the study area and investigating the former planned establishment of the defence system. The main principle behind the construction of the fortification objects was to attack the potential enemy from the flank. In the investigated area a higher ridge to the west provided protection behind the objects. To the south, earthworks and the bunkers' screen walls shielded the combatants. All the planned fire directions and sweep areas were oriented towards the East, allowing for the control, and firing from the flank of any enemy movements towards the North.

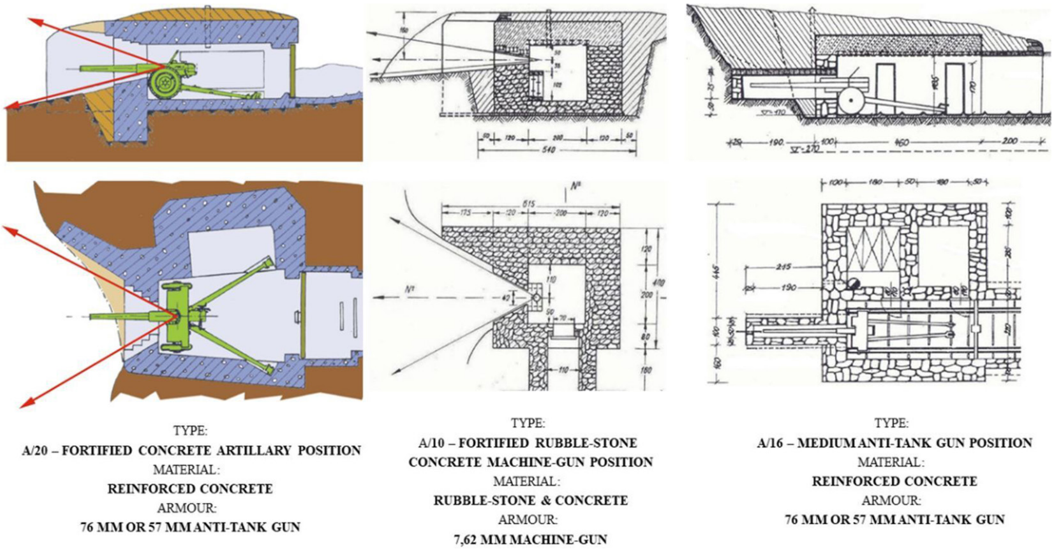

Figure 2: The archive detailed plans of the fortification objects (Suba et al., 2010, Collection of type fortifications and their camouflage, 1951).

Due to the current environmental conditions of the extremely dense vegetation, various laser scanning solutions were the only reasonable surveying methods to enable the study. In addition, we used Google Earth satellite images to get an overview of the current state of the study area. Furthermore, we checked and identified the military object positions on the former military maps in current environmental circumstances to prepare for the in-field work (Figure 3).

Due to the size of the defence line and the need to reconstruct and obtain an overview of the complete system, the investigation was carried out from airborne laser scanned data. Firstly, it was essential to analyse the involved area to identify the parts of the studied objects in the ALS point cloud, as these parts should be the base of the ALS and terrestrial laser scanning (TLS) point cloud alignment. The used ALS data were surveyed in 2012 and covered 140 km^2, the point cloud density is 10 points/m^2 (Bertók and Gáti, 2014).

The detailed object reconstruction was made from both UAV and TLS surveys. To obtain a comprehensive internal and external 3D model of the objects, TLS measurements were taken using the Leica BLK360 scanner. For large extended objects (A, D in Figure 8.), we additionally used the Leica BLK2FLY LiDAR UAV system to supplement and improve terrestrial surveys. Although all surveyed areas were smaller than 200 m^2, due to vegetation cover, a significant number of TLS measurement positions were required, resulting in large point clouds (Figure 4). Point reflected from vegetation had to be removed during processing.

Figure 3: Two fortification objects near Majs on Google Earth image (45°54′54.53″N, 18°36′8.15″E).

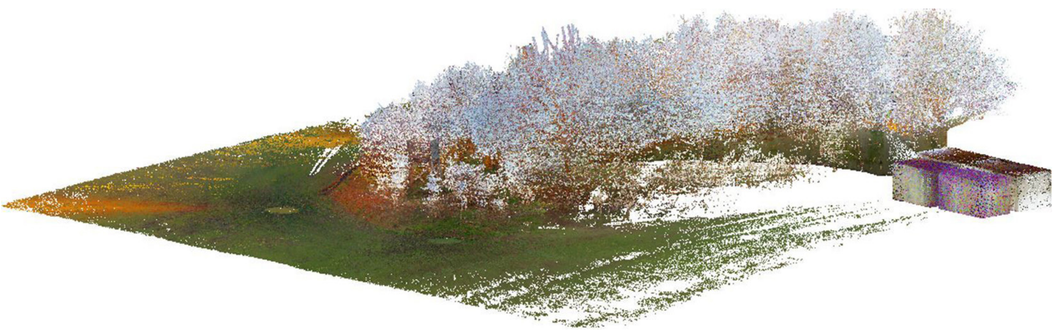

Figure 4: One of the raw TLS point clouds (~84 million points).

2.3 The reconstruction method

The reconstruction process aimed to integrate all available data into a GIS database to enable precise 3D modelling and analysis of the selected objects of the Hungarian Southern Defence System. Firstly, a detailed investigation of the surveyed bunkers was carried out. The preprocessing involved three major steps:

– *Registration of the TLS and UAV measurements of a single location*. Due to dense vegetation cover we acquired very dense point clouds (Figure 5). In two cases (A/20 bunker and A/16 bunker on Figure 8) both TLS and UAV laser scanning were carried out. The Leica Cyclone Field 360 and Leica Cyclone Register 360 software were used in processing. The first was applied to control and support the fieldwork, the second was used to execute the final registration. Despite difficult survey environment, in each case the average registration errors were under 2 cm.

- *Removing the irrelevant points (vegetation points) from point cloud*. In this step the number of the points was radically decreased, e.g. in case of A/20 bunker from 33 million to 4.3 million.
- *Resampling data*. To allow the efficient GIS handling, resampled point cloud of the bunkers was created with 5 cm x 5 cm grid. The resampling process is based on the use of spatial constraints with the definition of 5 cm point spacing.

AutoCAD 2020 environment was used to create 3D model of the bunkers in local coordinate system, based on the final resampled point clouds. However, only the internal dimensions were accurately modelled as the significant parts of the outer sides of the bunkers were covered by the vegetation or soil. The occluded parts were reconstructed from the archive fortification floor plans. 3D modelling was executed manually based on the dimensions measured on TLS point clouds. Due to the low number and simple geometry of the objects, manual processing rapidly provided accurate models. 3D editing of the loopholes and screen walls was the most time-consuming process, due to their relatively complex geometry. Finally, the 3D bunker models were converted to a GIS related .dae file format enabling further work in QGIS environment. The 3D models were fitted manually to the georeferenced TLS point cloud in QGIS based on well identifiable characteristic points and elements.

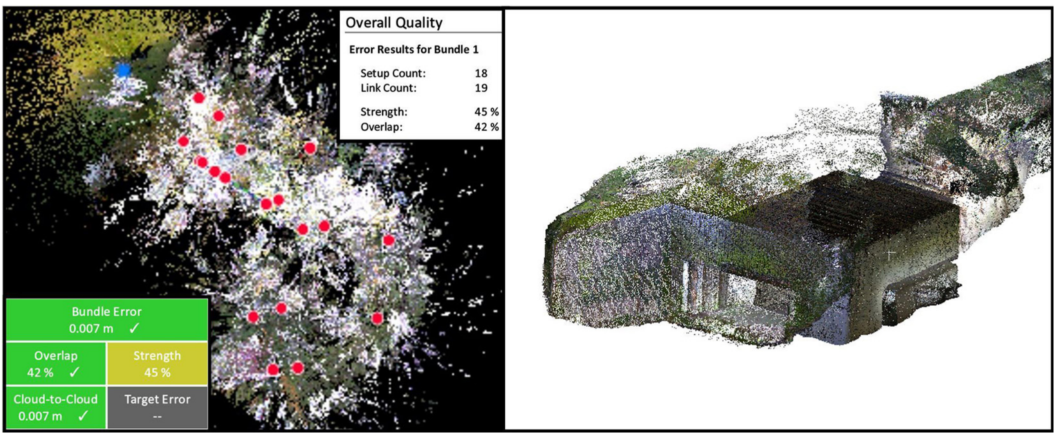

Figure 5: The original point cloud with the red dots representing the TLS scan locations (left) and the final point cloud of bunker A/20 type (right).

Additionally, a smaller scale study was conducted to obtain reliable information on the practical implementation, design, and complexity of the entire system. The relevant archive aerial imagery and former military map data have been georeferenced into the Unified national projection system of Hungary (EPSG:23700). This unified reference system enabled the study of the former military plan together with Google satellite images and terrestrial and aerial laser scanned data, which revealed the location and orientation of the existing and identifiable military objects. The steps of the process were as follows:

- Identify the exact location of the bunkers by investigating the existing maps together with the current satellite images and surveyed data. Because of their massive construction, there is always a good chance to detect them on different sources.

– The alignment of the TLS data to the georeferenced ALS data enabled to determine the specific fire directions, sweep areas and angles, based on the spatial orientation of the bunkers' loopholes. This task was challenging, especially when the studied bunker was filled or partially covered by soil, allowing only external survey.

To obtain the crucial properties above, we had to perform a challenging data processing. The ALS and TLS point clouds had to be matched as precisely as possible; CloudCompare 2.10 software was used in this process. There are significant differences between the two datasets due to their different survey dates, surrounding vegetation and spatial resolution, therefore, it was necessary to identify corresponding connection points and carry out a manual fitting process. The ALS point cloud contained only a limited number of well-identifiable points of the concrete surface elements. Typically, these included the points from complementary parts of the fortifications, such as artificial slopes, screen walls or the approximate boundary lines of the bunkers. To extract these small areas, elevation-based thresholding of the point cloud was applied (Figure 6).

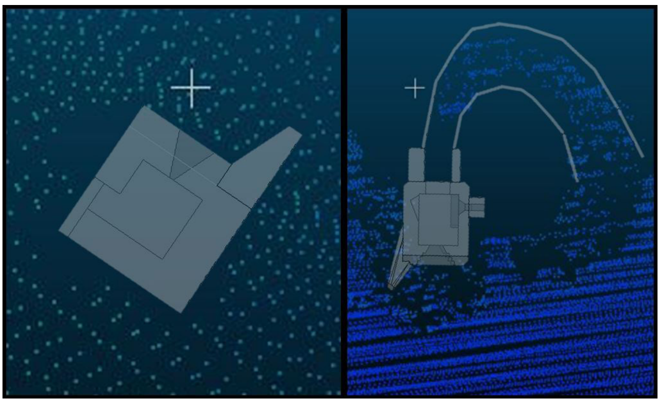

Figure 6: CAD models and the elevation-based thresholding ALS point cloud that reveal the suitable points and areas for the approximate fitting of the TLS data.

These small areas provided the basis of both approximate and precise fitting of the TLS point clouds. These identifiable elements were also partially covered by dense vegetation, which varied between the different studied objects, therefore, points of the surrounding terrain surface were used to improve fitting. Consequently, the precise manual fitting process has focused on selecting clearly identifiable objects and environmental details rather than on improving the global accuracy. The relevant section was extracted from the ALS point cloud and the higher vegetation points were removed. The previously cleaned TLS point cloud was aligned iteratively to the ALS data based on a set of key points, then the 3D models fitted to the co-registered TLS data. The quality of the fittings varied; for objects with typical subsurface parts, the average value of the cloud-to-cloud distances was 50 cm or higher. However, in case of terrain and bunker segments visible in both datasets, it was around 25 cm or lower (Figure 7). Given the circumstances that not only static man-made objects were used for registration and datasets were captured at different times, accuracy values were acceptable for the small-scaled reconstruction. The digital terrain model (DTM) of the study area was also generated in QGIS from the ALS in GeoTIFF raster format with 1 m spatial resolution to enable the spatial analysis of the defensive system. To map the area of the studied objects' control and fire, we generated viewshed raster layers from the DTM. The midpoints of the loopholes were defined as observer points. The definition of the firing angles and sweep areas is also based on the specific angles of loopholes, which could be measured on the 3D models. Based on the military objects' accurate position and orientation information, this process enabled the determination and visualization of the exact sweep areas in a unified spatial system and the investigation of the structure on this section of Hungarian Southern Defence System. Based on the presented method, the entire defence system can be reconstructed, as about 20 different types of bunkers have been implemented into it. If all types of bunkers can be surveyed and modelled, these detailed models can be integrated multiple times into ALS based DTM, where the given type occurs.

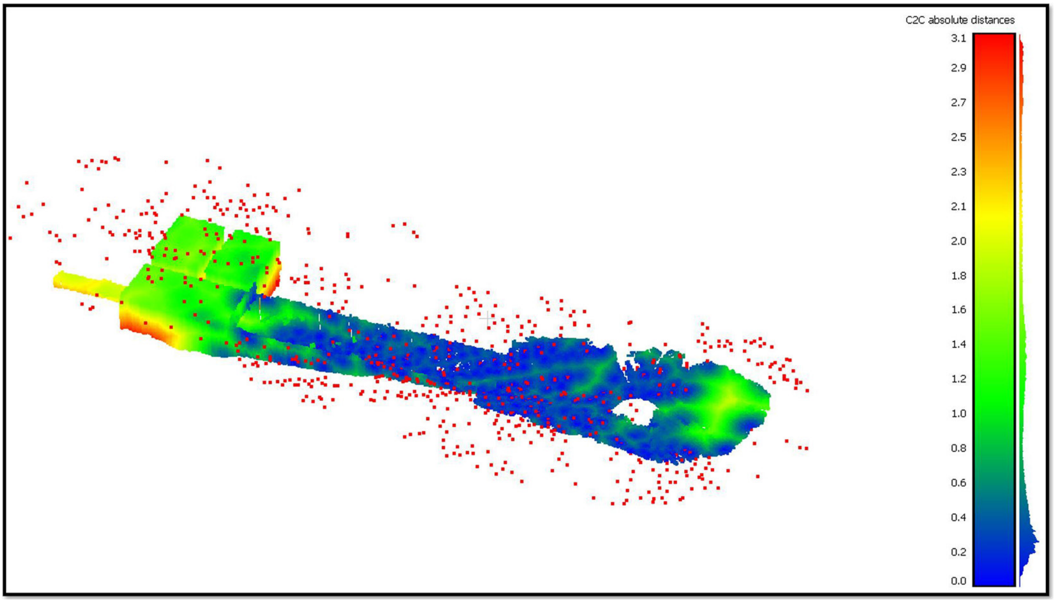

Figure 7: The resulted cloud-to-cloud distances (m) after the fitting of the ALS (red) and TLS point cloud.

3 THE RESULTS OF THE RECONSTRUCTION

In the analysed section of the Hungarian Southern Defence System near Majs, there were 4 different types of bunkers, 7 in total according to historic military map (Figure 1 A): 3 infantry shelters, 2 machine gun positions, 2 anti-tank gun positions. During field survey only 3 of them could be found. In other cases, the environmental signs indicated the former existence of the objects, but these bunkers were either demolished or completely filled in and covered with soil. The remaining bunkers were surveyed and identified. The fourth surveyed object (Figure 8 D) was a single bunker 7 km far from the study area (45°56'44.86"N; 18°40'58.97"E), not analysed in this study together with the other ones. 3D CAD models were created for all four bunkers to compare archive detailed floor plans with their current state (Figure 8 A-C). Furthermore, the three reconstructed bunkers near Majs enabled GIS analysis of the defence system. The analysis of the measurements and the 3D models showed that the built objects followed the main structure of each type, but there were differences in some internal dimensions in each case. These modifications – typically 10-20 cm – did not affect the functionality of the military objects. The accuracy of the 3D models (2 cm or less) derived from TLS point clouds was an order of magnitude lower than the detected modifications. Missing but presumably existing parts of the objects were represented with discontinuous elements, as in the case of the 360-degree firing direction position of an anti-tank gun (Figure 8 C).

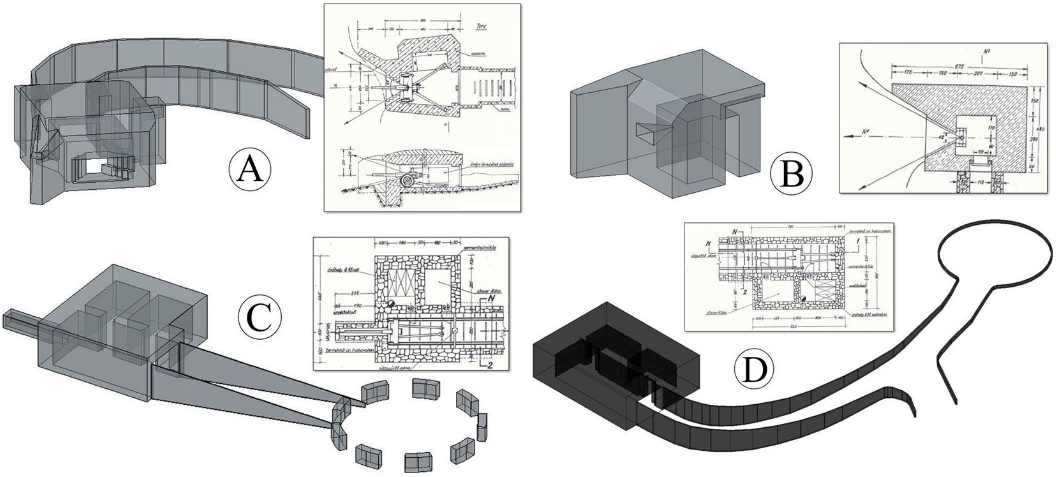

Figure 8: The 3D CAD models of the surveyed bunkers (A: A/20 type anti-tank gun position, B: A/10 type machine-gun position, C and D: A/16 type anti-tank gun position and shelter) and their detailed building plans (Collection of type fortifications and their camouflage, 1951).

In addition to the presentation of exact sizes, these models were also used to study the actual fire directions and sweep areas. Thus, after integration into a GIS database together with the DTM, a detailed 3D analysis of the tactical system of the study area was possible (Figure 9). After fitting the specific object models to the terrain and considering the orientations and the elevations of the loopholes the sweep areas were obtained both vertically and horizontally. The difference between the previously mapped and the reconstructed fire directions was about 10°, while between the fire angles it was even 20°. The presented (Figure 10) fire ranges are limited to 600 m in the case of machine guns, and to 1000 m in the case of anti-tank guns. The obtained GIS reconstruction consists of improved positions and orientations of the certain fortification elements, so a realistic presentation or even animation can serve and support historical, educational, and touristic purposes (Figure 10). Despite the limited time and equipment available, the results have demonstrated the potential and efficiency of the applied data and method for a future reconstruction of the entire defensive system. Unfortunately, currently only four bunkers could be captured during the 1-day survey, the further data processing and analysing took approximately a week.

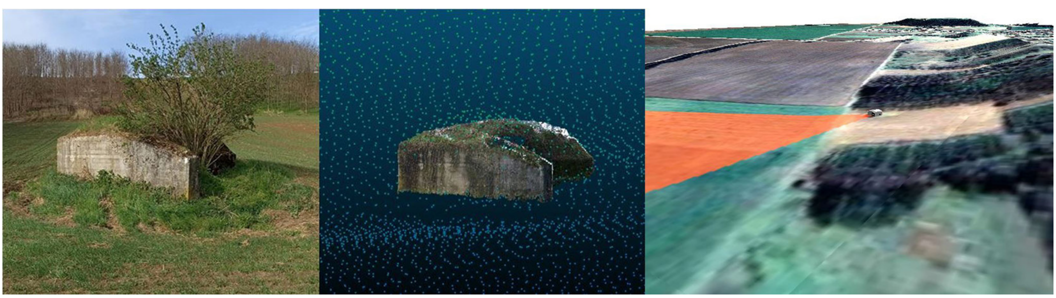

Figure 9: Machine gun position in the field (left), in the fitted ALS and TLS point cloud (middle), and in the GIS reconstruction (right).

Figure 10: 3D GIS reconstruction of the study area with the sweep areas and the bunker models.

4 CONCLUSIONS

There are several examples where GIS has been employed in the reconstruction of military objects from different periods (Cavero, 2020; Pattee et al., 2017; Juhász, 2004). In our recent research, the fortified objects of a typical section of the Hungarian Southern Defence System were studied and reconstructed. GIS provided a unified framework for processing and analysing spatial data with different spatial and temporal characteristics. In addition, it enabled multi-scalar investigation, which is essential in military reconstructions. Both a tactical and a strategic review of the study area are necessary to obtain a reliable and objective result. Although the selected defensive system is well documented based on archive military maps and object plans, integrated ALS and TLS surveys were required to model the current conditions of the remaining objects. Our main objective was to develop an efficient method that would utilise the available spatial data and have the potential to extend its use to the entire Southern Defence System area. The most challenging part of the work was the field survey, which was hampered by extremely dense vegetation, and made the adjustment of the ALS and TLS point clouds difficult. Detailed 3D models of the system's existing bunkers were created and compared with previous plans. It also allowed us to examine the deterioration level of the selected military objects. In order to analyse the tactical concept of the selected section, the exact positions and orientations of the objects are required. Only limited areas of the objects could be identified in the ALS data, but due to the regulated bunker type designs the detailed TLS data could be fitted with appropriate quality. The sweep areas were extracted and presented in GIS to update the previous tactical maps.

The experience gained from this study showed the potential of the applied method in the reconstruction of 20th century military objects that can be even extended to the whole defensive system. The integration of numerous 3D bunker models along hundreds of kilometres of the Southern Defence System allows the use of GIS reconstruction in multiple applications. The advantage of the presented method is that each bunker type only needs to be surveyed once and can be accurately matched several times based on details identified in the aerial scanning data. Thus, fieldwork can be minimized since during the construction of the defence system approximately only 20 types of bunkers were built. Obviously, some bunkers in good condition should be surveyed to develop detailed 3D models and the approximate locations of the bunkers are also needed to integrate the models into the DTM. The reconstruction accuracy is within a few decimetres, due to the very dense vegetation cover, however, the result has a significantly enhanced accuracy compared to only using archive sources.

5 ACKNOWLEDGEMENTS

This paper and research behind it would not have been possible without the support of Janus Pannonius Museum (Pécs). The used ALS data was collected within the framework of the "ArchaeoLandscapes Europe" (ArcLand) project to facilitate non-destructive site identification and archaeological work.

We are also grateful for the support of Leica Geosystem Hungary for the laser scanners and the processing software.

Literature and references:

Balatoni K. (2021). Rejtélyes katonai bunkerek nyomában [Hungarian, "In search of mysterious military bunkers"] https://honvedelem.hu/hirek/rejtelyes-katonai-bunkerek-nyomaban.html, accessed 26.02.2024.

Bertók G., Gáti Cs. (2014). Régi idők – új módszerek. Roncsolásmentes régészet Baranyában 2005–2013 [Hungarian, "Old times – new methods. Non-destructive archaeology in Baranya County 2005–2013"]. Budapest – Pécs, Archaeolingua, p. 171.

Boukhtouta, A., Bedrouni, A., Berger, J., Bouak, F., Guitouni, A. (2004). A survey of military planning systems. The 9th ICCRTS Int. Command and Control Research and Technology Symposium, 5-7.

Bruscino, T. (2020). Military geography and military strategy. https://warroom.armywarcollege.edu/articles/geography-and-strategy/, accessed 26.02.2024.

Butkiewicz T., Chang R., Wartell Z., Ribarsky W. (2008). Visual analysis for live LIDAR battlefield change detection. Proc. SPIE 6983. Defense and Security 2008: Special Sessions on Food Safety, Visual Analytics. Resource Restricted Embedded and Sensor Networks and 3D Imaging and Display. 69830B DOI: 10.1117/12.777158; http://dx.doi.org/10.1117/12.777158.

Cavero, J. (2020). A GIS for the study of the Villa of Diomedes. Dans: Hélène Dessales éd., The Villa of Diomedes: The making of a Roman villa in Pompeii. pp. 133-139. Paris: Hermann. https://doi.org/10.3917/herm.dessa.2020.01.0133

Christopher V. Maio, David E. Tenenbaum, Craig J. Brown, Victor T. Mastone, Allen M. Gontz (2013). Application of geographic information technologies to historical landscape reconstruction and military terrain analysis of an American Revolution Battlefield: Preservation potential of historic lands in urbanized settings. Boston, Massachusetts, USA. Journal of Cultural Heritage. Volume 14. Issue 4. pp 317-331. ISSN 1296-2074. https://doi.org/10.1016/j.culher.2012.08.002.

Clermont D., Kruse C., Rottensteiner F., Heipke C. (2019). Supervised detection of bomb craters in historical aerial images using convolutional neural networks. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W16, pp 67–74. DOI: https://doi.org/10.5194/isprs-archives-XLII-2-W16-67-2019.

Collection of type fortifications and their camouflage. 1951. (Archives of military history, Hungary, Budapest)

Fentrol.hu/en. https://www.fentrol.hu/en/, accessed 26.02.2024.

George M., Kyriacos T., Athos A., Silas M., Diofantos H. (2019). Detecting Underground Military Structures Using Field Spectroscopy. Military Engineering. Dekoulis G (ed.). IntechOpen. p 136. DOI: 10.5772/intechopen.86690.

Jucha W, Franczak P, Sadowski P (2021). Detection of World War II field fortifications using ALS and archival aerial images – German OKH Stellung b1 trenches in the south of the Polish Carpathians. Archaeological Prospection 28. pp 35–45. https://doi.org/10.1002/arp.1792.

Juhász, A. (2004): A XIX-XX. századi tábori erődítések a Kárpát-medencében. Hadtörténeti rekonstrukció térinformatikával. Várak, erődök, erődítések 2, [Hungarian, "Field fortifications of the XIX-XXth century in Carpathian Basin. Military historical reconstruction with GIS. Castles, Fortresses, Fortifications 2."] Budapest, TINTA. p 160.

Juhász A. (2005). Data collection methods for military historical reconstruction. Academic and Applied Research in Military Science (AARMS) Vol. 4. No. 3. pp. 413-420.

Juhász A. (2014). New achievements in WW II. military historical reconstruction with GIS. Academic and Applied Research in Military Science (AARMS) Vol. 13. No. 3. pp. 413-424.

Juhász A., Neuberger H. (2018). Automatic identification of bomb craters and their potential areas. Mitteilungen der Osterreichischen Geographischen Gesellschaft. Austrian Academy of Sciences Press. DOI: 10.1553/moegg158. pp. 241-258.

Kobiałka D. (2017). Airborne Laser Scanning and 20th Century Military Heritage in the Woodlands. Analecta Archaeologica Ressoviensia 12. pp 247–270. DOI:https://doi.org/10.15584/anarres.2017.12.14.

Kowalski S., La Placa S., Pettineo A. (2023). From archives sources to virtual 3d reconstruction of military heritage – the case study of port battery, Gdańsk. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLVIII-M-2-2023. pp 885–893. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-885-2023.

Luke B. (2020). The Bunker's After-Life: Cultural Production in the Ruins of the Cold War. Journal of War & Culture Studies 13:1. pp 1-10. DOI: 10.1080/17526272.2019.1698845.

Masiero A., Chiabrando F., Lingua A. M., Marino B. G., Fissore F., Guarnieri A., Vettore A. (2019). 3D modeling of Girifalco fortress. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLII-2/W9. pp 473–478. DOI: https://doi.org/10.5194/isprs-archives-XLII-2-W9-473-2019

Pattee A., Volkmann A., Untermann M. (2017). Integrative GIS-based investigation of the medieval fortress architecture of Pfalz, incorporating photogrammetry, geoinformatics and landscape analysis, In Garagnani S., Gaucci A., (eds.), Knowledge, Analysis and Innovative Methods for the Study and the Dissemination of Ancient Urban Areas, Proceedings of the KAINUA 2017 International Conference (Bologna, 18-21 April 2017), «Archeologia e Calcolatori», 28.2, pp. 521-530. https://doi.org/10.19282/AC.28.2.2017.42

Suba J., Jakus J., Négyesi L., Holló J., Bajáki B. (2010). Betonba zárt hidegháború [Hungarian, "Cold War encased to concrete"], Budapest. HM Hadtörténeti Intézet és Múzeum. p 207.

Juhász A., Balogh A. (2024). 3D GIS reconstruction of Hungarian Southern Defence Line. Geodetski vestnik, 68 (2), 211-222.
DOI: https://doi.org/10.15292/geodetski-vestnik.2024.02.211-222

dr. Attila Juhász
Department of Photogrammetry and Geoinformatics, Faculty of Civil Engineering, Budapest University of Technology and Economics,
Műegyetem rkp. 3., H-1111 Budapest, Hungary
e-mail: juhasz.attila@emk.bme.hu

Árpád Balogh
Department of Photogrammetry and Geoinformatics, Faculty of Civil Engineering, Budapest University of Technology and Economics,
Műegyetem rkp. 3., H-1111 Budapest, Hungary.
Department of Experimental Archaeology and Innovation, National Institute of Archaeology, Hungarian National Museum, Múzeum körút 14–16, H-1088, Budapest, Hungary
e-mail: balogh.arpad@emk.bme.hu