List of figures and tables

Figure 1. 3D model surface types: A: mesh-quads, B: mesh-quads, smoothed, C: NURBS. (Available at: https://andrewevs92.wordpress.com/2012/11/19/127/). 15

Figure 2. 3D mesh-triangles with different resolution (3D Modelling for programmers. Available at: https://cathyatseneca.gitbooks.io/3d-modelling-for-programmers/content /3ds_max_basics/3d_ representation.html. 16

Figure 3. Basic types of terrestrial 3D laser scanners (TLS) – a brief overview. A: Faro Focus 3DX130, B: Leica C10, C: Riegl VZ serie, D: Topcon GLS 1500, E: Surphaser 105HSX, F: Stonex X300.. 25

Figure 4. Basic types of portable scanners – a brief overview. A: Artec Eva, B: Artec Spider, C: David Scanner, D: Sense Scanner, E: Microsoft Kinect, F: Breuckmann Smart Scanner, G: Faro Scanner Freestyle, H: ZScanner, I: Creaform Go!SCAN. A-F, I: Structured light scanning (SLS) technology; G,H: Laser technology. 26

Figure 5. Manor house at Žehra, Hodkovce, Slovakia. Point cloud with RGB values showing exposure inconsistency due to poorly exposed composite photos taken by the native scanner camera (Leica C10). 32

Figure 6. 2D Photogrammetry, orthorectification procedure. A: ArcMap interface, B: Autodesk Civil 3D + Raster Design interface. 37

Figure 7. 2D Photogrammetry, basic workflow. A: georeferencing a photogram according to the measured ground control points (orthorectification), B: vectorisation of a photogram, C: print layout. 38

Figure 8. The principle of optical correlation. A: reference matrix, B: searching matrix. (Maliariková 2011, Figure 5). 39

Figure 9. Structure from Motion workflow (software Agisoft Photoscan). A: bundle adjustment, camera calibration – outer and inner camera orientation definition, B: bundle adjustment, sparse point cloud generation, C: Multi-View Stereo, dense point cloud generation, D: mesh creation, E: textured mesh, F: georeferenced orthophoto plan creation, G: georeferenced digital elevation model creation, H: survey data accuracy, mode resolution and quality report. 41

Figure 10. Photo shooting strategies for Image-based Modelling (IbM). (Available online at http://www.agisoft.com/pdf/tips_and_tricks/Image%20Capture%20Tips%20-%20Equipment %20and%20Shooting%20Scenarios.pdf). 44

Figure 11. Photo-shooting scenario of a solitary object. A: walk-around method, B: turntable method. (Available online at http://www.tested.com/art/makers/ 460142-art-photogrammetry-how-take-your-photos/). 45

Figure 12. Processing RAW files. An example of an image before and after correction. DxO Optics Pro interface. 49

Figure 13. Processing RAW files. An example of an image before and after correction. Detail. DxO Optics Pro interface. 51

Figure 14. Radoľa, Koscelisko (Slovakia). Burial mound, Bronze Age. IbM (180 photos, 24 Mpx). Textured 3D model. 55

Figure 15. Radoľa, Koscelisko (Slovakia). Burial mound, Bronze Age. IbM. Shaded 3D model. 56

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. 56

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. 57

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. 58

Figure 17C. Rajec, Charubina (Slovakia). Remains of dwellings from the Bronze Age. 3D model. IbM (193 photos, 12Mpx). Shaded 3D model. 58

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. 59

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. 60

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. . 61

Figure 21. Bratislava, Castle, northern terrace. Remains of the open settlement, partly destroyed by a later quarry, 10-12th century. 3D model. IbM (352 photos, 12Mpx). A: textured 3D model, B: shaded 3D model, C: georeferenced orthophoto plan. 62

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. 65

Figure 23. Senec, Synagogue (Slovakia). Remains of the economic section of the synagogue. Cross-section documentation derived from the 3D model. 65

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.. 66

Figure 25A. 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 25B) that focused on uncovering the west wing of the clausura. IbM (425 photos, 12+24Mpx). 67

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). 68

Figure 25C. Skalka nad Váhom (Slovakia). Remains of a medieval monastery, 14th-17th century. Textured 3D model – detail of medieval hypocaust. 68

Figure 26. Skalka nad Váhom (Slovakia). Remains of a medieval monastery, 14th -17th century. Examples of 2D documentation derived from the 3D model. 69

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. 70

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.. 71

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. 72

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. 73

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. 74

Figure 32. Brazda, Archaeopark (Macedonia). Remains of the stone-built tomb, 5th century BC. Examples of 2D documentation derived from the 3D model. 75

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. 77

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. 77

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. 78

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. 78

Figure 37. Považský Castle (Slovakia). North palace structure, 16th century. IbM (366 photos, 24Mpx). A, B: textured 3D model, C, D: shaded 3D model. 79

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. 80

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. 83

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) 84

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. 87

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. 88

Figure 43. Rajec, Renaissance Town Hall, 16th century. IbM. A: textured 3D model – isometric view, B: textured 3D model – ortho-view of the facade.. 89

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.. 90

Figure 45. Sazdice (Slovakia). Medieval church, 14th century. IbM. Textured 3D model – isometric view. 91

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. 92

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.. 94

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.. 95

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.. 96

Figure 50. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), exterior. IbM in combination with TLS. Ortho-views of the facades. 97

Figure 51. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), interior – 3 levels. TLS (168 TLS stations). Shaded 3D model. 97

Figure 52. Žehra, Hodkovce (Slovakia). Manor house (18-19th century), exterior. 98

A: example of 2D vectorisation of ortho-rectified east facade, B: example of 2D documentation derived from the 3D model – cross-section. 98

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. 100

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. 101

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. 102

Figure 56. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), exterior. IbM in combination with TLS. Ortho-views of the facades. 103

Figure 57. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), interior. TLS (9 TLS stations). Dense point cloud. 103

Figure 58. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), interior. Isometric views. A: shaded 3D model, B: textured 3D model. 104

Figure 59. Žehra, Hodkovce (Slovakia). Neo-Gothic church (19th century), exterior. Example of 2D vectorisation of ortho-rectified south facade. 105

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. 107

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. 109

Figure 62. Žehra, Hodkovce (Slovakia). Park, 19th century. IbM (800 photos 24Mpx). A: distribution of cameras, B: nadir view of the textured D model. 111

Figure 63. Banská Belá (Slovakia). Mining site, 15th century. IbM (691 photos 24Mpx). Isometric views. A: shaded 3D model, B: textured 3D model. 113

Figure 65. Banská Belá (Slovakia). Mining site, 15th century. Example of 2D documentation derived from the 3D model. 113

Figure 64. Banská Belá (Slovakia). Mining site, 15th century. IbM. Isometric views A: shaded 3D model, B: textured 3D model. 114

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. . . .116

Figure 67. Rajec (Slovakia). Burgess house (16th century), cellar. IbM modeling. Depiction of the alignment of cellar rooms processed individually through the control points. . . .117

Figure 68. Rajec (Slovakia). Burgess house (16th c.). IbM, Isometric view of the cellar interior. . . .117

Figure 69. Rajec (Slovakia). Burgess house (16th century), cellar. IbM. Isometric views of the exterior. A: shaded 3D model, B: textured 3D model. 118

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. . .121

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. 122

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. 122

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. 123

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.. 124

Figure 75. Čachtice (Slovakia). Castle, 13th-17th century. IbM (148 photos 12Mpx). Distribution of cameras during photo taking. 127

Figure 76. Čachtice (Slovakia). Castle, 13th-17th century. Isometric views of the textured 3D model. 128

Figure 77. Dobrá Voda castle, 13-16th century. TLS (150 TLS stations). Isometric views of the shaded 3D model.. 129

Figure 78. Dobrá Voda (Slovakia). Castle, 13-16th century. TLS. A: nadir view of the 3D model of the castle's ground plan, B: isometric view of the model of the castle complex. 130

Figure 79. Dobrá Voda (Slovakia). Castle, 13-16th century. TLS. A: isometric view of the 3D model of the outer walls of the upper castle, B: view of the inner facade of the upper palace. 131

Figure 80. Workspace of Artec Studio with the settings used for processing scans. 134

Figure 81. Workspace of Agisoft Photoscan. 135

Figure 82. Workspace of CapturingReality RC. 135

Figure 83. Sculptures of St. John Nepomuk and St. Florian, IbM. Positions of the cameras during photo taking. A: St. Florien (186 photos 24Mpx), B: St. John Nepomuk (269 photos 24Mpx). 136

Figure 84. Sculpture of St. John Nepomuk. A: textured 3D model, B: shaded 3D model.. 137

Figure 85. Sculpture of St. Florian. A: textured 3D model, B: shaded 3D model.. 137

Figure 86. Nové Mesto nad Váhom (Slovakia). Sculpture of the Virgin Mary, 18th century. IbM (184 photos 12Mpx). Distribution of cameras during photo taking.. 138

Figure 87. Sculpture of the Virgin Mary, Nové Mesto nad Váhom (Slovakia), 18th century. A: textured 3D model, B: shaded 3D model visualised in the ambient occlusion mode, C: shaded 3D model – detail. 139

Figure 88. Altar sculptures, church of St. Barbara, Žilina. SLS Artec Eva. Visualisation of particular scans (each scan is depicted with a unique colour) in Artec Studio. A: St. Joachim. 30 scans, B: Baroque angel, 29 scans. 141

Figure 89. Altar sculptures, church of St. Barbara, Žilina. SLS Artec Eva. 3D model of the Baroque angel. A: textured model, B: shaded model with ambient occlusion filter applied. 142

Figure 90. Altar sculptures, church of St. Barbara, Žilina. SLS Artec Eva. 3D model of St. Joachim. A: textured model, B: shaded model with ambient occlusion filter applied. 142

Figure 91. Plaster copy of the Virgin Mary sculpture (15th century, original), Žilina. SLS Artec Eva. A: visualisation of particular scans (each scan depicted with a unique colour) in Artec Studio (20 scans), B: visualisation of the final mesh (3D model) in Artec Studio. 143

Figure 92. Plaster copy of the Virgin Mary sculpture (15th century, original), Žilina. SLS Artec Eva. Shaded model with ambient occlusion filter applied. 144

Figure 93. Clay vessel, 9th century, Bratislava Castle. SLS Artec Eva. A: visualisation of particular scans (each scan is depicted with a unique colour) in Artec Studio (13 scans), B: visualisation of the textured final mesh (3D model) in Artec Studio. C: visualisation of the shaded final mesh (3D model) in Artec Studio. 145

Figure 94. Fragment of a vault rib, 14th-15th century. Nové Mesto nad Váhom. SLS Artec Eva, A: Visualisation of particular scans (each scan depicted with a unique colour) in Artec Studio (3 scans), B: Visualisation of the textured final mesh (3D model) in Artec Studio, C: Visualisation of the shaded final mesh (3D model) in Artec Studio. 146

Figure 95. Fragment of a vault rib, 14th-15th century, Nové Mesto nad Váhom. SLS Artec Eva. Cross-section generation in Artec Studio software. 147

Figure 96. Positions of photographs taken within the IbM 'turntable method'. Software: Capturing Reality RC. Although the camera was static and the object was turned on the turntable, software treats the whole procedure as SfM, i.e. as if the camera was moving. Left window – nadir view, right window – side view. A: ritual object made of clay (46 photos 12Mpx), B: ritual object made of clay (113 photos 12Mpx).. 148

Figure 97. Clay prosopomorphic lids, Neolithic period. IbM, turntable method. A: textured 3D model, B: shaded 3D model. 149

Figure 98. Clay object, Vinča, Neolithic period. IbM, turntable method. A: textured 3D model, B: shaded 3D model. 149

Table 1. Overview of the most commonly used point cloud editing and meshing software. 29

Table 2. Comparison of light and laser technologies. 31

Table 3. Overview of the most commonly used IbM software. 42

Table 4. Overview of the most commonly used RAW file editing software. 47

Table 5. Overview of the most commonly used HDR software. 48

Table 6: Overview of the most commonly used software enabling HDR filtering. 48

Table 7. Commonly used mesh editing software. 51