3D RECORDING OF ARCHITECTURE

Ján Zachar (Via Magna) & Perica Špehar (University of Belgrade)

Comprehensive digitisation of complex architectural forms usually represents the most demanding tasks within the framework of documentation of cultural heritage. Spatial and elevation variations, together with often very hard-to-access elements, require thorough planning of the data collection, as well as their systematisation and the nomenclature, for the purpose of smooth processing. Various lighting and spatial conditions offered by exterior and interior of the context in many cases require the application of different techniques of data collection, and the subsequent effective merging of the results.

Architectural structures of different sizes and different levels of complexity of exterior and interior elements were selected as the case studies within the framework of the CONPRA project. TLS and IbM methods were tested by using UAVs or monopod stands in order to assess the usefullness and effectiveness of the technological solutions in these particular cases.

The case studies were selected with a view of demonstrating possibilities and limits of 3D documentation in the context of various types of architecture. All case studies were processed in a workstation with the following parameters: Intel Xeon CPU E5-2620 v2@ 2,10 GHz, RAM 128 GB, GPU NVIDIA GeForce GTX 780 3GB,OS W7. In the case of TLS application, the resolution was always set to 6 mm per 10 meters. For IbM, two types of software were used: Agisoft Photoscan and CapturingReality RC (the latter was chosen based on the licence availablility). In Photoscan, the following parameters were set for the batch processing workflow: step – align photos (high accuracy with the key point limit of 80,000 and the tie point limit of 40,000 points); step – refinement of alignment (decreasing of global re-projection error to max. 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 the application of CapturingReality 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).

Jazernica, Medieval church

Site type:	Church
Location:	Jazernica, Turčianske Teplice District, NW Slovakia
Dating:	15th century
Recorded parts:	Exterior, roof
Recording technology:	IbM
Recording equipment:	Cameras Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX) and Sony Nex7, UAV
Software:	DxO Optics Pro 10.0, Agisoft Photoscan 1.1.0, CloudCompare 2.7, AutoCAD Civil 3D 2016 student version
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figure 41)
Short description:	The structure is situated within the residential area, in the area modified into a provisional park. It represents a single-aisle Gothic building with a semi-circular plan of the shrine and the sacristy in the north. On the outside, the shrine gradually extends into to the aisle, without any offset in the wall alignment. Three windows with simple tracery are installed on the south side of the aisle and the semi-circular shrine. The roof is covered with metal sheets. The church is a simple building without much diversity in the spatial configuration or the height. These are favourable conditions for the collection of raw data. The collection was also facilitated by the placement of the church in a relatively open space of the park. However, the accessibility for documenting was limited on the northern side of the sacristy, which is partially covered with a low shrubbery and is located in proximity of the fence that separates plots of land. Documentation of the facades was performed by a handheld camera. For collection of the data of the roof, an UAV was used. Navigation of the drone was complicated on the northern side of the building due to the high poles carrying high voltage lines. The data was collected in sunny weather with a high index of sunlight. The absence of diffuse lighting conditions caused significant contamination of the resulting texture with shadows of trees. Intensive sunlight also complicated documentation of the roof covering whose surface was very shiny (metal sheets).

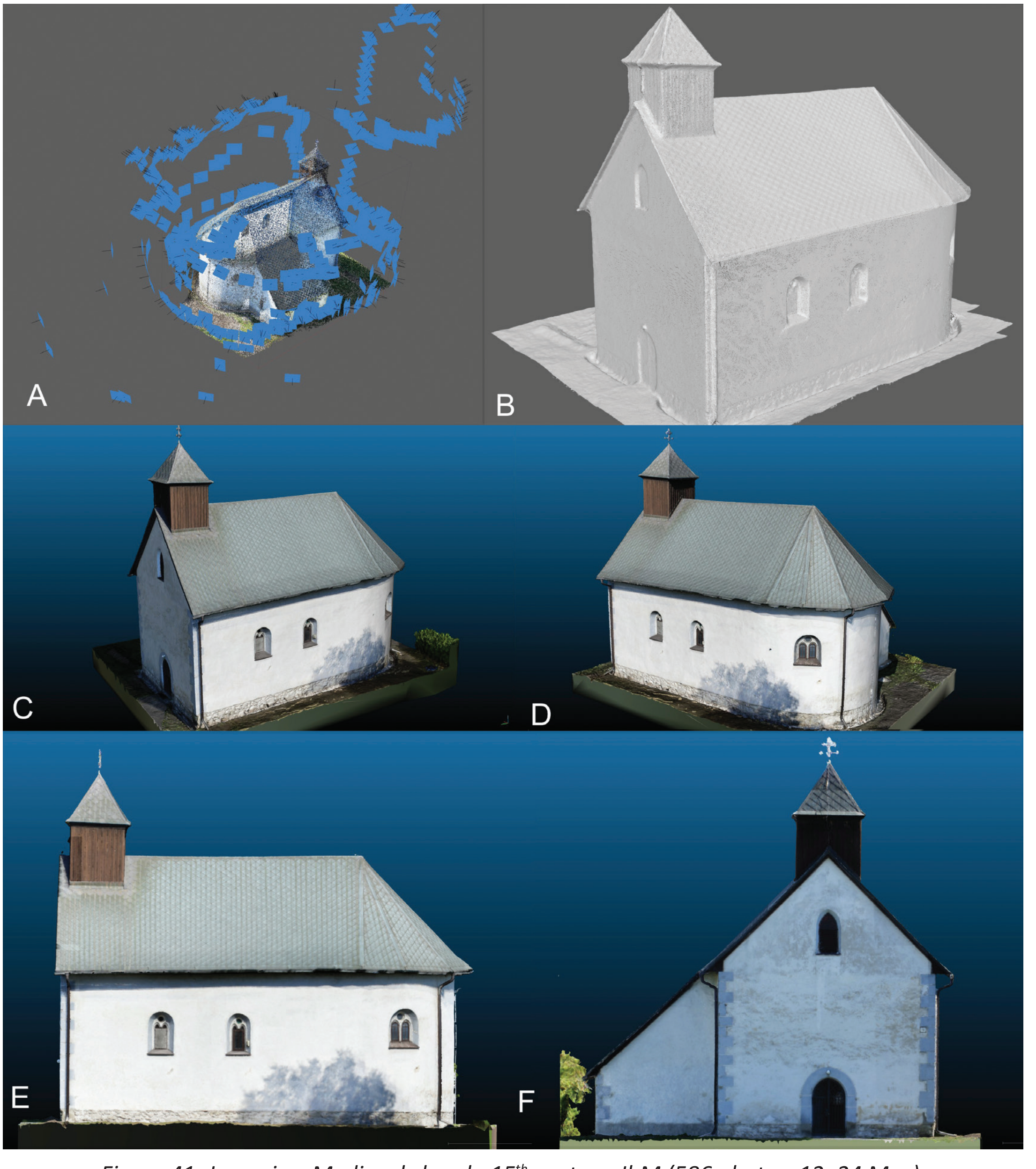

Figure 41. Jazernica, Medieval church, 15th century. IbM (586 photos, 12+24 Mpx).
A: distribution of cameras, B: dense point cloud, C,D: textured 3D model – isometric view,
E and F: textured 3D model – ortho-view of the facades.

Rajec, Historical Town Hall

Site type:	Architecture
Location:	Rajec, Rajec District, NW Slovakia
Dating:	16th -17th century
Recorded parts:	Exterior, roof
Recording technology:	IbM
Recording equipment:	Camera Nikon D 90
Software:	DxO Optics Pro 10.0, Agisoft Photoscan 1.2.0, CapturingReality RC, CloudCompare 2.7, AutoCAD Civil 3D 2016 student version
Record:	Scaled 3D model (mesh), scaled orthophoto plans (Figs. 42, 43)
Short description:	The Renaissance town hall in Rajec is a two-floor block building in the central part of a rectangular square. The ground floor is lined with an arcade. The high hip roof is covered with roof shingles. At the time of the recording, smooth white plastering covered the exterior facades. The walls and roof were not visually obstructed by other structures. The walls were photographed by a handheld camera. Photographs of the roof were taken from a larger distance using zooming of transfocal lens to capture the majority of its surface features with sufficient resolution. Certain problems appeared in processing of the raw data due to the glass inserts in the arches on the ground floor whose surface could not be captured with sufficient accuracy due to the transparency, reflectivity and shininess. Data processing proved problematic also for some parts of the monochromatic smooth facade plaster. The absence of plasticity as well as texture did not create good conditions for generating a sufficient number of SIFT points, consequently causing a higher level of noise with sparse and dense point cloud and surface deformations in the 3D mesh. Input photos needed to be edited prior to processing in order to optically highlight the surface structure as well as the colouring (DxO Optics Pro).

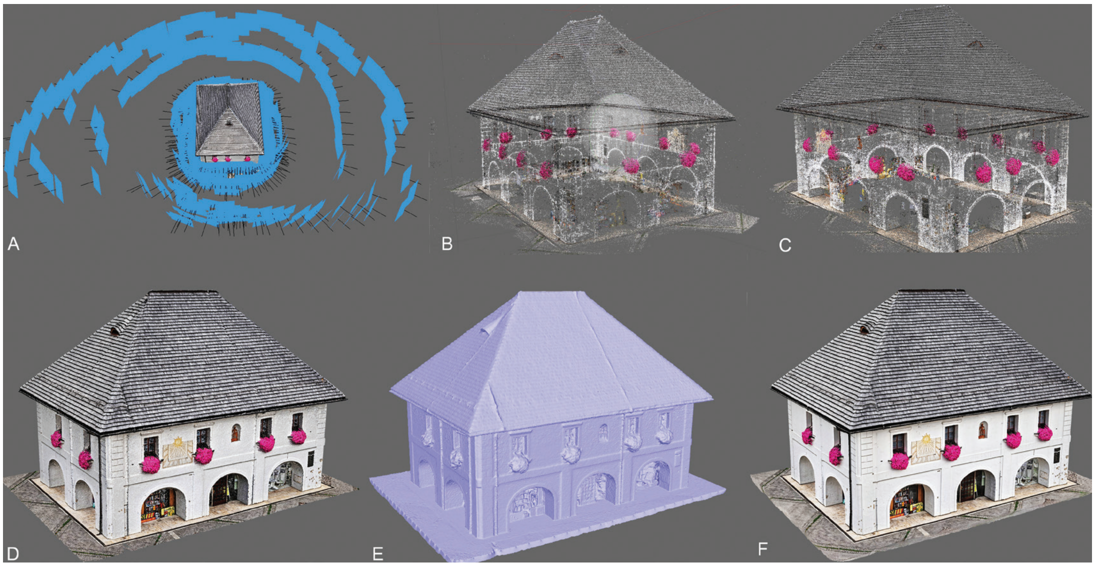

Figure 42. Renaissance Town Hall in Rajec, Slovakia. IbM (576 photos, 12Mpx). A: camera positions, B: sparse point cloud before reprojection C: sparse point cloud after the reprojection, D: dense point cloud, E: meshed 3D model, E: textured 3D model.

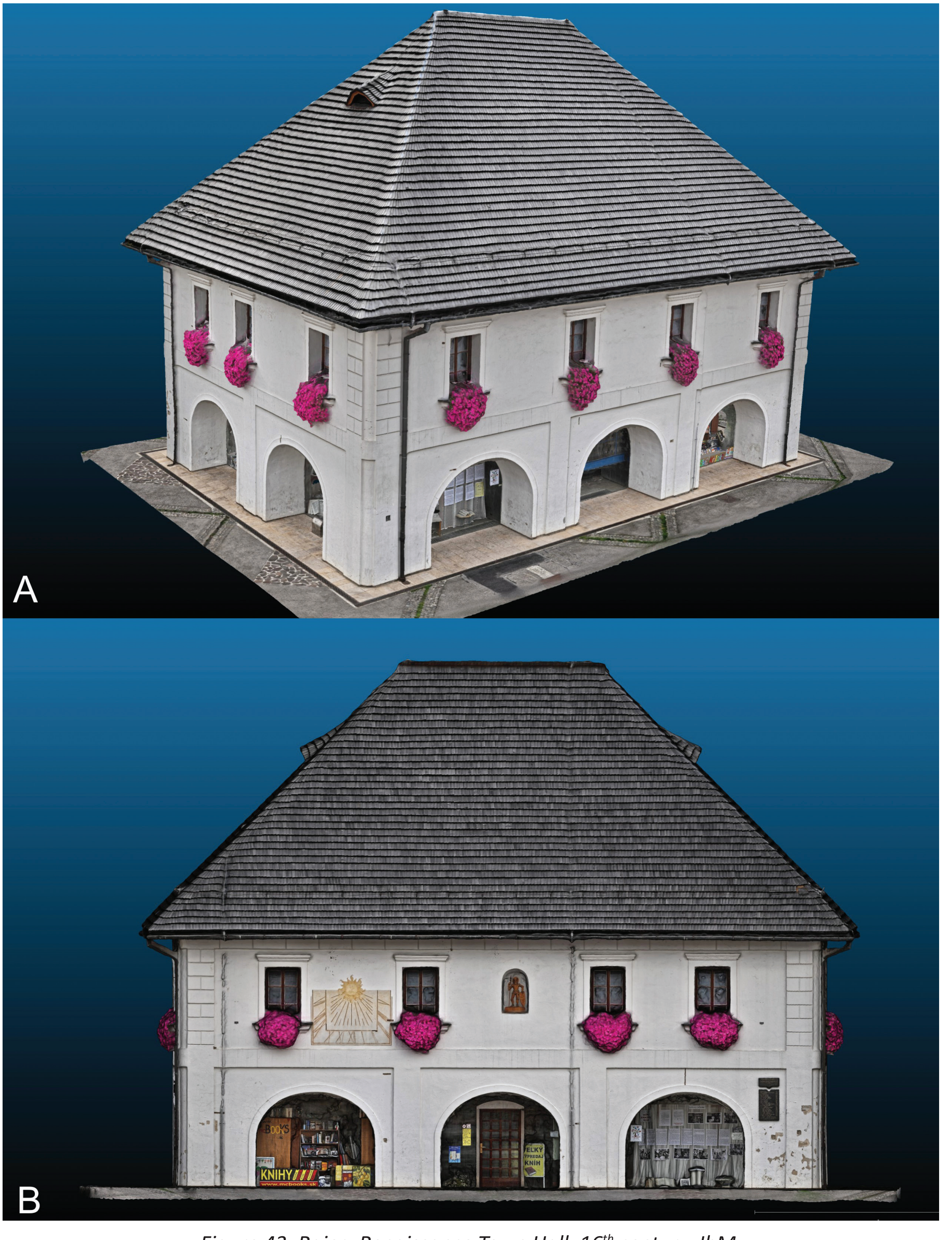

Figure 43. Rajec, Renaissance Town Hall, 16th century. IbM.
A: textured 3D model – isometric view, B: textured 3D model – ortho-view of the facade.

Sazdice, medieval church

Site type:	Church
Location:	Sazdice (district Levice), south-central Slovakia
Dating:	14th-15th century
Recorded parts:	External walls (facades)
Recording technology:	IbM
Recording equipment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX)
Software:	DxO Optics Pro 10.0, Agisoft Photoscan 1.2.0, CapturingReality RC, CloudCompare 2.7, AutoCAD Civil 3D 2016 student version
Record:	Scaled 3D model, scaled orthophoto plans (Figs. 44-46)
Short description:	The church is situated in the central part of the village located on a sloping terrain. Spacious but compact, the church was built in the Early Gothic style (ca. 1330) as a single-aisle building with the square-in-plan presbytery, to which the sacristy was added on the northern side. The structure was modified according to the Late Gothic style (end of the 15th c.) and was later subject to Baroque modifications (mainly of the interior) at the turn of the 17th to the 18th c.. The building was partially repaired in 1932 when an anteroom was added to the western facade. The recording was focused on the facades, which were subject to the reconstruction and required orthophoto plans to a specific scale in order to capture the condition of the brickwork. A scaled complete 3D model of the church exterior was used for making orthophoto plans to the required scale. The recording was performed with a handheld camera.

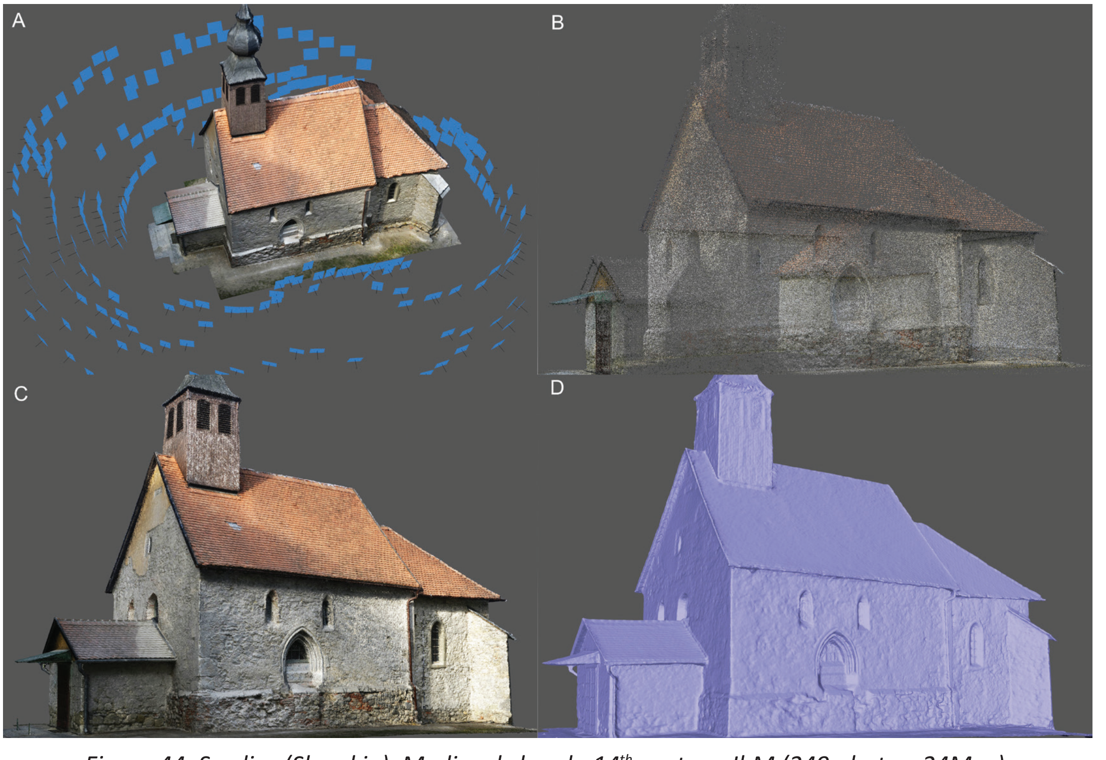

Figure 44. Sazdice (Slovakia). Medieval church, 14th century. IbM (249 photos, 24Mpx).
A: distribution of cameras, B: sparse point cloud, C: sense point cloud, D: meshed 3D model.

Figure 45. Sazdice (Slovakia). Medieval church, 14th century. IbM. Textured 3D model – isometric view.

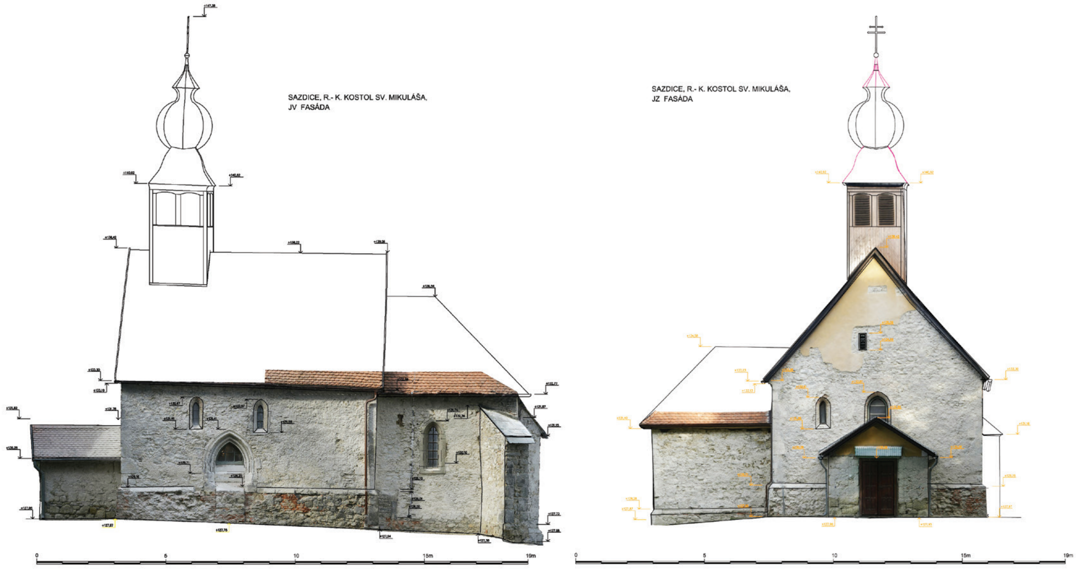

Figure 46. Sazdice (Slovakia). Medieval church, 14th century. IbM. Textured 3D model – isometric view. Examples of 2D documentation deliverables derived from the 3D model – ortho-view of the facades.

Žehra, Hodkovce, Manor house

Site type:	Manor house
Location:	Žehra, Hodkovce, Spišská Nová Ves District, E Slovakia
Dating:	18^{th}-19^{th} century
Recorded parts:	exterior (facades), roof, interior
Recording technology:	IbM, TLS
Recording equipment:	Cameras Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX) and Sony Nex7, TLS Leica C10, UAV, TS, GNSS Rtk Rover (differential GPS)
Software:	DxO Optics Pro 10.0, Agisoft Photoscan 1.1.0, CapturingReality RC, CloudCompare 2.7, Microstation V8i trial version, Cyclone
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans and cross-section views (Figs. 47-52).
Short description:	3D recording of the manor complex in Žehra, Hodkovce was completed in 2014. The recording included the manor house, adjacent park with a garden, a farm building and 2 other structures (church and garden architecture) situated in the forested part of the park. The whole complex is situated on a slope descending in W-E direction. The manor house is a four-wing single-floor building with internal courtyard/garden. The ground floor has the entrance side facing the park; the facade is divided by elongated windows lined with bands organised into lesene (pilastre-strip) frames. There are two windows in the centre of the east wing facade that has pilasters on the sides and a cornice on the wall; stucco ornaments were moulded in a semi-circular pediment above the windows. There is a large gable above them, originally with vases on the sides. The elevated terrace in front of the facade is accessed by two staircases with conical railing. In the east wing corners there are towers with elevated storied pavilions with garrets. The west wing was added in the 19^{th} c. The central part of the west wing consists of an open arcade set with Prussian arches and with strips in between the arches; it enabled access from the west part of the park to the manor's internal courtyard. The arcade is flanked (the north and south) with stylised square bastions, which are elevated one floor up and topped with stylised crenellation. The ground floors of individual wings are covered with saddle roof made of an artificial material. The open area of the garden in the park extends along the west and south sides of the manor. A pathway runs directly in front of the east facade. To the north, fence delimits the park area. The exterior of the manor was recorded with TLS (Leica C10), IbM methods, and using an UAV. The recording for IbM was difficult due to unfavourable weather with bad lighting conditions and occasional rainfall. Since the roof was not recorded with TLS, the only source of data was IbM. TLS data were processed in the Cyclone and IbM data in Agisoft Photoscan and Capturing Reality RC. Data from both digitising technologies were merged by registration in CloudCompare. The interior of the manor was documented solely with TLS. With regard to the elaborate interior structuring, a large number of camera positions was required. The digitisation of narrow and spatially complex rooms was very difficult because the scanner had to be moved many times and thus the number of positions grew. Registration of the data was carried out by the total station used for measuring the GCP.

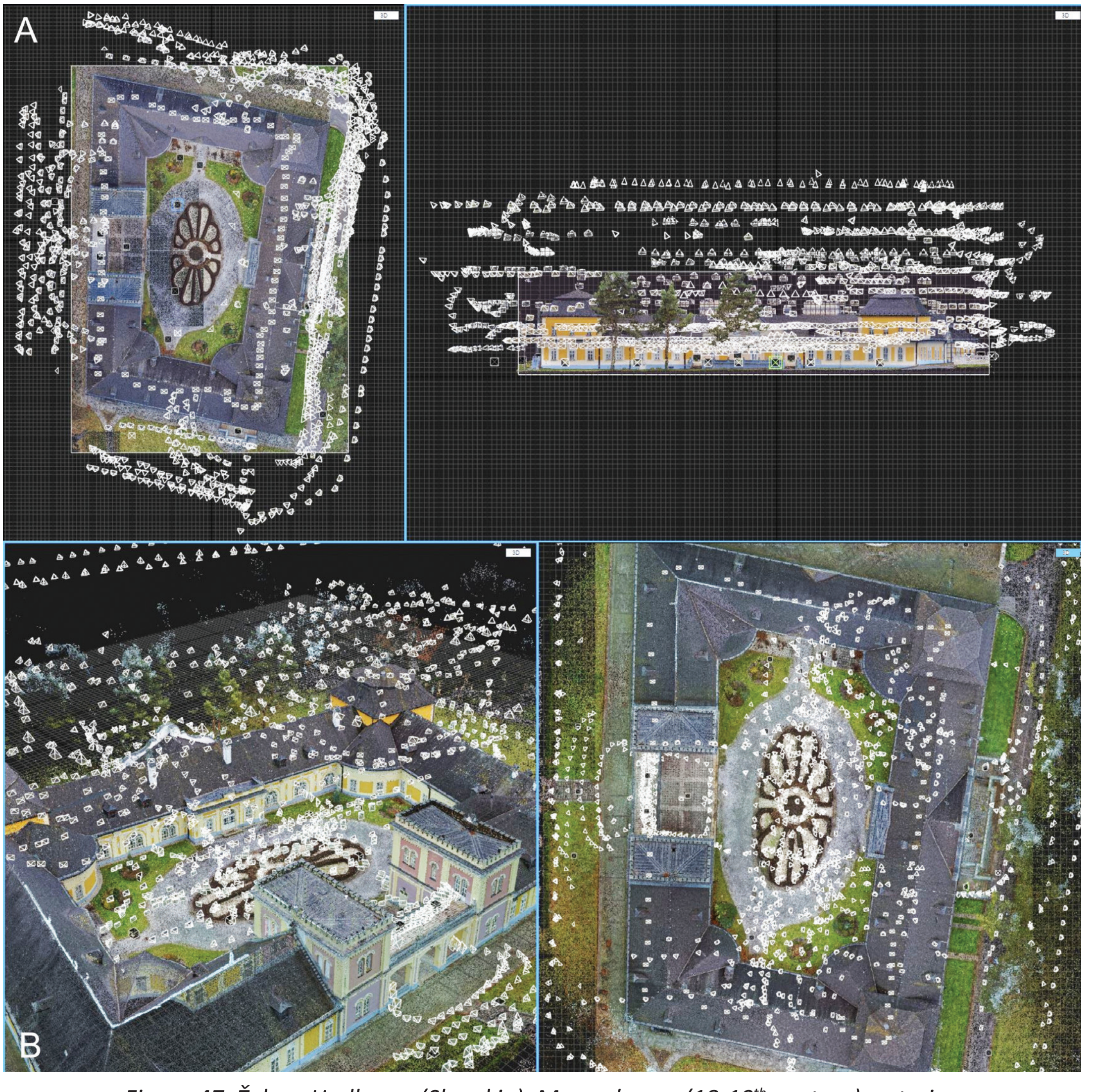

Figure 47. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), exterior. IbM in combination with TLS (1520 photos 24Mpx, 41 TLS stations). Distribution of cameras and stations. A: outer facades, B: inner courtyard.

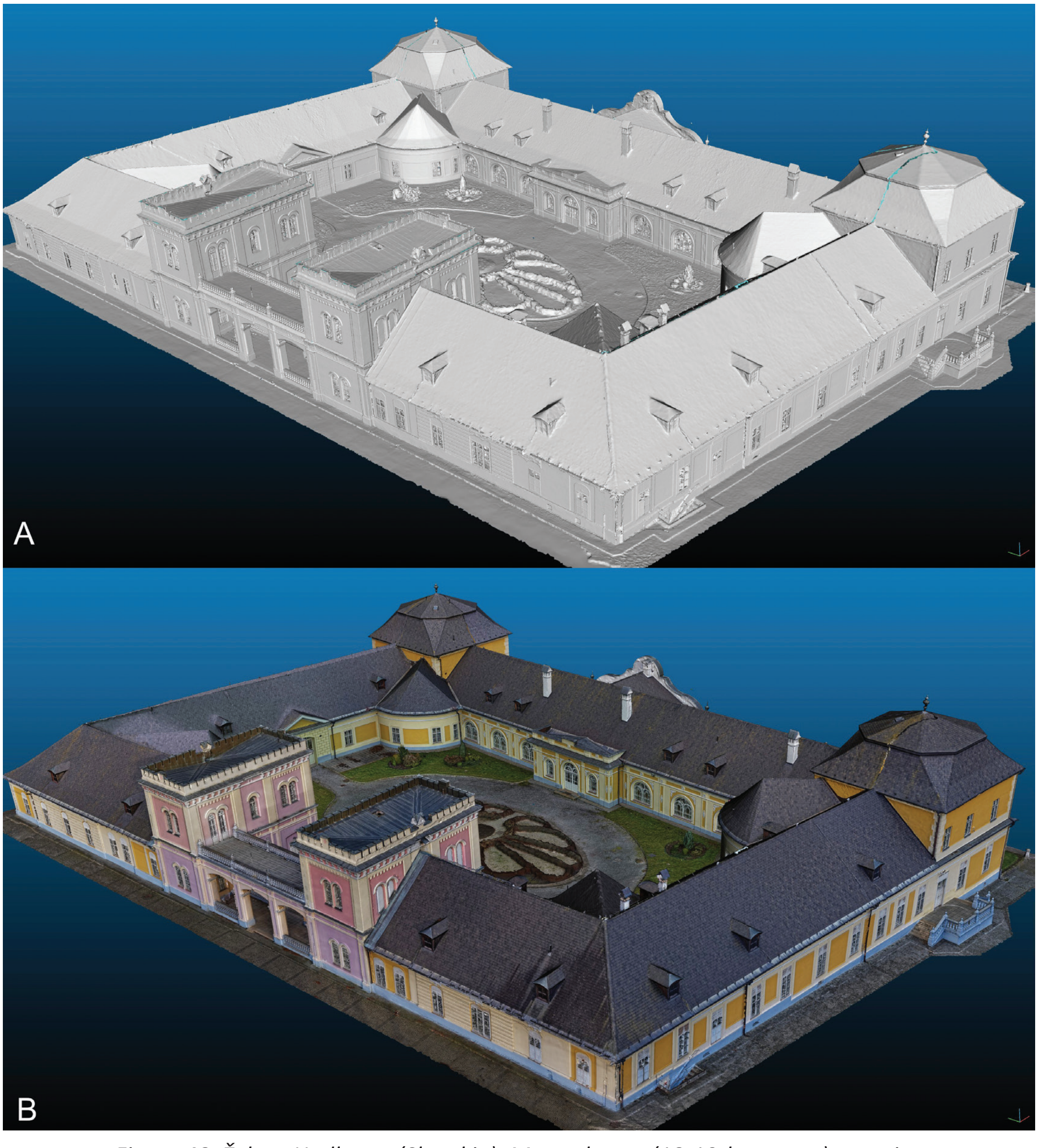

Figure 48. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), exterior. IbM in combination with TLS. Isometric views. A: shaded 3D model, B: textured 3D model.

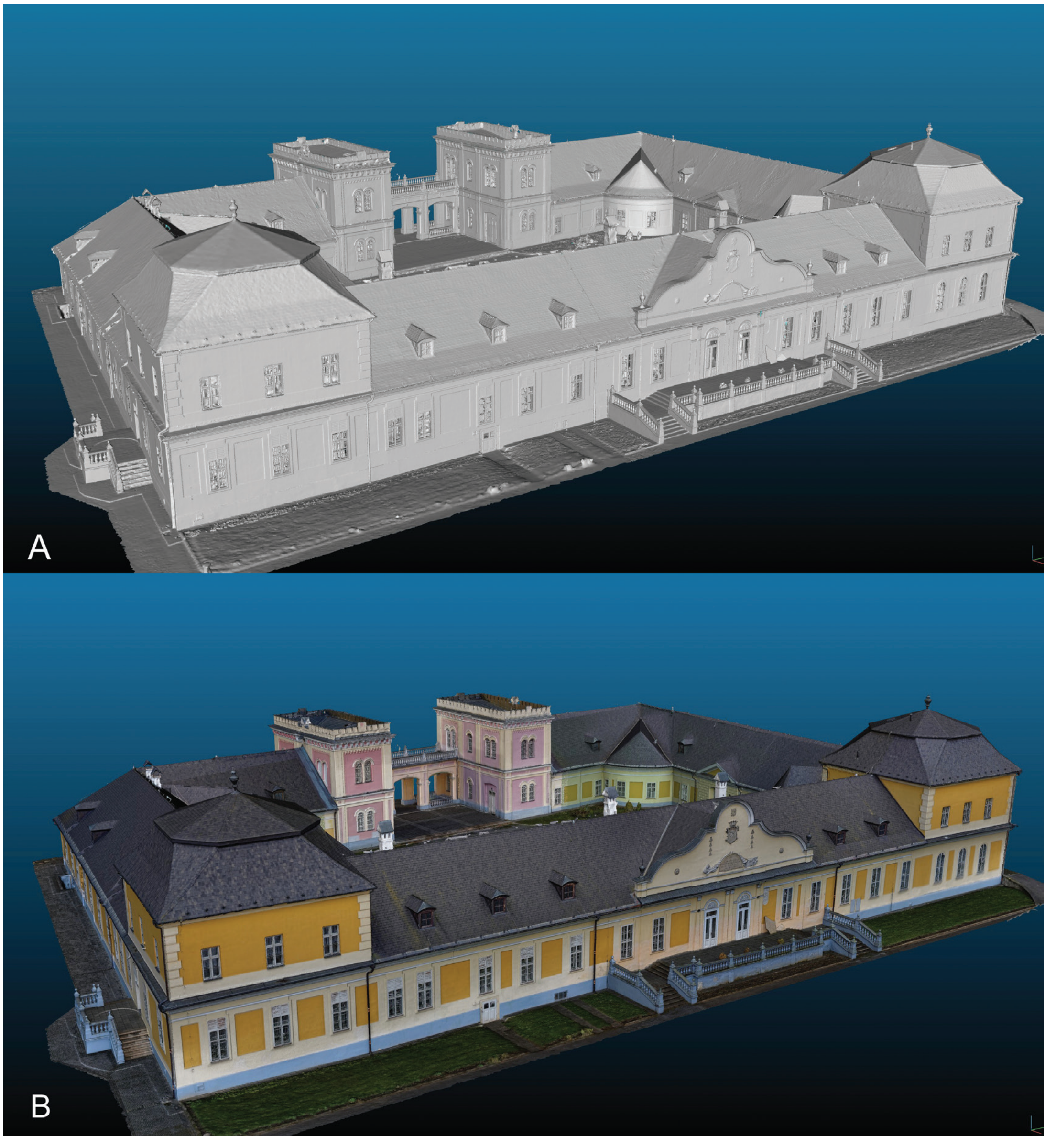

Figure 49. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), exterior. IbM in combination with TLS. Isometric views. A: shaded 3D model, B: textured 3D model.

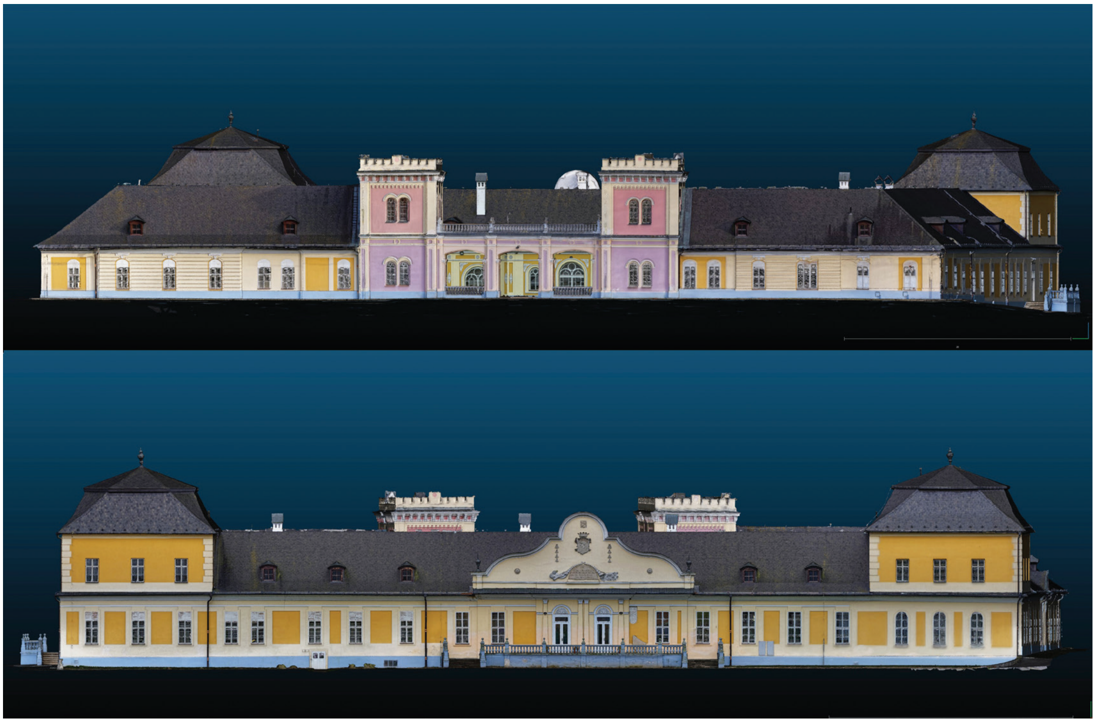

Figure 50. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), exterior. IbM in combination with TLS. Ortho-views of the facades.

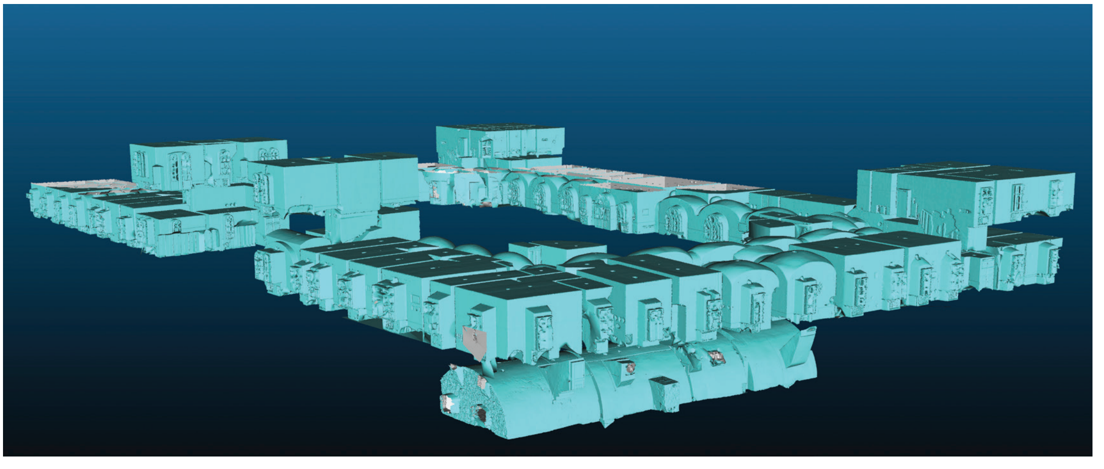

Figure 51. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), interior – 3 levels. TLS (168 TLS stations). Shaded 3D model.

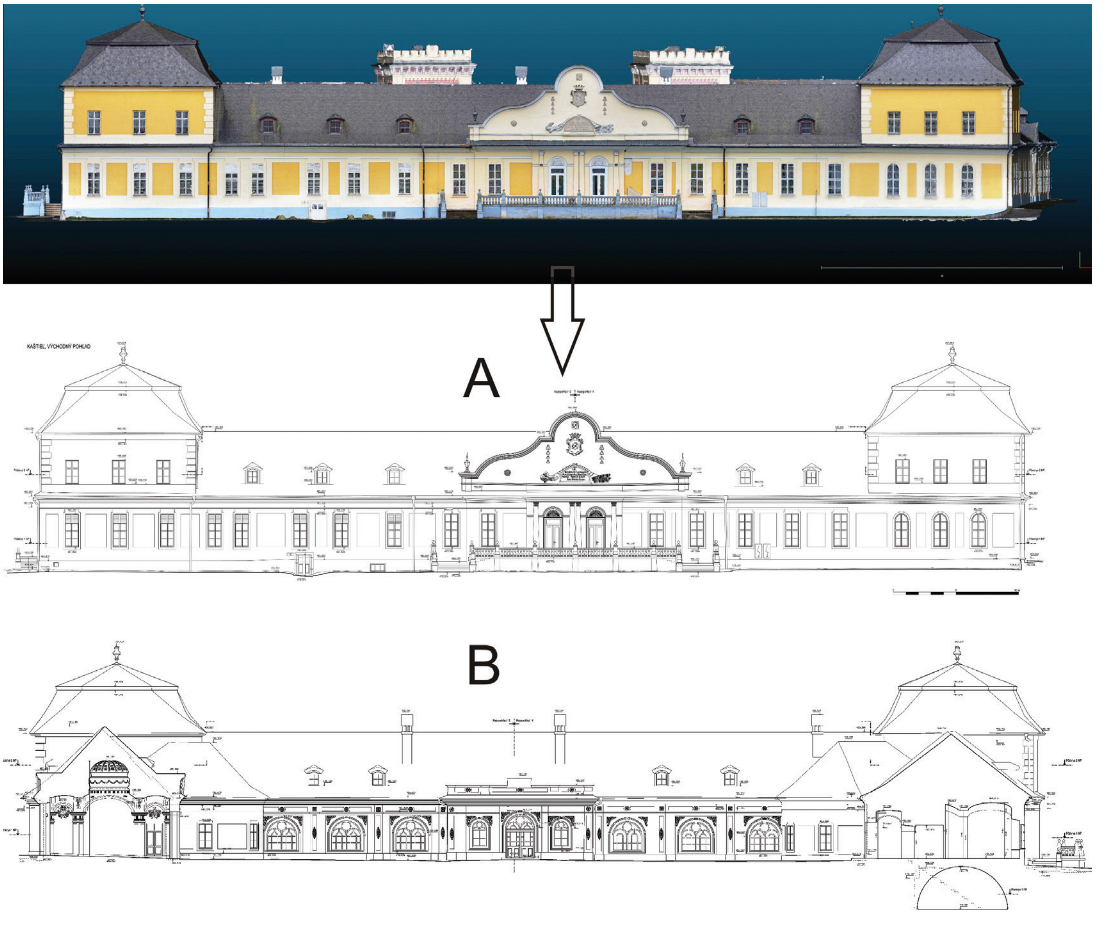

Figure 52. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), exterior.
A: example of 2D vectorisation of ortho-rectified east facade, B: example of 2D documentation derived from the 3D model – cross-section.

Žehra, Hodkovce, Neo-Gothic church

Site type:	Church
Location:	Žehra, Hodkovce, Spišská Nová Ves District, E Slovakia
Dating:	19th century
Recorded parts:	Exterior (facades), roof, interior
Recording technology:	IbM, TLS
Recording equipment:	Cameras Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX) and Sony Nex7, TLS Leica C10, UAV, TS, GNSS Rtk Rover (differential GPS)
Software:	DxO Optics Pro 10.0, Agisoft Photoscan 1.1.0, CapturingReality RC, CloudCompare 2.7, Microstation V8i trial version, Cyclone
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans and cross-section views (Figs. 53-59)
Short description:	The neo-Gothic church building is located in a park, in a densely forested area on undulating terrain. The church is oriented in the E-W direction, with the west end sitting on significantly elevated terrain. The transition between the single-aisle building and the semi-circular sanctuary is smooth and without breaks in the facade. There is a marked neo-Gothic portal on the west side. The width of the aisle and the sanctuary is greater in the east section, which gives the building an asymmetrical ground plan, with extension in the east part. The narrow, polygonal tower is situated to the west from the aisle and its roof is covered with sheet metal; the tower significantly exceeds the height of the saddle roof over the church aisle, also covered with sheet metal. The west part of the structure consists of a funeral chapel with neo-Gothic portal at the west end and a saddle roof covered with sheet metal. The external facades were documented by TLS (Leica C10) and IbM. The roofs were documented by IbM using an UAV. The usage of the drone was considerably complicated by the dense trees. The relatively low amount of light during the documentation process required subsequent detailed editing of the photos prior to their processing in the selected software environment. The absence of plasticity and texture of the smooth, monochromatic plastering of external facades caused a low number of SIFT points in the bundle adjustment in the software processing of IbM data and, consequently, high level of noise in the creation of the point cloud. This could be partially improved by HDR filtration of the photos in the phase of editing of the raw photographic material. The church interior was documented solely by TLS. The TLS data were registered in Cyclone. IbM data were processed in Agisoft Photoscan and CapturingReality RC. The DxO Optics Pro was used for basic editing of the photographic material. The processed and TS-georeferenced TLS data and outputs from IbM were merged in CloudCompare.

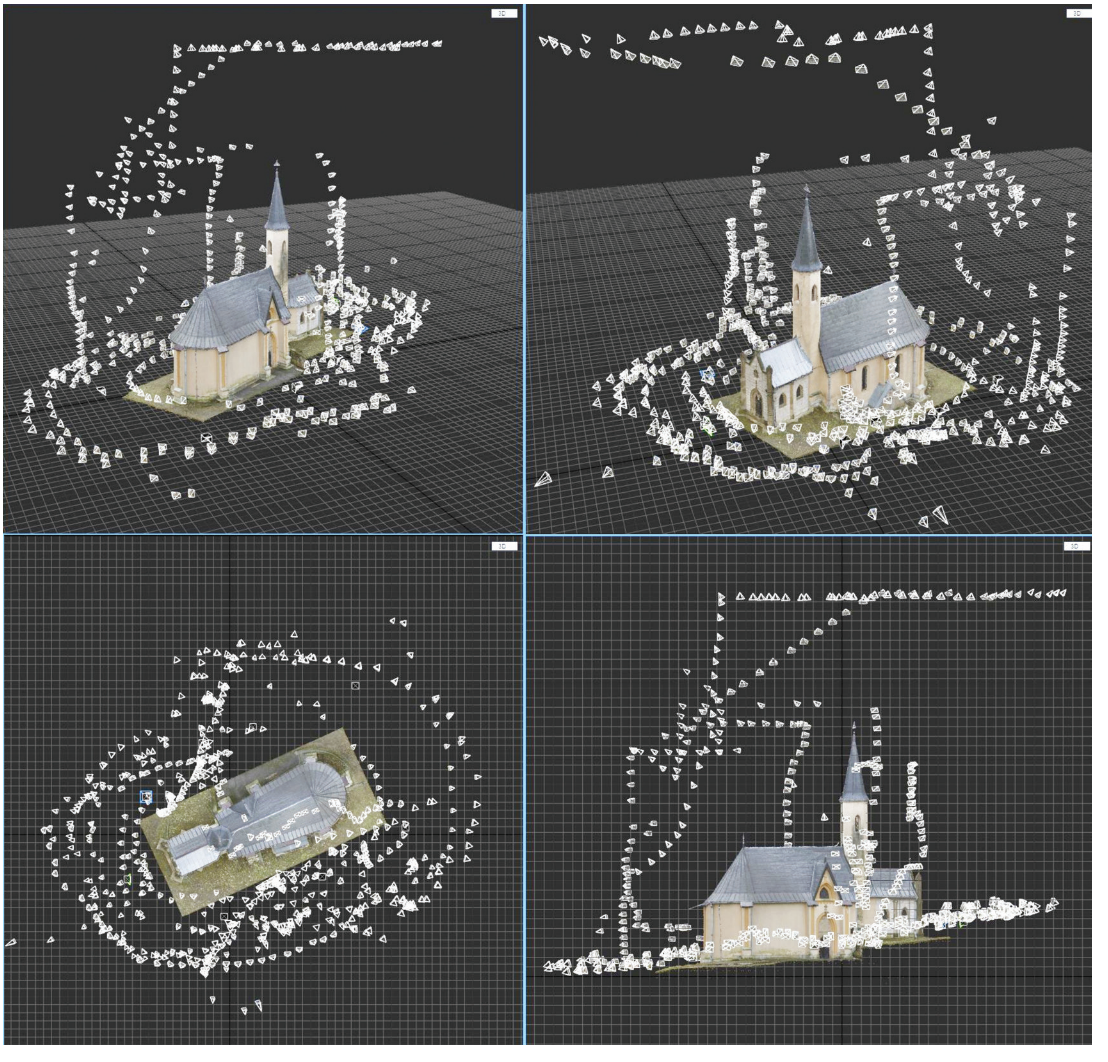

Figure 53. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), exterior. IbM in combination with TLS (713 photos 24Mpx, 10 TLS stations). Distribution of cameras and stations.

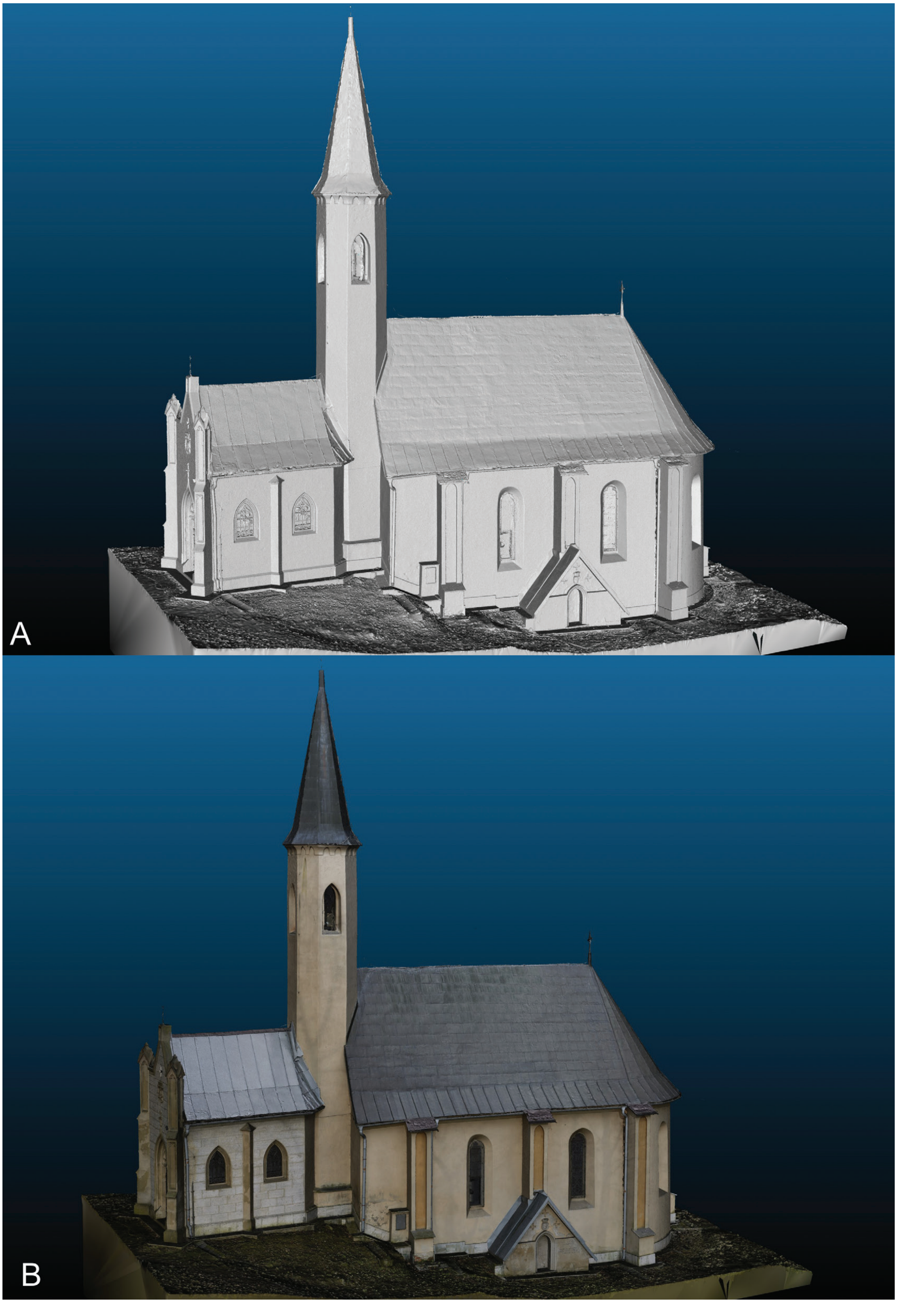

Figure 54. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), exterior. IbM in combination with TLS. Isometric views. A: shaded 3D model, B: textured 3D model.

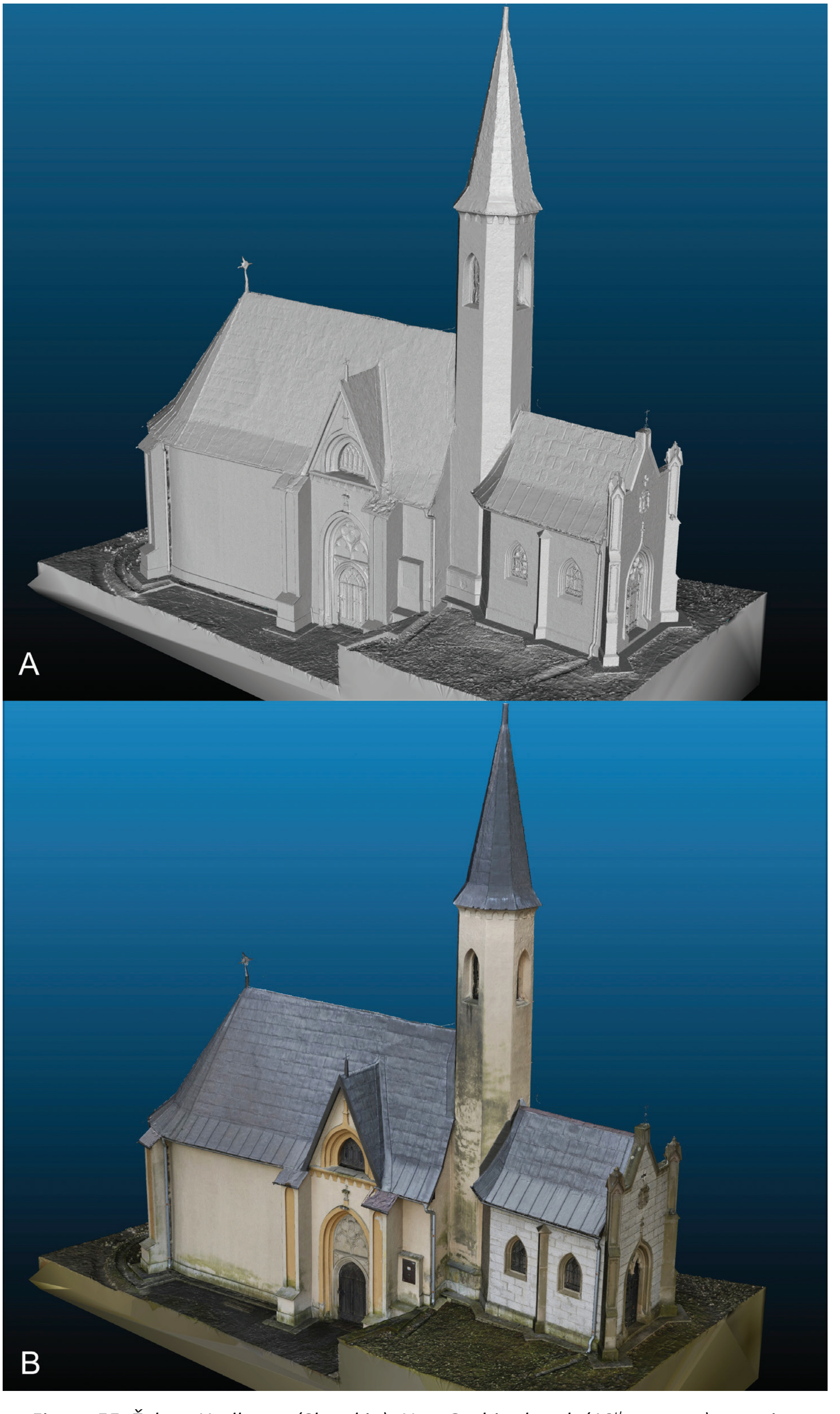

Figure 55. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), exterior. IbM in combination with TLS. Isometric views. A: shaded 3D model, B: textured 3D model.

Figure 56. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), exterior. IbM in combination with TLS. Ortho-views of the facades.

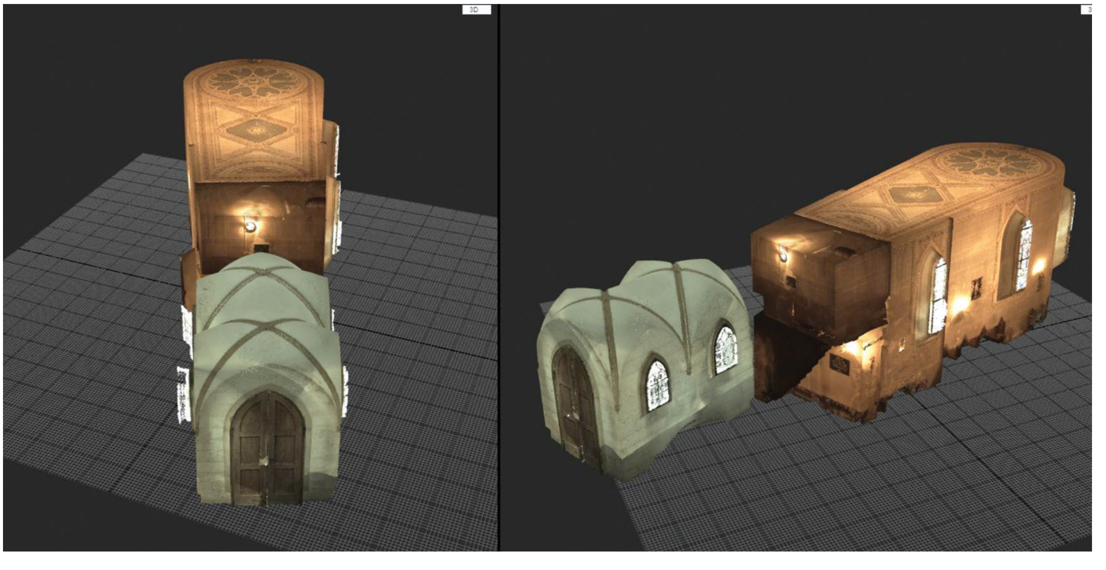

Figure 57. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), interior. TLS (9 TLS stations). Dense point cloud.

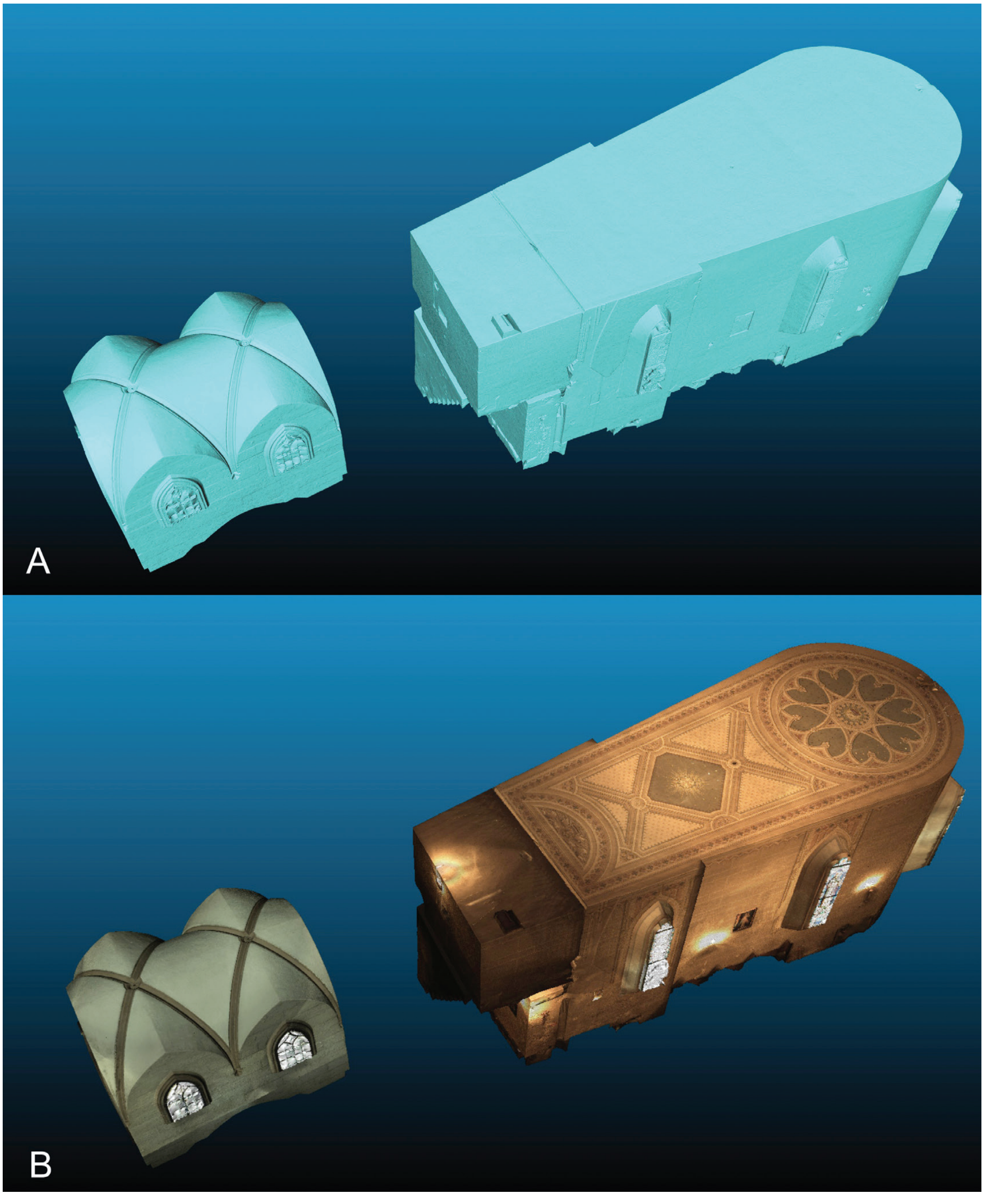

Figure 58. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), interior. Isometric views. A: shaded 3D model, B: textured 3D model.

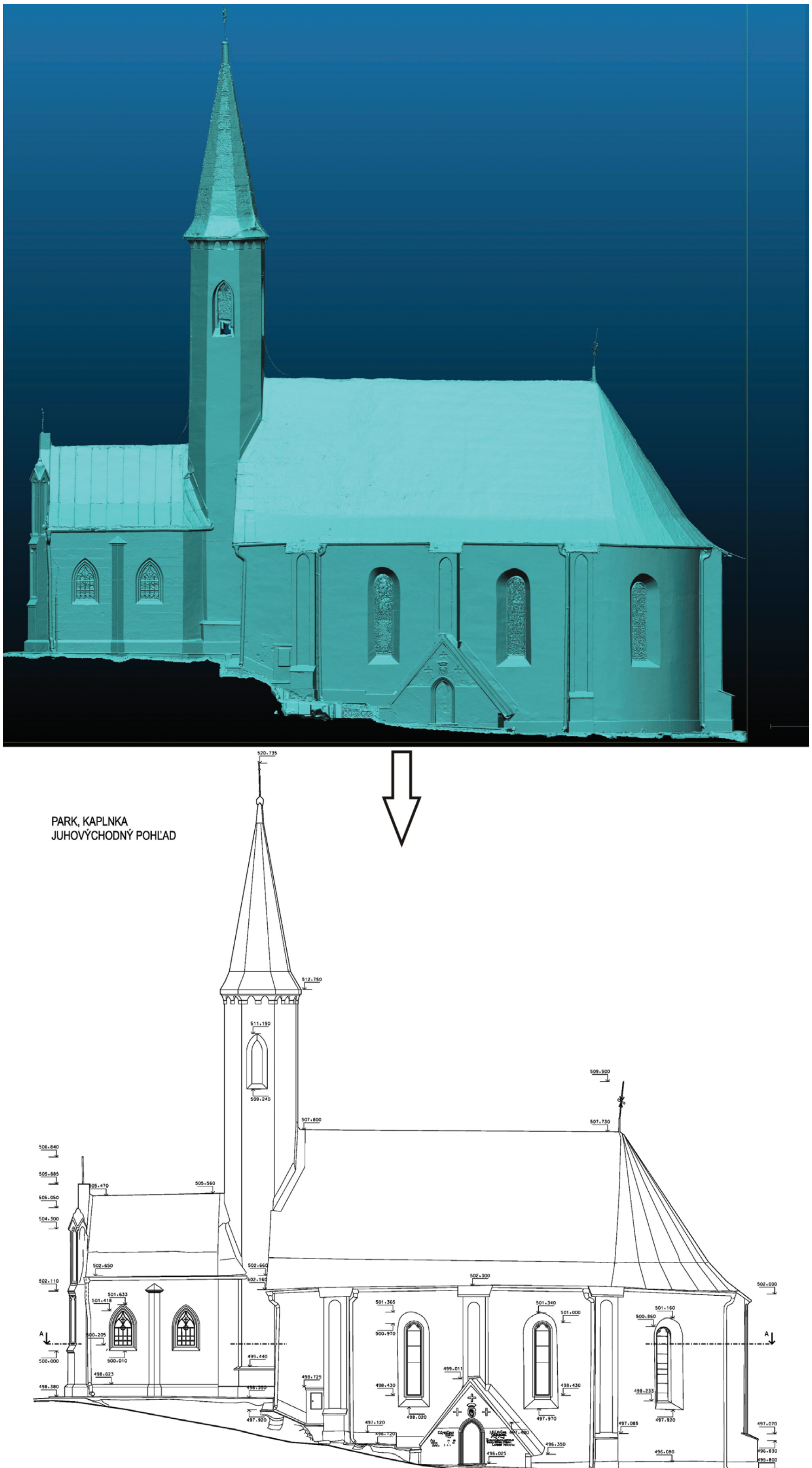

Figure 59. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), exterior. Example of 2D vectorisation of ortho-rectified south facade.

Žehra, Hodkovce, Neo-Gothic architecture

Site type:	Park architecture
Location:	Žehra, Hodkovce, Spišská Nová Ves District, E Slovakia
Dating:	19th century
Recorded parts:	Exterior (facades), roof, interior
Recording technology:	IbM
Recording equipment:	Cameras Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX) and Sony Nex7, UAV, TS, GNSS Rtk Rover (differential GPS)
Software:	Adobe Photoshop CC, Agisoft Photoscan 1.1.0, CloudCompare 2.7
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans and cross-section views (Figure 60)
Short description:	A fine piece of neo-Gothic park architecture is situated on the south-west end of the green area of the park. It is a block building open on all four sides, with opennings topped with pointed arches. It has a simple saddle roof with front (east) and rear (west) gable bearing stucco neo-Gothic ornaments. The structure is visually partially obstructed by trees and low plants growing along the west and the south side. The method of IbM was solely used for the digitisation of the building, whereas the roof area was documented by UAV. The data processing was complicated since smooth, white plastering that did not create sufficiently marked texturing elements. Thorough editing of the raw photos was necessary prior to their final processing (application of HDR filter in Adobe Photoshop CC).

Figure 60. Žehra, Hodkovce (Slovakia). Neo-Gothic park architecture (19th century), exterior. IbM (325 photos 24Mpx). Isometric views of the textured 3D model. A: visualisation with normals, B: visualisation without normals.

Žehra, Hodkovce, Farm building

Site type:	Farmhouse and auxiliary buildings
Location:	Žehra, Hodkovce, Spišská Nová Ves District, E Slovakia
Dating:	19th century
Recorded parts:	Exterior (facades), roof
Recording technology:	IbM
Recording equipment:	Cameras Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX) and Sony Nex7, UAV, TS, GNSS Rtk Rover (differential GPS)
Software:	Adobe Photoshop CC, Agisoft Photoscan 1.1.0, CloudCompare 2.7
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figure 61)
Short description:	The farm building is located on the eastern side of the park. It is a block single-floor building, with the longer axis orientated in the east-west direction. It is located on a slope gradually rising to the west. A high chimney rises from the central part. The structure has a saddle roof covered with sheet metal. The easter and western walls are shorter and topped with gables. The western gable masonry is interrupted with a neo-Gothic pointed arch. Both longitudinal facades are completed with a row of rectangular glazed windows. The structure was documented by the method of IbM with the application of an UAV. The photos were shot under unfavourable lighting conditions (low luminosity), as a result of which the photo documentation from the UAV also contained insufficiently sharp images due to the low value of aperture (the f-number). The low level of luminosity required setting of the aperture value of the camera to below F 5.6; otherwise, the high f-number could result in the longer time of exposure and this would produce highly blurred photos due to the drone movement. Increasing the ISO value was not a solution in this case, as it would mean additional layering of the noise level. Recording of the longitudinal facades from the level of the surrounding terrain was complicated due to fenced areas for animals in the close proximity. The problems with detection of the sufficient number of SIFT points on the images of the facades, which are flat and covered with smooth white plastering, again appeared. Photo editing was, therefore, necessary (Adobe Photoshop CC by applying the HDR filter).

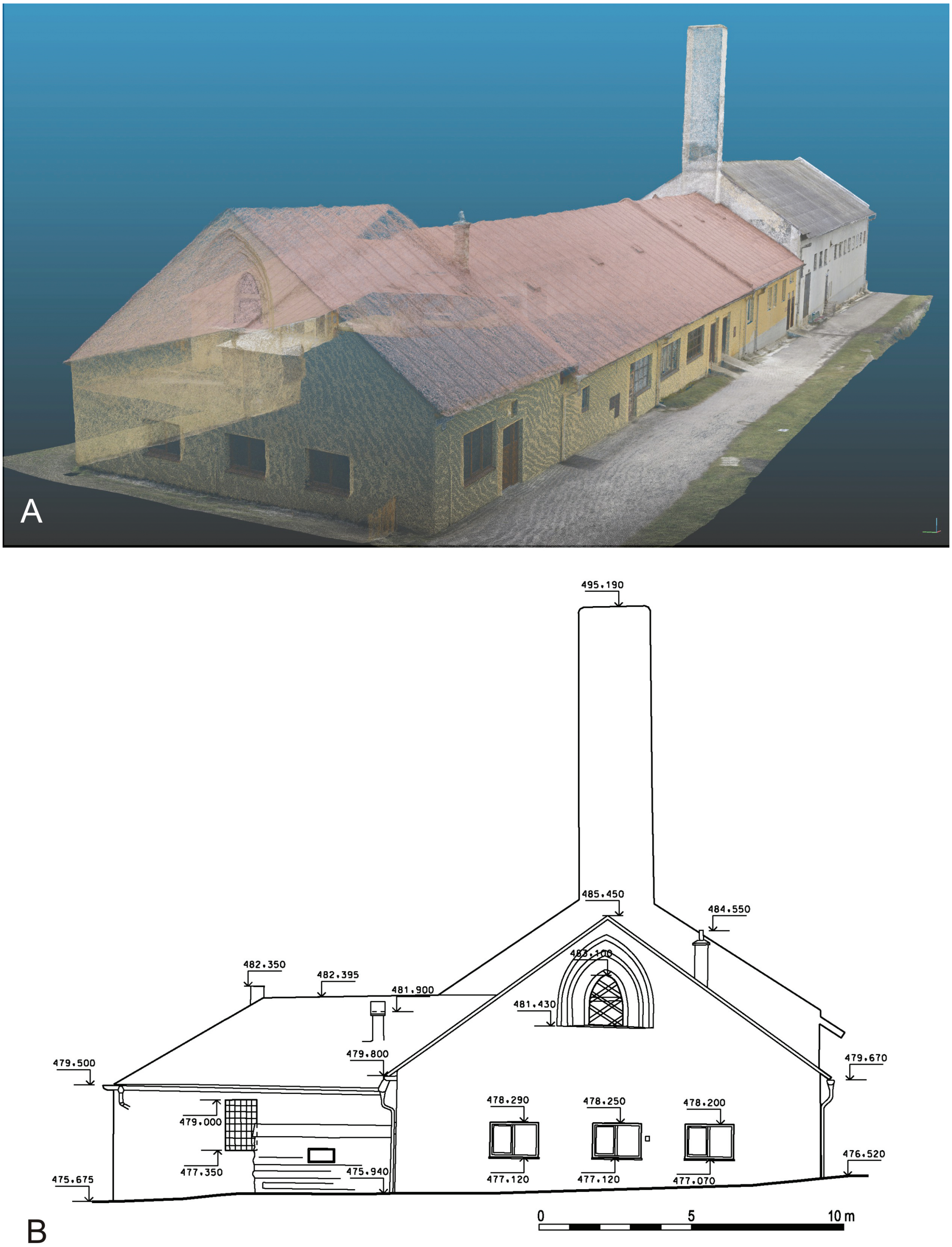

Figure 61. Žehra, Hodkovce (Slovakia). Farm building (19th century), exterior. IbM (472 photos, 24Mpx). A: dense point cloud, B: Example of 2D documentation derived from the 3D model – view of the facade.

Žehra, Hodkovce, Park

Site type:	Park with garden
Location:	Žehra, Hodkovce, Spišská Nová Ves District, E Slovakia
Dating:	19^{th} century
Recorded parts:	Ground plan
Recording technology:	IbM
Recording equipment:	Camera Sony Nex7, UAV, TS, GNSS Rtk Rover (differential GPS)
Software:	Adobe Photoshop CC, Agisoft Photoscan 1.1.0, CloudCompare 2.7
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figure 62)
Short description:	The park has an elongated shape and stretches in the east-west direction. It is divided into two approximately equally large parts, with the centrally placed manor house. The area adjacent to the western wing of the manor house represents a French garden with a central fountain and pathways covered with gravel. Other parts of the park are of a more 'casual' nature, including areas occupied by deciduous and coniferous trees. A large part of the eastern half of the park is currently used as anopen space for keeping horses and other farm animals. The part under trees, to the west, is on a considerably undulating terrain, upwardly sloping towards the west. The 3D digitisation was conducted by IbM with an UAV. Vertical images of the whole park area were made from a relatively constant height. The garden area with fountain was recorded from a much smaller flight height (to capture a higher level of details). The flight sequences were processed separately and were later merged. The GCP, measured with TS, were printed in A2 format in order to be visible from the greater flight height. In the meshing stage of the data processing, it became obvious that, in the case of data collected from a greater hight, branches of smaller trees could not be captured with sufficient resolution. Thus, although the point cloud captured the majority of trees in a compact manner, it was not dense enough to allow creating of a compact mesh of branches of smaller trees. In such a case, it is necessary to complete the data with images made from lower heights in order to capture individual branches as well.

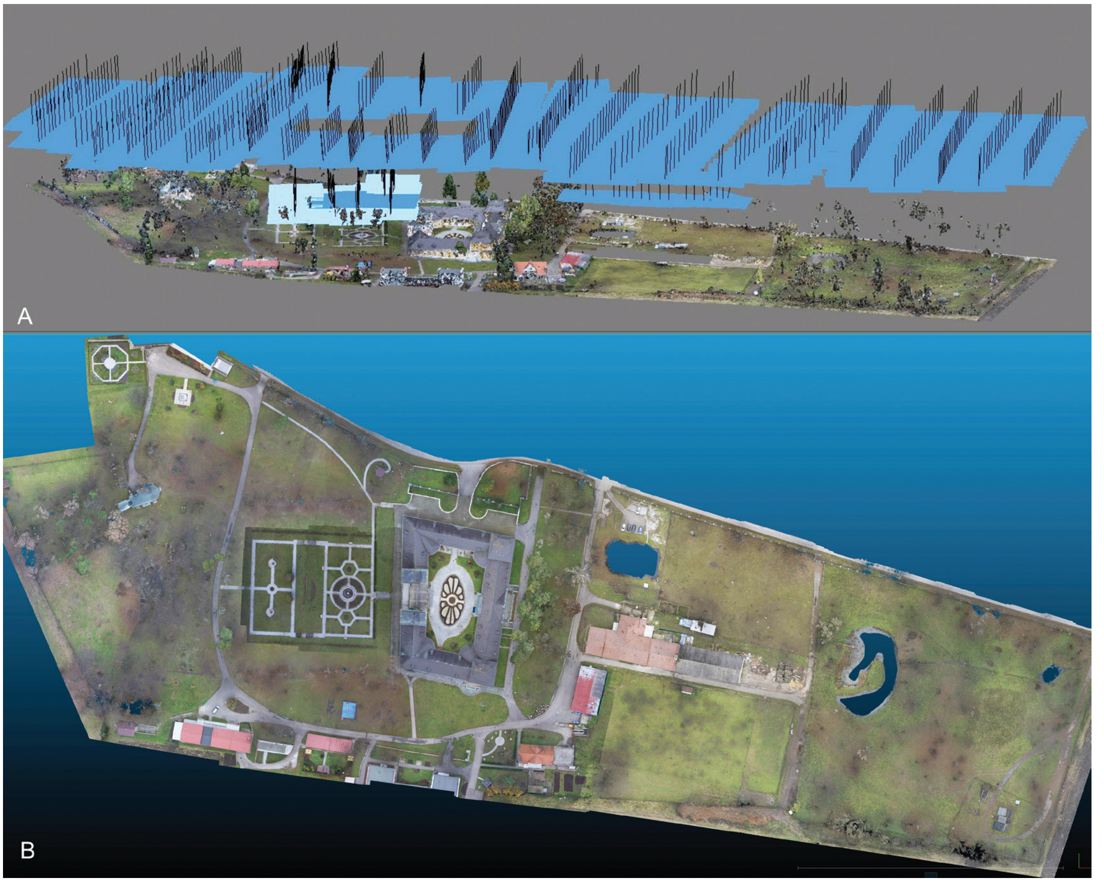

Figure 62. Žehra, Hodkovce (Slovakia). Park, 19th century. IbM (800 photos 24Mpx). A: distribution of cameras, B: nadir view of the textured D model.

Banská Belá, mine

Site type:	Mining tunnels
Location:	Banská Belá, Banská Štiavnica District, Central Slovakia
Dating:	15th century
Recorded parts:	Interior of mining tunnels
Recording technology:	IbM
Recording equiment:	Camera Nikon D5200 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX),
Software:	DxO Optics Pro 10, Agisoft Photoscan 1.1.0, CloudCompare 2.7, AutoCAD Civil
Record:	Scaled 3D model (mesh), scaled orthophoto plans (Figs. 63-65)
Short description:	The unfinished mining structure (a two-arm mining tunnel) is situated near the former town hall (?) building. The opening is in the area of the first above-ground floor; the tunnel extends perpendicularly to the mass of the rock where it turns at makes an almost right angle and leads to the basement of a medieval burgess house. One part of the tunnel was cut off while another part was blown up by gunpowder. There are beam holes on the tunnel walls, probably remaining from the wooden formwork supporting the ceiling. The collection of data was done with a handheld camera. A camera stand could not be used due ti the limited space, and resetting of the camera and re-compositioning of the photos would be slow and would significantly increase the working time. The most important principle followed during the photographic recording was to take care of the lighting to avoid shadows, which would cause artificial shadows in digitising. In practice, the best method was to place a halogen lamp perpendicularly to the selected part of the wall and two lamps at a certain distance from it, at 45 degrees angle to the centre of the part of the wall documented. This prevented creation of shadows in the rock crevices and, at the same time, maintained the sense of plasticity. In this way, it was possible to obtain the relevant input data with sufficient light parameters, which, after the basic editing (DxO Optics Pro), could be processed in software for IbM with high-quality output and without a non-standard/high level of noise. In order to define the scale of the 3D model and of the output derived from the 3D documentation, maximum distances between ad-hoc indicated GCP (cross-shaped marks drawn by a chalk because standard markers could not be fixed properly on damp walls) were measured by means of a laser meter. The measurements were entered manually as distance parameters of manually defined markers in the relevant software during processing.

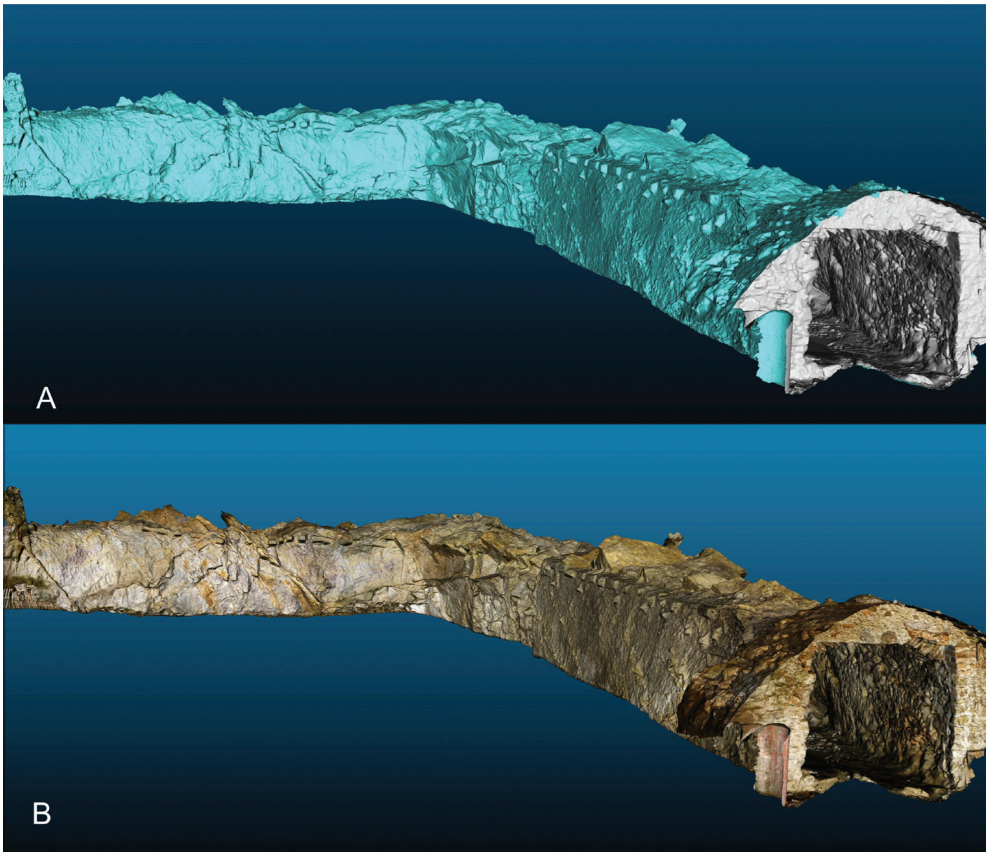

Figure 63. Banská Belá (Slovakia). Mining site, 15th century. IbM (691 photos 24Mpx). Isometric views. A: shaded 3D model, B: textured 3D model.

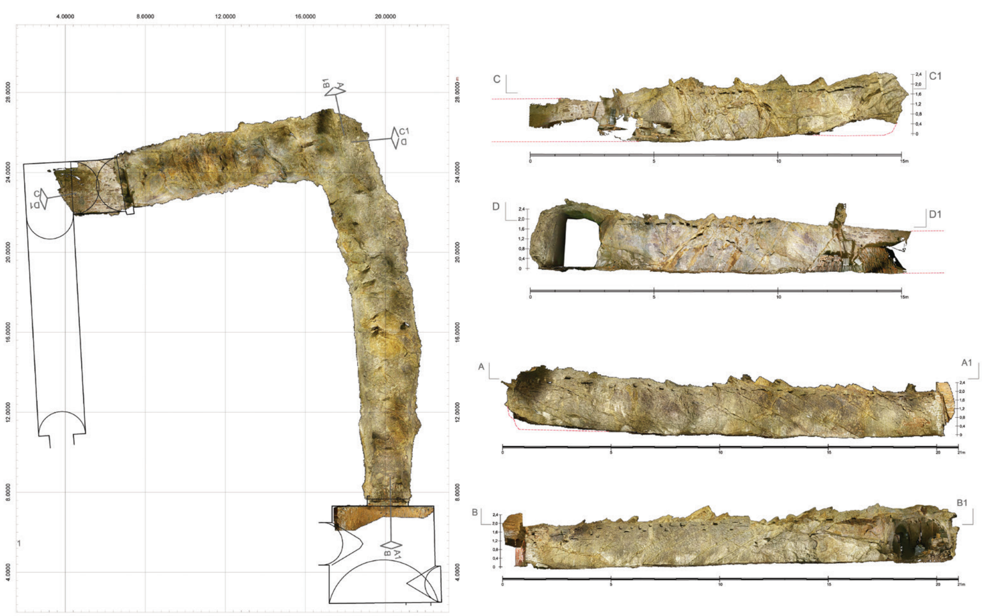

Figure 65. Banská Belá (Slovakia). Mining site, 15th century. Example of 2D documentation derived from the 3D model.

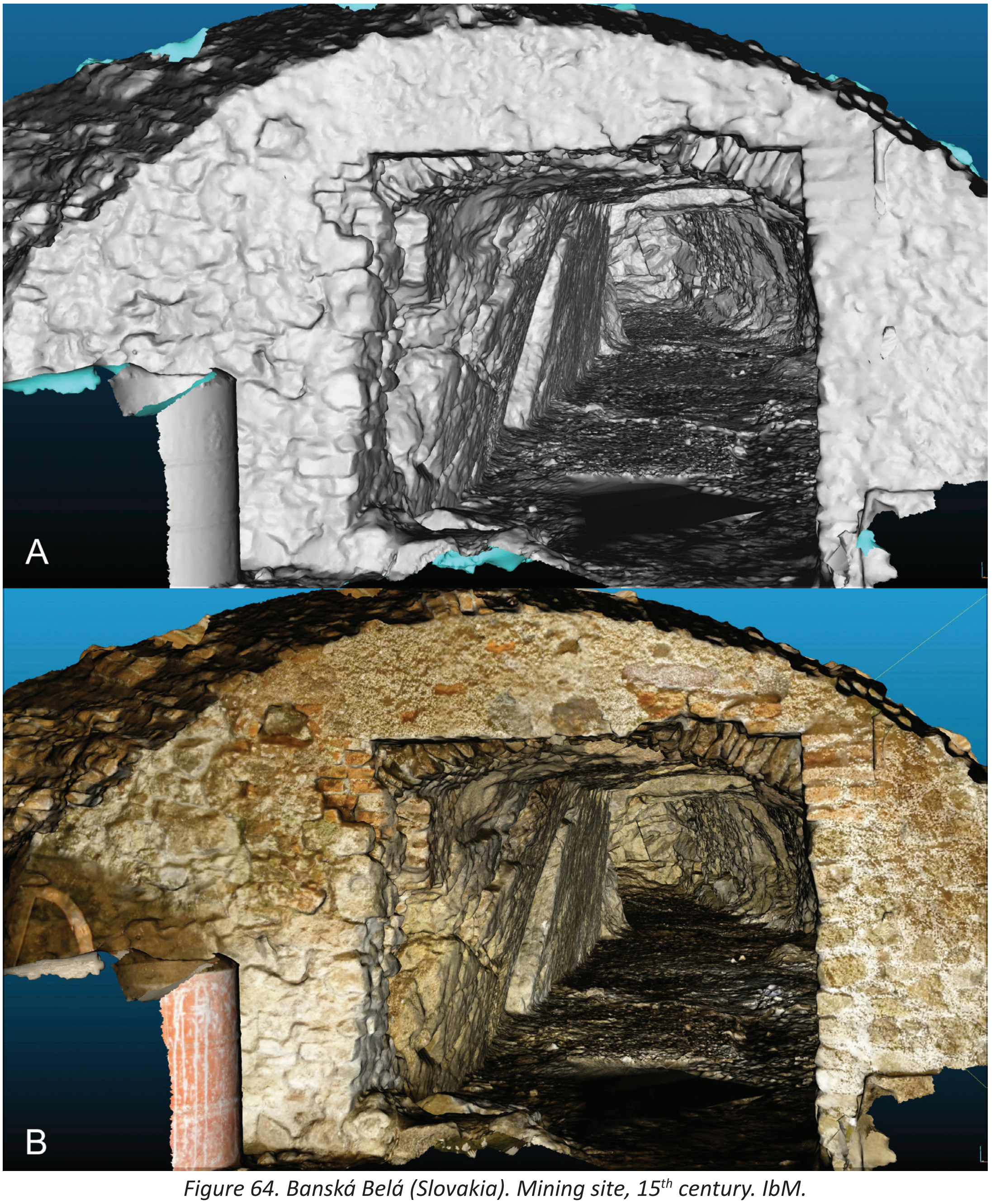

Figure 64. Banská Belá (Slovakia). Mining site, 15th century. IbM. Isometric views A: shaded 3D model, B: textured 3D model.

Rajec, Burgess house

Site type:	Burgess house, basement
Location:	Rajec, Rajec District, N Slovakia
Dating:	17th century
Research type:	Interior
Recording technology:	IbM
Recording equipment:	Camera Nikon D90 (optics AF-S Nikkor 16-85 f/3.5-5.6 ED VR DX)
Software:	DxO Optics Pro 10, Agisoft Photoscan 1.1.0, CloudCompare 2.7
Record:	Georeferenced 3D model (mesh), georeferenced orthophoto plans (Figs. 66-69)
Short description:	The Burgess house (nowadays a museum) is situated in a row of buildings on the southern side of the central historical square. Its northern (front) side has an entrance recess area slightly inclining to the street demarcating this side of the square. The object of 3D documentation was the basement which is situated under the right/west section of the burgess house. The basement can be accessed by a staircase from the central corridor of the ground floor. The staircase leads to a small central room, from which entrances lead into the southern and northern room. The ceiling of the southern room is represented by a compressed barrel vault with two pairs (one on each long side) of parallel pentagonal lunettes intersecting the vault. There is a vent opening in the southern wall leading to the inner courtyard. The northern room has a simple compressed barrel vault. Two vent openings are situated in the northern wall of this room, leading to the street delimiting the square. The documentation was created by the IbM. Data collection was done with a handheld camera without the stand. The area was lighted with two halogen lamps. One of them had a fixed position at the level of the underlying terrain, the other one was manipulated by the supporting assistant and always lighted one specific area, with the beam directed perpendicularly to the centre of the area. The rooms were documented and processed separately and were later merged in the single coordinate system. Although the wall and vault surfaces are covered with monochromatic white plastering, thanks to the thorough editing of individual photos prior to their processing (DxO Optics Pro), a sufficient number of SIFT points was identified on the images. The resulting 3D model thus contains only a minimum level of noise.

*Figure 66. Rajec (Slovakia). Burgess house (16th century), cellar. IbM (217 photos 12Mpx).
A: example of raw photos with markers indicating control points, B: distribution of cameras.*

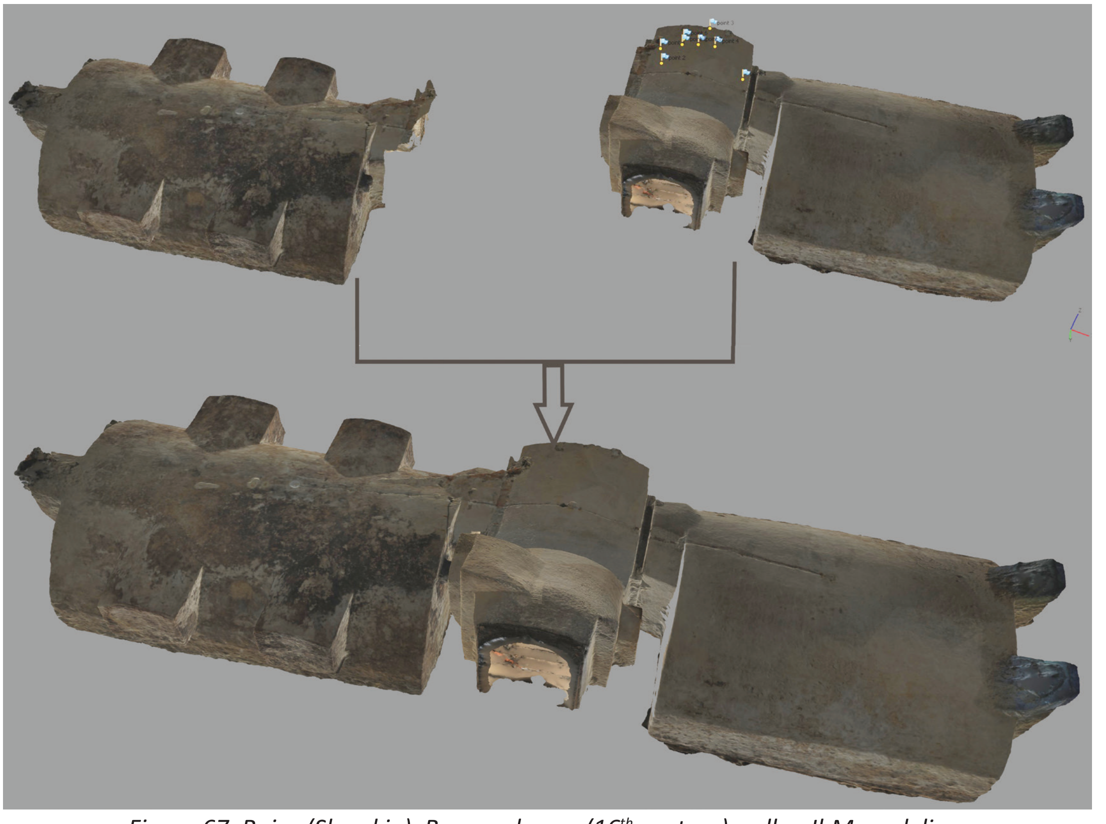

Figure 67. Rajec (Slovakia). Burgess house (16th century), cellar. IbM modeling. Depiction of the alignment of cellar rooms processed individually through the control points.

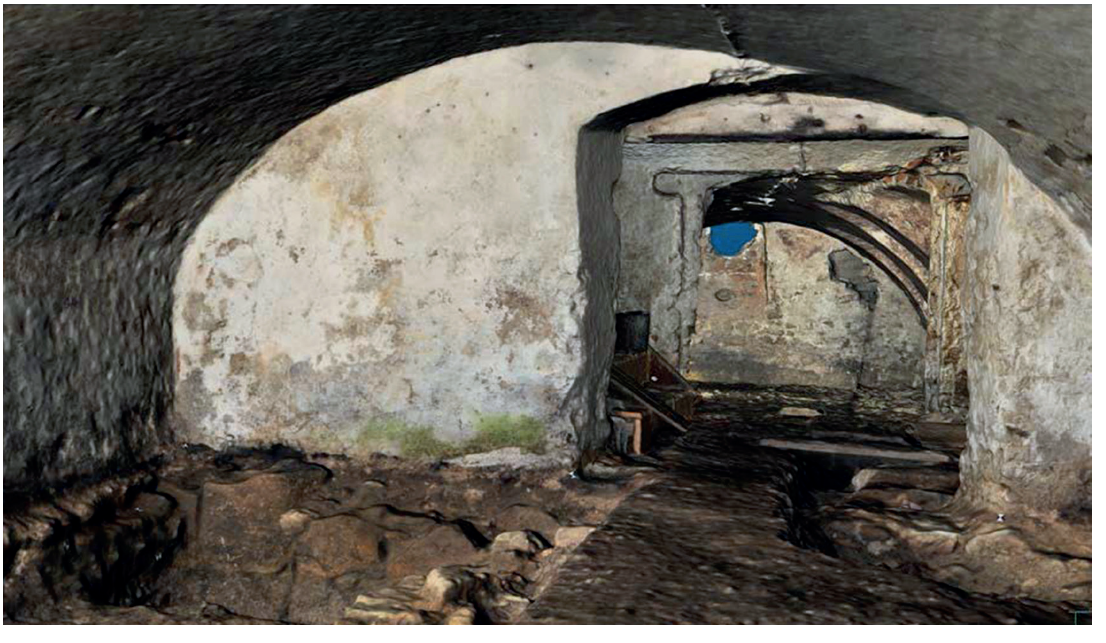

Figure 68. Rajec (Slovakia). Burgess house (16th c.). IbM, Isometric view of the cellar interior.

Figure 69. Rajec (Slovakia). Burgess house (16th century), cellar.
IbM. Isometric views of the exterior. A: shaded 3D model, B: textured 3D model.

DISCUSSION

Depending on the basic requirements of a digitisation project and the complexity and structuring of the architecture documented, it is necessary to define the strategy of 3D documentation, including the selection of digitising technologies and technical aids and tools. It is advisable to prepare a general digitisation scenario for more complex objects on the grounds of thorough reconnaissance of the area in question. Such scenario should determine the time schedule of tasks and the types of technology applied in relation to individual parts of the structure, as well as associated technical tools. In many cases, the project budget also needs to be prepared. It is recommended to make sketch drawings of the positions and the process of documentation and to mark GCP during data collection in the field. The obtained data should be saved in order to enable their simpler and clearer manipulation during the processing stage.[1]

The experience from the presented case studies suggests that, in the case of 3D digitising of interiors, it is better (although more cost-demanding) to use TLS than IbM from the perspective of accuracy requirements. Securing appropriate lighting in interiors tends to be much more demanding (more unfavourable) than in open space. This does not cause problems in the case of TLS with priority regard to the accuracy of surface geometry and not to the texture, but causes substantial complications in the case of IbM.

The basic precondition for successful digitisation of interior by means of IbM is an emphasis on optimal lighting of the documented area and usage of camera stand in combination with adequate setting of the camera (low ISO value, high f-number value nearing the ‘sweet spot’, correct setting of white balance etc.), which should provide the largest possible depth of field. The whole procedure of data collection is thus very slow and logistically demanding operation. Understandably, demands grow with the growth of complexity and structuring of the documented interior. Moreover, if IbM is applied one must take into account the higher noise level in the data processing than in the case of TLS, and also that the level of noise grows significantly in interior spaces. Interior structuring can lead to problems with registration of the data and often causes significant digitisation shadows. Documentation of parts of a facade around window openings poses a large problem in IbM. These parts have a sharp border, i.e. a break between different lighting parameters; in the case of photo-documentation, this leads to a situation where one part of the image is in overly bright colour or strongly under-exposed in shades of black, whereas the other part of the same image is at the correct exposure. The source data obtained in this way tend to cause digitisation shadows or noise during processing. In such cases, it is necessary to apply HDR processing of images, where exposures of 3 (or more) images with various EV values are merged into one image.

A factor significantly limiting the application of TLS in interior space is the structuring of the area, which may require frequent shifting of the scanner and thus increases the number of positions. A complication is also encountered when measuring (G)CP used for the registration and georeferencing, as they must be interconnected with the points measured in the exterior. However, the greatest disadvantage of TLS is the weak optical

1 Data should be saved with utmost transparency, especially in the case of multi-floor manor houses with many rooms, where both IbM and TLS methods are applied; otherwise, it can later be very difficult to associate individual datasets with specific spaces.

sensor for making composite images, which serve for the generation of RGB values of the point cloud and are often the only source for texturing the final 3D model. The lighting conditions of internal areas are inadequate and of poor quality and this significantly devalues the texture of the resulting model. The only effective solution is to texture the model, on the grounds of TLS data, in external software using the images made with DSLR.

IbM indisputably proved to be the effective method for 3D digitisation of external facades and roofs. A high monopod stand or an UAV are usually required for the documentation of roof areas and upper floors. The application of TLS is significantly limited in such cases.[2] The experience from the case studies shows that, the crucial advantage of applying IbM for documenting architectonic exterior (as well as interior) is, from the perspective of accuracy and quality of the resulting model, the quality and sufficient depth of field of the images. These aspects often depend considerably on the light parameters of the environment in which the documentation takes place. Although unfavourable weather conditions can partially be compensated by editing RAW files prior to their processing, sometimes the quality of final images cannot be improved sufficiently to create a 'clean' 3D model.

The structure of the documented surface can also represent a problem. The basis for a clean resulting 3D model with good resolution is the sufficient number of SIFT points[3] detected on input images at the stage of bundle adjustment of the SfM process. Insufficient number of SIFT points (or else 'key points') has, as a consequence, noise of the dense point cloud and substantial errors in the resulting 3D model (Figs. 70, 71). The number of captured SIFT points is, to a significant degree, determined by geometry and texture of the surface of the structure documented (Figure 72). The experience from the case studies demonstrates that, flat facades with smooth, monochromatic plastering do not have sufficient amount of texture components and curvature of the surface for detecting the necessary number of SIFT points and the successful final product – the accurate and clean, high-resolution 3D model. As it turns out, standard editing of the input data – the individual images – solves the problem only partially (Figure 73). Apparently, the best solution is to apply strong HDR filtration, which will highlight on the images even very small colour hues as well as minimum irregularities of the surface; this will give texture and plasticity to individual images (Figure 74). However, the increase of plasticity and texture structuring of an image comes at the cost of authenticity of the colour spectrum.[4] Thus, HDR-filtered images cannot be used for texturing of the resulting 3D model.[5]

The documentation of the premises of the manor house in Žehra, Hodkovce showed that, the combination of TLS and IbM is ideal from the perspective of achieving the highest possible accuracy. TLS guarantees calibrated accuracy of the data measured and, especially, a low level of noise, which is very important in the case of smooth surfaces (such as building walls). IbM enables capturing elevated parts of the structures (such as upper floors and roofs) through the use of an UAV and, at the same time, can be a source of quality texturing of the resulting 3D model.

2 Examples of connecting a TLS to a movable platform of an UAV have occurred recently, but this approach is still in its developmental stage and not common.

3 SIFT points can be identified with key points defined in Agisoft Photoscan,

4 HDR creates false colour spectrum of images.

5 The original images without HDR toning must be used for texturing. They should have the same name as the images used for creation of the model itself. It is sufficient to change the folder of source images in the stage of texturing.

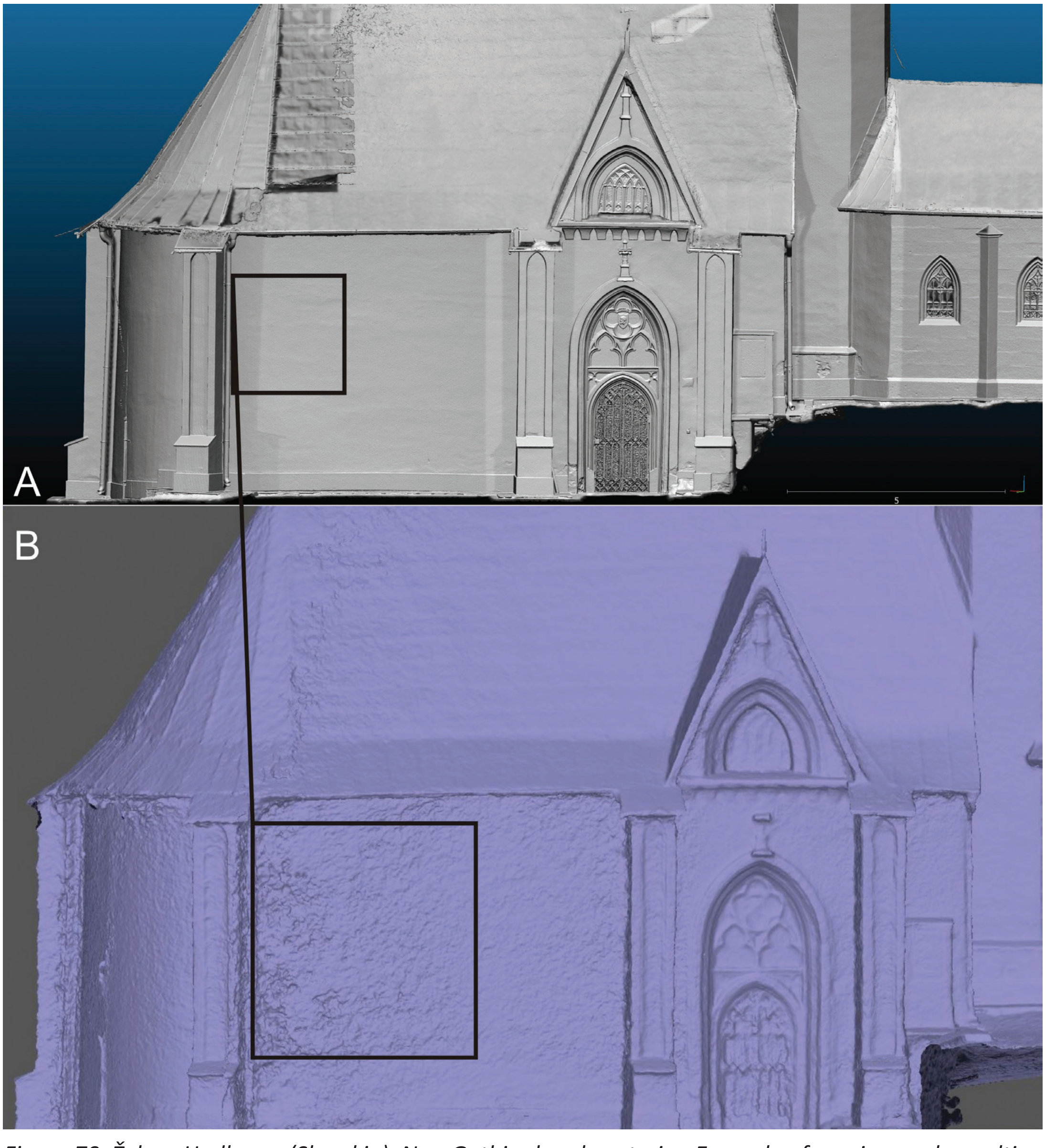

Figure 70. Žehra, Hodkovce (Slovakia). Neo-Gothic church, exterior. Example of a noisy mesh resulting from insufficient number of SIFT points detected on unedited photos. A: clean mesh derived from TLS data, B: noisy mesh resulting from IbM using unedited photos.

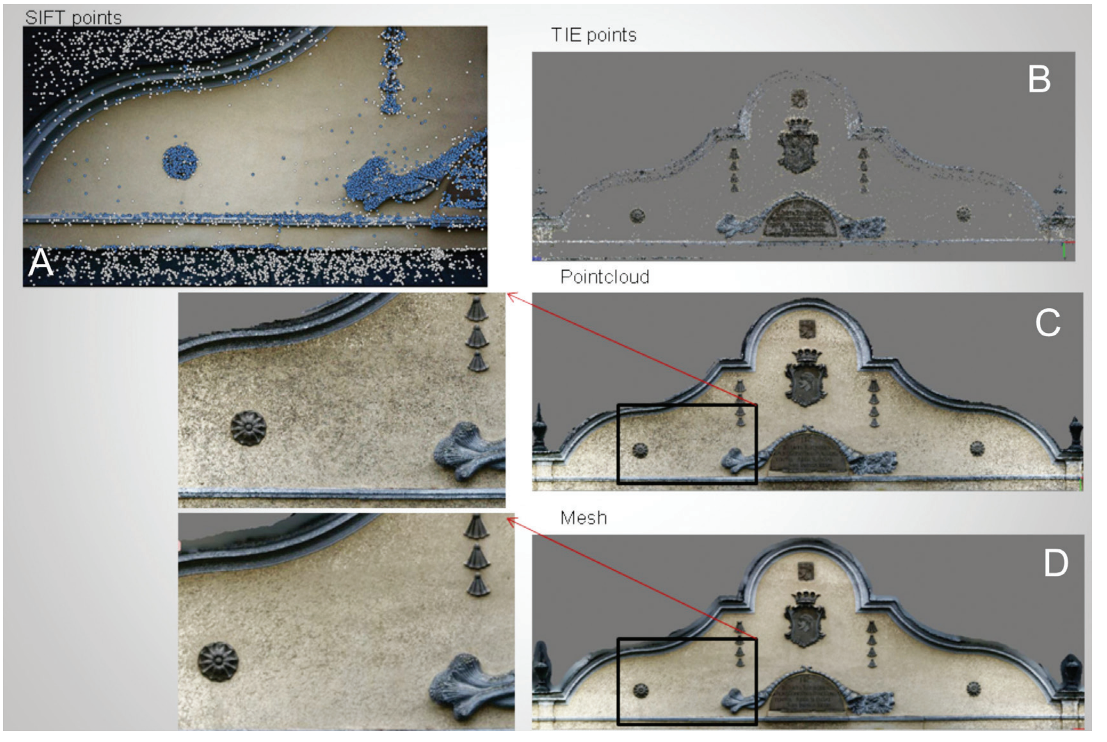

Figure 71. Žehra, Hodkovce (Slovakia). Manor house, exterior, tympanon. Example of noisy data resulting from insufficient number of SIFT points. A: insufficient number of SIFT points, B: sparse tie points with the lack of surface geometry, C: dense point cloud with the noisy part magnified, D: mesh with the distorted part of the surface magnified.

Figure 72. Distribution of SIFT points (key points) detected by bundle adjustment. A: raw stone structure, B: flat facade covered with single-colour fine plaster.

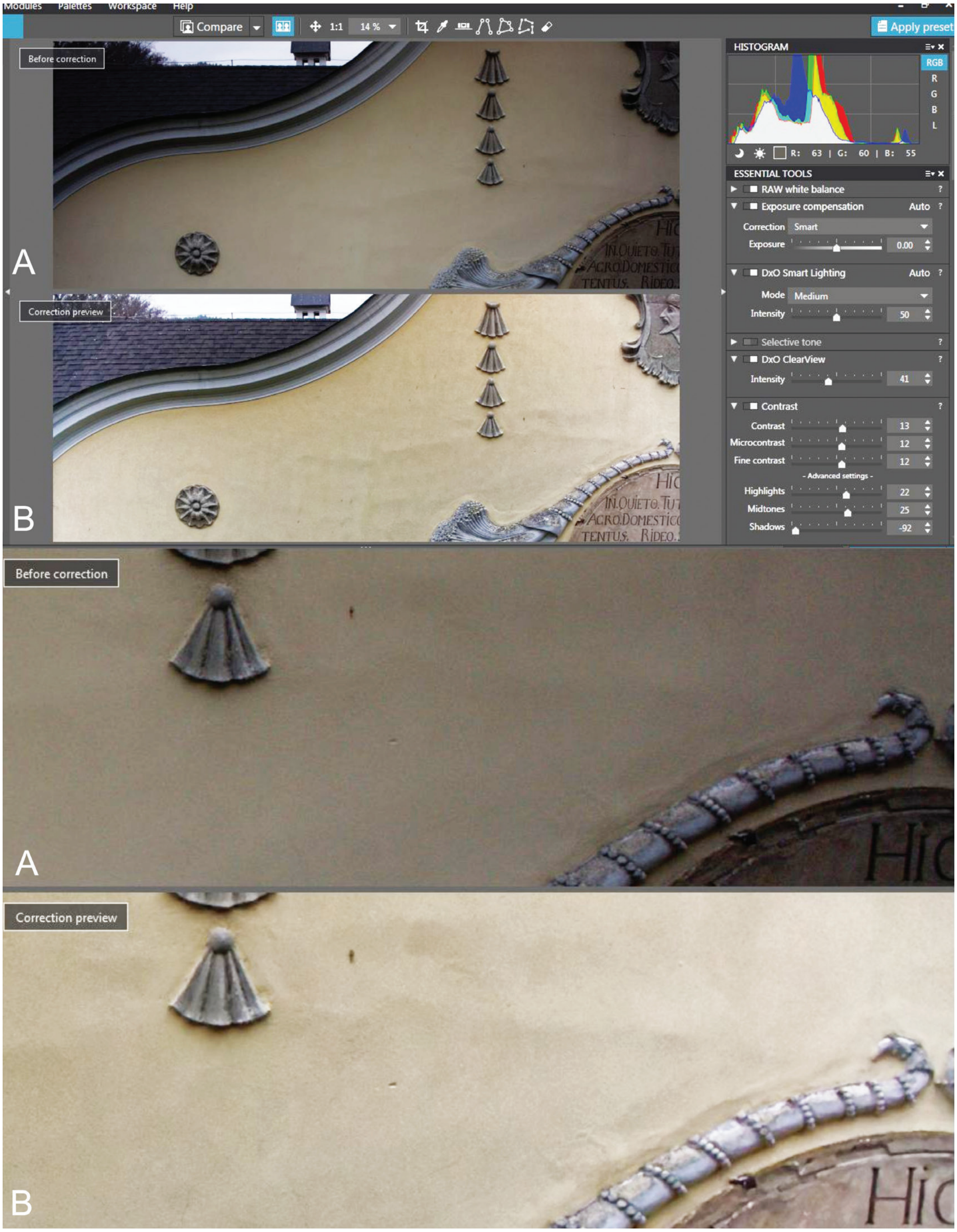

Figure 73. Examples of photo editing as a part of the pre-processing of raw data. Software DxO Optics Pro. A: raw photo, B: edited photo.

Figure 74. Example of HDR filtering/toning of photos leading to better quality of the final 3D model (mesh) on one hand, and false colour information on the other. A: mesh built from photos with default settings, B: mesh built from HDR-toned photos.