3D RECORDING IN ARCHAEOLOGICAL PRACTICE

Ján Zachar & Milan Horňák (Via Magna)

Within the framework of the preventive archaeology concept, the documentation of archaeological cultural heritage plays a crucial role. Until recently, the sphere of cultural heritage was dominated by tools of traditional 2D documentation, which were gradually expanded with modern geodetic tools such as the total station (TS) and differential GPS. However, these tools did not present any essential breakthrough in the documentation practice. It was basically an extrapolation of 2D documentation from analogue to the digital sphere. The real turning point came only with the mass expansion of 3D technologies into individual industrial sectors. The change was in the different concept of reality perception for the needs of the documentation practice. Recently, 3D documentation procedures have started to be applied more significantly also in the area of rescue archaeology.

One of the project CONPRA objectives was to test possibilities of application of 3D technologies in the recording practice of archaeological research, i.e. to verify their potentials and limits. It is especially the preventive archaeological research with its demands for tight time and budget schedules where suitable preconditions for the application of state-of-the-art technologies are created, especially from the perspective of the possibility to shorten the recording works in the excavation process. 3D technology also provides a significant improvement as to the accuracy of the documentation. On the other hand, general limiting factors of 3D documentation must be also taken into the account and problematic aspects of their utilisation, difficulties related to the application of individual procedures, as well as possibilities of dealing with the said in practice, must be also pointed out.

Archaeological cultural heritage is an internally structured category. However, for the purpose of the documentation practice, we can basically speak about the documentation of ongoing archaeological research, whether rescue or so-called scientific, or about the documentation of partially preserved archaeological locality adjusted or secured for the purposes of tourism (e.g. archaeoparks). It is equally important in both cases to determine the morphological structure of the cultural monument; for example, whether it is dominated by a pedological component or by architectural elements (in case of documentation of ongoing archaeological research), or what terrain adjustments need to be conducted (e.g. in case of archaeo-parks). Each one of the mentioned aspects affects in its own way the work methodology and the results.

Here we present a selection of case studies with the aim to demonstrate possibilities and limits of 3D documentation in the context of various site situations. The presented models are mainly related to the conditions typical for Central Europe. All case studies were processed in a workstation with the following components: Intel(R) Xeon(R) CPU E5-2620 v2@ 2,10 GHz, RAM 128 GB, GPU NVIDIA GeForce GTX 780 3GB, OS W7; or in notebook Lenovo Y50 with these components: Intel(R) Core(TM) i7- 4710HQ CPU@ 2,50 GHz, RAM 16 GB, GPU NVIDIA GeForce GTX 860M, OS WIN 8. In the case of TLS application, the resolution was always set to 6 mm per 10 metres. For IbM, two types of software were used: Agisoft Photoscan and CapturingReality RC.[1] In Photoscan the following parameters were set for the batch processing workflow: step – align photos (high accuracy with the key point limit of 40,000 points and the tie point limit of 20,000 points); step – refinement of alignment (decreasing of global re-projection error to at least 1px); step – build dense point cloud (medium quality, aggressive depth filtering); step – build mesh (arbitrary surface type, dense point cloud as source data, interpolation enabled, custom face count: various values); and step – build texture (generic mapping mode, texture from all cameras, blending mode Mosaic, texture size 8192, texture count 1, and no colour correction). In case of RC software, the parameters were as follows: step – align photos (+ laser scans) (max. feature per image 120,000, pre-selector feature 60,000, image overlap medium, detector sensitivity medium, max. re-projection error 2px); step – reconstruction (normal detail); step – build texture (Guter 3, texture resolution 8192, large triangle removal threshold 10, maximal texture count style, visibility based texture style).

SITES WITH SOIL LAYERS AND SEDIMENTED DEPOSITS

Situations in which the pedological component is the dominant are a product of archaeological investigations that expose anthropogenic soil sediments. These are usually cultural layers which can represent or contain remains of former lowland or hilltop settlements, open or fortified, with buildings and other structures made of stone, wood and/or earth. These localities display only a low value of local micro-elevation. From the perspective of local morphology, this can either be flat, horizontal or inclined surfaces. The exception are hilltop-fortified settlements – hill-forts – where possibly significant local elevation can be present due to the existence of a fortification system (e.g. rampart).

This type of localities is currently a frequent area of research of preventive archaeology performed outside the settlement area. After the top vegetation layer is removed by mechanisation, individual anthropogenic layers are gradually excavated. Before the onset

1 The application was chosen on the grounds of the license availability.

of 3D technologies, the said type of localities was documented by means of drawing archaeological situations, features and objects, or was recorded with the total station or differential GPS.

Radoľa, Kocselisko

Site type:	Mound
Location:	Radoľa (Žilina district Žilina, NW Slovakia); location Koscelisko
Dating:	Late Bronze Age
Research type:	Research for scientific and documentation purposes
Recording technology:	IbM
Recording equipment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX), TS, GNSS RTK Rover (differential GPS)
Software:	Agisoft Photoscan 1.2.6, AutoCad Civil 3D 2016 student version
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figs.14-16).
Short description:	The archaeological site was documented solely by IbM. The research was initially performed using test pits, which were then enlarged in order to expose the whole ground plan of the site composed of a stone ring of the original mound and a centrally located urn. In addition to the final stage of the research, the documentation also captured individual stages of the excavation. A handheld camera was used for the collection of data.

Figure 14. Radoľa, Koscelisko (Slovakia). Burial mound, Bronze Age. IbM (180 photos, 24 Mpx). Textured 3D model.

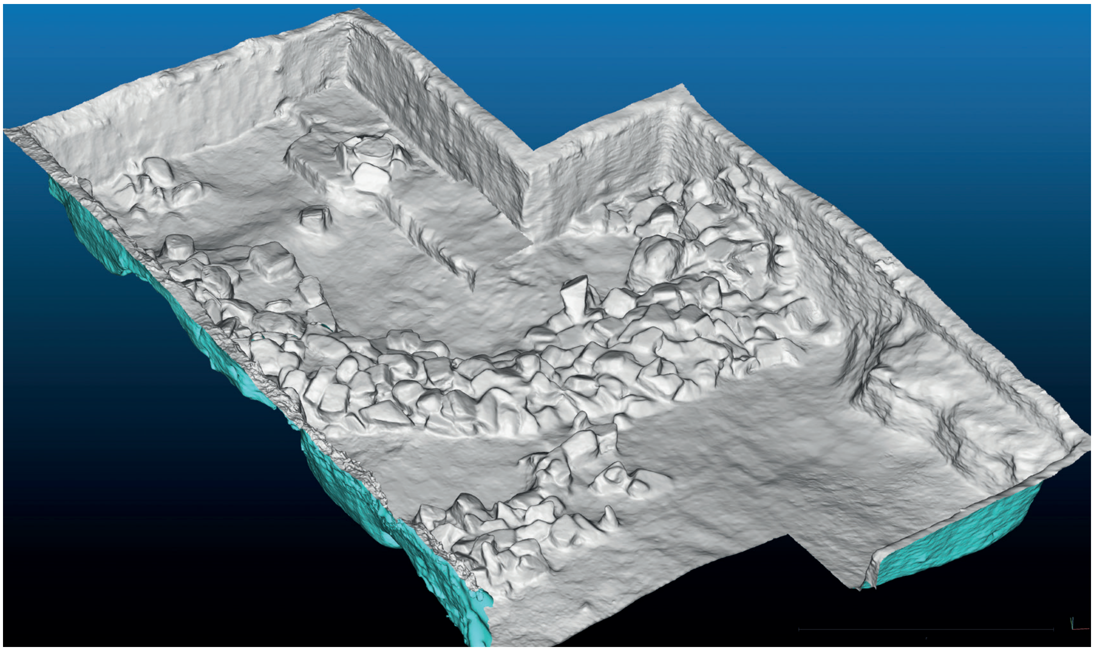

Figure 15. Radoľa, Koscelisko (Slovakia). Burial mound, Bronze Age. IbM. Shaded 3D model.

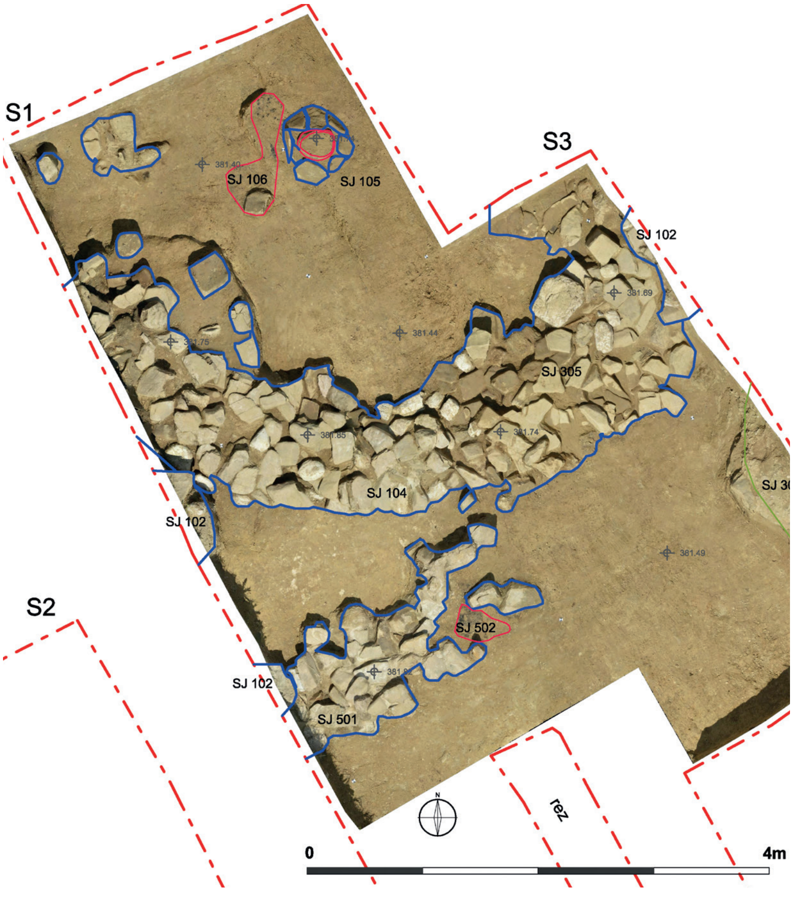

Figure 16. Radoľa, Koscelisko (Slovakia). Burial mound, Bronze Age. An example of 2D documentation deliverables – vectorisation of the georeferenced orthophoto plan derived from the 3D model.

Rajec, Charubina

Site type:	Settlement
Location:	Rajec (district Rajec), location – Charubina, NW Slovakia
Dating:	Late Bronze Age, Middle Ages (12th – 13th century)
Research type:	Preventive research
Recording technology:	IbM
Recording equipment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX), TS, GNSS Rtk Rover (differential GPS)
Software:	IbM
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figs. 17, 18).
Short description:	The excavated site probably represents a large settlement from the Late Bronze Age and High Middle Ages. A residential structure with remains of a wall with external cladding was revealed, as well as several locations with significant accumulations of ceramics, scree and charred material. The excavations revealed a flat micro-relief, i.e. without any elevations. Individual stages of the excavation of the remaining traces of housing from the Bronze Age, as well as the individual accumulations of ceramic fragments were documented using IbM. No monopod stand or an UAV were used for the collection of raw data. TS was used for the measurement of GCP.

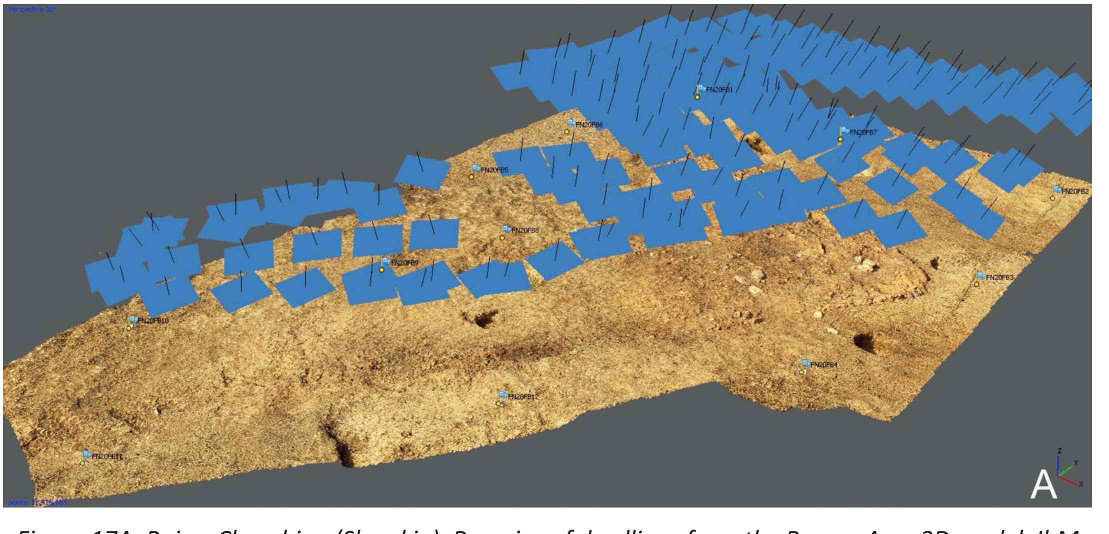

Figure 17A. Rajec, Charubina (Slovakia). Remains of dwellings from the Bronze Age. 3D model. IbM (193 photos, 12Mpx). Position of the cameras during data acquisition, B: textured 3D model, C: shaded 3D model.

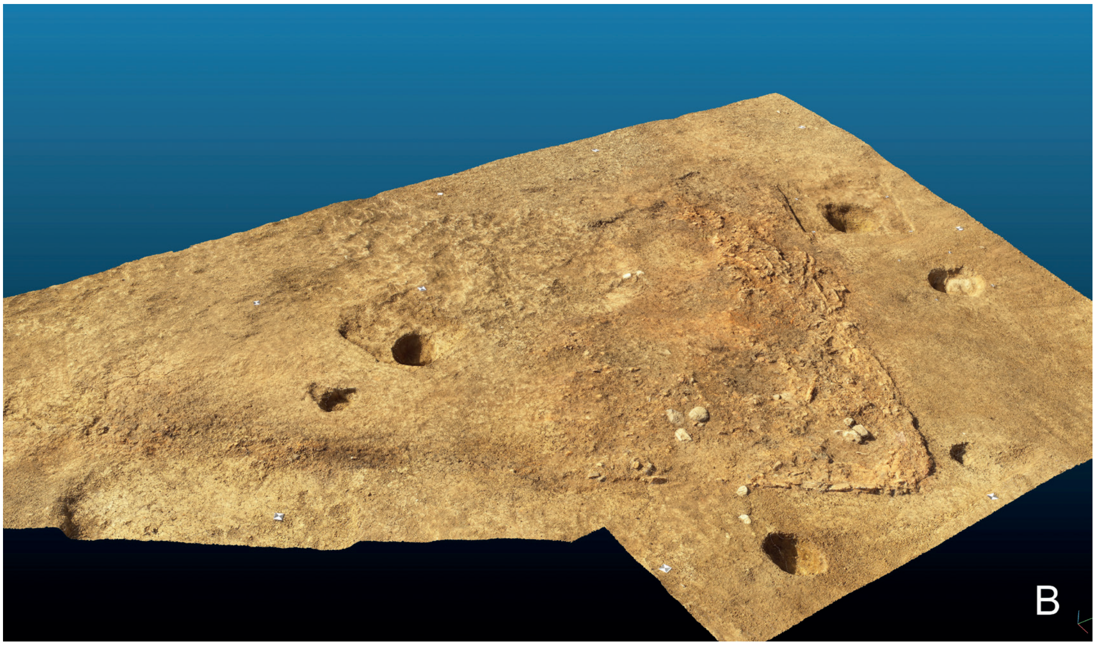

Figure 17B. Rajec, Charubina (Slovakia). Remains of dwellings from the Bronze Age. 3D model IbM (193 photos, 12Mpx). Textured 3D model. C: shaded 3D model.

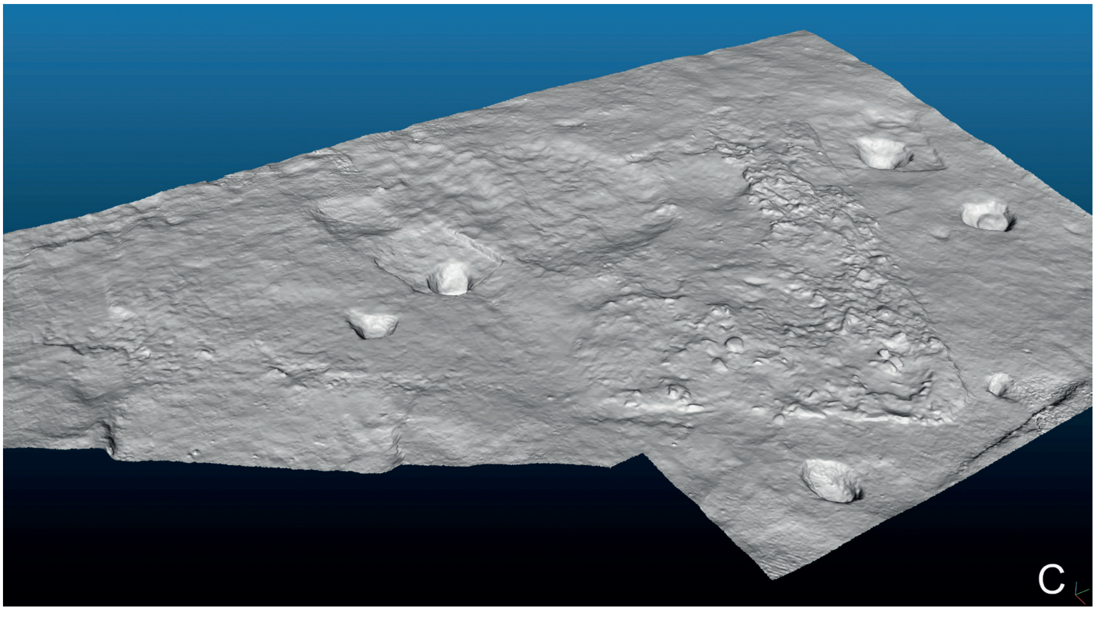

Figure 17C. Rajec, Charubina (Slovakia). Remains of dwellings from the Bronze Age. 3D model. IbM (193 photos, 12Mpx). Shaded 3D model.

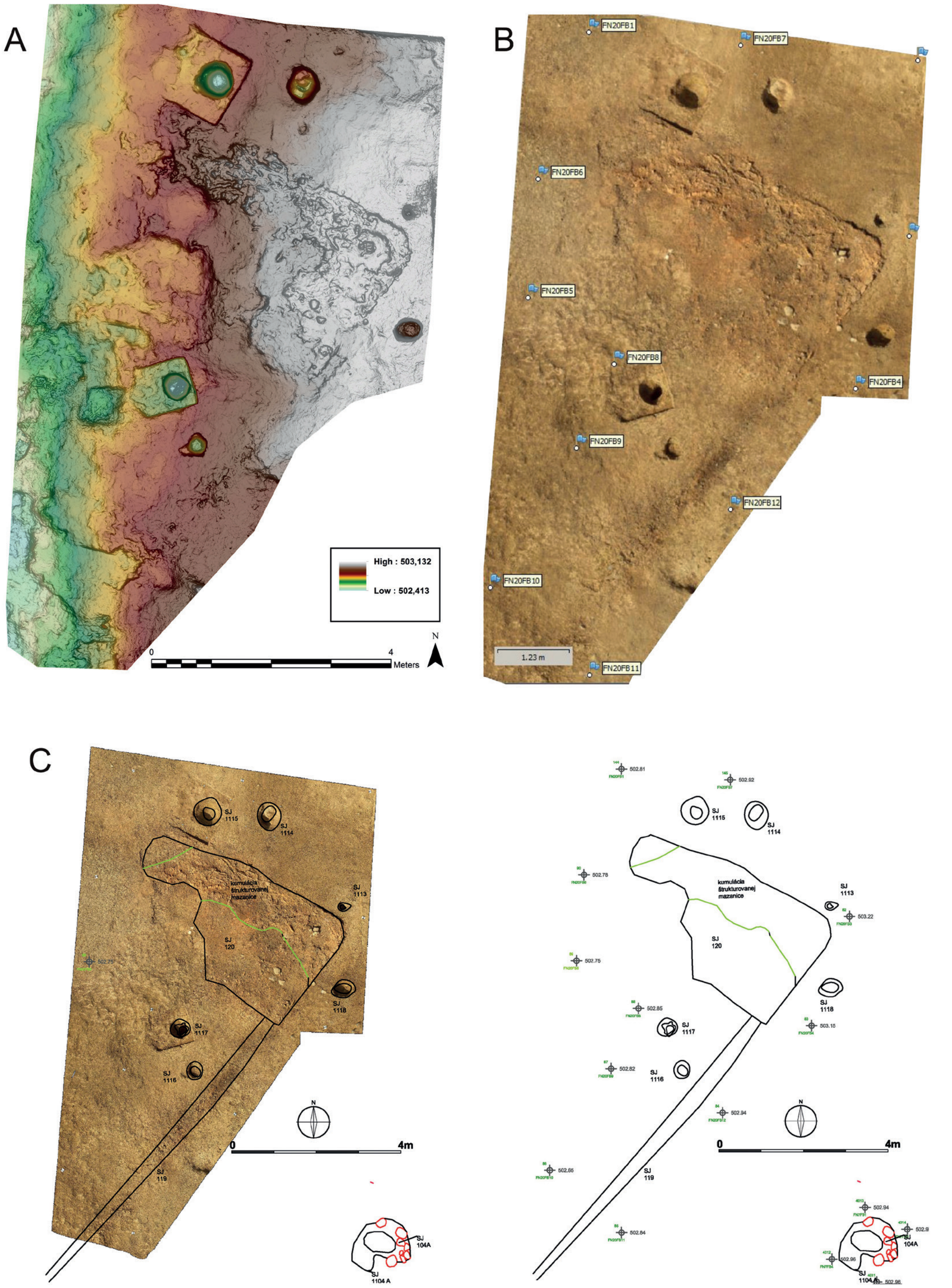

Figure 18. Rajec, Charubina (Slovakia). Remains of dwellings from the Bronze Age. An example of 2D documentation. A: digital elevation model (DEM), B: georeferenced orthophoto plan derived from the 3D model, C: vectorisation of the georeferenced orthophoto plan.

Mošovce, Hinterland of the residential area

Site type:	Settlement and its surroundings
Location:	Mošovce (district Turčianske Teplice), NW Slovakia
Dating:	Late La Tène period through later Roman period
Research type:	Preventive research
Recording technology:	IbM
Recording equipment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX), Nikon D90, TS, GNSS Rtk Rover (differential GPS)
Software:	Agisoft Photoscan 1.2.6, AutoCad Civil 3D 2016 student version
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figs.19, 20).
Short description:	Although the site is situated in a considerably dynamic landscape, with significant elevation differences, the archaeological excavation revealed a flat micro-relief. The research included recording of the area disturbed by present-day logging. IbM was aimed at capturing profiles of the current road communication within partially disturbed settlement structures and cultural layers, as well as for a smaller area showing evidence of prehistoric metallurgical activities.

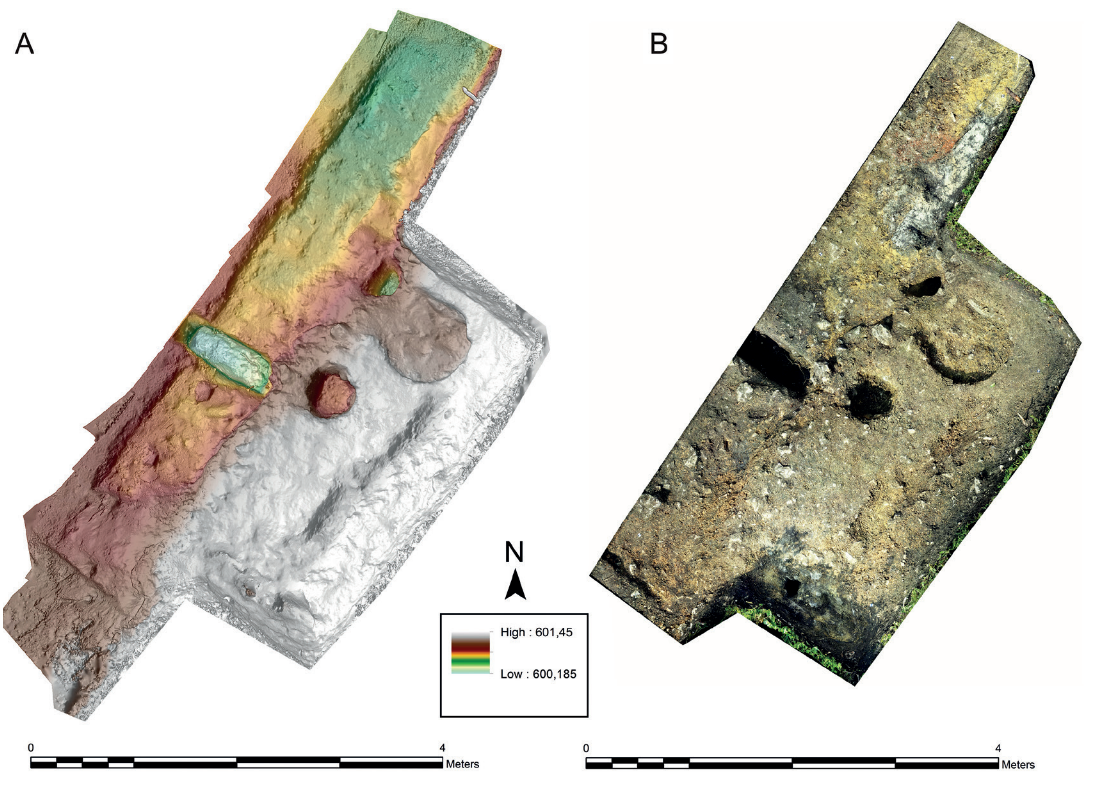

Figure 19. Mošovce (Slovakia). Remains of an Early Roman industrial area. An example of 2D documentation. A: DEM, B: georeferenced orthophoto plan derived from the 3D model.

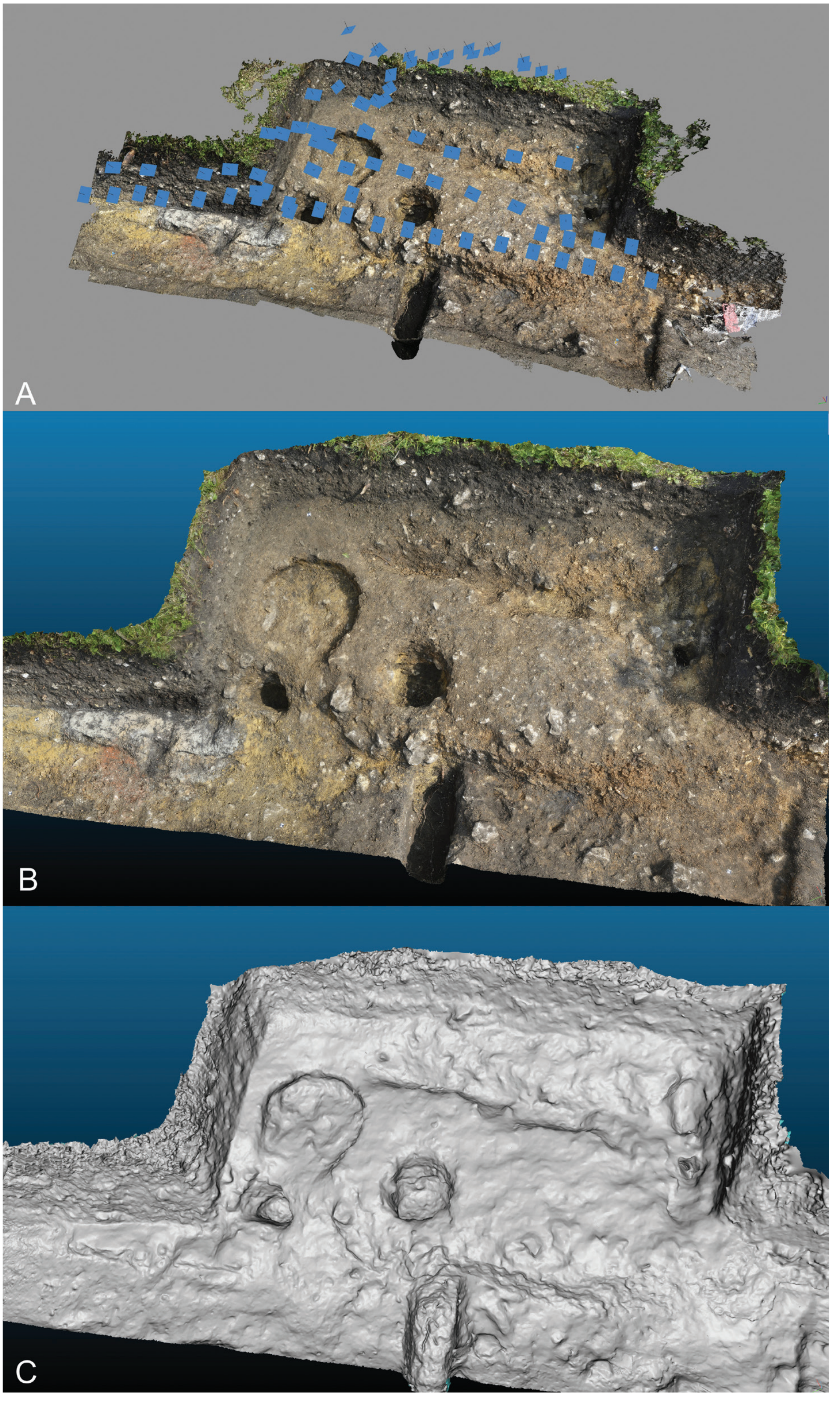

Figure 20A-C. Mošovce (Slovakia). Remains of an industrial zone, early Roman period. IbM (78 photos,12Mpx). A: position of the cameras, B: textured 3D model, C: shaded 3D model.

Bratislava, Castle

Site type:	Castle and settlement area
Location:	Northern terrace of the Bratislava Castle, SW Slovakia
Dating:	10^{th}-12^{th} century A.D.
Research type:	Preventive excavation
Recording technology:	IbM
Recording equipment:	Camera Sony Nex 7, unmanned aerial vehicle (UAV), TS, GNSS Rtk Rover (differential GPS)
Software:	Agisoft Photoscan 1.0.0, CloudCompare, AutoCAD Civil 3D 2016 student version.
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figure 21).
Short description:	Bratislava castle was subject of preventive excavations between 2008 and 2014. In the years 2013 and 2014, 3D recording of the excavated areas was the main method of recording the general and partial ground plans and sections. The area of the northern terrace contained several significant architectural remains. The site contained abundant anthropogenic evidences also in the soil which were also investigated. They consisted of a sequence of cultural layers and imprints of structures, indicating an open settlement dated to the 10^{th}-12^{th} century AD. The recording was performed by IbM. An UAV was used for collecting the raw data (vertical low-flight level photos). Due to flat terrain morphology the vertical images were not complemented by oblique photos.

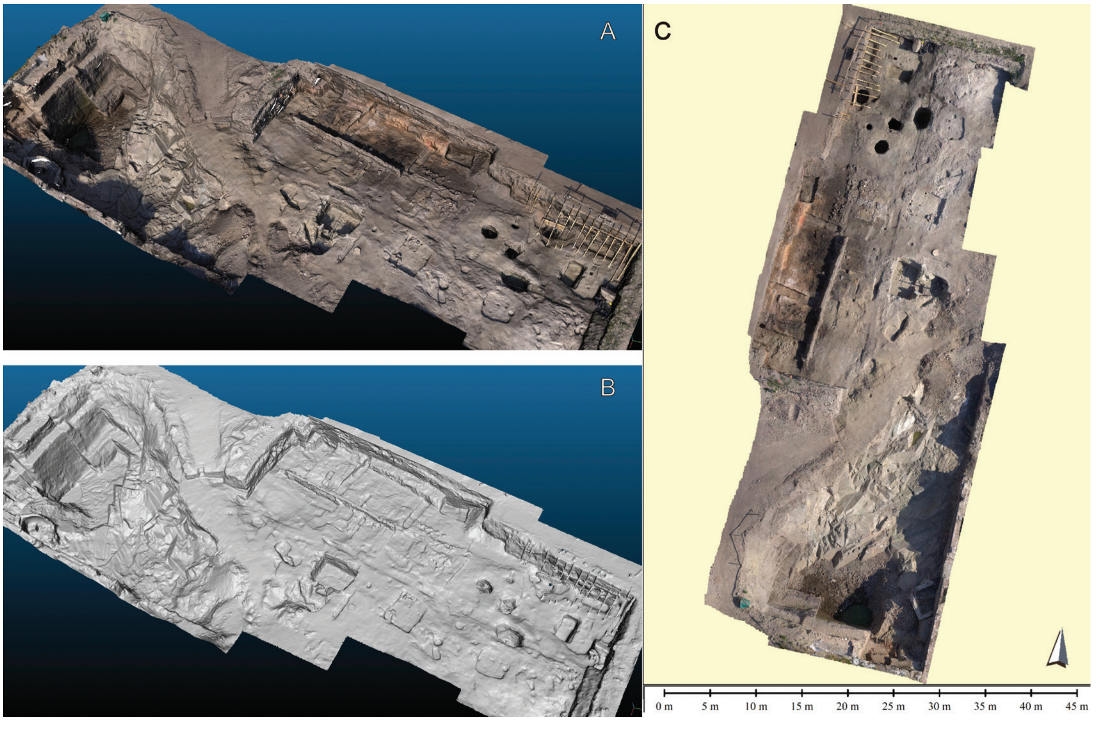

Figure 21. Bratislava, Castle, northern terrace. Remains of the open settlement, partly destroyed by a later quarry, 10-12^{th} century. 3D model. IbM (352 photos, 12Mpx). A: textured 3D model, B: shaded 3D model, C: georeferenced orthophoto plan.

SITES WITH ARCHITECTURAL REMAINS

Archaeological sites with significant architectural remains are typical for urban areas, where they represent the product of urbanisation process. They are characterised by a high level of local micro-elevation, the degree of which is determined by the level of preservation of the masonry. Some specific examples of these are castles, where significant quantities of debris occur, in addition to the compact components of the masonry.

Archaeological research of the sites of this type is usually performed in close cooperation with the research on the history of construction. Particular attention is paid to capturing mutual relationships of the masonry and the anthropogenic soil deposits (designated backfill areas, walking surfaces, cultural layers, etc.), which should reveal general aspects of the historical development of the construction. Previously, a frequently used method of documentation of this type of sites was 2D photogrammetry, which enabled capturing the complex structure of the surface with individual details of the architecture. However, its substantial disadvantage is the radial and tangential distortion of the 2D orthophoto plans, especially in the case of a significant elevation of masonry constructions compared to the level of the surrounding ground; this can markedly reduce the accuracy of the geodetic plan of the site.

Senec, Synagogue

Site type:	Synagogue and its immediate surroundings
Location:	Senec town, District of Senec, SW Slovakia
Dating:	19th century
Research type:	Research for scientific and documentation purposes
Recording technology:	IbM
Recording equipment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX), TS, GNSS Rtk Rover (differential GPS)
Software:	Agisoft Photoscan 1.2.6, AutoCad Civil 3D 2016 student version, CloudCompare 2.8
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans and cross-section views (Figs. 22-24).
Short description:	The production-related part of the synagogue was seen in a significantly destroyed architecture consisting of brick walls with cladding, a preserved furnace and a ritual bath (mikveh). IbM was used for documenting the process of research by recording the individual stages of cleaning of different spatial segments. The overall model was created by joining models of the parts using refential GCP. Since high monopod stand or drone were not used for the collection of the data, the crowns of higher walls have, in some places, digitisation shadows. However, the rate of coverage and capturing with the 3D model is relatively high with regard to the tools used (a simple ladder). Moreover, special attention was paid to the 3D documentation of the furnace, which was planned for dismantling and relocating. Cross- and longitudinal sections were made for this purpose, which subsequently served as an input for the creation of paper models at 1:1 scale used for the reconstruction of furnace at the original scale. Exterior and interior of the furnace were separately recorded (IbM). A torch was used for the collection of raw data of the interior.[51] The use of torch was not a markedly limiting factor in the processing of data, and the resulting 3D model did not show any significant deviation in terms of clarity of the surface geometry. In terms of the texture, it is understandable that the colour scale of the input data (i.e. photos) shifted chromatically (torch light), which also rendered the colour texture of the 3D model of the furnace interior artificial. The use of torch can thus be considerd as a partially limiting factor. The 3D model of the furnace exterior was connected with the 3D model of its interior (common reference points defined arbitrarily in Agisoft Photoscan). The sections were made in CloudCompare and were subsequently saved for further processing of the architectural model in native CAD format (dwg).

2 The use of torch is generally not recommended in photo-shooting for the image based modelling, but given the absence of any other light source, this was the only possible solution in this case. Moreover, it provided an opportunity for testing the flash usage and its effect in the subsequent data processing.

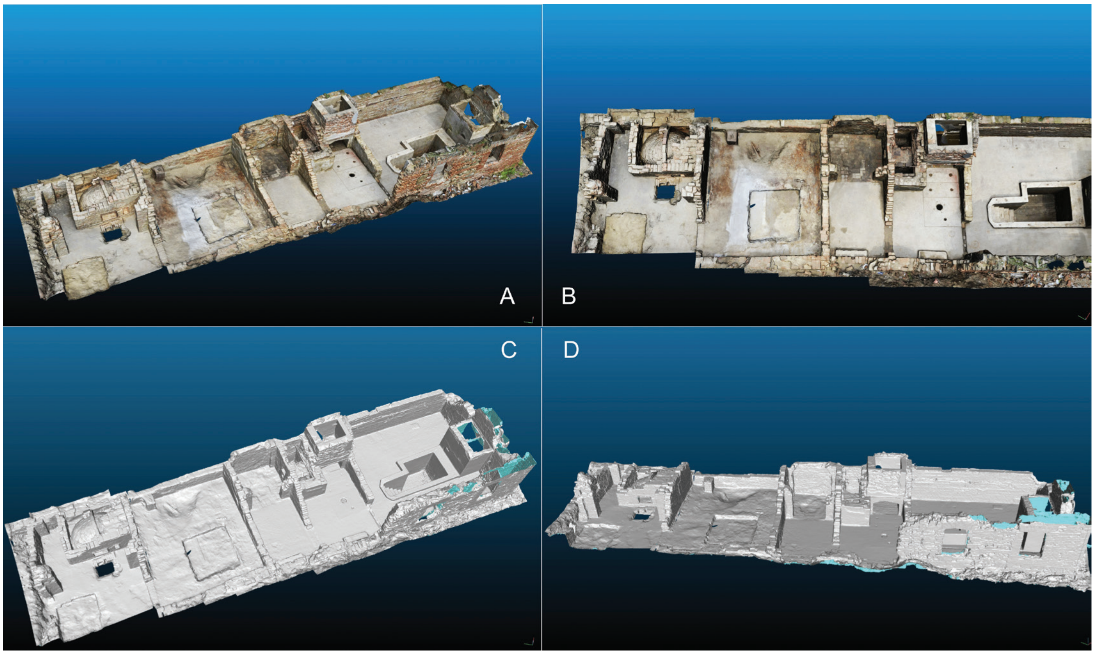

Figure 22. Senec, Synagogue (Slovakia). Remains of the economic section of the synagogue, with an oven and a mikveh, 19th century. IbM (1452 photos, 24 Mpx). A, B: textured 3D model, C, D: shaded 3D model.

Figure 23. Senec, Synagogue (Slovakia). Remains of the economic section of the synagogue. Cross-section documentation derived from the 3D model.

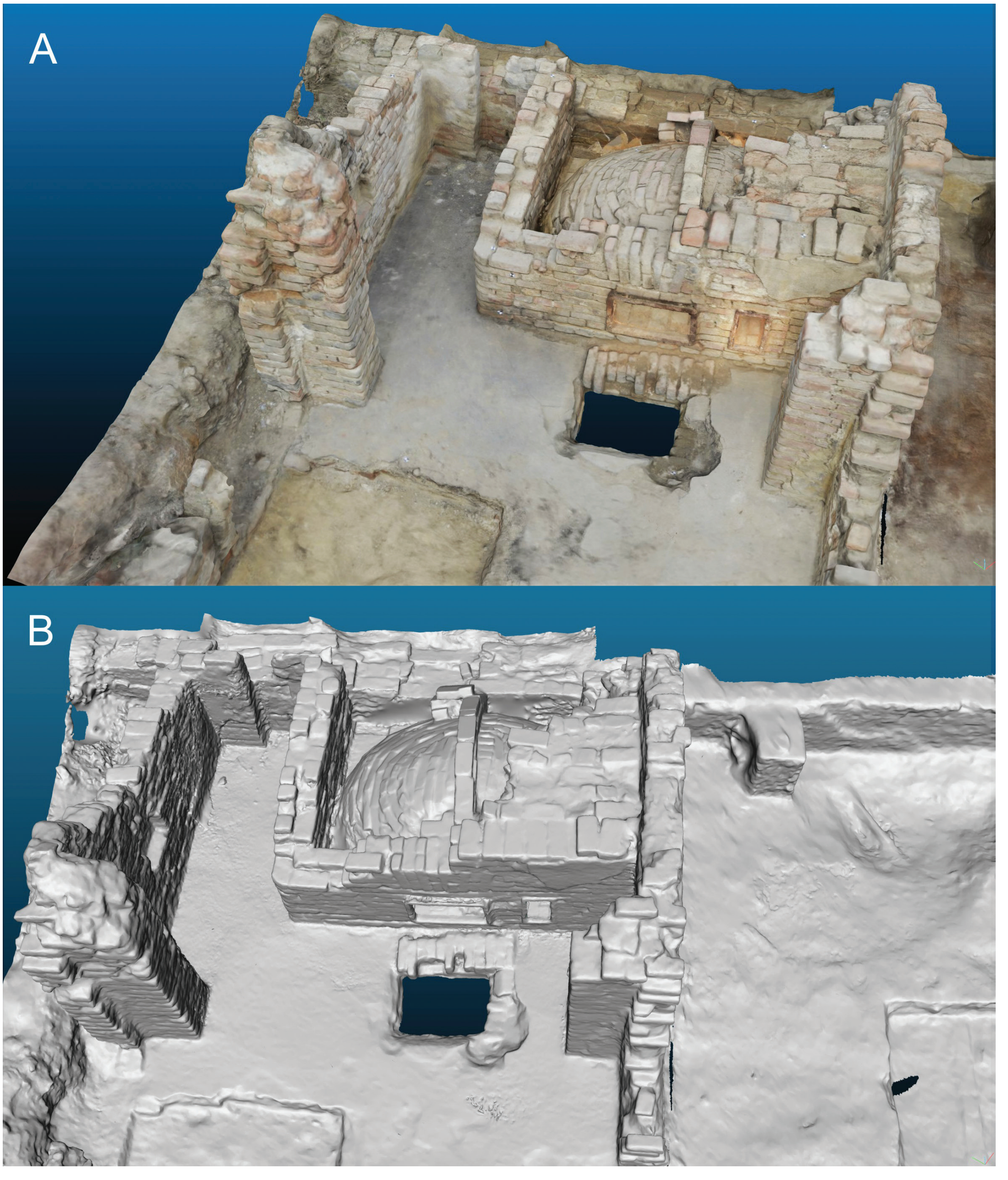

Figure 24. Senec, Synagogue (Slovakia). Remains of the economic section of the synagogue – detail of the oven, 19th century. IbM. A: textured 3D model, B: shaded 3D model.

Skalka nad Váhom, Monastery

Site type:	Monastery complex (Benedictines; Jesuits from the 17th century)
Location:	Skalka nad Váhom (district Trenčín), location – outside municipal/ residential area
Dating:	14^{th}-18^{th} century
Research type:	Preventive research
Recording technology:	IbM
Recording equipment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX), TS, GNSS Rtk Rover (differential GPS)
Software:	Agisoft Photoscan, AutoCad Civil 3D 2016 student version, CloudCompare 2.8
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figs. 25, 26).
Short description:	The premises of the Benedictine (later Jesuit) monastery are situated under a high rocky overhang. The research was focused on the significantly destroyed area of the western part of the former convent, whose one side leaned against the rock whereas the other side was open to the area of viridarium. The convent area is significantly affected by destruction of the masonry and the debris infills. The 3D documentation was performed in a sequence that followed the stages of research. The complete 3D model was created by connecting individual parts of the models, according to their georeferences, within a single coordinate system based on the GCP. Special attention was paid to the medieval hypocaust (underfloor heating). A drone or monopod stand was not used for the collection of the data.

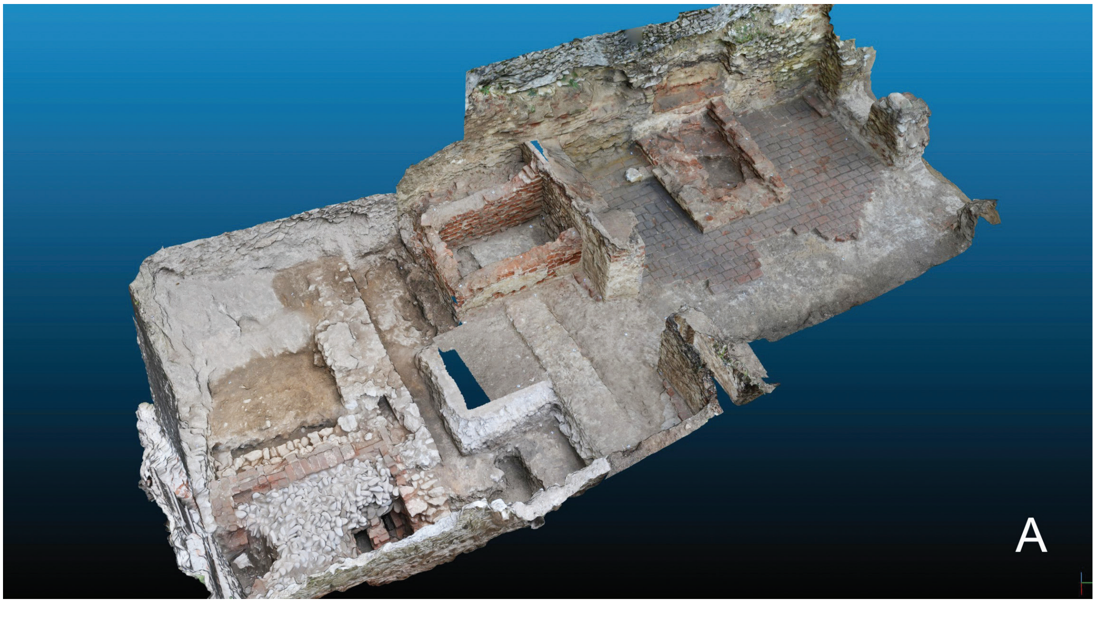

Figure 25A. Skalka nad Váhom (Slovakia). Remains of a medieval monastery, 14^{th}-17^{th} century. Textured 3D model combining the results from two archaeological seasons (see also Figure 25B) that focused on uncovering the west wing of the clausura. IbM (425 photos, 12+24Mpx).

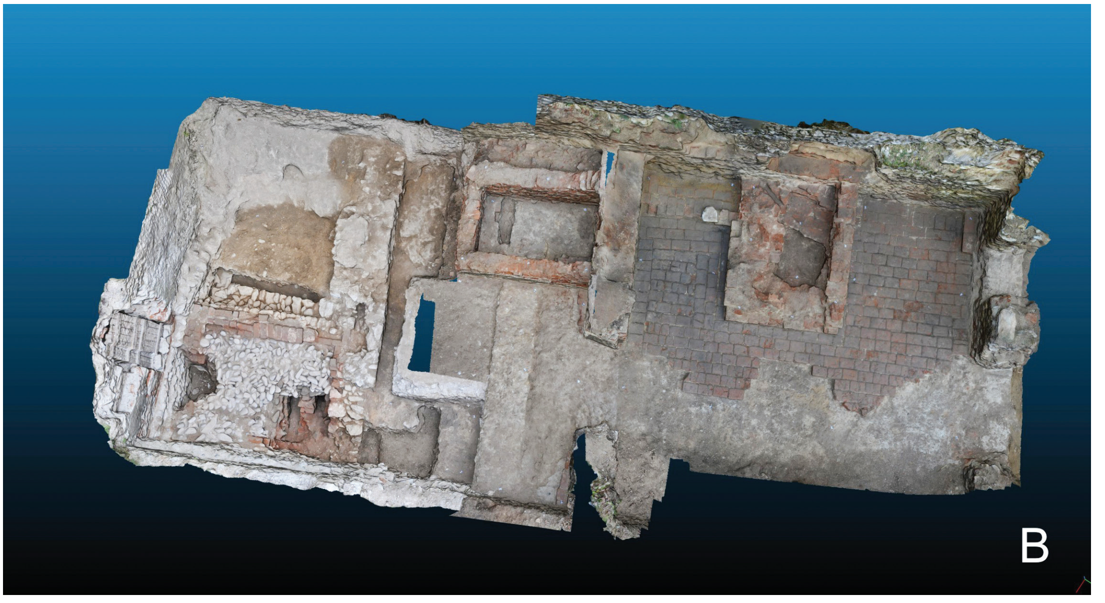

Figure 25B. Skalka nad Váhom (Slovakia). Remains of a medieval monastery, 14th-17th century. Textured 3D model combining the results from two archaeological seasons (see also Figure 25A) that focused on uncovering the west wing of the clausura. IbM (425 photos, 12+24Mpx).

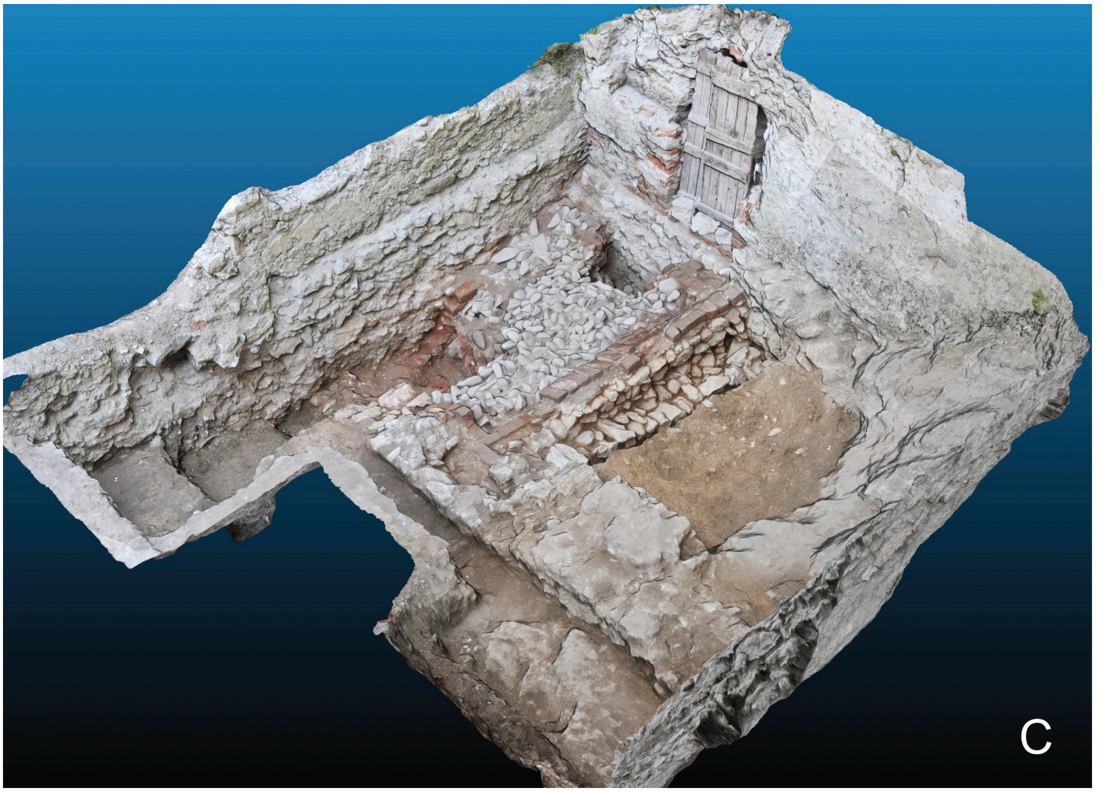

Figure 25C. Skalka nad Váhom (Slovakia). Remains of a medieval monastery, 14th-17th century. Textured 3D model – detail of medieval hypocaust.

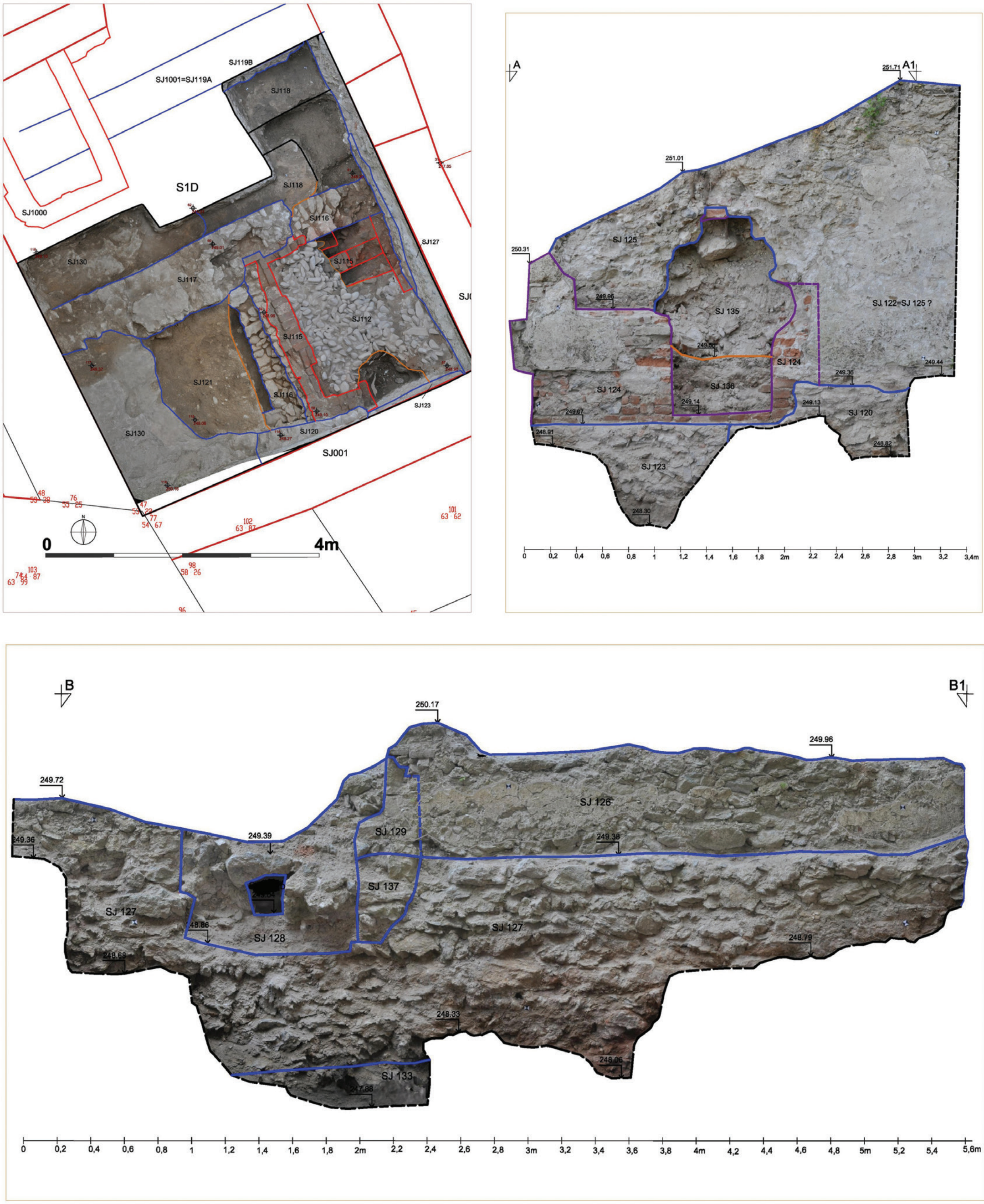

Figure 26. Skalka nad Váhom (Slovakia). Remains of a medieval monastery, 14th -17th century. Examples of 2D documentation derived from the 3D model.

Čachtice, Castle

Site type:	Castle
Location:	Čachtice, Nové Mesto nad Váhom District, W Slovakia
Dating:	13th-16th century
Research type:	Preventive research
Recording technology:	IbM
Recording equipment:	Camera Nikon D90 and Sony Nex 7, UAV (drone), TS, GNSS Rtk Rover (differential GPS)
Software:	Agisoft Photoscan 1.0.0, AutoCad Civil 3D 2016 student version, ArcGIS 10.0
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans. Georeferenced DEM, cross-section views (Figs. 27 - 29).
Short description:	The excavation at Čachtice Castle was conducted in 2012 and 2013 and was primarily focused on the north castle wing, which was planned for structural reinforcement. Many elements of the former historical structures were revealed, such as the partly destroyed residential area and the basement area with partially preserved vaulted roof. The 3D documentation was performed with a high monopod stand and an UAV. Individual parts of the uncovered architecture were documented and processed as linked spatial segments.

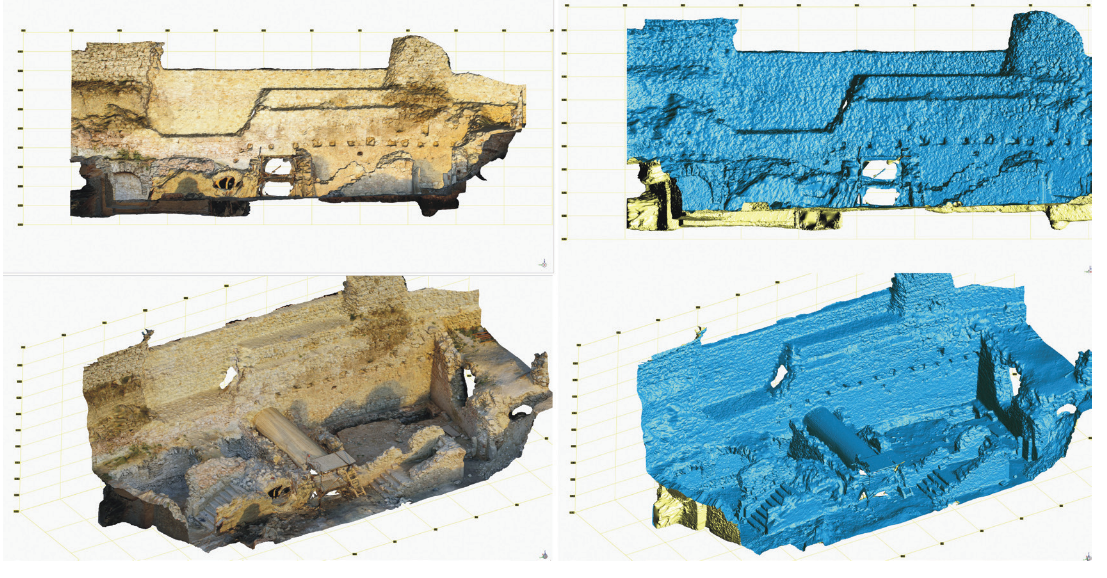

Figure 27. Čachtice (Slovakia). Medieval castle, 13th-16th century. 3D model of the eastern palace during the restoration process. IbM (250 photos, 12Mpx). Top – section through the interior of the eastern portion of the structure, bottom – isometric view of the same area.

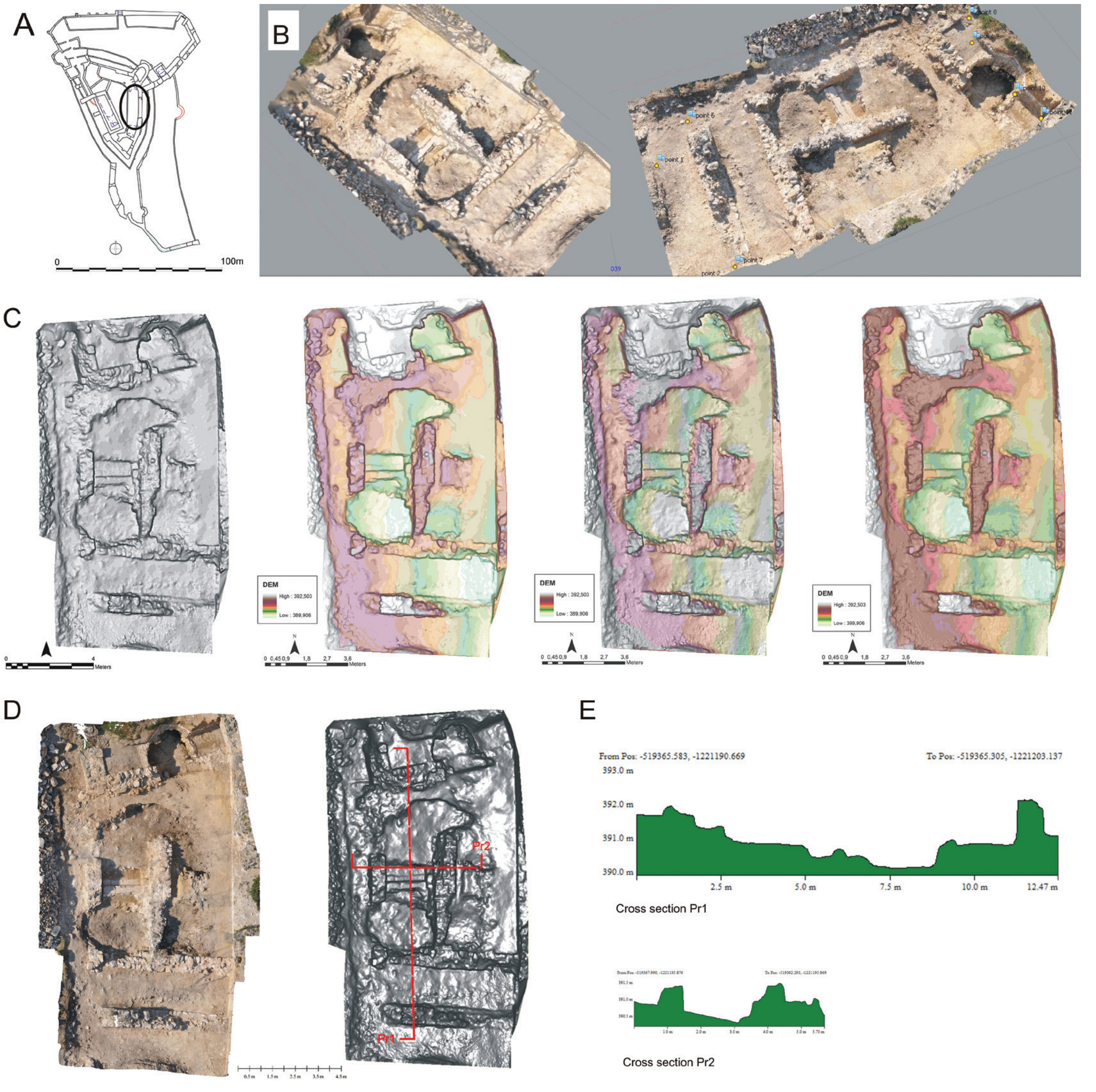

Figure 28. Čachtice (Slovakia). Medieval castle, 13th-16th century. Archaeological trench K25 in the eastern palace. IbM (65 photos, 12Mpx). A: ground plan of the castle with indicated location of the documented trench, B: solid 3D model of the trench with the texture map, C: DEM with different forms of visualisation (analytical hillshading and hypsometry), D: orthophoto plan, E: cross-sections.

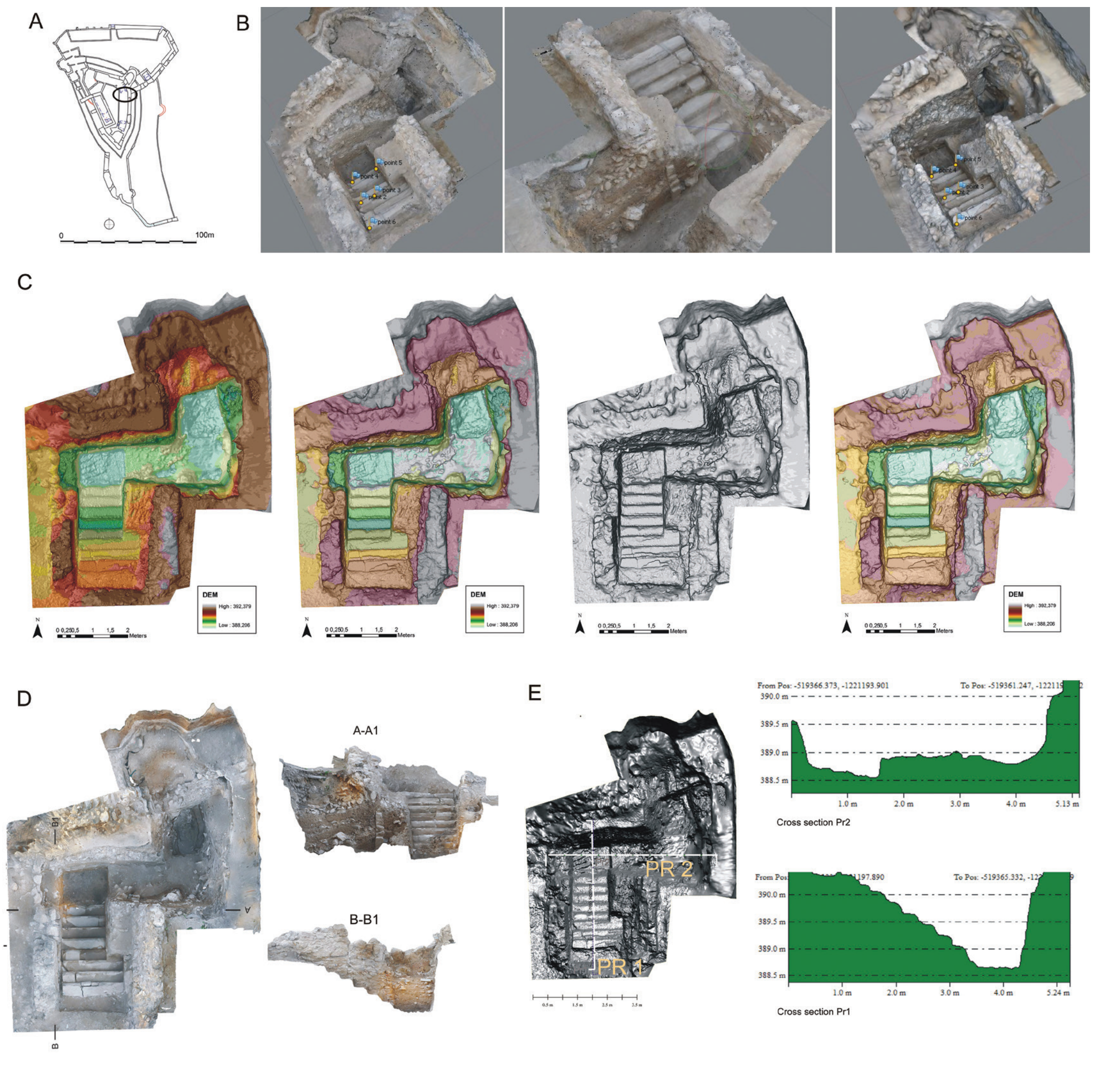

Figure 29. Čachtice (Slovakia). Medieval castle, 13th-16th century. Archaeological trench S3 in the eastern palace. IbM (30 photos, 12Mpx) A: location of the trench within the castle, B: solid 3D model of the trench with the texture map, C: DEM with different forms of visualisation (analytical hillshading and hypsometry), D: orthophoto plan of the layout and the profiles, E: cross-sections.

Brazda, Ancient sepulchral architecture

Site type:	Tomb
Location:	Brazda, Republic of Macedonia
Dating:	5th-3rd centuries BC
Research type:	Documentation of an archaeopark
Recording technology:	IbM
Recording equiment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX), TS, GNSS Rtk Rover (differential GPS)
Software:	Agisoft Photoscan 1.0.0, AutoCad Civil 3D 2016 student version, ArcGIS 10.0
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans. Georeferenced DEM, cross-sectional views (Figs. 30-32).
Short description:	The 5th century BC tomb is situated at the foot of a fortified hillfort Brazda, some 15 km to the north from Skopje. The overall structure of this probable princely tomb represents a unique example of its kind in the wider Balkan area. It contains a rectangular chamber (9.8 x 6.6 m) with a long dromos, which slopes steeply for 20 m towards the chamber entrance. The walls of the underground chamber were built of massive travertine blocks of an average weight of 500-1500 kg. The site was investigated in the 1990s and is nowadays part of a small archaeological park. The 3D documentation was prepared without a drone or a monopod stand. The elevation of the structure is small in relation to the ground on which it was erected, and the majority of photos were taken at a relatively acute angle. The absence of images taken perpendicularly to the structure subsequently caused a high level of noise in the software processing. The level of noise was also increased by the dense vegetation growing on the tomb.

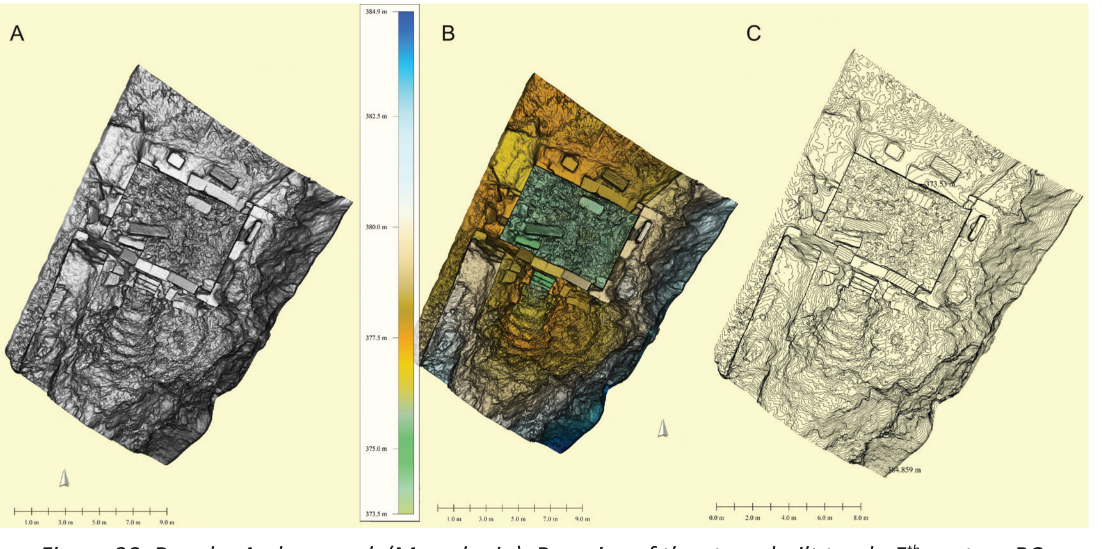

Figure 30. Brazda, Archaeopark (Macedonia). Remains of the stone-built tomb, 5th century BC. DEM derived from the 3D model. A: analytical hillshading, B: hypsometry, C: contours.

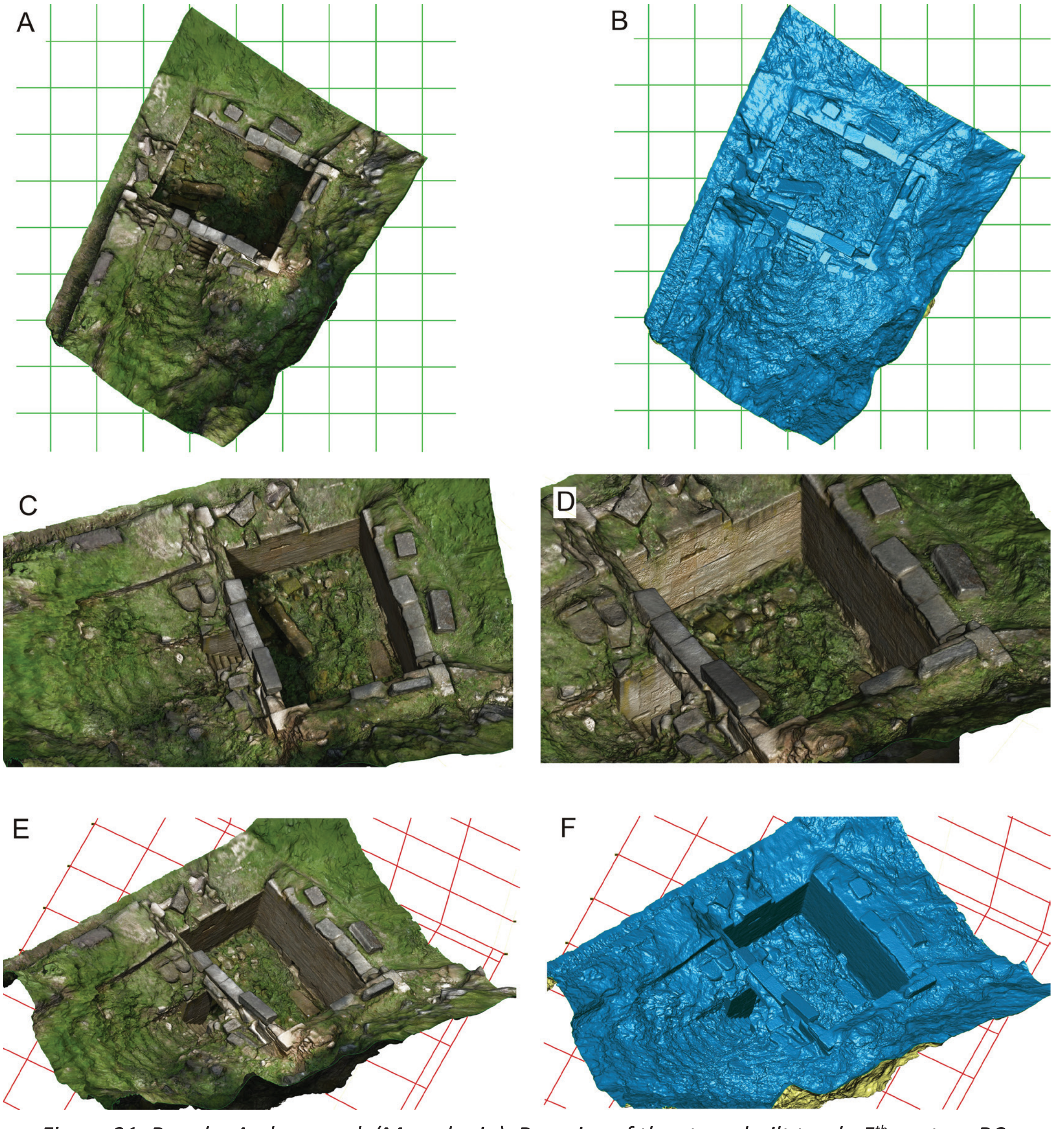

Figure 31. Brazda, Archaeopark (Macedonia). Remains of the stone-built tomb, 5th century BC. 3D model. IbM (476 photos, 24 Mpx). A,B: nadir view, C-F: isometric views.

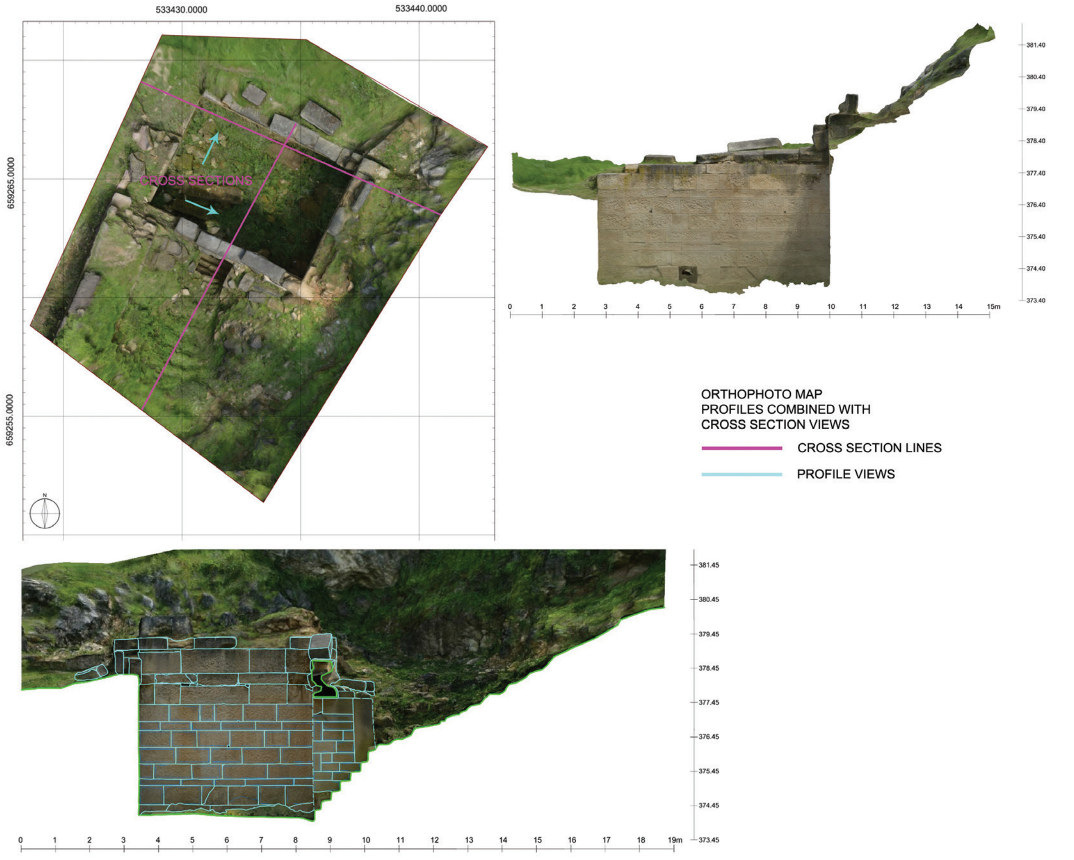

Figure 32. Brazda, Archaeopark (Macedonia). Remains of the stone-built tomb, 5th century BC. Examples of 2D documentation derived from the 3D model.

Bratislava, Castle

Site type:	Castle area, settlement area from the 1st century B.C., built-up area from the 16th century
Location:	Bratislava Castle, northern terrace, SW Slovakia
Dating:	Late La Tène period (1st century BC), 13th-17th century AD
Research type:	Preventive excavation
Recording technology:	IbM, TLS
Recording equipment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX), TLS Faro Focus X130, TS, GNSS Rtk Rover (differential GPS)
Software:	Agisoft Photoscan 1.0.0, Faro Scene, CapturingReality RC, CloudCompare, AutoCad Civil 3D 2016 student version, ArcGIS 10.0 trial version
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans. Georeferenced DEM, cross-section views (Figs. 33-36).
Short description:	The investigations in the area of the castle were carried out periodically between 2008 and 2014. The 3D documentation of archaeological situations was used as the basic recording type in the period 2013-2014 and as a sole method for creating plans and profiles of the entire site. Special attention was paid to the architectural remains discovered in the northern courtyard. These included foundations of two buildings constructed in the Roman style and dated to the 1st century BC. The main structural axis of the Building 1 formed two parallel masonry components, which, at their south end, were subsequently damaged by digging the moat for the medieval castle. The main axis was completed with two pillars with well-preserved elements of the above-ground structure and of the foundations. In the Building 2, cladding over the foundation walls, the cast mortar floor and two lines of four pillars along the main longitudinal axis were partially preserved. Some architectural remains related to the utilisation of the area in the 16th-18th century were also revealed. Especially remarkable was a 16th-century built-up area, located in place of an infilled medieval quarry. It consisted of structures made of stones bound by clay mortar. Here, a relatively well-preserved bread (?) oven was discovered. Remains of the 18th century Baroque garden were also discovered. All discovered structures were documented by IbM and using an UAV. However, the UAV was not used for recording of the 16th century built-up area and the remains of the medieval quarry. In these two cases, only oblique photographs were made. Terrestrial 3D scanning was used for the Roman-style buildings (TLS Faro Focus X130). Data from TLS documentation as well as from IbM were merged in the processing phase in CloudCompare and CapturingReality RC.

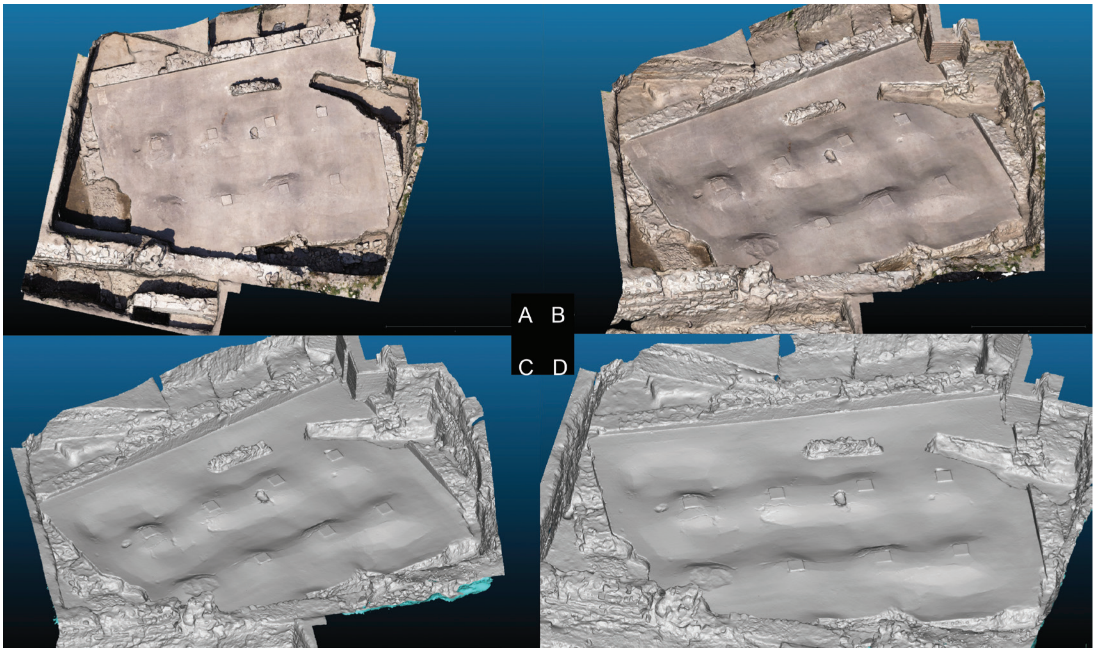

Figure 33. Bratislava, Castle, northern terrace. Roman-style Building 2, 1st century BC. 3D model. Terrestrial laser scanning (TLS) in combination with IbM. A, B: textured 3D model, C, D: shaded 3D model.

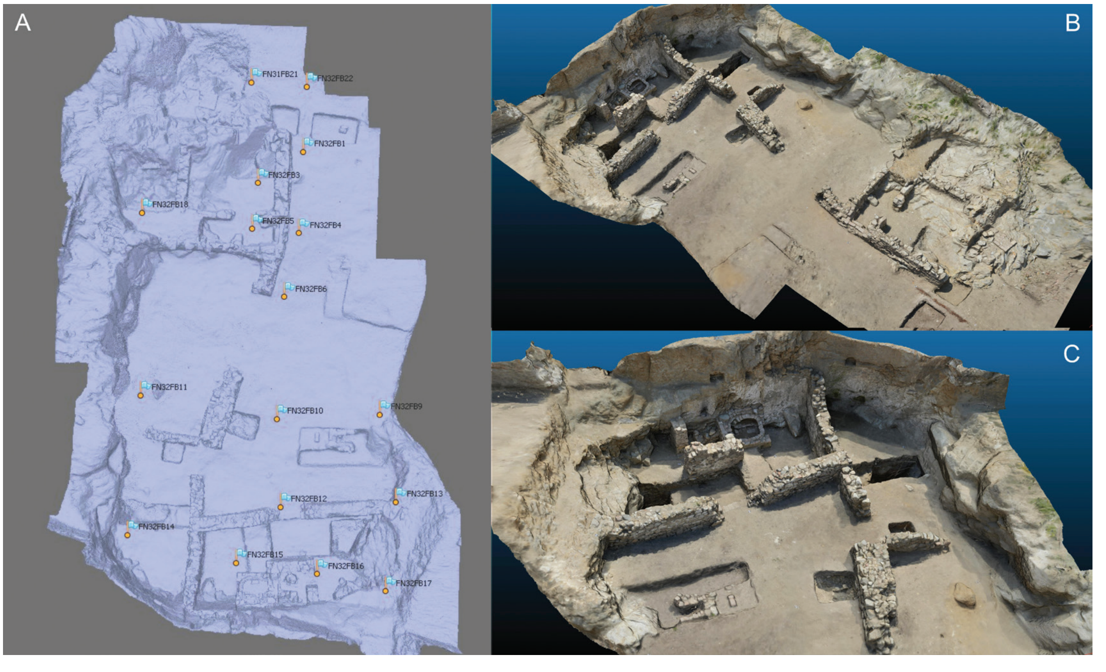

Figure 34. Bratislava, Castle, northern terrace. Remains of a residential structure, 16th century. 3D model. IbM (534 photos, 12Mpx). A: distribution of measured ground control points (GCP), B, C: textured 3D model.

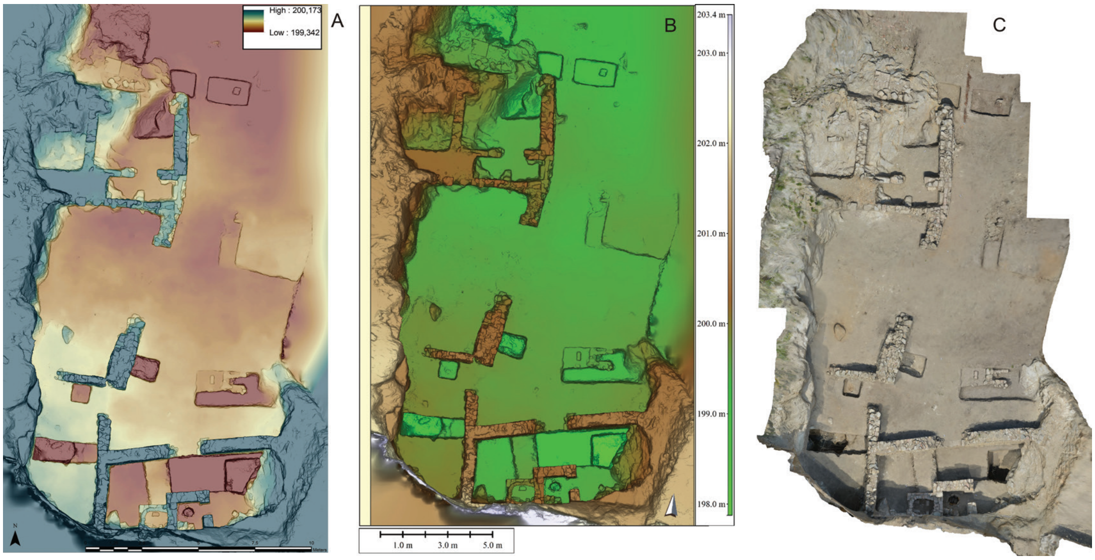

Figure 35. Bratislava, Castle, north terrace. Remains of a residential structure, 16th century. A, B: DEM derived from the 3D model, C: Georeferenced orthophoto plan derived from the 3D model.

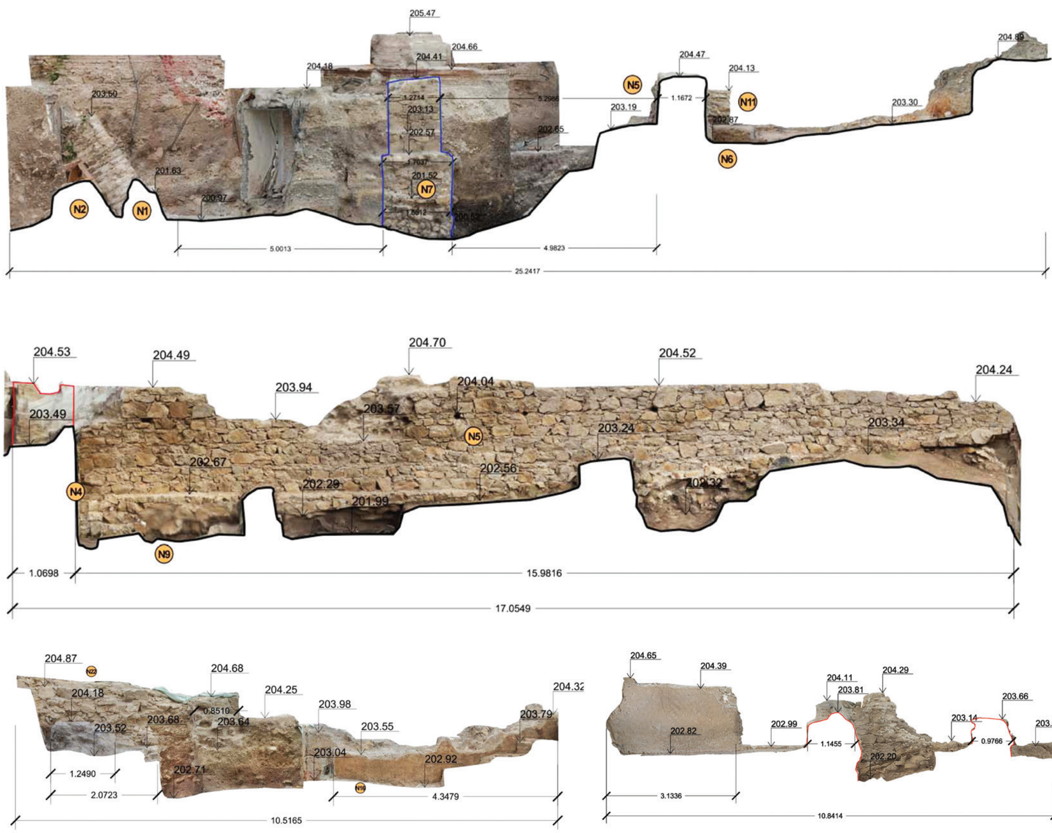

Figure 36. Bratislava, Castle, northern terrace. Roman-style Building, 1st century BC. Examples of 2D documentation deliverables derived from the 3D model. View of the cross-section.

Považská Teplá, Castle

Site type:	Castle
Location:	Považská Teplá - Považský castle (district Považská Bystrica), W Slovakia
Dating:	16th-17th century
Research type:	Preventive research
Recording technology:	IbM
Recording equipment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX), TS, GNSS Rtk Rover (differential GPS)
Software:	Agisoft Photoscan 1.2.0, CloudCompare, AutoCad Civil 3D 2016 student version
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans, cross-section views (Figs. 37, 38).
Short description:	The subject of 3D documentation was the northern wing, revealed during the excavations in 2016. This was a rectangular structure with four columns in the corners placed on stone bases probably built from the secondarily used stone blocks. Effective collection of the data was hindered by the fact that the interior space did not allow to always obtain sufficient distance for taking the photos. Moreover, given the significant local elevation defined by the capitals, it was very difficult to capture the upper part of the structure from a sufficient number of sides. As the surrounding walls were considerably destroyed, they could not be used as an elevated platform. The top of the structure was possible to capture only by oblique photos taken from the west side. The absence of vertical photos of the top part of the structure resulted in a smeared colour of the texture in this part of the 3D model.

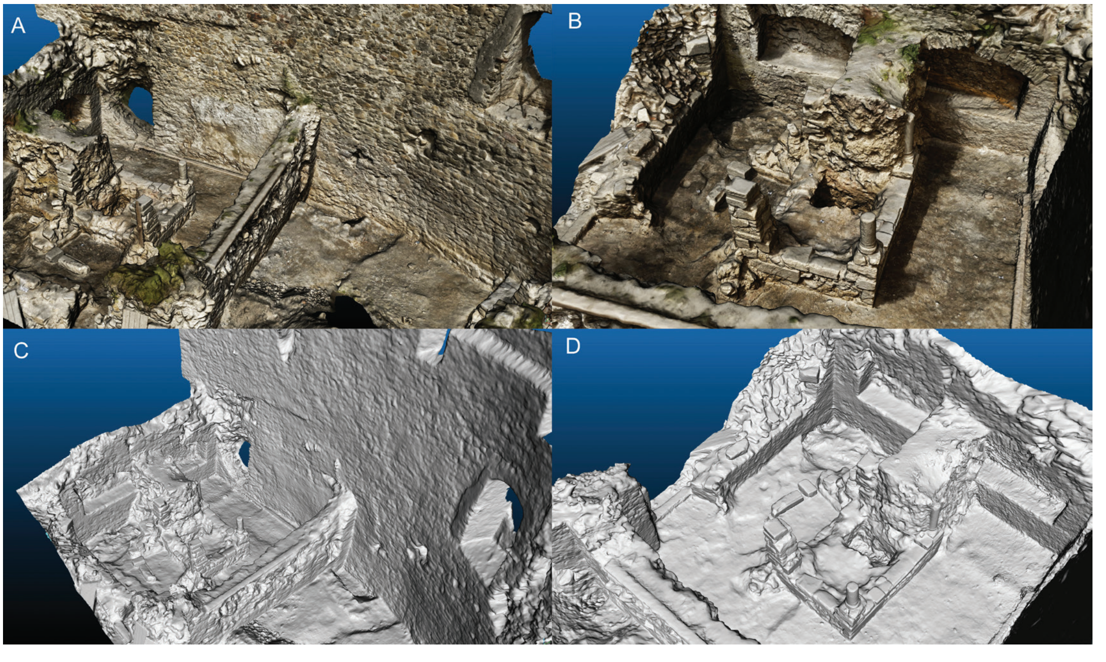

Figure 37. Považský Castle (Slovakia). North palace structure, 16th century. IbM (366 photos, 24Mpx). A, B: textured 3D model, C, D: shaded 3D model.

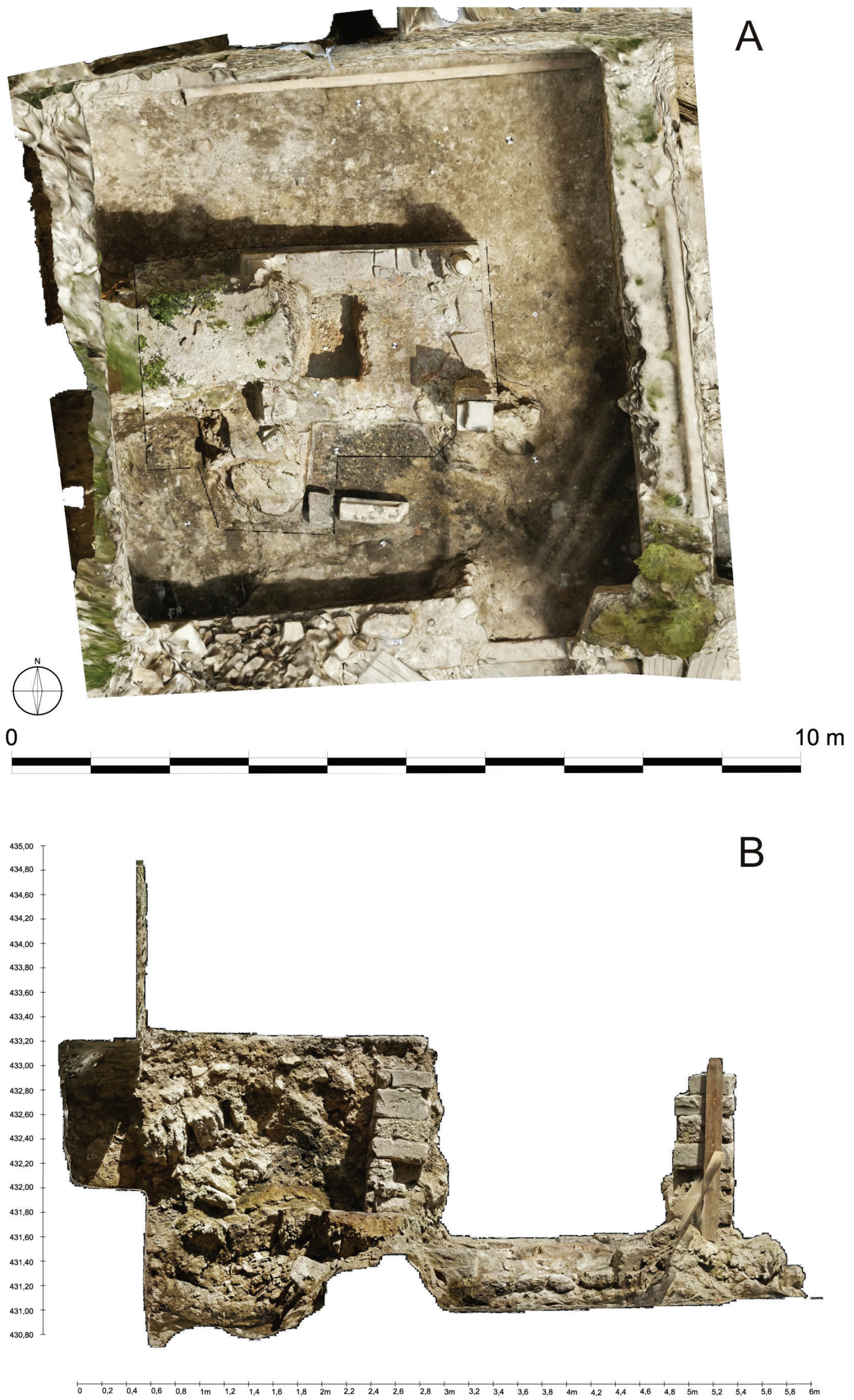

Figure 38. Považský Castle (Slovakia). North palace structure, 16th century. Examples of 2D documentation deliverables derived from the 3D model. A: groundplan orthophoto, B: profile orthophoto.

DISCUSSION

The experience from the presented case studies shows that IbM is the most suitable method for 3D digitisation of archaeological cultural heritage. Its advantage lies in the speed of the data collection, which is highly important in the rescue research. Moreover, compared to TLS, IbM represents a better alternative in terms of the total cost, because the only costly items are the camera and the high-performance computer. In the case of archaeological situations in which the largest part of the documented area is situated at the level of the surrounding terrain, and where vertical structures are represented only by sporadic and largely destroyed architectural elements, the application of TLS is significantly limited. This is because TLS scanners usually have limited manoeuvring ability of the sensor when placed vertically in relation to the terrain.

When photographing extensive flat areas of archaeological sites for the IbM documentation, it is suitable to use an UAV (drone) or a high monopod stand, which enable taking photos from above and from an adequate distance. In case a drone is used, it is recommended to limit the flight distance (flight level) in order to maintain the sufficient image resolution. In the case of structures with parts preserved up to a certain height (e.g. masonry preserved to a height exceeding 1 m), it is necessary to complete the vertical photography with oblique photo documentation. In many cases, it is required to combine aerial documentation with terrestrial photography, whereby the scanning circuits must be merged in a respective software using GCP.

For georeferencing a 3D model and the creation of basic 2D and 2.5D documentation products (georeferenced orthophoto plan and DEM), it is necessary to distribute, and subsequently measure, GCP in space. Depending on the size of the area documented, and the planned distance of the camera from the photographed space (especially as regards the expected flight level), GCP should be sufficiently large to be visible on individual images. The distribution of points should include the whole area. Although it is not required to distribute GCP over a grid, certain regularity is welcome (Figure 34: A). If calibrated coded reference markers are used, some software packages (e.g. Agisoft Photoscan and Pix 4D) have the option of automatically conducting their identification (Figure 40). In addition to calibrated coded markers, standardised markers can be also used, such as bicolour squares placed diagonally or with overlapping angles; they can, depending on the software used, also be identified on the images using a semi-automatic method.

Given that archaeological sites usually have significantly structured geometry of the surface, as well as rich texture, the SfM algorithm has no problem to detect a sufficient number of SIFT points on the input photos without a significant 'dead zone'. The resulting 3D model is thus clean and sharp. A problem can occur if the structure is also captured by vertical photography and if its surface is documented only with oblique photos made at an acute angle (see the case study of Brazda) from various sides. In such a case, a high re-projection error can occur in the process of 'bundle adjustment'; this can result in high noise as well as in the occurrence of ghosting effect in the process of creation of a dense point cloud. If this cannot be prevented by using a drone or a high monopod, the re-projection error must be thoroughly and precisely reduced in the given software environment (ideally, to below 1px) (Figure 39).

In addition to the digitisation of ground plans, the concept of IbM is also suitable for documenting complex profiles, especially those of large length or composed of several layers created by diverse architectonic elements. In addition to the creation of a 3D information database, the main significance of 3D digitisation of archaeological finds, especially in the case of rescue archaeological research, lies in the fact that it represents extraordinarily effective method of generating 2D documentation in the form of georeferenced orthophoto plans and digital elevation models (DEM). These are necessary elements of the research documentation. From the perspective of practical utilisation of 3D digitisation by professional archaeologists, 2D documentation still prevails. Nevertheless, a tendency has appeared towards the application of 3D mesh for the purpose of 3D vectorisation, subsequently interconnected with the database model in 3D GIS solution. However, it characterises mainly long-term research projects that hire professional research teams.

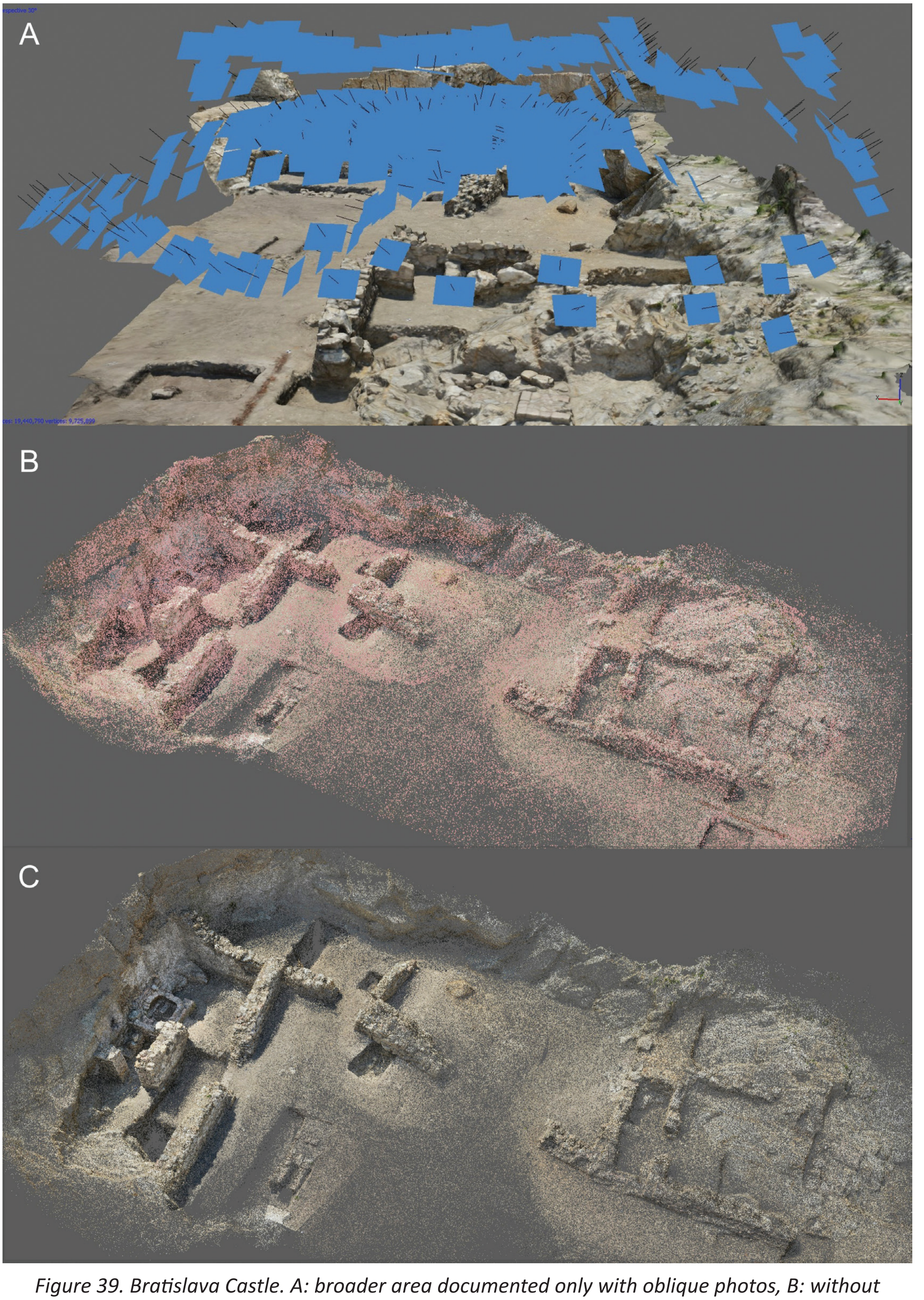

Figure 39. Bratislava Castle. A: broader area documented only with oblique photos, B: without verticals, resulting in a noisy sparse cloud, C: with large number of points with a high re-projection error that needs refinement in the iterative process.

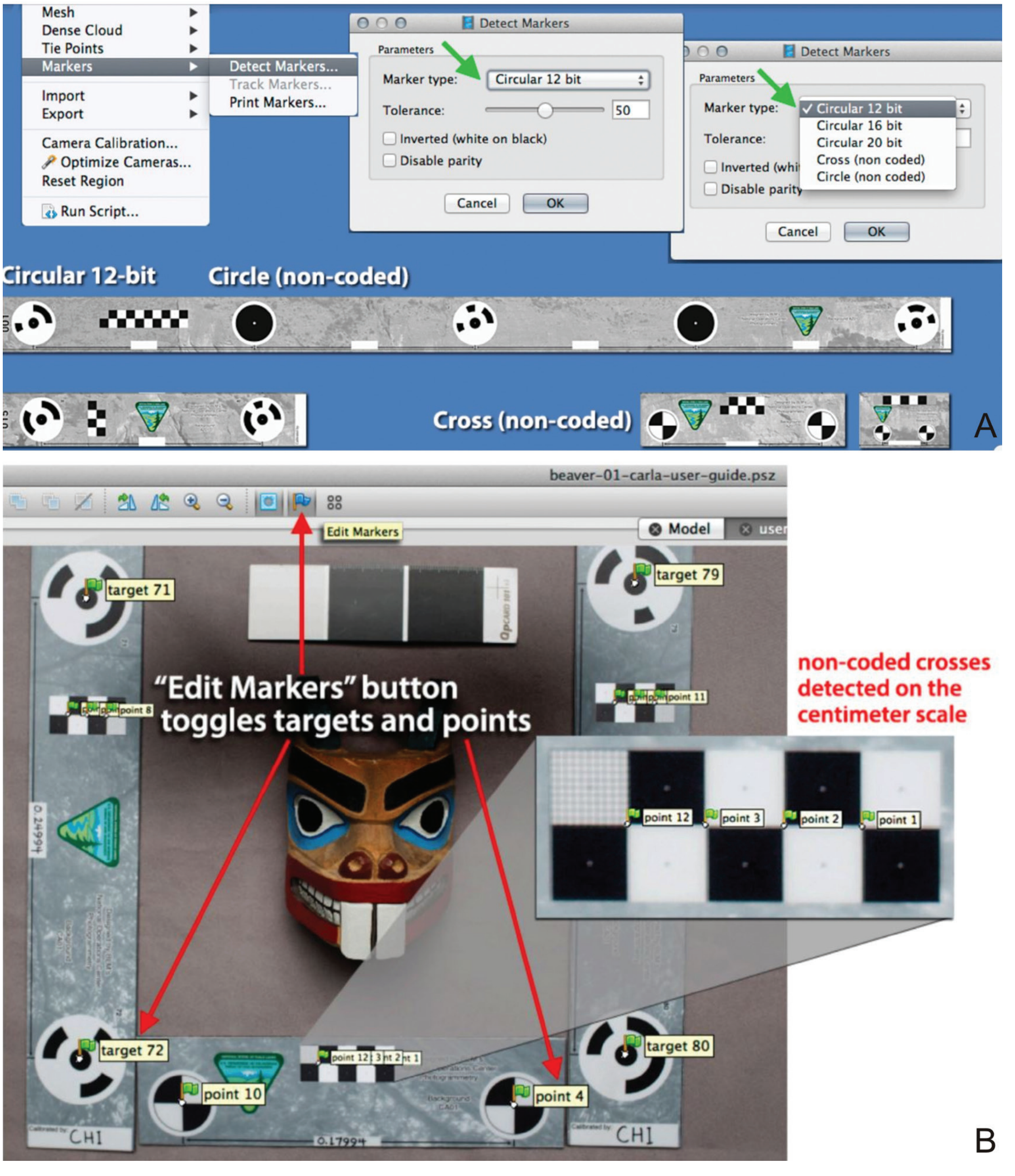

Figure 40. A: Types of calibrated coded and non-coded targets, B: the process of automatic recognition of coded and non-coded targets in Agisoft Photoscan. (Available at: http://www.agisoft.com/pdf/tips_and_tricks/CHI_Calibrated_Scale_Bar_Placement_and_Processing.pdf).