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TRUEDOP – A NEW QUALITY STEP FOR OFFICIAL ORTHOPHOTOS

With 23 figures and 2 tables

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Abstract

The National Mapping Agencies (NMA) of the German federal states derive nationwide digital orthophotos with a ground resolution of 10 to 20 cm by aerial surveys at regular cycles of two or three years. Standard surveys use large format cameras, the direct georeferencing informations and normal overlap ratios of 70% forward and 30% sideward overlap. These basic geodatasets are in use in a variety of applications. Most commonly authoritive agencies use these orthophotos as a fundamental dataset in their GIS-systems.

Interactive work for deriving the orthopohotos is necessary for updating the terrain model and for defining seamlines for objects above the reference plane. With respect to the developments in dense image matching using the semi global matching algorithms it is possible to derive surface models with pixel resolution and full color informations of the aerial photos. Using these high resolutioned height informations for the orthophoto procedure some software solutions are able to derive the quality of true orthophotos without remaining occluded areas. The rectification additionally uses always a height model from the same survey so that there will be no interactive steps in the working process left. TrueDOP visualises the correct position of all objects without the fault effect of the central perspective. This is a basic condition for using the dataset for effective rasterbased classification applications, in special for the use in change detection.

The Working Committee of the Surveying Authorities of the States of the Federal Republic Germany (AdV) evaluates the replacement of the classical ATKIS-DOP by the TrueDOP. In this connection the TrueDOP is understood as a qualitative upgrading of the existing AdV-product ATKIS-DOP. The resulting advantages and disadvantages in reference to the technical and economical aspects are considered and compared.

1 INTRODUCTION

Digital Orthophotos (DOP) are raster datasets of the photographic presentation of the earth surface, which are principally free of distortion and true to scale. They are derived from orientated aerial photos and a digital terrain model. DOPs are based on photographs, which are raster-oriented, geocoded and provide precise positioning. They are not generalised, complete and provide a view with respect to their use.

The German National Mapping Agencies (NMA) realise cyclical aerial survey campaigns for their authorities by tender and derive DOP. According to a nationally standard of the AdV these DOPs are managed in the Topographic-Informationsystem ATKIS®. DOPs are available with the ground resolutions of 20 cm (DOP20) and 40 cm (DOP40), in some German Länder also with the ground resolution of 10 cm (DOP10). The product specifications for DOP are specified in the product standard for digital orthophotos. The product standard is provided as a no-charge download (www.adv-online.de).

True Orthophotos are mainly characterized by the fact that occluded areas are removed and no tilting of objects above ground level is remaining. For the derivation of TrueDOP a high resoluted surface model is necessary.

The AdV evaluates the replacement of the classical ATKIS-DOP by the TrueDOP. In this connection the TrueDOP is understood as a qualitative upgrading of the existing AdV-product ATKIS-DOP. Therefore studies were made with reference to the necessary technic modifications, organisation-changes in aerial surveys and postprocessing as well as in budget requests.

Figure 1 – Left: ATKIS-DOP; Right: TrueDOP

Since the introduction of the Dense-Image-Matching (DIM)-technology efficient production workflows of TrueDOP became realistic. DIM-technologies derive surface point clouds up to pixel-wide resolutions and can also combine these datasets with spectral informations. The color-coded surface informations reduced to a 2D-space can be interpretated as a TrueDOP. Afterwards modern photogrammetric software solutions enforce radiometric improvements and geometric corrections, like edge adjustments. Contemporary the German NMAs have made experiences with TrueDOP-products derived from the software Surface Recognition SURE (nFrames GmbH). Meanwhile the processing of multispectral images (RGBI) is solved in these software. According to Trimble Inpho an implementation of similar workflows in their product chain (Match-T DSM and OrthoBox) is announced for the Intergeo 2016 in Hamburg.

The tilting of objects above ground level grows to the edges of aerial images caused by the central perspective projection. This effect is eliminated at TrueDOP orthorectification processes due to highly accurated and high-resolutioned digital surface models (DSM). Thus the derivation of TrueDOP is independent of additional digital height model informations.

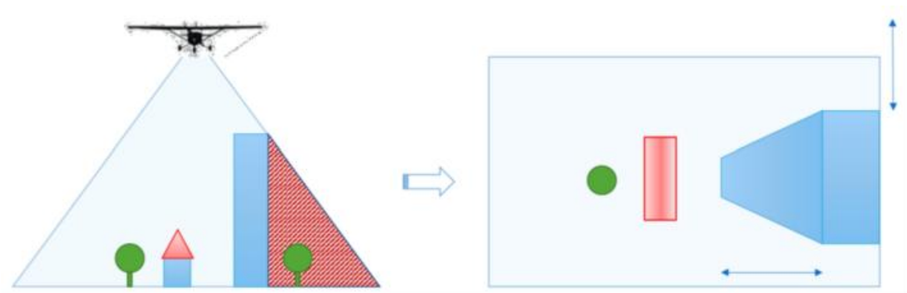

Figure 2 – Tilting effects in classic DOP (Source: Wenzel, nFrames GmbH)

2 TRUEDOP - ISSUES

2.1 Requirements to aerial survey parameters

The TrueDOP can in principal be obtained based on the same aerial image data from which even a classic ATKIS DOP has been derived, which has been prepared for the ortho-rectification on a ATKIS DGM. By TrueDOP algorithms tilting effects can be prevented and all objects on the ground can be displayed at the correct position. Occluded areas are filled by information from other perspectives. Optimized image flight parameters, in particular by increasing the forward and sideward overlapping, improve the image content by additional information derived from further valuable angles, so that hidden areas can be minimized.

Table 1: Stereo models depending on Forward Overlaps

Forward overlap	Stereo Models
> 50%	2
> 67%	3
> 75%	4
> 80%	5

An optimal TrueDOP requires a gapless surface model with a reliable height accuracy. Depending on the locality and especially on the small-scale varieties of object-heights (buildings, narrow streets, bridges or even forest paths) this can be achieved by increasing forward- und sideward overlapping parameters. Areas, where 2.5D-pixels cannot be derived, are figured out as “no-data-areas”. If there is a high overlap the pixel-information of nearby pixels can be used for colour interpolation and afterwards smoothing.

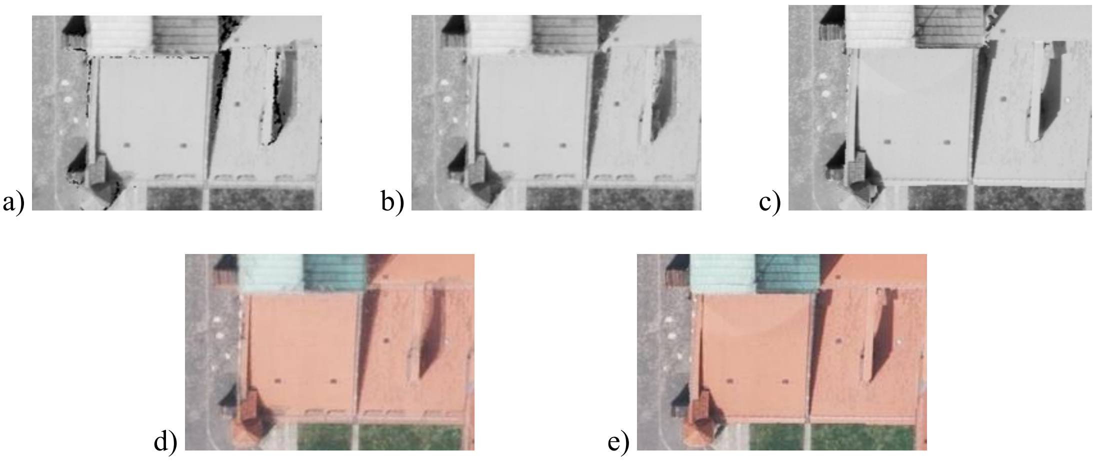

Figure 3 – TrueDOP:
a) PAN- without post processing; b) PAN-with interpolation; c) PAN-with anti aliasing
d) RGBI-with interpolation; e) RGBI-with anti aliasing

Own experiences as well as statements of the software manufacturers prove that especially a forward overlap of 80% leads to a significant improvement of the image quality of the TrueDOP.

Figure 4 – up-left: L80%/Q60%; up-right: L80%/Q30%
down-left: L60%/Q60%; down-right: L60%/Q30%

On the other hand an exclusively increasing of the sideward overlap leads to less advantages, because the main correlation of the software is done in the images in flight direction (with homogenous lighting conditions). Increasing the sideward overlap can help to fill gaps across to the flight direction.

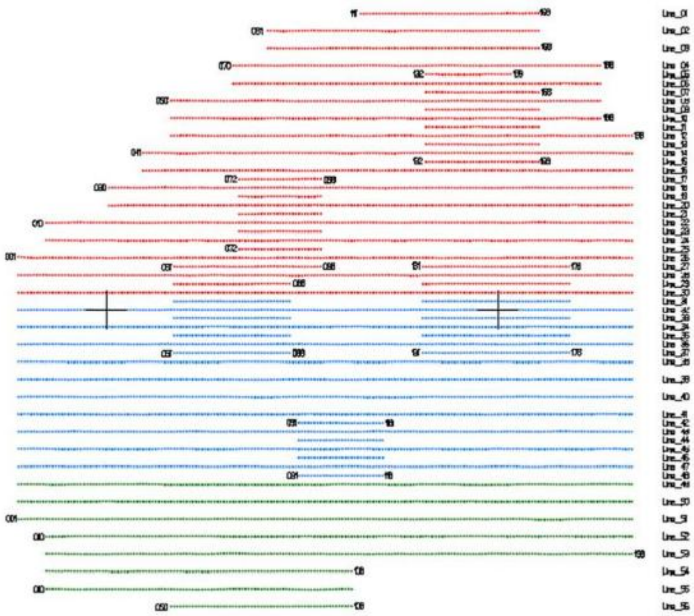

Figure 5 – Aerial survey project - Q60% and Q30% combination

In terms of TrueDOP processing out of aerial survey projects of NMAs it is recommended to use forward overlapping L=80% and at least a sideward overlapping Q=30%. These flight parameters are standard for the majority of NMAs aerial survey projects.

In dense urban areas, a covering of L = 80% and Q = 60% is recommended. Both parameter-sets (L80/Q60 and L80/Q30) can be well aeronautically combined within one aerial survey project.

The other aerial survey parameters behave identically to the parameters of the classic DOP workflow.

2.2 Requirements to Hardware-environment

Deriving TrueDOP is - similar to the production of image-based surface models - a very compute- and memory-intensive process. Therefore a high-performance and stable hardware environment is required. Current benchmarks have yet to be completed. The following factors influence the calculation time:

- Use of CPU or GPU processors
- Available hardware memory
- Server / Workstation / Network environment
- Memory System (S-ATA / Raid)

In the German Länder Bavaria and Mecklenburg-Vorpommern the following calculation times are measured:

Table 2: Computing times for TrueDOP derivation

BY	GSD 20cm / L80% / Q50%	Ca. 30 min / km² for bDOM20 and TrueDOP20
MV	GSD10cm / L80% / Q30%	1 h / km² for bDOM10 and TrueDOP10

2.3 Possible errors in TrueDOP

A correct digital surface model with geometrically identical resolution is the precondition for a geometrically correct TrueDOP. Height errors in the surface model have a direct effect on the pixel representation from the digital aerial image into the TrueDOP.

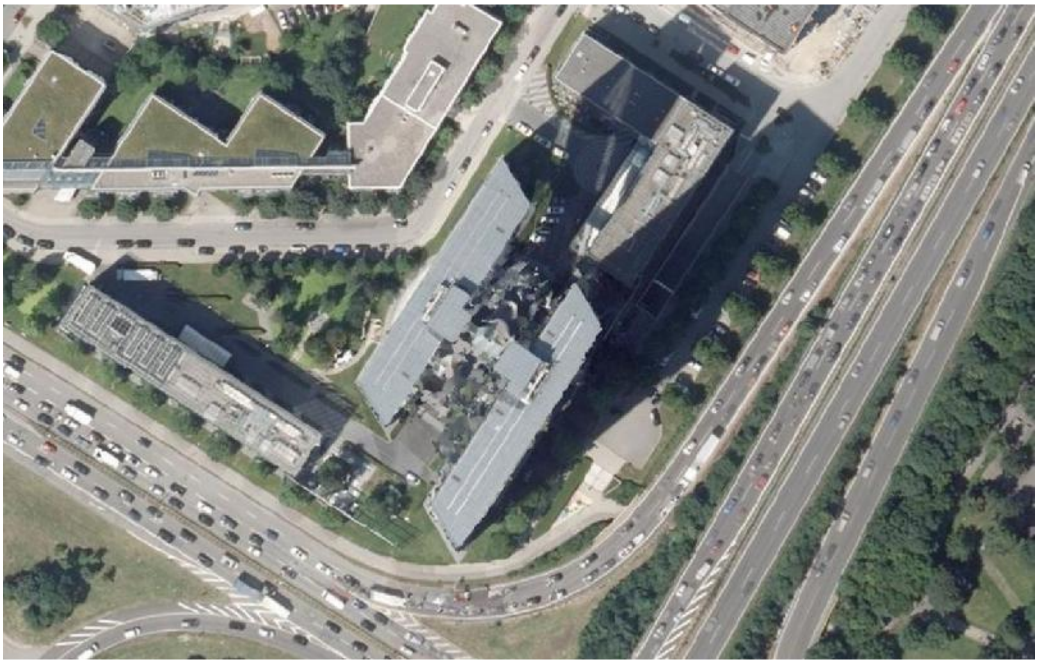

Figure 6 – DSM-Error caused by occluded areas

Figure 7 – Error caused by missing power line information in DSM

Figure 8 – Error caused by DSM-noise in water areas

The above figures show that the manner of representation of the TrueDOP directly depends on the quality of the surface model. The following aspects of quality therefore have to be observed in the generation of the surface model and also have to be corrected interactively:

- Remove of position- and height offsets
- Remove of noise in the water surfaces
- Treatment of gaps in surface models
- Detect and eliminate outliers (for example, moving objects)
- Improve the corners of buildings (if necessary)
- Remove of altitude errors in DSM caused by faults in the aerial images (for example clouds or cloud shadows)

The potential of image-based surface models is not limited by the derivation of TrueDOP. The application potential extends currently also to the generation and updating of the Digital Terrain Model ATKIS-DTM (restricted), digital surface models DSM and the AdV-3D building models. Considering the varied fields of applications the effort to improve the quality of the DSM is justifiable.

2.4 Advantages of TrueDOP in comparison to classical ATKIS-DOP

TrueDOP show a lot of advantages in comparison to classical ATKIS-DOP:

- Correct mapping position of objects above ground level
- Improved results for image-based classification processes
- Conflict-free combination with other geodatasets

- Improved initial datasets for other georeferenced applications
- Optimized mapping of bridges
- Increased positional accuracy
- No time difference between DOM and image recording
- Increased information content

The advantages have an effect on the geometrical accuracy, the dense of information as well as on the effort of human interactive working steps. Increasing quality in combination with reducing interaction are basic reasons for introducing TrueDOP in the ATKIS-production-chain.

2.4.1 Correct mapping position of objects above ground level

In classic orthophotos the representation of objects above ground level and the consequent tilting depends on the distance to the image centre. Variations in the used digital camera sensors and the associated record areas combined with the project parameters L and Q lead to random tilting of objects.

Figure 9 – ATKIS-DOP (2014)

Figure 10 – ATKIS-DOP (2012)

Figure 11 – ATKIS-DOP (2008)

Figure 12 – ATKIS-DOP (2005)

Figure 13 – True-DOP (2012)

In consequence of the location-correct mapping of objects no seamlines in orthophoto mosaics are necessary. This leads to savings on interactive human efforts.

2.4.2 Improved results for image-based classification processes

In automated image-based classification methods such as Change Detection better results can be achieved due to the correct position of objects above ground level. Tilting caused error effects are omitted. Buildings can be classified at their correct position and can therefore be used for change analysis.

2.4.3 Conflict-free combination with other geodatasets

In contrast to the classical DOP in TrueDOP correct mapped objects such as buildings can be represented with other spatial data sets such as ALKIS / ALK without conflicts.

2.4.4 Improved initial datasets for other georeferenced applications

For other applications, such as forest-mapping, arise improved initial datasets for classifications or other georeferenced issues. The treetops are mapped at their correct position in TrueDOP. This is a requirement of the environmental and agricultural management.

Figure 14 – Forest in TrueDOP

Figure 15 – Forest in ATKIS-DOP

2.4.5 Optimized mapping of bridges

In classical ATKIS-DOP workflows particularly the topographical representation of bridge elements is a major challenge and represents a high interactive effort. The reason for this is that bridges by definition are not part of the DTM and therefore have to be modeled manually in the production process of ATKIS-DOP. In TrueDOP the bridge elements are automatically displayed correctly because bridges are integrated in the DSM.

Figure 16 – Bridge presentation in TrueDOP

2.4.6 Increased positional accuracy

Due to the correct position of objects (without tilting) object points (above the terrain model) can be digitized with the identical accuracy as ground points in TrueDOP. The uncertainty due to the tilted display is deleted.

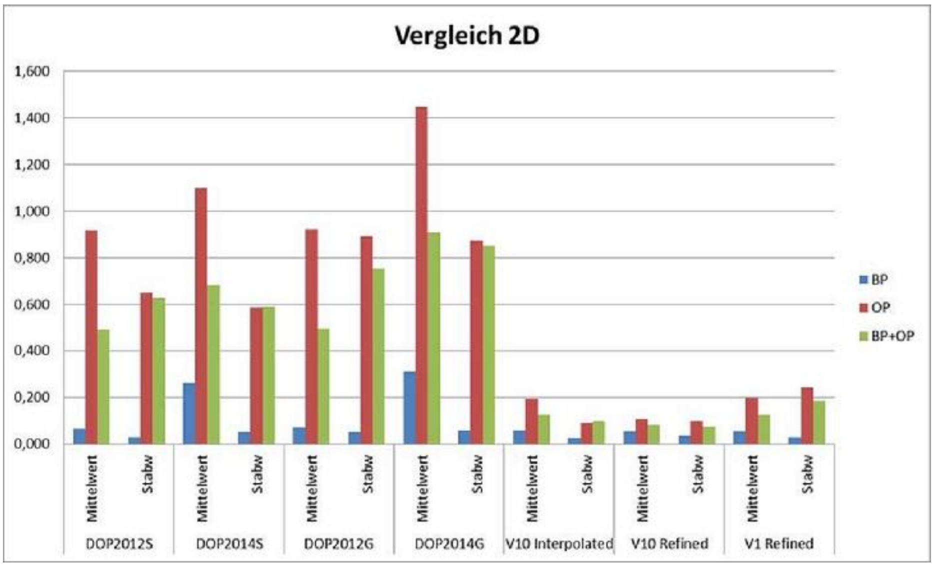

Figure 17 – Comparison of 2D-accuracy for Ground Points (BP) and Object Points (OP)

2.4.7 No time difference between DOM and image recording

The quality of ATKIS-DOP is as well influenced by the orientation accuracy of the aerial images as on the used digital terrain model (DTM). DTM errors make an impact on the sitional error in ATKIS DOP with up to 50%. Inaccuracies and possible missing actuality lead to positional errors in the orthophotos. In particular, linear elements such as railways or roads require interactive reworking.

This error source is not applied in TrueDOP processes, because the resolution of the initial DSM is pixel-sharp and the currentness of the DSM is identical to the capture-date of the aerial images.

2.4.8 Increased information content

Tilting leads to missing information for occluded areas. By TrueDOP processes and corresponding image flight parameters, these areas can be filled and displayed as additional content in the TrueDOP from other viewing directions, so that the information content of TrueDOP compared to the classic digital orthophotos can be increased.

Figure 18 – ATKIS-DOP with occluded areas in small alleys and backyards

Figure 19 – TrueDOP presentation without occluded areas

2.5 Disadvantages of TrueDOP in comparison to classical ATKIS-DOP

An honest comparison of the new technology and the classic production workflow concurrently shows some disadvantages, which also have to be figured out:

- Omission of height interpretation from perspective presentations
- Interactive effort shifted in the DSM-quality analysis
- Ghosting effects of mobile objects
- Remaining fringes at object-edges due to geometric and radiometric shadow

2.5.1 Omission of height interpretation from perspective presentations

In classic ATKIS-DOP users were able to interpret relative height information out of the tilted objects. In TrueDOP this is only indirectly possible over the length of the presented shadows. As already mentioned before it should be noticed that the degree of the tilting due to the central perspective presentation and object distance from the principal point in the individual image is random.

In particular objects like wind turbines or power poles, whose structural elements are close to the size of the geometric resolution of the initial DSM, are displayed incomplete. These effects, which influences the DSM as well as the TrueDOP, has to be made familiar to the users.

Figure 20 – TrueDOP presentation of an electricity pylon

Figure 21 – TrueDOP presentation of a wind mill

2.5.2 Interactive effort shifted in the DSM-quality analysis

The advantages proved the reduction of interactive steps in the TrueDOP-processing. For example, Bridge corrections Seamlines and DTM corrections are dropped. But the effort for the image-based DSM quality analysis is not to be neglected, so that human resources have to shift in the interactive quality assurance (error analysis and correction) of image-based DSM. This effort, as already mentioned before, produces parallel appreciation of all 3D geodata products, so that it is justifiable.

2.5.3 Ghosting effects of mobile objects

Mobile objects such as driving cars or trains, which have moved during the individual captured aerial images, are mapped transparently in TrueDOP (ghosting effect).

2.5.4 Remaining fringes at object-edges due to geometric and radiometric shadow

At the edges of objects with strong height differences such as buildings data gaps may still be left in the DSM, caused by occlusion and/or shadows. Geometric and radiometric interpolation as well as edge improvements in areas, where no pixel sharp information or only "noisy" information by shadows is available, lead to remaining defects at the edges of objects. These become visible in the image data by using a strong zoom.

Figure 22 – TrueDOP presentation of a building object with fringes at the object edges

Figure 23 – ATKIS-DOP presentation with tilting

3 CONCLUSIONS

The German NMA are responsible for basic geodata sets. One standard product, which is well distributed, is the ATKIS-DOP. The improving developments in deriving image-based surface models have made the production of TrueDOP effective and efficient. The experiences in the AdV demonstrate that the most aerial survey projects already fulfil the requirements for derivation of qualitive TrueDOP.

The hardware environment in the NMAs have to be adjusted. Some NMAs have to invest in additional software licenses for deriving the complete capture area in a sufficient time.

The comparison between TrueDOP and classical ATKIS-DOP delivers more advantages than disadvantages for the decision to use TrueDOP in future. Both increasing quality and reducing human interaction steps are good reasons for TrueDOP introduction. Researches in the quality analysis of image-based surface models have to be enhanced.

Further points, which have to be analysed and discussed in front of the implementation of TrueDOP are:

- Computing Time as a function of hardware environment
- Statements about aerial survey- and data-storage costs
- Costs for the image-based DSM quality management
- Customer feedback for new product quality

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AdV, Productstandard for digital orthophotos (ATKIS®-DOP), www.adv-online.de

HIGH DENSITY AERIAL IMAGE MATCHING: STATE-OF-THE-ART AND FUTURE PROSPECTS

With 14 figures and 1 table

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Abstract

Ongoing innovations in matching algorithms are continuously improving the quality of geometric surface representations generated automatically from aerial images. This development motivated the launch of the joint ISPRS/EuroSDR project “Benchmark on High Density Aerial Image Matching”, which aims on the evaluation of photogrammetric 3D data capture in view of the ongoing developments in dense multi-view stereo-image matching. Originally, the test aimed on image based DSM computation from conventional aerial image flights for different landuse and image block configurations. The second phase then put an additional focus on high quality, high resolution 3D geometric data capture in complex urban areas. This includes both the extension of the test scenario to oblique aerial image flights as well as the generation of filtered point clouds and 3D meshes as additional output of the respective multi-view reconstruction. The paper uses the preliminary outcomes of the benchmark to demonstrate the state-of-the-art in airborne image matching with a special focus of high quality geometric data capture in urban scenarios.

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1 INTRODUCTION

The reconstruction of 3D surface representations from large sets of overlapping imagery has been, and still is, a vivid research topic in photogrammetry and computer vision. Driven by advances in digital airborne camera technology and algorithms, limits of automatic image based 3D data capture especially for complex scenes are still pushed regarding precision, robustness, processing speed and scale. While applications are manifold, this paper focuses on scene reconstruction from airborne imagery. Traditionally, this comprises the evaluation of nadir airborne image configurations for the reconstruction of Digital Surface Models (DSM). While such 2.5D surface representations are sufficient for applications at small or medium scale, a growing number of scenarios in complex urban environments require explicit 3D geometric information. This for example includes appropriate representations of façades elements like doors and windows as well as other vertical objects. To support the extraction of such features, façade imagery as captured from oblique camera systems or unmanned aerial vehicles (UAV) is increasingly used. Additionally, the respective matching pipelines for dense surface reconstruction have to be extended to true 3D processing, including the generation of output like 3D point clouds or meshes.

Within this paper, we discuss the potential of such pipelines and the state-of-the-art in photogrammetric 3D data capture on examples from the project “Benchmark on High Density Aerial Image Matching”. The basic scope of this joint ISPRS/EuroSDR initiative is the evaluation of 3D point clouds and DSM produced from aerial images with different software tools. Originally, the benchmark was limited to two image blocks captured with standard photogrammetric camera systems. Section 2 briefly summarizes the evaluation based on results from this imagery provided by different software systems. Such multi-view matching pipelines for the evaluation of airborne nadir imagery usually generate DSM rasters at a grid size corresponding to the average pixel footprint as standard results. While such 2.5D models are suitable for a number of applications, data collection based on oblique airborne imagery has developed to an important alternative source of information especially in complex urban environments. This motivated the extension of the benchmark to an additional test scenario aiming at the evaluation of dense 3D point clouds from such imagery especially at building objects. Section 3 presents and discusses these results as the main contribution of this paper, while the concluding remarks in section 4 briefly summarize the current state-of-the-art and future prospects in high density aerial image matching..

2 DSM FROM AIRBORNE NADIR IMAGERY – AVAILABLE QUALITY AND LIMITATIONS

Important factors influencing the quality of DSM from dense airborne image matching are surface texture and image overlap. This motivated the provision of two data sets with different landuse and block geometry for the first phase of the benchmark. The data set, Vaihingen/Enz was selected as an example for data usually collected during state-wide DSM generation at areas with varying landuse. It covers a semi-rural area at undulating terrain with elevation differences of 200m. The aerial images were collected at height above ground of 2900m and a ground sampling distance (GSD) of 20cm. The sub-block selected for the benchmark consists of three strips with 12 images each. The available overlap of 63% in flight and 62% cross flight results in variations of four to nine images per object point. Test participants had to generate a DSM at a size of 7.5kmx3.0km at a grid width of 0.2m, corresponding to the GSD of the imagery. The second test data set München is more typical for data collection in densely built-up urban areas. Since this presumes images at a higher overlap and resolution, the image sub-block to be processed consists of 3 image strips with 5 images each, captured with 80% in flight and 80% cross flight overlap. This results in a considerable redundancy by up to fifteen-folded object points. However, the available high buildings result in occlusions especially for surface parts close to the façades. Thus, visibility can be limited for such regions, which will potentially aggravate the matching processes during DSM generation. The area to be processed has a size of 1.5x1.7km in the central part of the city of München. The DSM had to be generated at a grid width of 10cm, again corresponding to the GSD of the image block.

For quality assessment of generated DSM, the comparison to ground truth from independent measurements is most suitable. During the benchmark, a median DSM was generated alternatively from the different results as provided from the participants. Of course, this median DSM does not provide independent ground truth at higher order accuracy. Still, since generated from more than 10 available software solutions, it is very useful to illustrate differences between the respective results. Figure 1 depicts the shaded relief of this reference DSM for a small section of the test area. Additionally overlaid is a colour-coded representation of the RMS values from all DSM solutions with respect to this median.

Our accuracy investigations presented in more detail in (Haala, 2014) clearly show that a growing number of software tools allowing for detailed, reliable and accurate image based DSM generation are available. To eliminate erroneous matches reliably, processing especially takes advantage from large image overlaps. State-of-the-art stereo image matching algorithms provide a considerable reliability of DSM at vertical accuracies close to the sub-pixel level. The results of the nadir image benchmark additionally show acceptable run-times even if a standard hardware environment is used. Data sets like the provided benchmarks can be processed without problems. As it is exemplarily visible in Figure 1, some solutions showed decreasing accuracies at cast shadows. Differences between the respective results also increased at fine object structures close to the resolution of the available images. Typically the amount of captured 3D structure is limited if nadir views from standard aerial image flights are used. In such scenarios, the restricted look angles result in rather sparse reconstructions of 3D façade geometry.

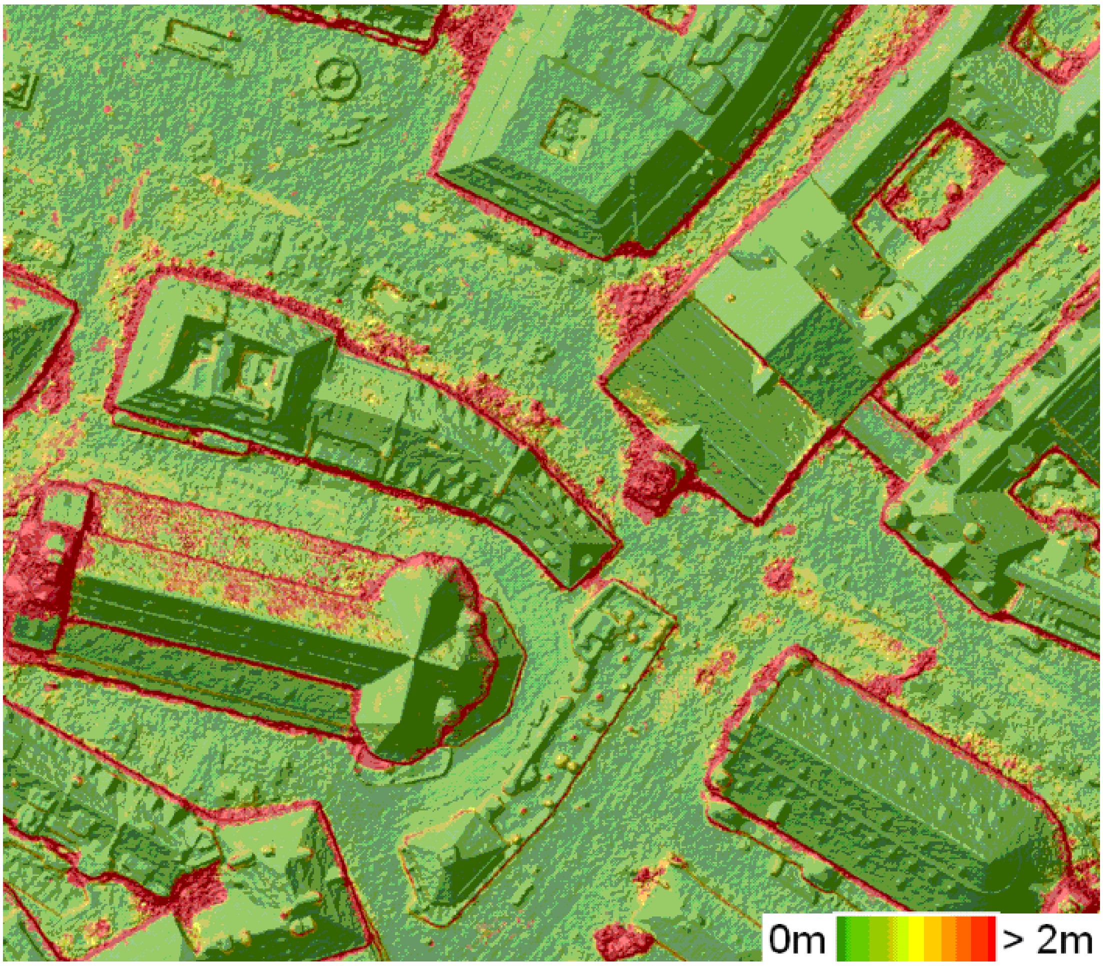

Figure 1 – Shaded DSM for test area München with RMS differences for all solutions overlaid

The data set München features imagery captured by the DMC II 230 camera, which features a Field of View (FoV) of 49.9° cross track and 47.3° along track. If imagery from such a wide angle camera is available at a sufficient overlap (e.g. 80%/80% for this example) even standard nadir configurations can provide façade texture at resolution sufficient for a number of applications. As an example, the pipeline described by Rothermel et al. (2016) follows an approach proposed by Waechter et al. (2014) to pick an adequate, consistent texture for such purposes.

As it is visible in Figure 2, such an approach already provides rather appealing results for visualisation by mapping aerial image texture against the available 2.5D DSM data. Since visualization pipelines use triangle meshes, these primitives have to be extracted from the reconstructed DSM raster as a first processing step. For this purpose, multi-resolution triangulations are available in computer graphics since decades (Lindstrom et al., 1996). Since computational complexity of both, visualization and texture mapping directly depend on the number of triangles, it is desirable to construct meshes which solely consider elevation data contributing to the actual geometry and neglect data possessing elevation variances close to the noise level (Rothermel et al., 2014). While the top of Figure 2 depicts the wireframe of the model to visualize the structure of the generated meshes, the bottom image shows the respective triangles filled with their corresponding texture as provided from the aerial images.

Figure 2 – Texture mapped triangulated DSM raster showing vertices (top) and faces (bottom)

3 DENSE IMAGE MATCHING IN COMPLEX BUILT-UP ENVIRONMENTS

While the nadir data sets presented in section 2 aim at the evaluation of software systems for DSM generation, an additional test scenario was set up to investigate the potential of high density image matching for oblique airborne imagery. This was motivated by the increasing use of oblique imagery for photogrammetric purposes (Rupnik et.al., 2015). Since oblique images depict building façades and footprints, they are easy to interpret also for non-expert users. Thus, they are frequently integrated for visualization in global map services such as Google Maps. Furthermore, they can be used for 2.5D or 3D information extraction in applications like monitoring, urban area classification or administration services. In principle, oblique images are also very suitable for image matching while aiming at the generation of dense 3D point clouds in the context of 3D city modelling. However, applying DIM algorithms to oblique imagery introduces some major new challenges to the processing pipeline. In addition to greater illumination changes, these include multiple occlusions as well as large scale variations due to a higher depth of field.

3.1 Benchmark data from oblique aerial imagery

The test data provided for the aerial oblique benchmark consists of two image blocks. The first block was acquired over the city of Zürich with the medium format camera Leica RCD30 Oblique Penta. The camera features a maltese cross configuration with one nadir and four oblique cameras. Nadir imagery is captured with a GSD of 6cm and an approximate overlap of 70% in flight and 50% across flight direction. The imagery of the four oblique views mounted at a tilt angle of 35° has a GSD of 6-13cm. Cavegn et al. (2014) present the test scenario and gives preliminary results for this data set. Our paper discusses the evaluation of the second oblique data set collected for a part of the city of Dortmund. This data set was provided from the ISPRS Scientific Initiative on "Multi-platform Very High Resolution Photogrammetry" (Nex et al., 2015). It features 905 oblique images taken by AeroWest with the PentaCam IGI system. Again, the PentaCam IGI features a maltese cross configuration, the tilt angle of the oblique views for this camera is 45°.

The image subset mainly depicts the Museum Zeche Zollern close to the city of Dortmund. Figure 3 shows the area and the surrounding buildings in an exemplary oblique image from the block. The GSD of the benchmark data is 10cm in the nadir images and varies from 8 to 12cm in the oblique views. Rather high overlap is available. It is 75%/80% in along/across-track direction for the nadir views and 80% /80% for the oblique images. While the complete image block consists of 881 images, a subset of 85 images was selected after bundle block adjustment for the dense image matching benchmark. For these images lens distortion was eliminated by image rectification. Participants were asked to use the given orientation parameters without modification. All information concerning the Benchmark for Multi-Platform Photogrammetry and the Benchmark on High Density Aerial Image Matching, including a description and a link to the data is available on the websites:

http://www2.isprs.org/commissions/comm1/icwg15b/benchmark_main.html

and

http://www2.isprs.org/commissions/comm1/wg2/benchmark.html.

Figure 3 – Exemplary image for test area Museum Zeche Zollern

3.2 Additional scenario from terrestrial and UAV imagery

As a further scenario images captured by a rotary wing UAV platform and from the ground are additionally available for the dense matching benchmark. The UAV was equipped with a Sony Nex 7 camera, while the ground imagery was collected by a Canon D600 SLR camera.

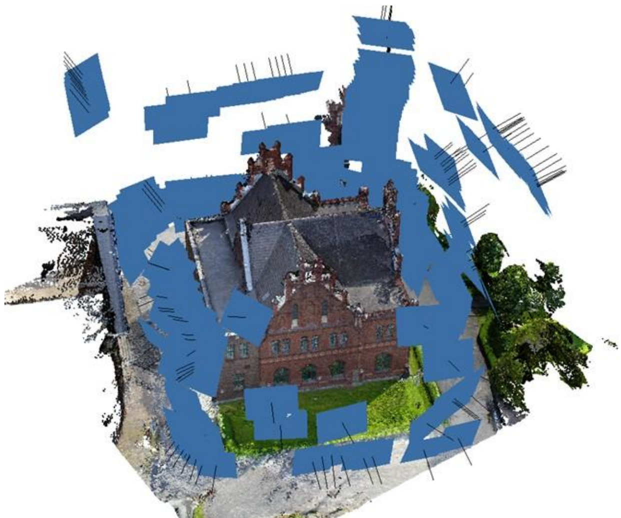

Figure 4 – Image configuration for combined terrestrial and UAV block

Figure 4 shows the block configuration for these 228 images. As it is visible, data capture is limited to a single building of the Zeche Zollern area, the administration building (“Verwaltung”). With an average GSD of 0.5cm, the image resolution of the terrestrial and UAV imagery comparably high and potentially provides a lot of detail. The terrestrial and UAV images show large differences in viewing directions, which potentially aggravates matching however, a high overlap is available, which provides a high redundancy during matching.

3.3 Evaluation procedure

Participants of the test have to provide point clouds from their respective matching tools for the evaluation. For this purpose, several high quality terrestrial laser scans were performed using a Z+F 5010C laser scanner in the test area. Figure 5 shows the TLS point cloud for the building “Verwaltung”. As it is visible, the available amount of detail is not only sufficient to evaluate the results from the oblique aerial images to be generated at a point distance of 10cm, but can also be used for the high resolution results from the UAV and terrestrial imagery, which are close to the sub-centimeter level. Similar data sets from TLS are available for two additional buildings. Figure 6 shows the TLS references point cloud for the building “Lohnhalle” in grey.

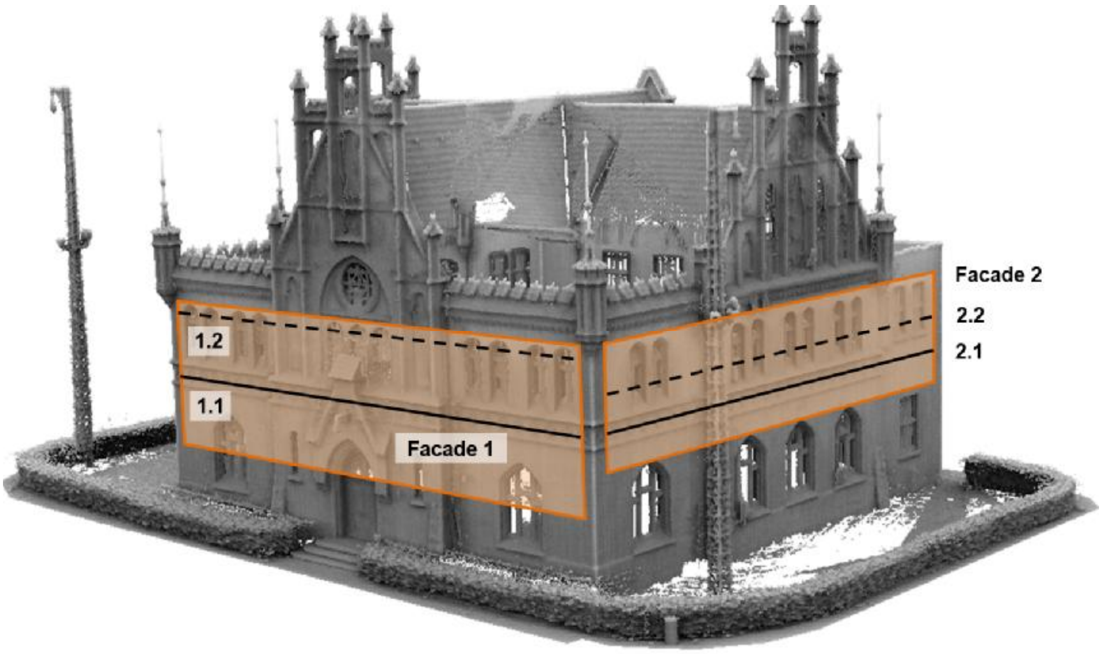

Figure 5 – Point cloud from TLS for building “Verwaltung”.

Figure 6 – TLS point cloud “Lohnhalle” in grey, coloured point cloud from software PhotoScan overlaid.

Figure 7. Exemplary point cloud generated with software SURE

Figure 6 additionally visualises a DIM point cloud for a part of the area. For better discrimination, this point cloud as provided from the company AgiSoft using their software system PhotoScan, is coloured using image texture from available oblique imagery. Figure 7 gives another example for a point cloud delivered from a benchmark participant. This result from the software system SURE processed by the company nFrames also shows some parts of the test areas, which includes rather complex 3D structure like the shaft tower.

For evaluation of the DIM point clouds provided by the participants, the approach already described in Cavegn et al. (2014) was used. In a first step, a simple surface representation is generated from the reference measures by TLS for patches at building facades. These patches are already visualised for the TLS reference measures given in Figure 5.

Table 1: Density and deviation values for all administration building facades using SURE (S) and PhotoScan (PS)

	Patch size [m^2]	Density [Points / m^2]	RMSE DIM-TLS [mm]	Mean DIM-TLS [mm]
Fac.1 S	139	31	138	-6
Fac.1 PS	139	40	169	-84
Fac.2 S	102	29	100	-16
Fac.2 PS	102	40	145	-103
Fac.3 S	126	19	81	-16
Fac.3 PS	126	33	142	-46
Fac.4 S	101	28	94	-3
Fac.4 PS	101	39	112	29
Mean S	117	27	103	-10
Mean PS	117	38	142	-51

As it is visible in Table 1, certain features like mean density of computed points as well as a mean difference or RMSE with respect to the TLS reference can be computed easily. However, the conclusiveness of these numbers is rather limited. In contrast, the point-to-point differences between the façade surfaces from DIM to the reference surface from TLS is much more useful. This would presume a suitable surface representation e.g. by a meshed 3D point cloud. Nevertheless, to simplify data processing and thus to increase the number of potential test participants, we requested raw 3D points as the final deliverable. For evaluation of these point clouds during the benchmark, we used a simple gridding process for surface computation at building facades, which is almost identical to standard DSM raster as discussed in section 2. A DSM provides rasterized elevations, which refer to a horizontal plane. Similarly, we compute a raster representing the vertical distances of the collected 3D point clouds to patches of building facades.

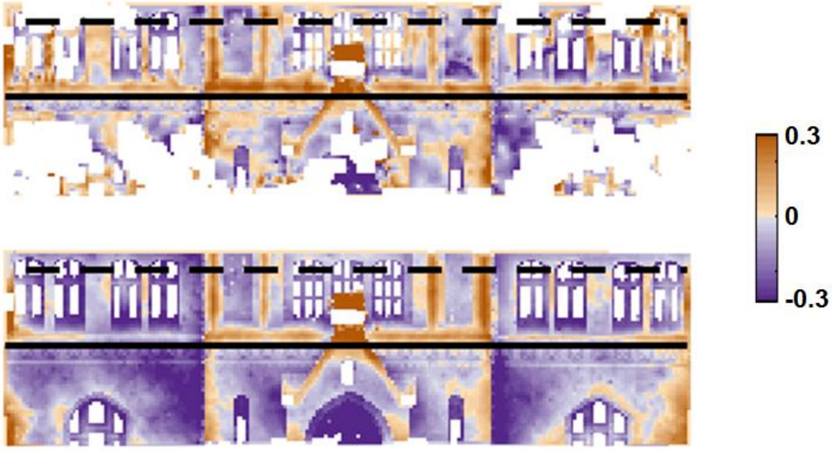

Figure 8 – Deviations SURE-TLS (top) and deviations PS-TLS (bottom) of façade 1

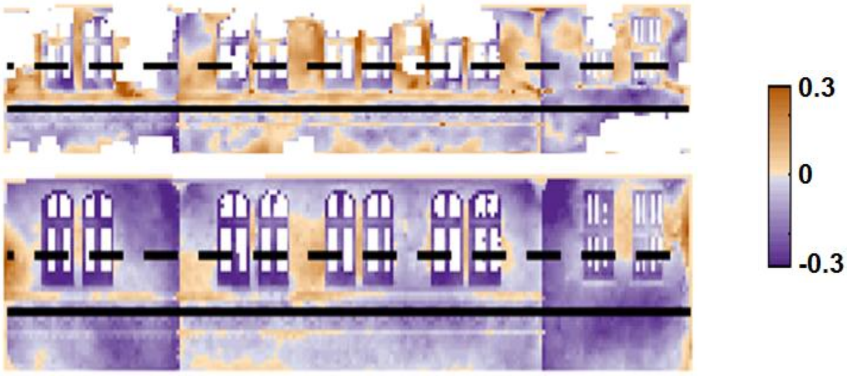

Figure 9 – Deviations SURE-TLS (top) and deviations PS-TLS (bottom) of façade 2

Figure 8 and Figure 9 show the results of this process for façade 1 and façade 2, which were marked in the TLS reference point cloud depicted in Figure 5. To generate raster surfaces from the TLS point cloud for these patches, we selected a grid width of 10cm, which corresponds to the average GSD of the available oblique aerial imagery and applied the gridding process. Similarly, raster representations were generated from the point clouds provided by the participants. By these means, differences between the respective surfaces can be computed very easily. As an example, the top of Figure 8 and Figure 9 shows the differences of a surface generated from a point cloud provided by the software SURE to the reference surface from TLS. For the images on the bottom, we subtracted this reference from results provided by the software PhotoScan.

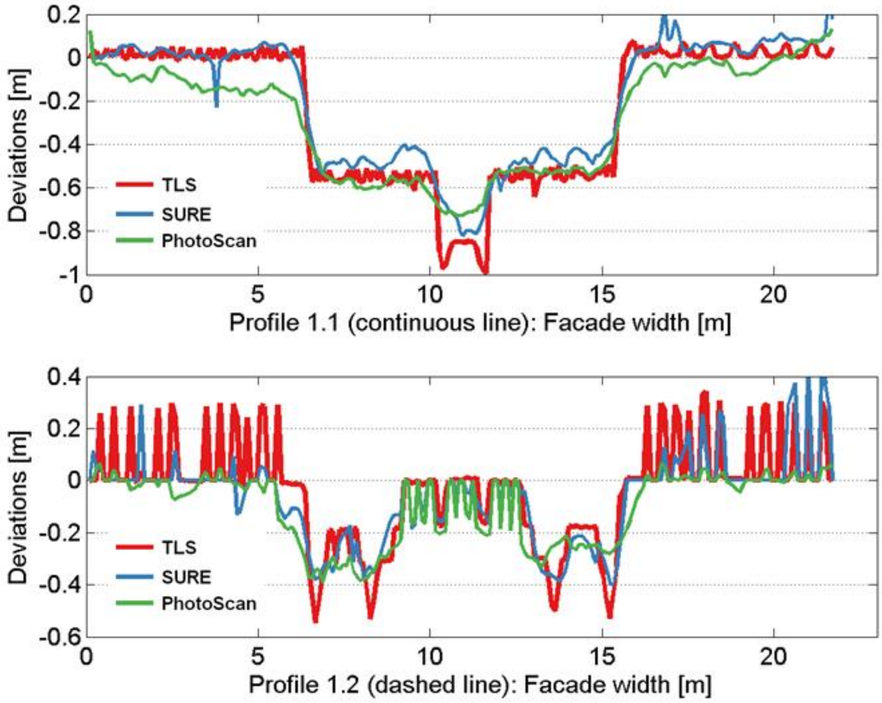

Figure 10. Horizontal profiles of façade 1

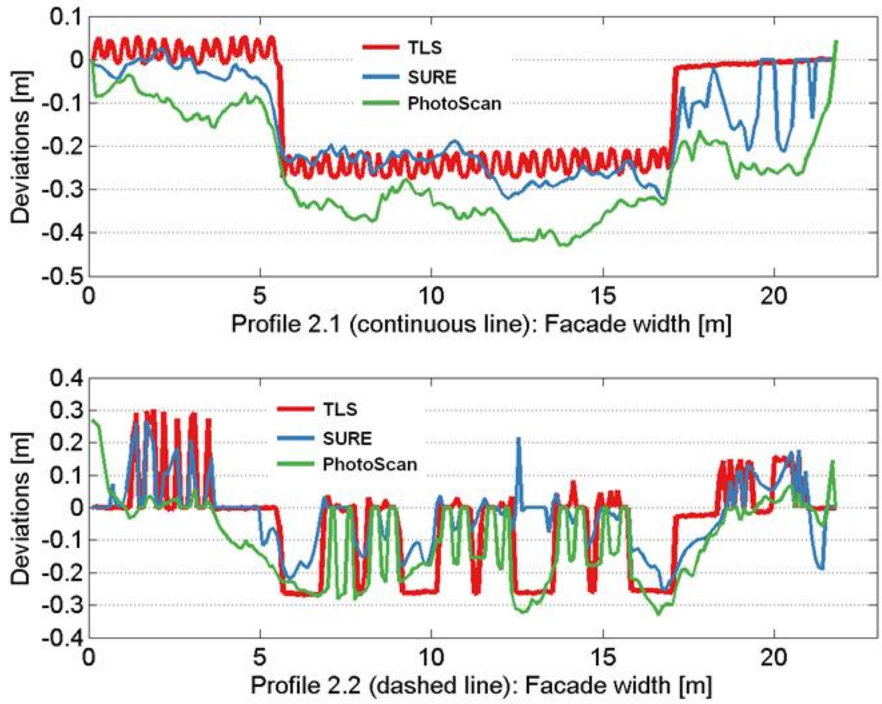

Figure 11 – Horizontal profiles of façade 2

As it is visible, these differences of the respective data from SURE and Photoscan to the TLS reference in Figure 8 and Figure 9 were color-coded in an interval of ±0.3m. This already gives a first impression on the available amount of detail in the DIM results. Figure 10 and Figure 11 show some profiles extracted from the surfaces provides by TLS and DIM using SURE and PhotoScan, respectively, in order to provide a better visualisation of numerical values. These profile lines are also shown in Figure 5. Due to the limited resolution of the oblique aerial imagery of 10cm, not all of the fine details can be reconstructed. However, the general shape of the building facades is available.

An increased amount of detail is of course available based on the dataset described in section 3.2., which consists of the terrestrial and UAV imagery. Since these images provide a much higher resolution, a DSM raster width of 2cm was selected for the gridding, which corresponds to the mean GSD of the captured images.

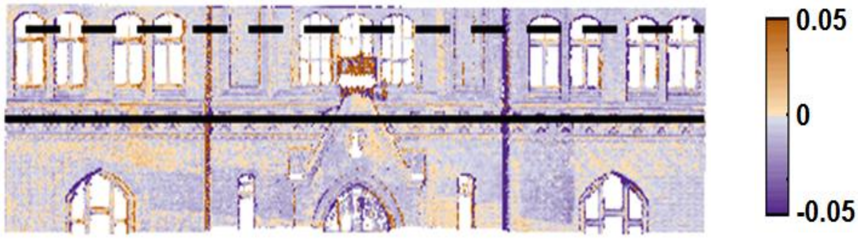

Figure 12 – DIM from terrestrial and UAV imagery: Deviations DIM-TLS of façade 1

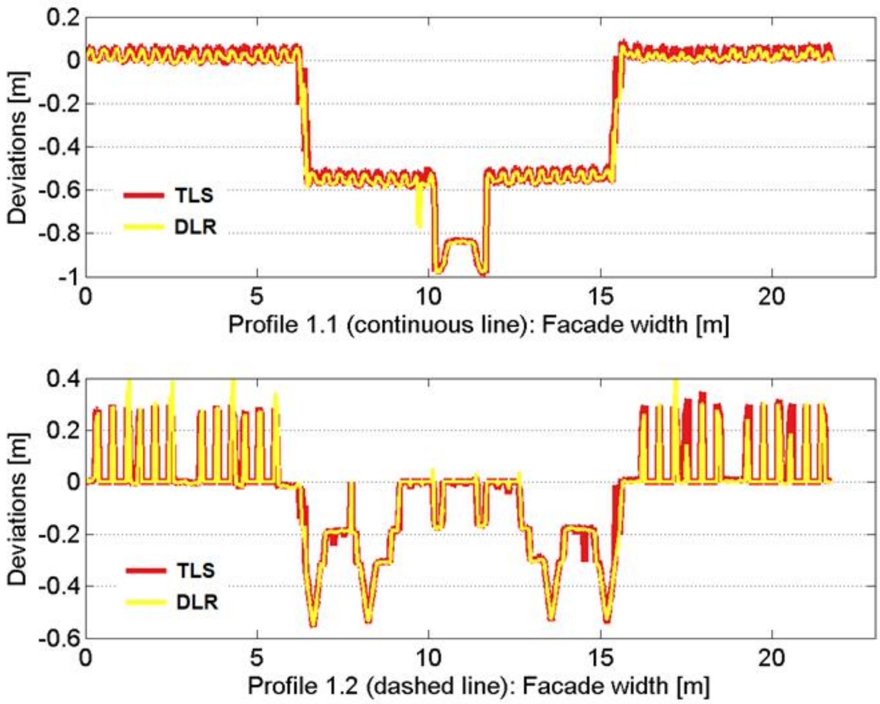

Figure 13 – DIM from terrestrial and UAV imagery: Horizontal profiles of façade 1

Figure 12 and Figure 13 were generated from results provided by DLR Institute of Robotics and Mechatronics for the UAV and terrestrial image data set. The amount of detail within the reconstructed surface geometry is much higher than for the results from oblique aerial imagery in Figure 8 to Figure 11. Apparently, the evaluation of the UAV and terrestrial image data set benefits from the high image resolution and the large overlap, which is available for this block. In such scenarios, the results from DIM are almost comparable to the quality of the TLS data.

4 CONCLUSIONS

Dense multi-view stereo in principle generates one 3D point for each pixel of an image block configuration. This results in considerable point densities also for standard airborne imagery. During DSM generation, these dense 3D point clouds can e.g. be fused by a simple gridding process, which computes the final height value of each grid cell as the median of the z-components of the points assigned to each single cell. This intuitively applies filtering of the points in a direction normal to the observed surface. Algorithms based on an optimization of these criteria are easy to implement for airborne nadir configurations. However, robust filtering of reconstructed 3D points can become rather complex for oblique scenarios. In contrast to nadir views with both homogenous look direction and resolution, such configurations are much more challenging. Now geometric processing is required in true 3D space, which is far from trivial especially. As an example Rothermel et al. (2016) present the filtering and fusion of oriented point sets, which are very well suited for generation of meshed surface by standard Poisson surface reconstruction (Kazhdan & Hoppe, 2013) in a following step. An example for the test data set Zürich is given in Figure 1.

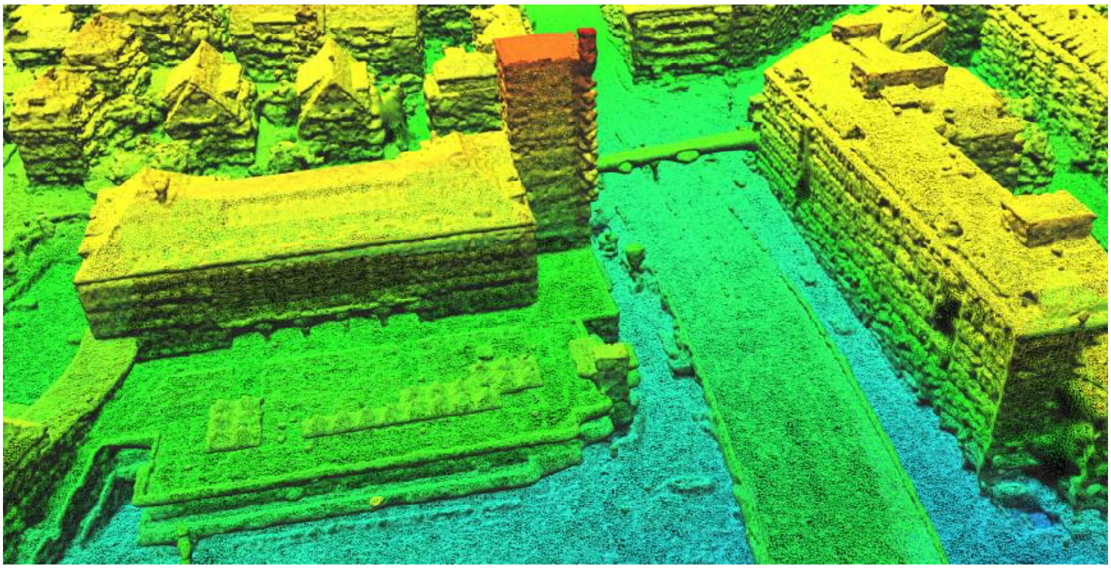

Figure 1 – 3D meshes from multi-stereo matching of oblique aerial images

Within this paper, we presented the current state of 3D data capture in urban areas by dense multi-view-stereo for different scenarios and camera configurations. Meanwhile, a number of commercial software solutions can generate DSM raster grids at the resolution of the captured imagery from standard airborne nadir imagery. While such 2.5D raster representations are sufficient for a number of applications, data capture in urban environments presumes 3D object representations. Within our benchmark aiming at the evaluation of oblique aerial imagery, these representations are provided from 3D point clouds. Despite of challenges for the matching process the preliminary results as provided from the participants already provide a remarkable quality of the delivered 3D point clouds. The results clearly show the potential of recent matching software to derive point clouds at an accuracy and resolution corresponding to the ground sampling distance (GSD) of the original images also for rather complex urban environments.

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CHANGING THE PRODUCTION PIPELINE – USE OF OBLIQUE AERIAL CAMERAS FOR MAPPING PURPOSES

With 9 figures and 3 tables

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Abstract

This paper discusses the potential of current photogrammetric multi-head oblique cameras, such as UltraCam Osprey, to improve the efficiency of standard photogrammetric methods for surveying applications like inventory surveys and topographic mapping for public administrations or private customers.

In 2015, Terra Messflug (TM), a subsidiary of Vermessung AVT ZT GmbH (Imst, Austria), has flown a number of urban areas in Austria, Czech Republic and Hungary with an UltraCam Osprey Prime multi-head camera system from Vexcel Imaging. In collaboration with FBK Trento (Italy), the data acquired at Imst (a small town in Tyrol, Austria) were analysed and processed to extract precise 3D topographic information. The Imst block comprises 780 images and covers an area of approx. 4.5 km by 1.5 km.

Ground truth data is provided in the form of 6 GCPs and several check points surveyed with RTK GNSS. Besides, 3D building data obtained by photogrammetric stereo plotting from a 5 cm nadir flight and a LiDAR point cloud with 10 to 20 measurements per m² are available as reference data or for comparison. The photogrammetric workflow, from flight planning to Dense Image Matching (DIM) and 3D building extraction, is described together with the achieved accuracy. For each step, the differences and innovation with respect to standard photogrammetric procedures based on nadir images are shown, including high overlaps, improved vertical accuracy, and visibility of areas masked in the standard vertical views. Finally the advantages of using oblique images for inventory surveys are demonstrated.

Acknowledgement

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1 INTRODUCTION

In recent years, capturing and processing of oblique imagery has become a mature technology for 3D information extraction based on photogrammetric principles (Remondino and Gerke, 2015). When the first commercial oblique camera systems appeared on the market in the early 2000s, users looked at this new technology with curiosity but considered it a tool for supplementary functionalities rather than for photogrammetric deployment. In fact, the main applications of oblique images so far are visualization of buildings roofs and facades from a 360- degree perspective (Gerke and Kerle, 2011), realistic texturing of 3D city models (Jurisch and Mountain, 2008) and measurement of distances in monoplotting mode - the latter depending on the availability of an existing digital terrain model. Applications for cartography and accurate mapping were not an option.

Since then, significant developments took place at sensor level and in the processing chain. The number of manufacturers of oblique camera systems has increased, thus opening market competition. With respect to the design, more recent oblique cameras are a combination of two cameras (fan configuration) or four cameras (Maltese-cross architecture). The Maltese-cross family dominates the market. The most common design uses one photogrammetric nadir viewing camera combined with four tilted cameras with forward-, backward-, left- and right-viewing directions. With respect to their spectral characteristics, the oblique sensor heads acquire the visible (RGB) bands. Some recent models also include the NIR channel for the nadirlooking sensor head (Gruber, 2015).

Parallel to the progress driven by the manufacturers, these new sensors caught the interest of researchers and software providers. At scientific level, investigations have focused on the quality of the images, on acquisition geometry, on block triangulation accuracy and Dense Image Matching (DIM). Research topics include optimal viewing angles of the oblique sensor heads (in relation to surface characteristics), optimal overlaps between images and strips, tie point extraction approaches, and image orientation strategies, and have been reported in a number of publications (Jacobsen, 2008; Gerke and Nyaruhuma, 2009; Wiedemann and More, 2012; Rupnik et al., 2013; Rupnik et al., 2015).

Given the increased number of oblique cameras on the market and the increased use of oblique imagery, software providers have updated the standard algorithms designed for vertical imagery, e.g. including oblique images in the aerial triangulation (AT). Since the first application of oblique imagery, their potential to see areas masked in nadir views was obvious. Other than that, the higher degree of image overlap that is typical for oblique projects favour dense point cloud generation and orthophoto production in urban areas. At least theoretically, dense matching of oblique images has the potential to surpass LiDAR acquisition in the modelling of building facades. Recent results seem to confirm this idea (Haala and Rothermel, 2015).

While these developments are very promising in theory, their real-life capabilities for the commercial market still need to be fully demonstrated.

At Terra Messflug GmbH (TM), a subsidiary of Vermessung AVT ZT GmbH (Imst, Austria), there is a strong belief that oblique imaging can significantly improve the efficiency of photogrammetry for precise mapping applications. AVT is a well-established surveying company, offering various services ranging from cadastral surveying to topographic mapping, engineering geodesy and aerial photogrammetry. One important branch is cadastral surveying and topographic mapping for public administrations or private customers. So far, such projects involved a nadir photo flight along with stereo plotting complemented by terrestrial on-site surveying. By extending the photogrammetric process with oblique flights, the efficiency, and thus the market position, can be improved substantially. Based on these considerations, TM has flown a number of urban areas in 2015 with an UltraCam Osprey Prime multi-head camera system from Vexcel Imaging. In collaboration with FBK Trento (Italy), the joint research project "GEOBLy" was initiated to optimize the photogrammetric processing chain of oblique imagery and to develop a software solution with specific functionalities for mapping projects at AVT.

In this paper, the achievements obtained from the oblique images acquired over Imst (a small town in Tyrol, Austria, with 10.000 inhabitants) are presented and commented. After an outline of the Imst dataset in Section2, the geometric image processing is presented. The specifics of aerial triangulation (AT) are described in Section 3, followed by DIM, 3D pointcloud generation and automatic LOD2 building extraction in Section4. Finally, the application of oblique images for building mapping is presented in Section 5. In each step, the differences and innovation compared to standard procedures based on nadir images are commented, paying attention not only to accuracy but also to productivity aspects.

2 IMST DATA SET

The Imst data set was recorded with an UltraCam Osprey Prime. Nadir images are obtained from two PAN cones with focal length 80 mm stitched together yielding a total image size of 11674 pixels across and 7514 pixels along flight direction, respectively. Colour is provided by an RGB cone (Bayer pattern) and an NIR cone with pan-sharpening ratio 2. Oblique images are taken in RGB mode (Bayer pattern) in the four cardinal directions (forward, backward, left, right) at an inclination of 45°. The oblique focal length is 120 mm and the image size is 8900 pixels across and 6650 pixels along flight direction, respectively. The physical pixel size of all eight sensors is 6 µm.

The camera was flown on a fixed-wing aircraft modified for aerial shooting, suspended in a gyro-stabilized mount, and supported by GNSS/INS equipment from IGI (Aerocontrol IMU II-d 256 Hz with drift better than 0.1°/h, NovAtel OEM V-3). The project area is the central part of Imst, located in the Austrian Alps, with approximate size 4.5 km by 1.5 km and

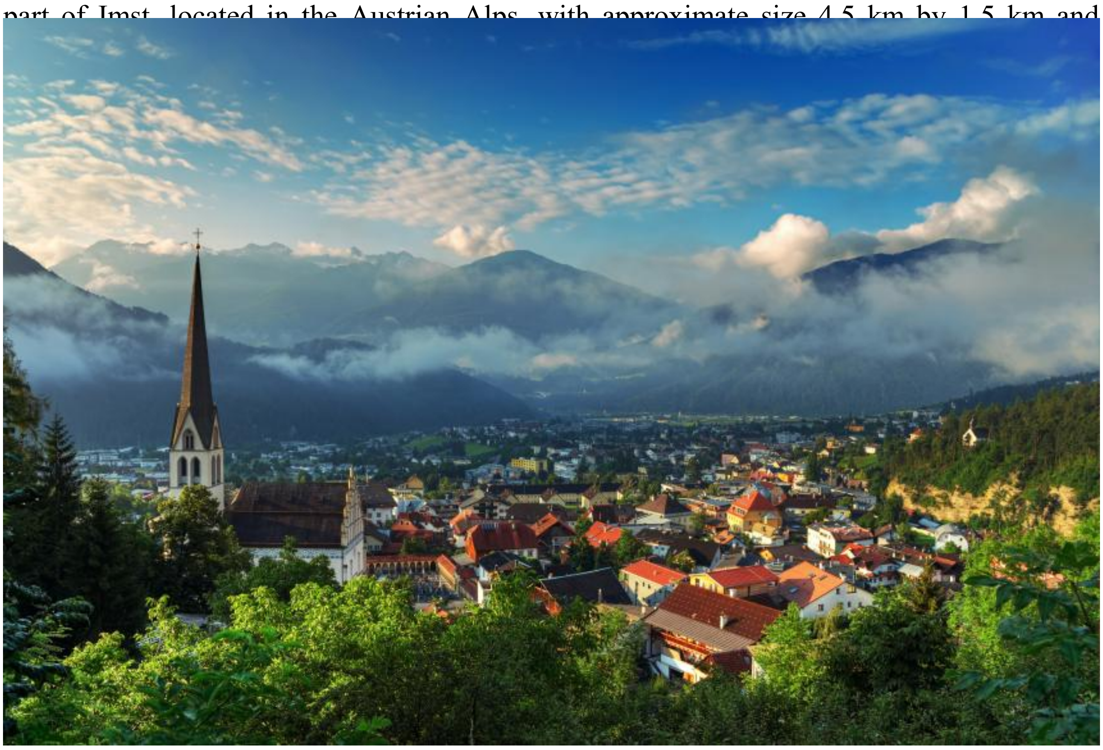


Figure 1 – View of the project area (© Edgar Moskopp, 2014)

During flight planning of oblique projects, special care has to be placed on expected ground-sampling distance (GSD) in the nadir and oblique images as well as spatial coverage, according to the camera parameters and terrain characteristics (Rupnik et al., 2015). The aim is to minimize the presence of occlusions in the images and to guarantee that the project area is fully covered by all five viewing directions. In case of Imst, the flight plan was designed using an average nadir GSD of 6 cm, and alongand across overlaps of 75% and 60%, respectively. It resulted in 5 strips and a total of 780 images (Figure 2, right-hand side), i.e. 156 images for each camera, with mean scale ca 1:7400. The flight was executed on 1st October 2015 with favourable weather conditions.

Ground truth data was provided in the form of 6 ground control points (GCPs) and 14 independent check points (CPs) surveyed with RTK GNSS with a mean 3D accuracy of 5 cm (Figure 2, left-hand side). Moreover 3D building data generated from an earlier photogrammetric (nadir) campaign and a LiDAR point cloud with 10 to 20 measurements per m² were available.

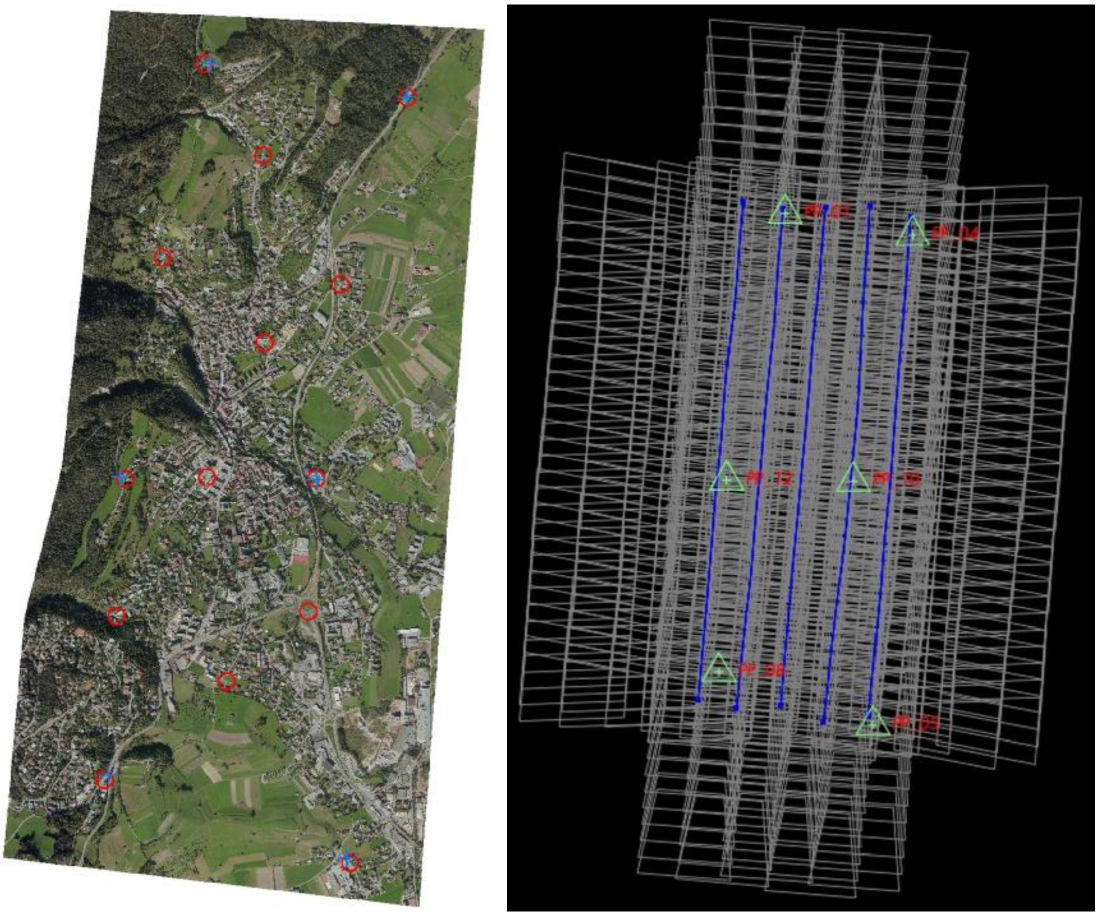


Figure 2 – Imst data set. Left: location of GCPs (blue crosses) and CPs (red circles); right: flight plan (strips, GCPs and footprints)

3 AERIAL TRIANGULATION

The main strategy followed during direct georeferencing and aerial triangulation (AT) was to consider the Osprey system as a rigid assembly of cameras, rather than a system of five independent cameras. The standard image-to-ground transformation for nadir images was extended to include the four additional oblique views by means of relative orientation parameters (offsets, misalignments) available in the camera calibration certificate.

Prior to the AT, a self-developed (FBK) forward ray intersection tool was used, to analyse the quality of the GPS/IMU observations and calibration parameters.

The AT was then run with up-to-date versions of three commercial software packages: Match-AT (Match-AT, 2016), UltraMap AT (Gruber, 2015) and Pix4D (Pix4D, 2016). The apriori standard deviations were chosen according to empirical results from earlier projects: for the GCPs 5 cm in planimetry and 7 cm for the height; for the GNSS/INS observations 10 cm in planimetry, 15 cm for the height, 0.002° for omega and phi, and 0.005° for kappa; and for the tie points 3 µm for automatic and 5 µm for manual image measurements. Image correspondences were automatically extracted across themultiple aerial views.

In all tests, the initial values of IO parameters (focal length, principal point) and additional parameters of all sensors were estimated by self-calibration. Furthermore, both forward intersection and AT were carried out with and without the oblique images.

Despite their different design concepts, software packages delivered similar results for AT. For this reason, only results obtained from Pix4D are shown here. In Table 1, the root mean square errors (RMSE) on CPs are reported as measures of adjustment accuracy in object space. The horizontal accuracy from (pre-AT) forward intersection is around 20 cm using nadir only or nadir + oblique images. In contrast, the vertical accuracy improves from 40 cm (nadir only) to some 23cm (nadir + oblique). Using the AT results, the horizontal accuracy reaches 3 to 4 cm in both variants (the numerical differences are not significant). Similar to the pre-AT scenario, the vertical accuracy improves from 9 cm (nadir only) to 6 cm (nadir + oblique). Clearly, the height benefits from the addition of oblique images which is mainly due to the improved intersection geometry of the rays.

Table 1: Results of forward intersection and AT of Imst nadir (N) and oblique (O) images. The RMSE values refer to 14 independent CPs

	Images	*RMSE X [m]*	*RMSE Y [m]*	*RMSE Z [m]*
Forward Intersection	*N*	*0.216*	*.200*	*0.400*
Forward Intersection	*N + O*	*0.230*	*0.212*	*0.227*
AT	*N*	*0.044*	*0.028*	*0.089*
AT	*N + O*	*0.035*	*0.027*	*0.058*

One interesting issue is the number of matches between camera views, as shown in Table 2. Similar considerations are presented in Gerke et al. (2016). As expected, image pairs acquired with different viewing directions get fewer correspondences (orange and blue cells), if compared to pairs pointing to the same direction (green and yellow cells). It has to be noticed that images generated by right (R) and left (L) cameras, as well as backward (B) and forward (F) cameras, in adjacent strips, have similar aspect, due to the symmetric design of the camera system and the parallel flying directions (Figure 3). If the pairs consist of images from R (or L) camera and B (or F) camera (orange cells), the feature information is clearly different due to the perpendicular incidence angles and aspect of the objects. The aspect in the images is displayed in Figure 4 for a point of interest, where the similarity between B / F and L / R images in two adjacent flight strips is evident. In the F / L and B / R pairs, on the other hand, there is little feature similarity.

Table 2: Median / maximal number of matches between camera views

	Backward	*Forward*	*Right*	*Left*	*Nadir*
B	*3547/22919*	*399/8321*	*4/40*	*6/44*	*23/2305*
F		*3291/25305*	*2/27 2/45*	*8/1405*	
R			*3774/22203*	*429/8849*	*125/2837*
L				*701/22845*	*133/4254*
N					*1366/25796*

Same camera	*Same aspect, oblique cameras*	*Perpendicular aspect, oblique cameras*	*Different aspect, nadir + oblique cameras*

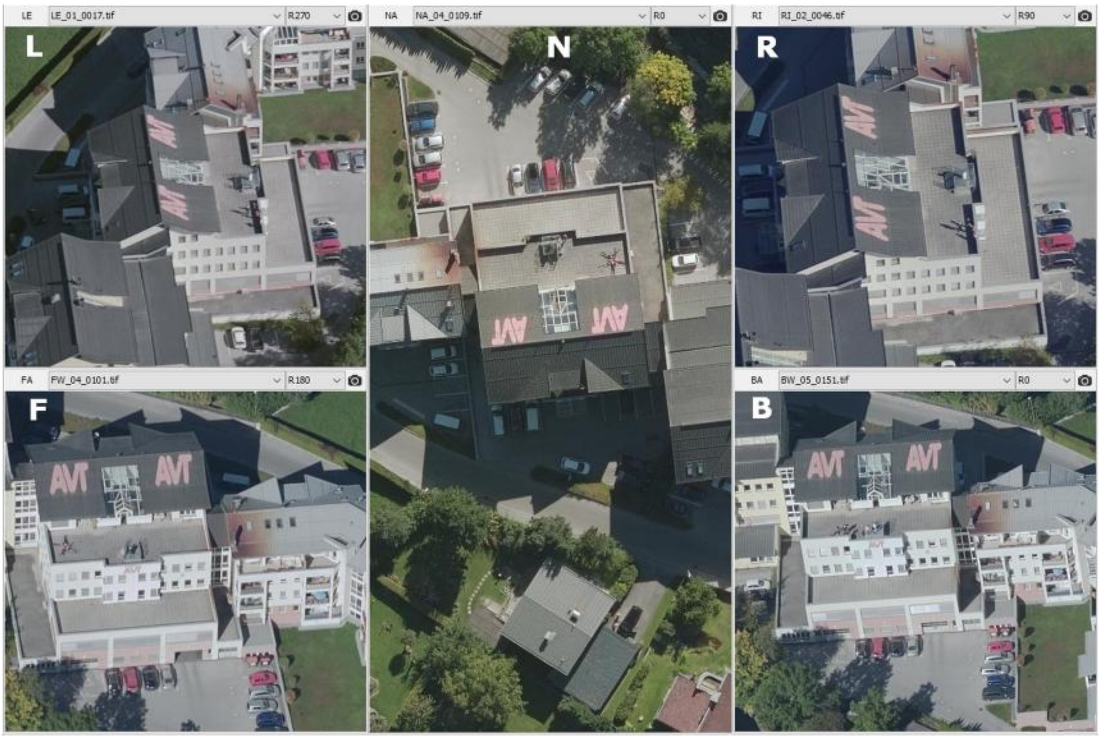


Figure 3 – Similarity of B/F and L/R Osprey images from different strips. Zoom on AVT building in Imst. Visualization in the GEOBLy tool

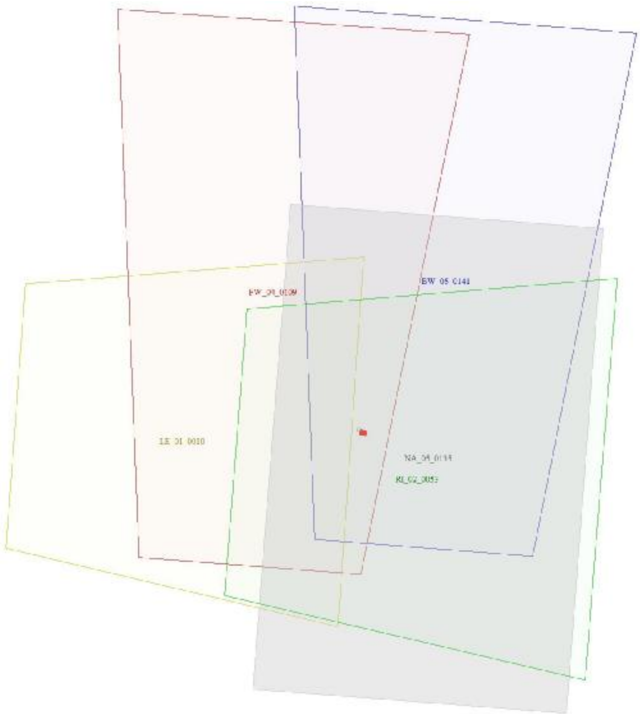


Figure 4 – Image footprints of five Osprey Prime cameras on AVT building (indicated in red) in adjacent flight strips

To investigate the impact of automatic tie point extraction on computational costs, the AT was run on the same work station at half and quarter image size and the results compared to those achieved with the full-size images. Table 3 compares, in percent, the processing times. Despite a bigger GSD, no significant changes (in terms of accuracy of object coordinates) are found when reduced image sizes (half and quarter) are selected for the tie point extraction.

Table 3: Processing time of AT, when tie point extraction is performed at 0.5 and 0.25 image scales. Time is represented in % with respect to full-size images (image scale 1, as reported in Table 1)

	Image scale	*Processing time*	*RMSE [m] X/Y/Z*
AT (N + O)	*0.5 (1/2)*	*63%*	*0.045/0.027/0.066*
	0.25 (1/4)	*34%*	*0.048/0.029/0.071*

4 3D FEATURE EXTRACTION

4.1 Dense point cloud extraction

Starting from the AT results, the 3D reconstruction process was aimed at providing an accurate and easy-to-handle representation of the urban environment. In this context, mapping applications require clear information for the building facades and footprints. Since such features are difficult to be extracted from traditional nadir imagery, DIM from multi-view aerial blocks can be an effective solution to overcome the problem of viewpoint restrictions. From an algorithmic point of view, this means coping with the well-known potential difficulties of DIM in oblique scenarios, i.e. large scale variations, multiple occlusions and severe illumination changes (Rupnik et al., 2014). Furthermore, the traditional 2.5D processing for DSM raster production from nadir images should be replaced by a more compelling modelling in "real" 3D space. State-of-the-art commercial solutions allow for dense pointcloud generation from both nadir and oblique aerial imagery (Haala and Rothermel, 2015). Such results can be used as input for automatic 3D building reconstruction (Tutzauer and Haala, 2015; Remondino et al., 2016).

Figure 5 – 3D point cloud of Imst extracted with Pix4D using nadir + oblique images (top). Close up views (bottom) in 3D point cloud extracted using only nadir (left) and nadir + oblique images (right)

The dense image matching algorithm implemented in Pix4D was adopted in this study to derive dense point clouds from the Imst data set. This was carried out using images reduced at one quarter of the original geometric resolution with a multiscale approach and a matching window size of 9 x 9 pixels. To investigate how the quality of the final output is altered by the introduction of oblique views, both image block scenarios were tested, i.e. nadir only and nadir + oblique. The derived dense point clouds feature an average point density of 8.93 pts/m² (nadir only) and 10.88 pts/m³ (nadir + oblique). Figure 5 shows the result of dense matching from nadir + oblique images on a subset of the project area, with close up views in the nadir and nadir + oblique clouds.

In addition, some height profiles were generated in the nadir, nadir + oblique and LiDAR point clouds in correspondence of a selection of buildings for comparisons (see Figure 6).

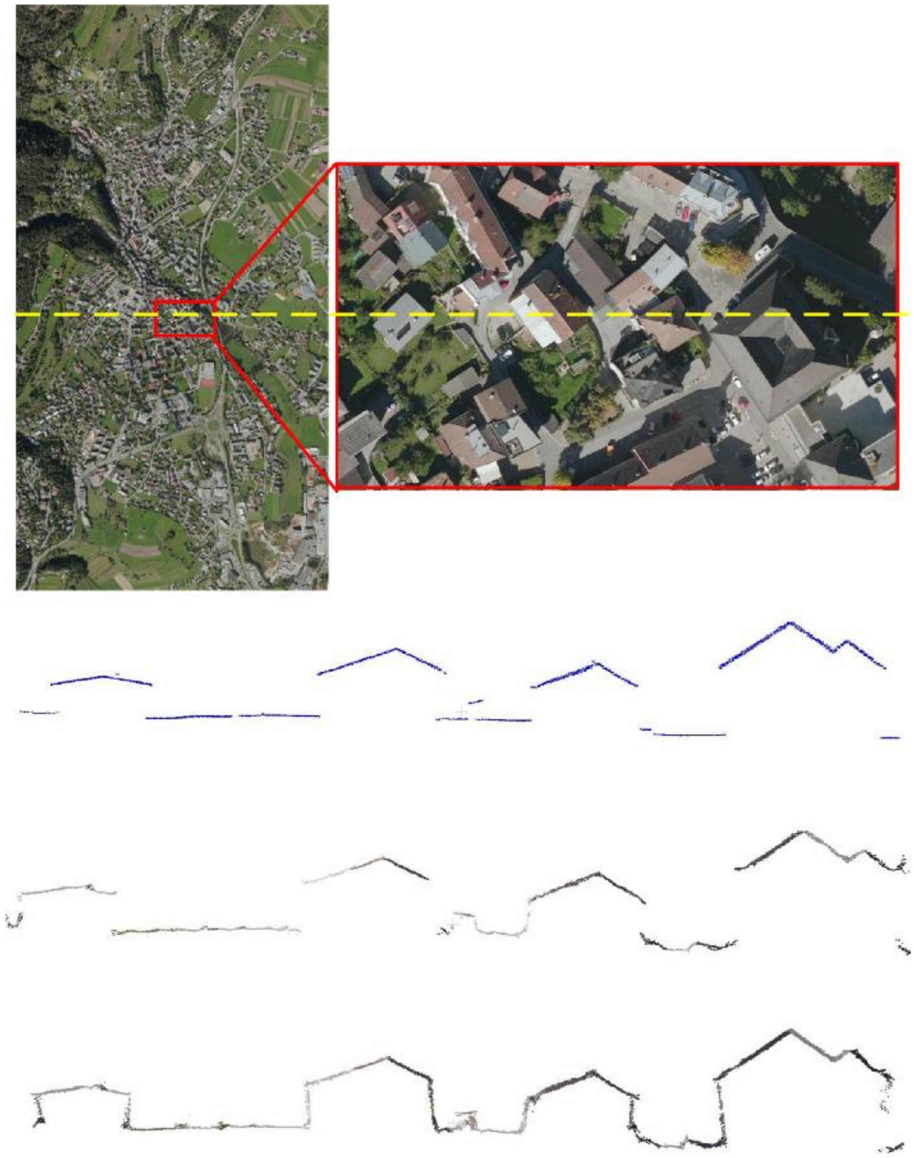


Figure 6 – Height profiles in LiDAR (top), nadir (middle) and nadir + oblique (bottom) point clouds. The profile section is indicated in yellow in the orthophoto

The qualitative comparison of the point clouds highlights the significant improvement on the reconstruction of the building façades when the oblique images are added to the dense matching procedure.

4.2 3D building reconstruction

The high amount of data obtained by state-of-the-art pixelbased dense matching algorithms, although suitable for simple point-based visualization purposes, is not suited for GIS packages and topologies need to be extracted. With focus on buildings, the development of tools for automatic 3D city modelling has been facing this challenge for almost three decades. The most popular approaches can be categorized as follows (Haala and Kada, 2010): (i) reconstruction with parametric shapes, (ii) reconstruction based on point-cloud segmentation and (iii) reconstruction based on simplifying a meshed DSM to the required abstraction level.

For the Imst data set, 3D building models were automatically generated using the tridicon/Hexagon suite of tools (tridicon, 2016) which adopts the second aforementioned strategy to reconstruct the building shapes through best fitting the input elevation data with geometric primitives. The two modules “BuildingFinder” and “CityModeller” were tested. The latter requires building footprints as input which often do not exist in a complete form or are not up-to-dated. This former issue was faced in the project, thus the BuildingFinder tool was adopted as it automatically detects buildings from point clouds without the need for any auxiliary information. The point cloud was first segmented, thus deriving a partition of the points into segmented planar regions. The detection of building objects was then performed by searching for selected types of internally defined roof types. To support the detection of building ground heights, an available DTM (1 m resolution) was used in the processing. Furthermore, points belonging to vegetation were filtered out and excluded from the building search. The resulting output (see Figure 7) consists in building models that feature flat façades (details like windows or doors are not currently modelled by the tool) and distinctive roof structures, i.e. consistent with level of detail 2 (LOD2) within the OGC standard CityGML (Gröger and Plümer, 2012). The same building extraction procedure was tested on both dense point clouds, i.e. with and without the inclusion of oblique imagery. To evaluate the achieved results, 3D building models from a previous stereo restitution project (2013 - approximate LOD2 standard) were used as ground truth data. Due to the difference in age, some differences in the building mass have taken place. The changed buildings have been excluded from our analysis of the results.

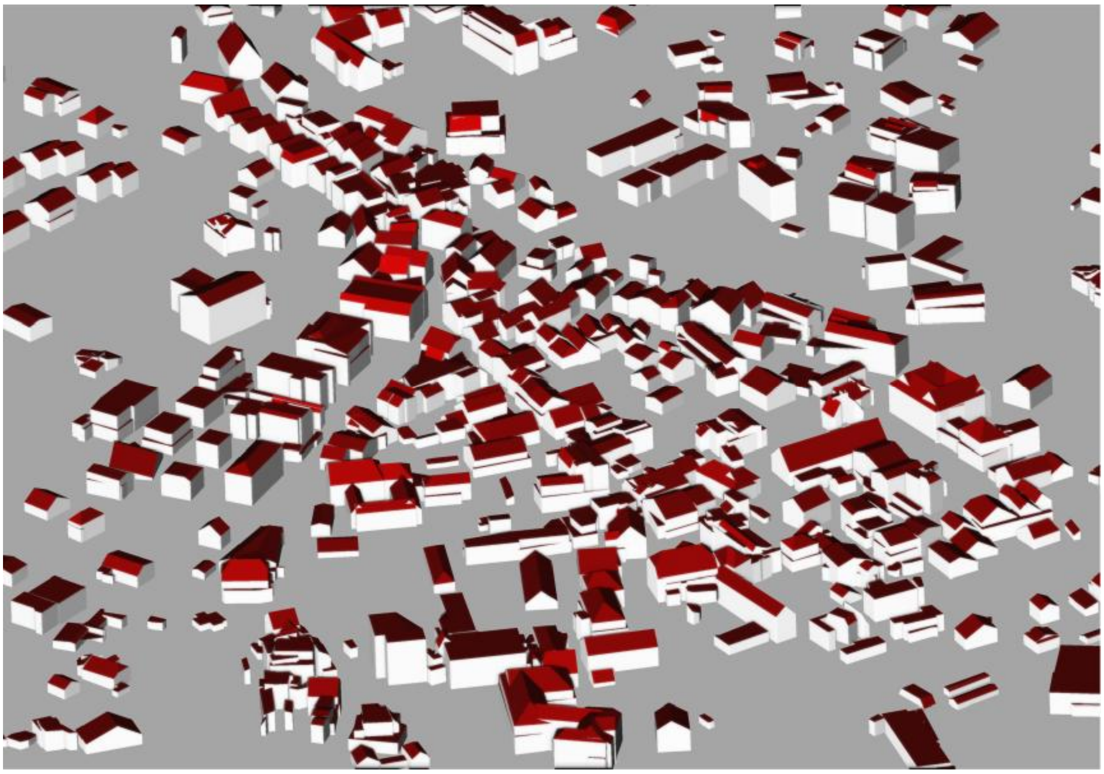


Figure 7 – Visualization of 3D building models (LOD2) extracted from nadir + oblique images

4.2.1 Gain from oblique imagery for automated building model extraction

A twofold approach was chosen to determine whether and to what extent automatic building detection benefits from oblique imagery: (i) a geometrical error evaluation and (ii) an independent visual assessment by a human operator. A sample set of 22 buildings was selected randomly from the central area of Imst. The following three data sets were used in the evaluation process:

1. Reference model: 3D building models from the manual reconstruction based on photogrammetric stereo measurements and editing in UVM Systems' CityGRID Modeler (CityGRID Modeler, 2016).
2. Model nadir: 3D buildings generated with the tridicon suite based on the dense point cloud derived from nadir imagery only.
3. Model oblique: 3D buildings generated with the tridicon suite based on the dense point cloud derived from a combination of nadir and oblique imagery.

With CloudCompare 2.6.2 (CloudCompare, 2016) absolute distances between the reference model and the two comparison models were calculated. From the 22 compared buildings, 15 show smaller distances for the nadir + oblique model. For the other remaining 7 buildings, the nadir-only model shows smaller distances. The geometrical analysis is based on the 3D faces of the building models that were converted into point clouds utilizing a random point sampling with an average pointto- point distance of 20 cm. Point-wise for every building in the sample set, the absolute distances between the reference model and the comparison models were calculated using a Hausdorff distance algorithm (Girardeau-Montaut et al.,

2005) as well as least-squares local plane fitting resulting in different distance values but in similar outcomes in the comparison process. The human operator was instructed to visually analyse the 3D buildings (shaded faces) and determine which of the comparison models – oblique or nadir – best fit the reference data regarding topological resemblance and completeness. Buildings were classified as “nadir + oblique better”, “nadironly better” and “same quality”. The results from this analysis were consistent with the outcome of the geometrical discrepancies. All 13 buildings that were manually classified as “nadir + oblique better” had smaller geometric discrepancies in the oblique model and all 5 buildings classified as “nadir-only better” had better geometric results in the nadir model. In four cases the operator chose “same quality”, two of which had superior geometric outcomes in the nadir + oblique version and vice-versa.

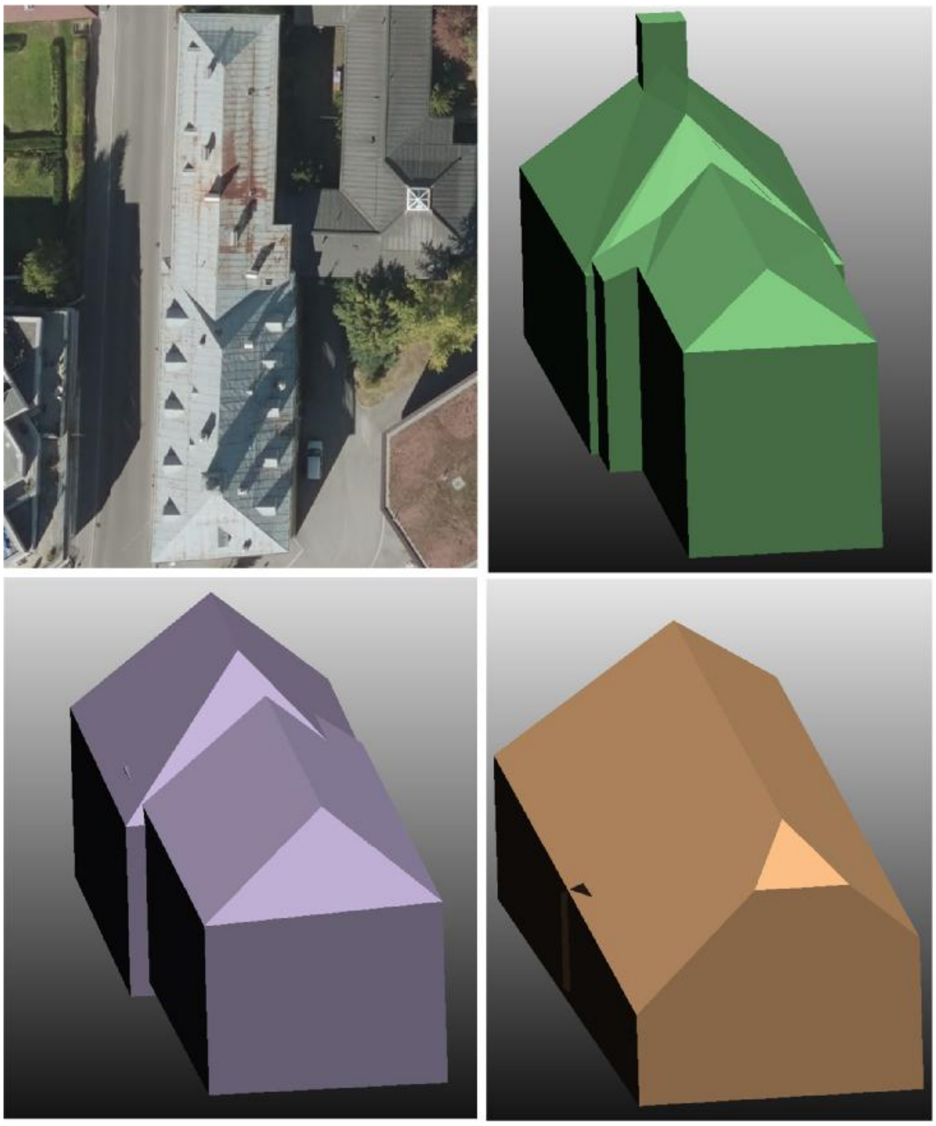


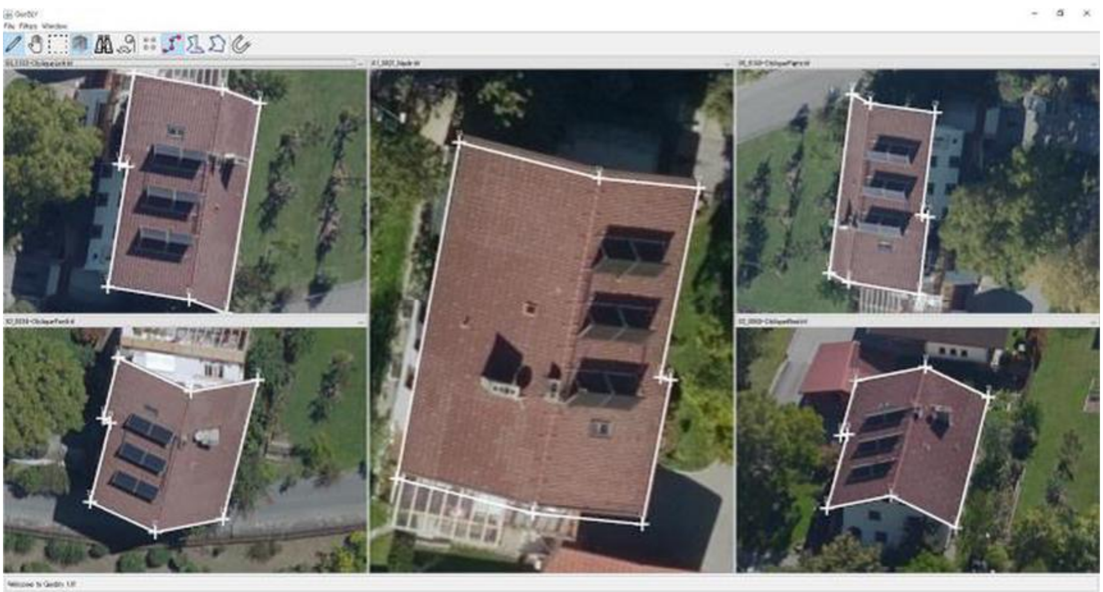
Figure 8 – Comparison of orthophoto, reference model (green), LOD2 model nadir + oblique (lilac) and LOD2 model nadir-only (orange)

LOD2 does not include structures on the roofs. An increase in model's detail could be observed in the nadir + oblique comparison. The difference is apparent in Figure 8 which depicts the model variants used in the process as well as the orthophoto for one of the sample buildings. The comparison model nadir + oblique discriminates correctly the two parts of the building, while the nadir-only model combines them into one entity. The small tower on the roof is omitted in the comparison models as they are limited to LOD2.

5 MAPPING APPLICATIONS

In AVT the main aim of oblique image acquisition is the improvement of the current performance for mapping purposes (i.e. cadastral building update, surface mapping of water and canalization and other detailed restitution of objects). The main advantage of oblique imagery is the improved visibility of objects partly occluded in the nadir view, such as facades, building footprints, road edges, walls, man-holes or roofs with special overhanging features. In cadastral surveys, such information has traditionally been collected through expensive and time-consuming ground surveys. Our aim is to reduce the burden of field surveying for such projects. Clearly, not all occlusions are eliminated by adding oblique views, but the share of objects measured by photogrammetry can be increased significantly. With oblique imagery providing a level of accuracy (after AT) similar to or even better than nadir-only flights, the only remaining hurdle is the lack of an effective measurement and inspection tool.

Within the framework of the research project GEOBLy, AVT and FBK have developed a very useful tool to aid operators in this task, combining precisely oriented imagery and several 3D measurements techniques (Figure 9). A new pipeline for AVT's surveys has been set up in the GEOBLy tool where oblique imagery and feature measurements are an integrated part. As existing data can also be imported into the measurement tool, it is also very well fitted for map update projects.



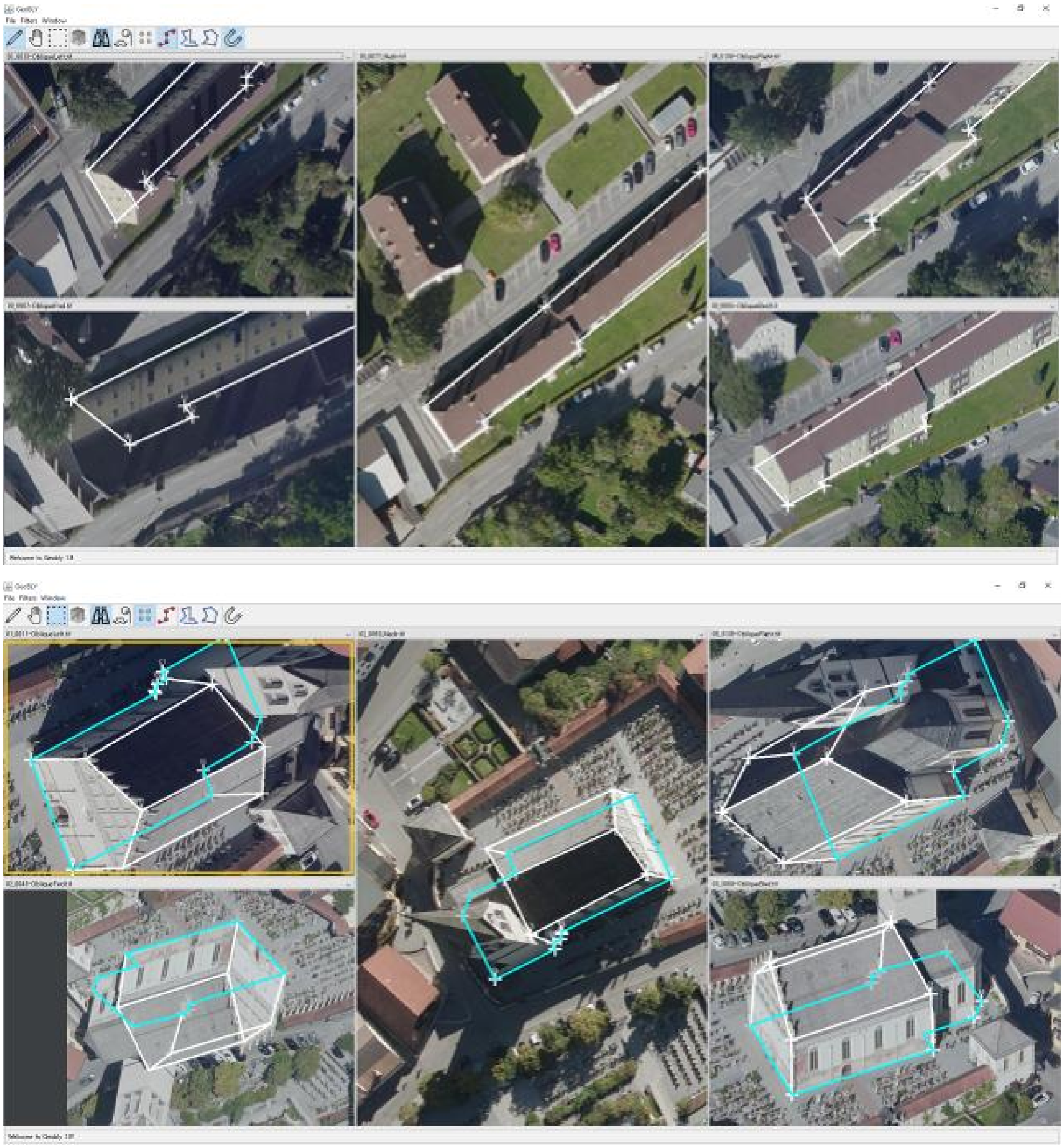


Figure 9 – Image measurements in the GEOBLy tool: “Traditional” roof edge measurements (top) and measurements of complete building footprints (middle and bottom).

6 CONCLUSIONS

AVT, TM and FBK have conducted some investigations on the potential of photogrammetric techniques applied on oblique aerial images for mapping purposes. The tests performed on the Imst data set, acquired with an UltraCam Osprey Prime and processed with FBK-developed and commercial software solutions, have shown a quality in the orientation comparable, and even better, to that achieved with only nadir image blocks, if the calibration parameters of all cameras are properly introduced in the geometric sensor model. Beside AT outperformances, oblique views offer important benefits also in the dense point cloud generation, as they allow to reconstruct, e.g. buildings façades or other features generally not visible in the nadir views, thus overpassing the capability of LiDAR acquisitions in urban areas. The gained value is also evident in the performance of the subsequent automatic building reconstruction. Results achieved with tridicon software package over a small test area proved significant advantages from including well-oriented oblique imagery into automatic building reconstruction. Also for inventory survey and other mapping purposes, the advantages of oblique imagery for 3D restitution have been demonstrated. To compensate the lack of a suitable tool for digitalization in oblique imagery, an ad-hoc software was developed to satisfy operational needs.

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OBLIQUE AERIAL IMAGERY FOR NMA – SOME BEST PRACTICES

With 8 figures and 1 table

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Abstract

Oblique airborne photogrammetry is rapidly maturing and being offered by service providers as a good alternative or replacement of the more traditional vertical imagery and for very different applications see Figure1). EuroSDR, representing European National Mapping Agencies (NMAs) and research organizations of most EU states, is following the development of oblique aerial cameras since 2013, when an ongoing activity was created to continuously update its members on the developments in this technology. Nowadays most European NMAs still rely on the traditional workflow based on vertical photography but changes are slowly taking place also at production level. Some NMAs have already run some tests internally to understand the potential for their needs whereas other agencies are discussing on the future role of this technology and how to possibly adapt their production pipelines. At the same time, some research institutions and academia demonstrated the potentialities of oblique aerial datasets to generate textured 3D city models or large building block models. The paper provides an overview of tests, best practices and considerations coming from the R&D community and from three European NMAs concerning the use of oblique aerial imagery.

a)  b) 

Figure 1 – Results from oblique aerial datasets: a 3D city model as textured polygonal mesh (a) or as textured LOD2 building block models (b).

Acknowledgement

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1 INTRODUCTION

Oblique airborne photogrammetry is quickly growing and entering the workflow of service providers which are trying to complement (or replace) the more traditional pipeline based only on vertical images. Various camera systems exist, with 2 up to 8 (Octoblique MIDAS) slanted views see Figure 2) based on middle- or large-format cameras (Remondino and Gerke, 2015).

The virtue of oblique imaging lies in its simplicity of interpretation and understanding for inexperienced users and the revealing of building façades and footprints. These qualities, together with high density and accuracy of point clouds that can be generated with matching techniques, endorse the use of oblique imagery in very different applications, such as 3D city modelling, land-cover updating, urban classification, identification of unregistered buildings, damage assessment, building registration, parcel boundary determination, etc. In Fritsch et al. (2012) the name "All-In-One Photogrammetry" was proposed as oblique aerial photogrammetry offers more potential for information extraction to provide - besides 3D point clouds, detailed Digital Surface Model (DSM) and true orthoimages, also 3D roof structures and corresponding 3D building models needed for updating 3D urban databases.

The necessity of having rich information in urban areas is growing along with the urbanization of the world, understood as a population shift from rural to urban areas. According to the UN World Urbanization Trend (http://esa.un.org/), in 2050 about 66% of the world population will live in urban areas. By 2030, the world is projected to have 41 mega-cities with more than 10 million inhabitants. It is clear that a better mapping, understanding and management of the urban ecosystem is required including new environmental applications that allow us to characterize our cities for better planning of urban growth. In such a context, the need for a realistic (3D) modelling of cities, including all its volume and morphology for overlaying and exploiting all thematic and administrative information becomes evident. Therefore, 3D city models will play an increasingly important role in our daily lives and will become an essential tool of the modern city information infrastructure which is integrated in the so-called "Smart City" concept.

From an economic point of view, Smart Cities are expected to be a 1.5 trillion-dollar market in 2020, with a 25% of growth rate per year (Frost & Sullivan, 2013).

Figure 2 – Maltese-cross camera acquisitions: a nadir view and the 4 cardinal views showing building footprints and facades.

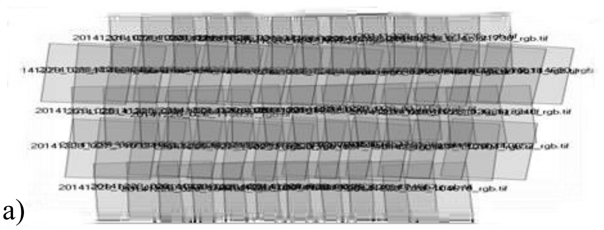
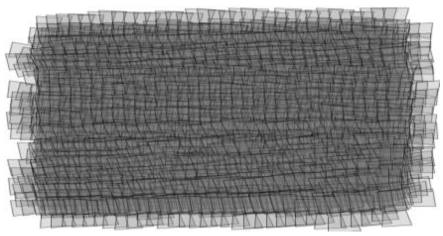
a)  b) 

Figure 3 – A footprint comparison - over the same area and with the same GSD - among a traditional nadir flight (a - ca 60 images) and an oblique flight coverage (b - ca 700 images) which requires more strips and thus more flying costs.

Hence, all these numbers and economic forecast support the rapidly growing sector of oblique cameras as well as investments in such sector.

National Mapping Agencies (NMAs) are still relying on the traditional workflow based on vertical photography but changes and convergence towards oblique imagery are slowly taking place also at production level. Today some mapping agencies have already run some internal tests whereas others are discussing on the future role of this technology and how to possibly adapt their production pipelines. The same applies to photogrammetric companies which are more and more interested in testing and using oblique cameras in order to deliver more innovative products.

EuroSDR, the international organization composed of European NMAs and research organizations of most EU member states, is following the development of oblique aerial cameras since 2013, when a research activity was created to continuously update its members on the developments in this technology.

As camera systems consolidated, a new momentum was given in order to explore more deeply the potential of oblique aerial cameras for national mapping purposes. At the same time, research institutions and academia demonstrated the potentialities of oblique aerial datasets to generate textured 3D city models or large building block models. NMAs need practical and costeffective methodologies to remap areas with legacy issues or create, update and manage (3D) cadastre information. For NMAs substantial technical and operational benefits become obvious although not many clear statements or best practices have been yet reported.

The paper presents R&D experiences with oblique aerial imagery. Inputs from selected NMAs are also given, with their experience, foreseen advantages and benefits.

2 R&D EXPERIENCES WITH OBLIQUE IMAGERY

Since some years, FBK Trento and ITC/Twente University are both running investigations on aerial oblique imagery (Gerke and Nyaruhuma, 2009; Nyaruhuma et al., 2012; Xiao et al., 2012; Nex et al., 2013; Rupnik et al., 2013; Rupnik et al., 2014; Remondino and Gerke, 2015; Rupnik et al., 2015). The studies are driven by the clear problems in processing oblique image blocks and by the numerous applications opened-up by oblique aerial views.

2.1 Research issues

Automated aerial triangulation of oblique blocks is the main research topic. Indeed, the much more complex image network geometry and the larger number of images see Figure 3) cause problems to traditional triangulation strategies tailored for nadir image blocks. Problems arise also due to scale and radiometric changes, low similarity due to wide baseline configurations as well as few tie points across viewing directions. Strategies go from multi-step orientation methods to sub-block independent adjustment, connectivity maps or relative orientation procedures (Rupnik et al., 2013). Direct geo-referencing provided by GNSS/IMU onboard sensors is still not applicable to all flights and a bundle adjustment refining is still advisable (Moe et al., 2016).

Once the nadir and oblique imagery is oriented, dense image matching (DIM) methods are applied in order to retrieve dense 3D point clouds and, successively, (true) orthoimages. DIM methods (Remondino et al., 2014) are recently less investigated as actual state-of-the-art multi-view pixel-based algorithms are sufficiently reliable and productive. Coupling oblique & nadir images, there is a substantial increase of completeness in comparison to nadir-only datasets (Fritsch and Rothermel, 2013). Indeed due to the additional slanted views, façade points can be extracted, facilitating the automatic derivation of 3D building models (Haala et al., 2015; Toschi and Remondino, 2015 - Figure 4).

2.2 Benchmark

In the research community, a common way to evaluate new platforms, data and algorithms is to prepare and share benchmarks. Inspired by this concept and previous successful results (Rottensteiner et al., 2013; Haala, 2014), within an ISPRS Scientific Initiative and in collaboration with EuroSDR, a multiplatform photogrammetry benchmark (Nex et al., 2015)[1] was proposed in order to (i) create and manage new image datasets consisting of different kind of images over the same area and (ii) assess the accuracy and reliability of the current methods in the calibration/orientation as well as integration of photogrammetric data for dense point cloud generation and feature extraction. The benchmark consists of airborne oblique images (acquired with an IGI PentaCam camera flown by Aerowest), nadir and oblique UAV images (acquired with a multirotor DIJ S800), convergent and redundant terrestrial images of some selected buildings, ground truth data in form of Airborne Laser Scanning (ALS) and Terrestrial Laser Scanning (TLS) point clouds as well as topographic and GNSS-based points. Results obtained by different groups and with various software packages are presented in Gerke et al. (2016).

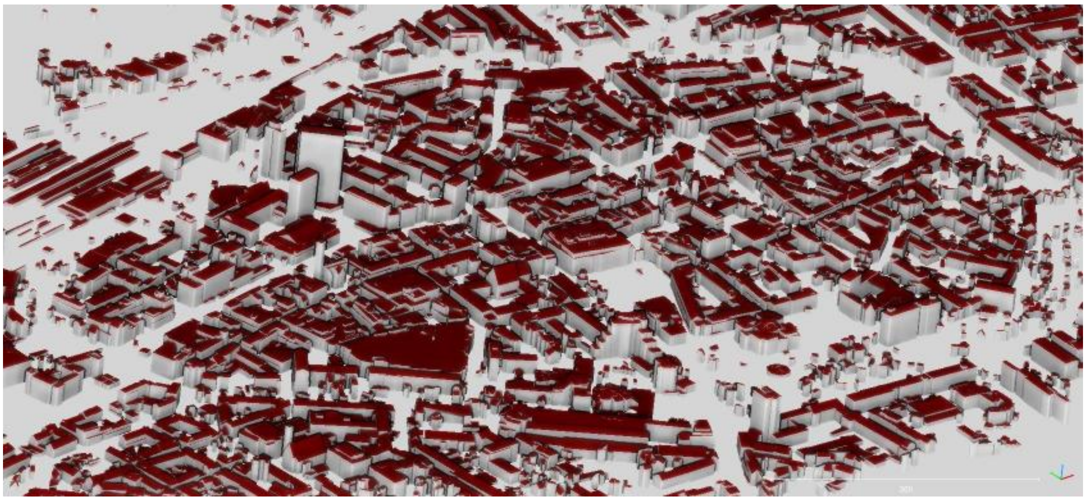


Figure 4 – LOD2 building models (no roof overhanging) over Dortmund automatically generated from a dense point cloud derived from nadir & oblique imagery – ISPRS/EuroSDR benchmark, IGI PentaCam.

2.2.1 Other research activities

First experiences with oblique imagery and automated aerial triangulation were presented in Jacobsen (2008) and Wiedemann, and Moré (2012). Yang et al. (2012) proposed a multi-stage algorithm based on SIFT matching to improve automatic aerial triangulation results of oblique imagery. Xiao et al. (2013) used approximated exterior orientation elements in NAIF algorithm (Nicer Affine Invariant Feature). Karel and Pfeifer (2015) presented an in-house tool (Oriental) for processing oblique datasets. Hu et al. (2015) proposed a reliable feature matching method using various spatial relationships and geometrical information for problems raised by large viewpoint changes, image deformations, blurring, etc. Frommholz

[1] http://www2.isprs.org/commissions/comm1/icwg15b/benchmark_main.html

et al. (2015) delivered semantically annotated LOD-2.5 CityGML objects from oblique imagery. Moe et al. (2016) present how oblique imagery affect the traditional photogrammetric production pipeline, comparing software and products. Ostrowski and Bakula (2016) evaluate the performances of commercial software in processing image blocks acquired with oblique camera systems.

3 OBLIQUE IMAGERY AT OS UK

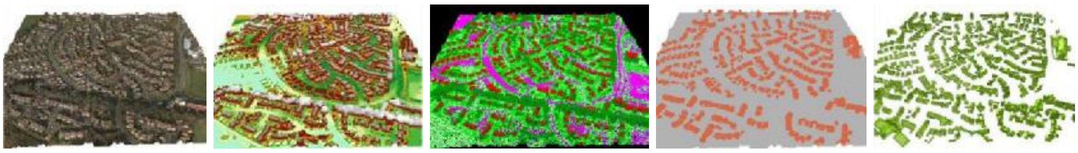
Ordnance Survey (OS) UK, the national mapping agency for Great Britain, is one of the world's largest producers of maps and since April 1st 2015 it has operated as Ordnance Survey Ltd, a government-owned company.

3.1 Needs for using oblique flights/images

OS routinely captures aerial imagery from two Cessna 404 survey aircraft and Vexcel UltraCam Xp cameras. These provide data for the update of topographic mapping, the production of the OS MasterMap Imagery Layer product, the creation of national-wide DSMs/DTMs and the OS MasterMap Topography Layer – Building Height Attribute (derived from the available DSMs/DTMs). Although we have always been interested in the capture of 3D data, at the moment OS UK does not produce 3D city models as a standard product. Having tested several methods of creating 3D models from our standard imagery (with overlaps up to 80% forward and 60% sidelap) we were very interested in investigating what could be produced from oblique aerial imagery at production level. Our main requirement for oblique imagery is to produce 3D models of urban areas, for use in planning, energy monitoring, noise modelling and various "smart city" applications. For these applications, a high resolution dataset is required (e.g. imagery at 10cm GSD and point clouds with a point spacing of around 10cm). The final product of an oblique image dataset is not immediately obvious, as it often depends on the requirements of the end-user. Products could include a 3D point cloud, a 3D mesh, a true-orthoimage, a 3D city model (e.g. in CityGML form) or simply an oblique image viewer.

3.2 Advantages

One potential use of oblique imagery is the capture of topographic vector data directly from a 3D point cloud generated by image matching on oblique imagery. This has the advantage that 3D information could be collected within a monoscopic environment, without the need for expensive stereo software and hardware. A second advantage of oblique imagery is the ability to view features which would be occluded in nadir aerial photography. One of the obvious instances of this is the ability to see building facades from multiple viewing angles. In addition, narrow streets in dense urban areas can be completely occluded in areas of nadir images away from the principal point, while they are more likely to be visible in at least some of the oblique images.



a) b) c) d) e)

Figure 5 – Different products realized from an oblique flight: dense and coloured point cloud (a), colour-coded DSM (b), classified dense point cloud (c), extracted points representing buildings (d) and reconstructed building block models in LOD2 (e).

3.3 Experiences

In November 2014 Leica Geosystems kindly flew an area of Bournemouth on the English south coast, using their RCD30 penta oblique camera. One of the goals for OS UK was to generate 3D building models using the Building Finder and City Modeller modules of the Tridicon/Hexagon software see Figure 5). City Modeller requires as input building footprints, it generates dense point clouds and then it tries to fit a pre-defined roof types (flat, hipped, gable, etc.). The Building Finder module generates 3D building models without requiring existing building footprints, detecting faces from which 3D building models are assembled. During our testing we noted that both modeling modules use only the nadir images from the dataset to create the geometry, and not the whole set of oblique images. The best results were obtained when a 3D point cloud was generated from the full set of oblique imagery using external software (Acute3D) and was then imported into the Tridicon system. We found that Tridicon was good at finding simple buildings, even when no building footprints were input. However, all but the simplest building models required some manual editing (again within Tridicon) in order for them to be truly representative of the buildings they depicted. We have used Acute3D software to create 3D point clouds from the Bournemouth oblique imagery and found that it does produce cleaner and more representative point clouds than those produced from conventional overlapping nadir imagery. Further testing on the resulting data will be carried out to determine the effectiveness of such data in a non-stereo data collection process.

3.4 Limitations

In order to make the most of oblique imagery, the processing flowline at OS UK would have to be changed considerably, especially as the current flowline is strongly linked to the camera system used (e.g. UltraMap software dedicated to the UltraCam sensors). A potentially major limitation of the oblique image acquisition process is the overlap required of the nadir images in order to produce a 3D point cloud and associated 3D models. In a production flowline, an increase in the speed of acquisition can sometimes take precedence over a small increase in the resolution or quality of the final product. For this reason, imagery for topographic map update is often flown with an 80% fore/aft overlap and a 30% sidelap. With oblique imagery a greater sidelap would be required in order to make the most of the imagery and this, together with the smaller footprint of oblique camera systems, will lead to the need for many more flight lines and consequently a more expensive aerial survey process.

3.5 Vision

For the future we can see a requirement for oblique imagery to give a more detailed depiction of urban areas and to create high resolution 3D datasets. Our investigations have shown that oblique imagery can be used to produce a more representative 3D point cloud than that produced using multiple-overlap nadir imagery. At the moment, this requirement is not yet compelling enough to result in a commitment to operational use of oblique imagery at OS UK. We will continue to monitor the hardware and software and to develop our use cases for oblique imagery, in the expectation that it will become an operational data collection method in the near future.

4 OBLIQUE IMAGERY AT OS IRELAND

Ordnance Survey Ireland (OSi) is the NMA of Ireland. It was established in 2002 as a body corporate and successor to the former Ordnance Survey of Ireland, originally formed in 1824.

4.1 Needs for using oblique flights/images

Ordnance Survey Ireland (OSi) is currently focusing on its geometry positional accuracy resolution in light of modern technological advances and in particularly in urban areas that require Positional Accuracy Improvement (PAI). To date a number of applications have been developed to assist with PAI. PAI is not the only option that OSi is considering to deal with these issues. Our preferred option would be to address these accuracy issues by re-capturing the landscape features. Having just completed the implementation of our new data model and data management system that is designed to store and manage 3D data, we have embarked on testing oblique imagery to develop a methodology to automate/semi-automate a process to survey and digitize the landscape in 3D as solid objects, to accuracies that are related to image resolution.

4.2 Advantages

There are various advantages of using oblique imagery for this purpose, particularly: (i) reduced occlusion in city landscapes due to increased angled views, (ii) better modelling of 3D surfaces such as sheers, overhangs, canopies and underpasses. The ability to apply the imagery automatically for texturing is a major advantage. A particular advantage is if buildings do not change shape but do change business occupancy. It thus becomes possible to re-texture buildings reflecting their current function automatically. OSi is currently in the process of merging with the Property Registration of Ireland and the Valuation Office of Ireland to form a new organisation called Táilte Éireann. Work carried out by the other two entities of this merger will benefit greatly in their ability to improve identification and interpretation from an office environment thus facilitating a much more efficient evidence-based decision making process.

4.3 Experiences

OSi has commenced the design of flowlines to integrate into its existing infrastructure. An area in the north east of the country was flown with Hexagons Pentapod Camera System (Leica RCD30). The newly captured imagery was triangulated based on the national active GNSS network and a point cloud was extracted from the imagery. The intention was to then automatically extract 3D buildings from the generated point clouds using Tridicon/Hexagon applications (City Modeller and Building Finder). We then compared results in terms of positional accuracy and percentage success in building identification see Figure 6). Our conclusions when comparing both outcomes was that the City Modeller produced a higher percentage of success in identifying buildings. Where buildings were of more uniform shapes, typically in sub-urban areas, the success rate was higher than areas such as city centre locations where building shapes were more unique.

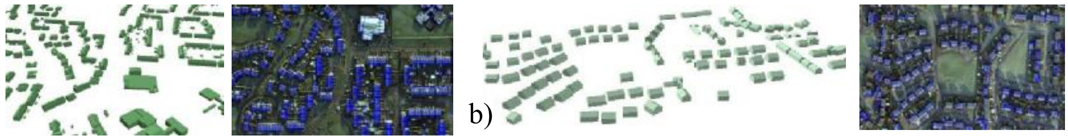
a) b)


Figure 6 – Result from City Modeller application determined from building foot print and point cloud (a) and Building Finder which uses only point clouds (b).

4.4 Limitations

How will the fusion of the point cloud data extracted from nadir and oblique images be managed and will there be issues with relative accuracies? Target identification and pointing accuracies in the geo-referencing process can be more challenging. The volume of images in a project increases dramatically affecting image management, processing times, bundle adjustments, point cloud generation, storage and archive operations. Camera calibration is also much more complex with respect to nadir-only cameras. A further limitation during the tests we conducted was that the software application used to process the aerial data for the construction of the 3D buildings, did not consider façade points. This may have had an effect on the outcome.

4.5 Vision

As we complete the merging process into Táilte Éireann, we will be in a position to provide the definitive source of all required geospatial information for land management in Ireland from a single authoritative source. OSi has a vision to utilise oblique imagery initially in urban areas to assist in improving positional accuracies. As the National Mapping Agency we will move our data offering into the 21st century by enhancing our Prime2 data model to store, manage and provide textured 3D real world objects.

5 OBLIQUE IMAGERY AT ICGC SPAIN

The Institut Cartogràfic i Geològic de Catalunya (ICGC) is the regional mapping agency of the Government of Catalonia (Spain). From its creation in late 1982, ICGC activities have been focused on providing valuable geoinformation to territorial planners and decision makers. ICGC produces topographic databases in urban areas at 1:1.000 scale that results in LOD1 building models (2.5D) in vector format as a by-product see Figure 7). The roadmap of ICGC includes the 1:1.000 urban map upgrade to the LOD2 standard. For modelling urban areas, ICGC uses also LIDAR-based solutions for obtaining point cloud data that will be used to develop environmental applications (such as analysis of solar potential) or obtain LOD2 building models.

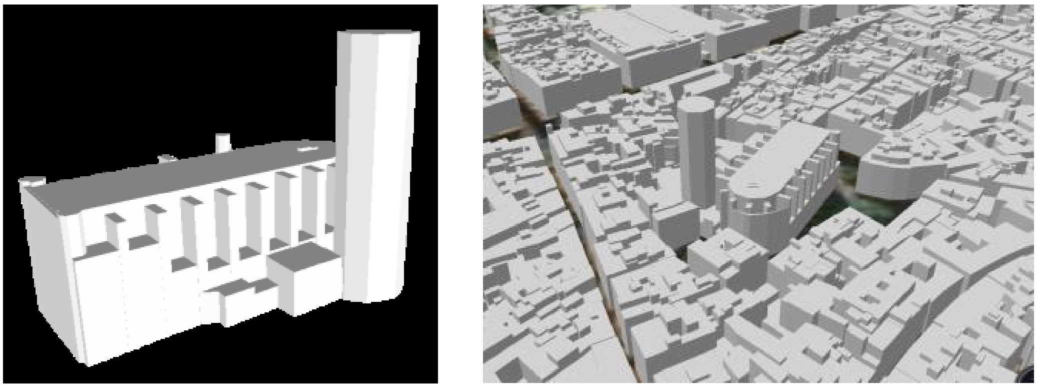


Figure 7 – LOD1 building model from the 1:1000 topographic database of ICGC.

5.1 Needs for using oblique flights/images

To improve the realistic appearance of its products, ICGC decided to add real texture to existing models. Moreover, oblique images are tested to generate 3D textured meshes of urban environments for enhancing the benefits of the very high resolution orthoimages and the 3D building models in terms of geoinformation contents and user's experience. As a consequence, oblique imagery has become an important part of ICGC's strategy for urban mapping.

5.2 Advantages

ICGC believes that implementing a production pipeline based on oblique imagery would help to improve the quality of its products, primarily in terms of visual quality, in the near future also in terms of geometric quality. The combination of dense image matching and multiple view reconstruction algorithms enables the collection of façade information, becoming the natural evolution of twodimensional orthophoto layers and allowing the creation of 3D city models or 3D orthoimages.

5.3 Experiences

According to ICGC's experience, the new oblique camera systems offer a better performance when approaching the 80x80 overlap configuration with a GSD in the order of 6-7cm. Reducing overlap to the usual 60x60 or 60x40 will result in noisier correlation and higher occlusions. At the same time, due to the fact that most of the available systems rely on medium format cameras (using Bayer filter for multiband capture), the apparent resolution is smaller than the nominal flight GSD and, therefore increasing flight altitude is not recommended. Using synthetic targets and images acquired with the Leica RCD30, ICGC has measured effective resolutions of 1.98xGSD, 1.32xGSD and 2.21xGSD for the Red, Green and Blue bands, respectively. Considering the typical sizes of oblique aerial blocks in a real production environment, ICGC has switched to parallelizing processes and established infrastructures, policies and mechanisms for handling large datasets with the level of quality assessment and quality control expected in a standard photogrammetric workflow. From the executed tests ICGC could produce photo-realistic polygonal city models see Figure 8) to improve the realistic appearance of building models and with the possibility to add semantics and share such info over the web.

Figure 8 – Photo-realistic 3D city model produced with oblique imagery with possible semantics and webGIS exploitations.

5.4 Limitations

Limitations

The high overlap at low altitude and the multi-capture system challenge the flight execution and processing capabilities. Covering large areas requires high amount of flight hours so illumination conditions should be carefully considered. These are more complicated in oblique imagery due to the very different illumination situations that affect the different viewing cameras for a single shot. Processing oblique flights with high overlap involves dealing with very large datasets (Table 1) and requires adapting data management and processing as well as data preservation policies for product scalability prior to move from prototyping to production phase. Current off-the-shelf workflows for image processing, aerial triangulation (AT), dense point cloud and 3D data generation have important room for improvement. Software providers are trying to catch up with these problems which result in failure of AT or manual intervention for subdividing blocks that will require further actions for joining the resulting products. Finally, 3D data visualization and exploitation is limited by few systems with performant 3D capabilities (nor with vector data and even worse with 3D meshes) and it is required to go further in format standardization and system interoperability.

Table 1: Typical nadir-based (up) and oblique (down) flight information

25 sq. km @ 7cm GSD	***#images***	***flight time***
60x40 conf. w/ large format camera	*< 400*	*< 1h*
80x80 conf. w/ oblique camera	*> 6000*	*> 3h*

5.5 *Vision*

Further improvements in oblique data processing and management are quickly foreseen. Similarly to the improvements in DSM generation thanks to the Semi Global Matching approach, oblique imagery will continue pushing developments towards the automatization of LOD2 building extraction based on multi-view algorithms. This will be achieved not only due to the future improvements of processing methods, but also because a reduced time-to-market will change user's expectation with respect to the current and classical approach. A similar roadmap should be expected for 3D textured meshes - with an improvement on the quality of the 3D reconstructions using new algorithms and combining different data sources (planar constraints, LiDAR data, etc.) - and a growth of new applications combining 3D meshes and external information to derive structured information that goes beyond the 3D ortho by adding also a semantic interpretation.

6 CONCLUSION

The paper presented the growing interest and availability of oblique imagery and data, in particular for NMAs. Oblique airborne photogrammetry is indeed quickly developing and entering the processing / production pipeline of companies and agencies which are trying to complement (and in some areas replace) the more traditional workflow based only on vertical images. Many applications embrace the advantages of airborne slanted viewing geometry which comes close to human perception of scenes. Most of European NMAs still rely on the traditional workflow based on vertical photography but changes are slowly taking place also at production level. Experiences and considerations from 3 NMAs belonging to EuroSDR were reported. Although weaknesses and problems are still present in data processing and management, the rise of airborne oblique systems will foster a variety of urban applications and force the geospatial sector to face new challenges like: more flight lines to have similar coverage as nadir-only flights, improve actual bundle adjustment approaches, smooth integration and visualization of 3D geo-data, automated generation of LOD2/3 for large urban areas, common acceptance of 3D textured and segmented meshes, semantic 3D city models, etc.

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AUTOMATED GENERALISATION WITHIN NMAs IN 2016

With 6 figures

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Abstract

Producing maps and geo-data at different scales is traditionally one of the main tasks of National (and regional) Mapping Agencies (NMAs). The derivation of low-scale maps (i.e. with less detail) from large-scale maps (with more detail), i.e. generalisation, used to be a manual task of cartographers. With the need for more up-to-date data as well as the development of automated generalisation solutions in both research and industry, NMAs are implementing automated generalisation production lines. To exchange experiences and identify remaining issues, a workshop was organised end 2015 by the Commission on Generalisation and Multirepresentation of the International Cartographic Association and the Commission on Modelling and Processing of the European Spatial Data Research. This paper reports about the workshop outcomes. It shows that, most NMAs have implemented a certain form of automation in their workflows, varying from generalisation of certain features while still maintaining a manual workflow; semiautomated editing and generalisation to a fully automated procedure.

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- General Command of Mapping, Turkey
- Head Office of Geodesy and Cartography, Poland
- IGN Belgium
- IGN France
- Institut Cartogràfic i Geològic de Catalunya
- Kadaster, The Netherlands
- Land Survey Office, Czech Republic
- Landesamt für Geoinformation und Landenentwicklung Baden-Württemberg
- Lantmäteriet, Sweden
- Latvian Geospatial Information Agency
- Norwegian Mapping Authority
- Ordnance Survey United Kingdom
- Ordnance Survey Ireland
- Santiago de Compostela University
- Survey of Israel

• Swisstopo

• T-MAPY spol. s r.o.m, Czech Republic

• Delft University of Technology

• University of West Bohemia

• VUGTK vvi: Czech Republic

• 1Spatial

1. INTRODUCTION

The automatic derivation of small-scale maps with less detail from larger-scale maps with higher degree of detail (see Figure 1) has been intensively studied during the last twenty years. For a long time this process, called “automated generalisation”, has been considered as something to be never reachable (Anderson- Tarver et al. 2011) for National Mapping Agencies (NMAs). Mainly because of the complexity of automating a process that heavily depends on human interpretation. An automated generalisation solution would significantly reduce the costs and time required for producing multi-scale map series. In addition, for Spatial Data Infrastructures automated generalisation would be one of the keys to collect and maintain geographical information once and to use it many times by dynamically deriving a map with the required content and at the required level of detail when needed.

Figure 1 – Map series of Netherlands’ Kadaster (1:10k, 1:50k, 1:100k, 1:250k, 1:500k)

1.1 Developments within NMAs

At the beginning of this century a few NMAs had implemented automated generalisation in specific parts of their production lines (Stoter 2005; Foerster et al, 2010). However, only recently NMAs succeeded to implement automated generalisation to derive a complete map with no or little human interaction (Duchêne et al. 2014). These achievements have several reasons First, successful research results have found their way into software. Secondly, because these software solutions do not provide off-the-shelf solutions, NMAs had to be willing to seriously invest in the development of automated generalisation workflows with the available toolboxes. Recently, NMAs were encouraged to do so by an increasing call from society to produce up-to-date maps. Update cycles of 4-6 years used to be common, but are not acceptable in our current information society in which people are able to capture and compare spatial information about the current environment, e.g. with help of smartphones and GPS devices. A final reason that made it possible to automate the production of multi-scale maps, related to the just mentioned increasing information demand of society, is that the output is no longer only driven by cartographic criteria, but also by the up-to-dateness. Consequently, resulting maps may be considered “good enough” by users even though they may not be cartographically perfect.

1.2 Sharing experiences

Although automated generalisation has resulted in successful implementations, open issues remain. To identify the state-ofthe- art and to discuss remaining issues a workshop was organised by the Commission on Generalisation and Multiple Representation of the International Cartographic Association and the Commission on Data Modelling and Processing of EuroSDR (European Spatial Data Research) on 3rd and 4th December 2015 at Kadaster in Amsterdam. Over 60 people from 18 NMAs exchanged experiences on this topic and discussed issues for further research. Questions that were addressed during the workshop are:

- How to deal with heterogeneous source data, which are more and more frequent since NMAs act more and more as integrators of data produced by other administrations?
- How can successful implementations of some NMAs be transferred to others while all NMAs have their specific context? A key for success is for example a clean and semantically rich source data set.
- What does “good enough” mean in terms of cartographic generalisation? Some NMAs chose to go for fully automated processes while accepting a lower cartographic quality or a less rich content of the resulting maps, while others prefer to keep some manual edits to assure the best cartographic quality.
- If generalisation of a complete map is feasible, is there still a need to maintain object identifiers for the derived products? Maintaining these identifiers also implies to support incremental updates as part of the automated generalisation process. This is yet an unresolved problem.
- How can maps be generalised on-the-fly as required when disseminating these via the web within SDIs? Since current automated generalisation solutions do not fulfil this requirement, maps at intermediate zoom levels are currently being pre-processed
- Is it necessary to distinguish and maintain Digital Landscape Models and Digital Cartographic Models at several levels of detail?
- How can automated generalisation solutions be used to derive on-demand maps for different purposes (hiking, cycling, water navigation etc.)?

1.3 Structure of the paper

The workshop consisted of presentations from the participating NMAs about their multi-scale workflows as well as of break out sessions on common issues.

This paper gives an overview of the main workshop outcomes. It starts with an introduction of attendees (section 2) and continues with the state-of-the-art in automated generalisation as concluded from the workshop materials (section 3). Section 4 elaborates on one of the open issues in automated generalisation related to updates of multi-scale maps with either support of incremental updates or automatically generalise a complete map in case of updates. The paper closes with concluding remarks in section 5.[1]

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[1] The workshop materials can be found here: http://generalisation.icaci.org/index.php/prevevents/11-previousevents-details/92-nma-symposium-2015-presentations

2. BACKGROUND OF ATTENDEES

The interest in the themes of automated generalisation and multiple resolution databases is increasing, as is evidenced by the number and background of participants. At the first NMA workshop, held in Barcelona in 2013 (Duchene et al. 2013), there was a group of approximately 25 participants from 12 countries/regions, all from a regional or national mapping agency.

This second NMA workshop was attended by a larger audience with diverse backgrounds: besides the 48 attendees from 17 NMAs, nine representatives from two software vendors were present, as well as four academics from different universities (see Figure 2).

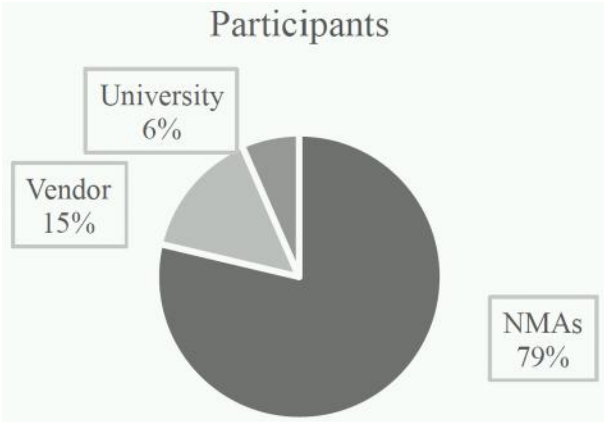

Figure 2 – Composition of participants

Also the variation in lands of origin increased: attendants were from Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Israel, Latvia, the Netherlands, Norway, Poland, Spain, Sweden, Switzerland, Turkey and United Kingdom (see Figure 3).

Figure 3 – States of origin of participants in 2013 (small dot) and 2015 (large dot)

Given the diverse backgrounds, also the experiences with automated generalisation and map production is wide-ranging. Some NMAs should be considered as veterans, having spent more than twenty years on studying generalisation, while others are relatively new in the domain, having started one or two years ago. And there are many NMAs in between. As could be expected, most veteran NMAs have implemented semi-automatic procedures years ago, while the novice NMAs are targeting on fully automated procedures. Another evident difference between veterans and novices is the scale of the base data: nowadays NMAs start with the largest available scale, while in earlier years mid- and smaller scale base data were generalised by semi-automated procedures.

Figure 4 illustrates the shift in focus to large-scale data as input data.

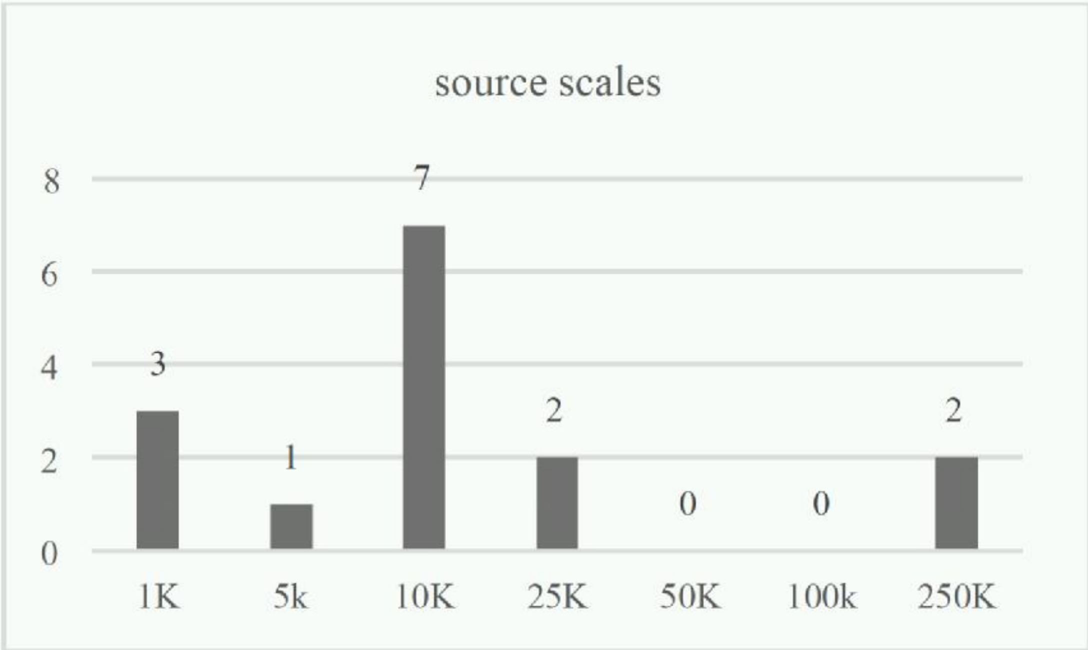

Figure 4 – Source map scales of generalisation processes at NMAs

The focus of target data is also shifting to larger map scales as figure 5 illustrates.

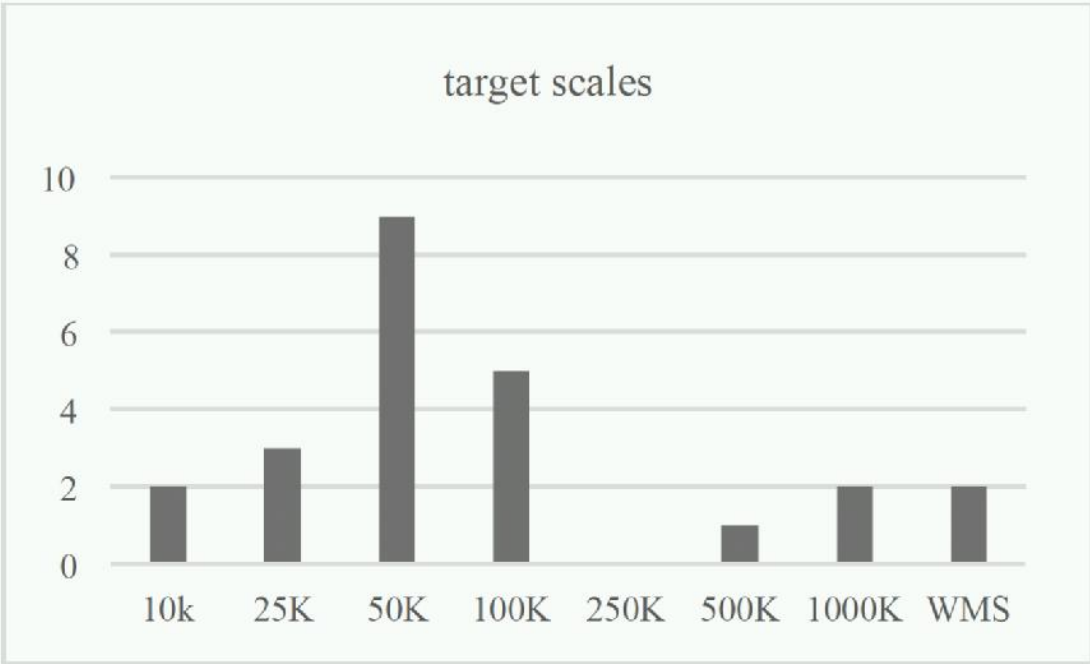

Figure 5 – Target map scales of generalisation processes at NMAs

Most NMAs use similar software in their production workflows (most of the time highly customised): 1Spatial – 1Generalise (Regnauld 2015), Esri ArcGIS (Hardy 2015), Clarity, SCAN Express, Safe FME, Geomedia, Lamps2, Axpand and Peikka. Databases in use are Oracle, Gothic and filegeodatabases.

3. STATE OF ART WITHIN NMA'S

At the workshop, each NMA provided an abstract and presentation on the state of the art of "Automated Generalisation" within its own organisation. Details can be found in the corresponding abstracts and presentations: (Augustýn 2015; Baella et al. 2015; Çelik & Simav 2015; Curtinot 2015; Færch-Jensen et al. 2015; Fechir 2015; Frick & Johansson 2015; Goldner 2015; Haug 2015; Howland & Walters 2015; Käuferle et al. 2015; Kettunen et al. 2015; Lebiecki 2015; Madden et al. 2015; Reimerink 2015; Urbanke 2015; Wehrhan 2015).

The paragraphs below provide a summary of the most significant items: (1) What are the drivers for studying and implementing automated generalisation? (2) How is the issue of generalisation approached? (3) How are the individual NMAs progressing in the field of automated generalisation? (4) Which level of automation is achieved in the generalisation process? (5) How much tailoring of out-of-the-box software is applied and at what expenses? (6) What are the open issues currently being met and/or addressed?

1. Drivers for automated generalisation: NMAs in the twenty-first century are challenged by several issues. First, society is demanding data with a higher update cycle. The speed of traditional update cycles, between five to ten years, does not meet the need of society nor legal demands. Second the economical crisis caused austerity measures and accompanying budgets cuts, which made costs-effectiveness an even more urgent issue. Actual staff sizes and traditional workflows were not sufficient to comply to legal demands or to the pressure from society to obtain derived products for visualisation in internet and mobile devices.

A third driver for automated generalisation, open data policy, is faced by some countries. Automation of generalisation contributes to solving this issue in two ways: some NMAs seek to (fully) automate their workflow to reduce costs and opening up their data to society, while others use automation to provide open data-sets as a 'light'- alternative to their premium data. Fourth, Volunteered Geographical Information - initiatives such as Open Street Maps and commercial solutions like Google Maps, Bing Maps challenge the original tasks of governmental topographical datasets in the 21st century.

Fifth, more and more NMAs have to cope with the incorporation of external datasets. Some of the NMAs do not have a full coverage in their source database, or policies are to combine data from multiple providers to one data set. This urges NMAs to look into efficient procedures for quality control and automation of manual procedures.

2. Approaches for generalisation: Although most NMAs are facing the same challenges, the approaches to study and implement automated procedures vary. This variation is explained by the history and culture within an NMA (Duchêne et al. 2014). Some NMAs have a vivid and lengthy history in studying automation of mapping procedures, which has also contributed to the current implementation of algorithms in commercial software. Other NMAs started recently, driven by external factors as explained in the previous paragraph.

The veteran NMAs usually approached the study of automated generalisation in a classical form, starting with specifications, technical design and implementation. New coming NMAs tend to approach the issue from a more pragmatic point of view looking at the lessons learnt from other NMAs, interacting with customers and working together with industry partners.

A common approach of automating the generalisation process of multiple scales from a single source cannot be recognised:

both star (where all small scale maps are derived from the same most detailed map scale) and ladder approaches (where maps are derived from the next-higher scale map) are applied, as well as a hybrid form which mixes star and ladder approaches.

3. Progress: The progress in the implementation of automated procedures varies from NMA to NMA. Some NMAs have just started preparations and still have to face the challenge to create multi-scale data models and implement them in appropriate databases, e.g. relational or object oriented databases (Augustýn 2015). Others have small-scale-generalisation processes implemented for years (Kettunen et al. 2015; Lebiecki 2015), and are now developing towards the design of a large scale architecture for generalisation. Novices in the field of automated generalisation, who have taken the hurdle of designing and implementing data models for their map data tend to start with automation of large scale databases (10K) to medium-scale databases (50k). Three NMAs have implemented fully automatic procedures (Stoter et al. 2014; Regnauld 2014; Lafay et al. 2015) and other NMAs aim on following within the near future (Madden et al. 2015; Frick & Johansson 2015). Many others have automated parts of the generalisation workflow.

Alternative approaches are applied by Danish Geodata Agency (Færch-Jensen et al. 2015) and Norwegian Mapping Authority (Haug 2015) since they have to cope with external source data provided by manifold municipalities. Their main focus is on quality assurance and control as well as on leveraging customizable products via web portals.

4. Level of implementation of automated processes: The extent of implementation and thoroughness in implementation within NMAs varies. Most NMAs have implemented a certain form of automation in their workflows. The level of implementation varies from generalisation of certain features while still maintaining a manual workflow; semi-automated editing and generalisation to a fully automated procedure (like the aforementioned three examples). Most of the NMAs that have implemented semi-automated workflows planned to substitute these by fully automated workflows within the next two years (2016-2018).

5. Tailoring: While some NMAs use out-of-the-box tools only, most of them develop specific customisations of the out-of-thebox tools, often outsourced to the software provider. The main instruments to develop additional custom-designed workflows are geoprocessing tools and python scripts. Incidentally, more advanced programming languages (such as ArcObjects or C++) are used to tailor generalisation processes.

6. Issues: Several NNMAs are facing obstacles to explore, develop or implement automated generalisation. For instance, NMAs lack the required amount of staff and budget resources. Also the role of several NMAs has changed from data collector into data distributor. This causes several NMAs to sincerely reflect upon their existing workflows, upon the use of external source data, quality demands, update cycles and processing units. It is not said these reflections necessarily cause the replacement of existing workflows (sometimes a considerable amount of time and budget has been spent and redesign does not improve the end results per sé), but it opens up doors to other solutions. In addition, it causes the discontinuation of production flows and the replacement by automatic procedures.

4. UNIVERSAL IDENTIFIER AND THEIR PROPAGATION THROUGH SCALES

With the possibility to automate the generalisation process, an important question arises about the design of future production workflows of multi-scale maps. If generalisation of a complete map is feasible, will updates consist of the generalisation of complete maps or the generalisation of only the updates? The last requires the support of incremental updates and maintenance of object identifiers of derived prodcts. Besides that object identifier might be used by the NMA themselves for incremental updates, they may also be used by customers of NMA data, who combine topographic with thematic data and may have to update NMA (background) reference data independent or in combination with own thematic data. The maintenance of incremental updates is yet an unresolved problem.

The issue of incremental updates fits within the developments of Life-cycle management and traceability of objects by a Universal Identifier (UID) through several scales. And the question is whether NMAs or customers really need those.

From the one side, it can be argued that both Lifecycle and Unique Identifier are needed. The arguments are: 1) it is a userrequested feature (but the discussions during the workshop showed that we can mention no or little real examples that shows this and also not why users would need it), 2) for certain applications you do not want to use your source data, 3) NMAs would like to be able to deliver a subset of changes only; 4) UID's enable implementation of Linked Data concepts also for small scale data, and 5) Software vendors do provide the option. Other arguments advocate why we do not need these lifecycle information or Unique Identifiers for small-scale data and therefore we can suffice with generalisation of complete maps. Objects in the most detailed map should always be identifiable. However UID's should not be created for derived small scale data, because: 1) given the current hardware and software environments, it is much easier to reprocess a derived dataset completely instead of managing the complex lifecycle information; 2) some argued that the analysis with generalised data should be discouraged, because generalisation decreases the quality of the data which takes away one of the requirements for UID's; 3) traceability is difficult to maintain and implement at a conceptual level specifically within multi-scale production workflows where objects are aggregated, typified, selected and deleted and in some cases also enlarged and displaced.

To meet both points of view, it was suggested to use the URI for objects and to consider geometrical representations at several scales as attributes. This sounded as an interesting suggestion, but then the question was: What is an object? Do we mean the object in real life or do we mean an object stored in the database? If the latter, how should an object be defined? And how to handle relationships between objects in the case of n-1 or m-n transformations?

Uniformity or a general definition of objects appeared to be an illusion, since an object definition is dependent on the use case, user context and related target scale.

Since a "one size fits all" solution was not an option, it was proposed to consider groups of users who can agree upon object definitions. These objects could be provided an URI or UID for the given context. This raised a new question: If we are to do this, are the members of the group willing to pay for these efforts of NMAs, since it will take a considerable amount of time and effort to first agree on these definitions and secondly to implement generalisation processes accordingly. Underneath this question about the URI's lies another question: "why do users want a URI or UID?". The reason usually mentioned is to carry out updates on reference data, which might be combined with additional thematic information. However, as mentioned before, the workshop participants provided arguments in favour and against but were not able to fully answer this question from the users' perspective.

5. CONCLUDING REMARKS ON REMAINING ISSUES

From the presentations, abstracts and discussions of the workshop several open issues were identified that need further attention by either academics or industry.

At first, operators for automated generalisation provided by industry are often implemented as black boxes. Since successful generalisation requires adjustments, the generalisers at NMAs mentioned a need for more transparency and better possibilities to experiment with the underlying implemented algorithms. Another remaining issue in generalisation is the lack of appropriate personnel. Implementing automated generalisation within NMAs requires high-qualified people with knowledge on information technology and skills on data-generalisation. Both are characterised by steep learning curves and the lack of such personnel may hinder the implementation of automated solutions within NMAs.

Also automated generalisation at NMAs requires an improved scalability of processes. One of the challenges for the full automation of the generalisation process lies in the possibility to process a complete country. Besides computer power, this requires a smart way for partitioning to be able to apply areaand context dependent algorithms and parameter values as well as a tool to handle feature morphology (Altena 2014) for morphology-tailored generalisation processes. A good solution for partitioning also includes distribution of the computation as well as the management of dependencies between partitions. Finally the integration of 2D, 3D and 4D was mentioned as open issue by most of the participants. Many NMAs are making the step from 2D mapping to 3D mapping with maintenance of temporal information (4D). The 3D maps are increasingly considered within the context of multi-scale products and some NMAs even maintain 3D data as source data from which 2D data is derived, like implemented by swisstopo. This brings another challenge for generalisation, i.e. deriving small-scale products via 3D generalisation. While automated generalisation research in 2D has a rich history, research on generalisation of 3D urban models is rather new. Several researchers have studied the generalisation of individual buildings and groups of buildings. However, they often focus on a single generalisation problem while we have learned from the 2D cartographic domain that for successful generalisation solutions it is essential to generalise urban objects with respect to their surroundings. This context dependent generalisation is hard to implement and not yet well understood in 3D (see Figure 6).

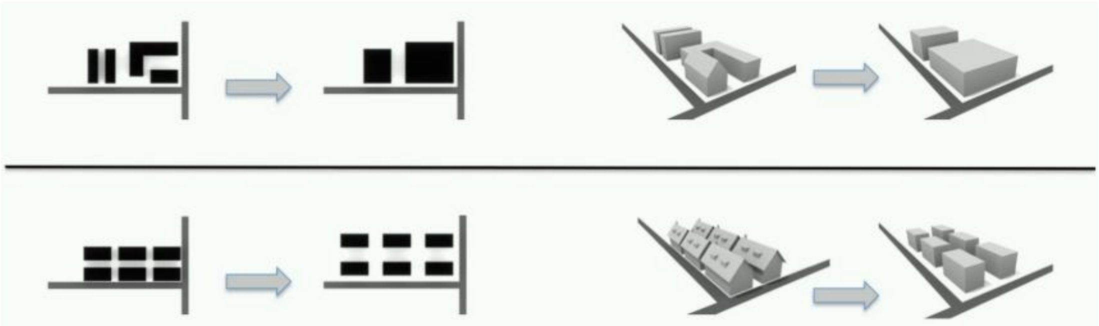

Figure 6 – Context dependent generalisation solutions in 2D extended into 3D. Simplification and amalgamation (above) and simplification and displacement (below)

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STATE-OF-THE-ART OF 3D NATIONAL MAPPING IN 2016

With 13 figures

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ABSTRACT

Techniques for 3D mapping are maturing. At the same time the need for 3D data is increasing. This has pushed national (and regional) mapping agencies (NMAs) to consider extending their traditional task of providing topographic data into the third dimension. To show how research results in 3D mapping obtained over the past twenty years have been adopted by practice, this paper presents the ongoing work on 3D mapping within seven NMAs, all member of the 3D Special Interest Group of European Spatial Data Research (EuroSDR). The paper shows that some NMAs are still in the initial (experimental) phase of 3D mapping, while others have already built solid databases to maintain 2.5D and 3D topographic data covering their whole country.

1 INTRODUCTION

Techniques for collecting, reconstructing and maintaining 3D information have matured and many applications make use of 3D data ranging from flooding and noise simulations to energy and urban heat island calculation. Consequently, there is an increasing need for up-to-date, countrywide 3D data. Several National and Regional Mapping Agencies (NMAs) in Europe are making the step from 2D to 3D mapping to produce such data or are considering to make this step.

To join experiences and pursue the research agenda for 3D mapping, twelve European National Mapping Agencies have organised themselves in a 3D Special Interest Group within the organisation “European Spatial Data Research” (i.e. EuroSDR 3D SIG). This paper summarises the progresses on 3D national mapping made by a selection of these NMAs and the remaining issues that they face. It updates the paper that this group wrote in 2014 (Stoter et al, 2014). More specifically the paper describes the following recent developments:

- Section 2: ICGC (Catalonia) experiences on the generation of 3D raster models derived from the oblique camera and the improvement of the vector model for urban data to accommodate richer information related to 3D city modelling.
- Section 3: The Swedish experiences on a common national 3D visualisation environment for 3D geodata from the NMA, maritime administration, geological surveys and municipalities.
- Section 4: Activities by GUGiK (Poland) on setting up a 3D building database for the whole country and their plans to make it available for customers before end of 2018.
- Section 5: 3D mobile mapping at IGN France: recent developments resulted in a production vehicle and many developed tools to exploit such data in the IGN France research Lab.
- Section 6: 3D mapping at national level in Finland.
- Section 7: 3D mapping at swisstopo, Switzerland.
- Section 8: 3D national mapping at Kadaster NL.

The paper ends with concluding remarks in Section 9.

2 3D MAPPING AT ICGC

The Institut Cartogràfic i Geològic de Catalunya (ICGC) is the regional mapping agency of the Government of Catalonia. From its creation in late 1982, the ICGC activities in the cartographic production have been focused continuously in the improvement of the production workflows.

The production of topographic data includes the scales 1:1.000 (CT-1M) in urban areas, and 1:5.000 (BT-5M) and 1:25.000 (BT-25M) covering all the country. The data are collected mainly using photogrammetric systems, completed in urban areas by data surveyed on the field, and updated in a period of 5 years and more frequently if there are important changes in infrastructures. Data are stored in an ORACLE database using 2.5D data models, where each vertex is defined by X, Y and Z coordinates. Data at 1:1.000 and 1:5.000 scales include a rich collection of altimetric data, including break lines, that allows to derive a digital terrain model (DTM) and a digital surface model (DSM). These elevation models are widely used in orthophoto rectification and in the contour and shadow relief generation ensuring a complete coherence between planimetric and altimetric information.

LoD1 city models are automatically derived from 1:1.000 scale and 1:5.000. Since 2002 LiDAR systems are an additional source to obtain elevation data, with a full coverage of Catalonia available with 0,5points/m^2, and a partial coverage at higher densities along the coast and over other specific areas. In 2014 an oblique camera was bought to obtain more accurate 3D information on urban areas. The ICGC products, including data, metadata and specifications, are distributed free-of-charge according the Creative Commons licence CC-BY.

Current tasks in 3D work focus on the improvement of the CT- 1M data to accommodate richer information related to LoD2 city modelling, in the generation of 3D raster models derived from images obtained with the new oblique camera and 3D products derived from LiDAR data, in the dissemination of 3D data and to find new applications of its enormous potential.

2.1 Improvement of the topographic model at 1:1.000 scale

The first line of the 3D work in progress is focused in the enrichment of the CT-1M data model, adding detail of the roofs for obtaining LoD2 city models (see Figure 1) and the topographic information under bridges and other constructions. In the current topographic model, buildings include flat polygons derived from linear boundaries, where each vertex of the boundary is collected in the coordinates X,Y, Z at the real height, and a centroid to indicate the highest or the more significant value of the roof. In the new model it is planned to collect the roofs with all the 3D details, including the overhangs. After some tests on Tridicon software for obtaining inclined roofs automatically, based on oblique image correlation and building boundaries, the results are promising although manual tasks will be required to refine them. Main limitations of Tridicon software are related to its pattern recognition method using predefined types of buildings, which in most cases are not well adapted to the irregular buildings and constructions of the territory.

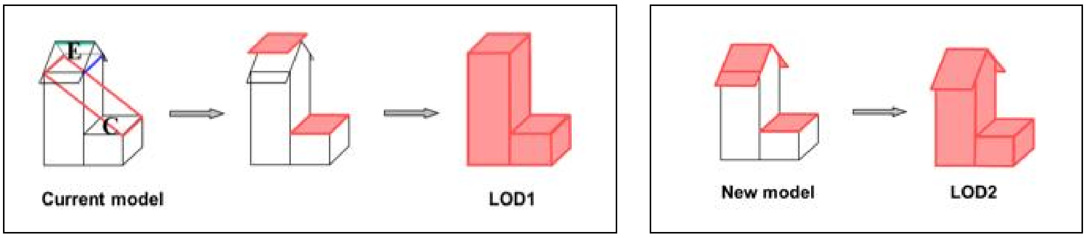

Figure 1 – Building data capture in the current and in the new models

Data model improvement will also consider transportation networks. In the current model the network is collected by linear elements. In bridges, all the required information is collected to model the terrain under the bridge (DTM) and to model the upper construction (DSM). In the new model polygons will added on top of the bridges to facilitate the classification and the exploitation of the topographic information under them (see Figure 2).

Figure 2 – Bridges data capture in the current (left) and in the new (right) models

As it is in use in the BT-5M and the BT-25M databases, this model will include for each feature instance an identifier unique and persistent along its whole life-cycle, and its characterization by temporal, metadata, and thematic attributes. The life-cycle information will describe temporal characteristics to make feature versioning possible; the metadata attributes will contain the information related to quality and lineage (survey, stereoplotting, field collection, external databases or other); and, finally, features will have a set of thematic attributes to characterize them. The availability of identifiers and life-cycle attributes will facilitate the updating processes, will allow the distribution to the users of incremental updates and the relationships with related databases (addresses, map names, etc) to facilitate, for example, the propagation of changes. The design of the new model will also guaranty the compatibility between the concepts existing in the ICGC data model if they exist in other models and standards, as CityGML and INSPIRE.

Main issues in this work are the identification of real customer needs and the achievement of a balance between the complexity of the model and the cost to be maintained during the updating processes. Regarding to the customers need: although the model is designed as a corporative task involving producers and users of the data of different government administrations being mainly municipalities, at the moment the main use is still visualization. Related to complexity and cost, the ICGC approach is to enrich the model by steps, avoiding features, attributes and relationships existing in the standards but not to be used in the next future, for example, the new ICGC model probably will not yet include polygons of the surfaces of roads and streets.

2.2 3D products from oblique images and LiDAR data

Additional to the 3D vector data, ICGC is providing also 3D products based on raster data collected using the recently acquired Leica RCD30 Oblique Camera and, since 2002, the LiDAR systems.

One of the main uses of the oblique images is the generation of the textures to the LoD2 buildings of the new topographic model and the generation of 3D raster models. Current vector LoD1 data is provided without textures. Although some pilot projects have been performed to add textures to the model using aerial or terrestrial images, the results have been poor or too costly. Multiple views from the oblique camera images will allow the addition of the textures to the LoD2 buildings of the new topographic model, solving the previous limitations (see Figure 3 and Figure 4).

Figure 3 – Multiple views collected by the oblique camera

Figure 4 – Current LoD1 model without textures and the LoD2 model texturized using oblique images

Because the new topographic model is yet in design phase, and it will require some time before to get it implemented in the production environments and to have a significant coverage of data available, it has been considered that the production of 3D raster models based on hyperrealistic textured triangulations can provide a 3D product very useful for most visualization applications (see Figure 5).

Figure 5 – Hyperrealistic textured triangulation from the oblique images

ICGC is preparing a workflow to generate automatically this product, shortcoming the problems of the software provided together with the oblique camera, which is not robust enough to manage the huge volume of data required to generate the ICGC annual production.

First coverage of LiDAR data was collected between 2008 and 2011 at 0,5 points/m², and the main uses were related to flood analysis. Since 2008 regular flights have been collecting higher density LiDAR data, at 1 point/m² along the coast for monitoring the littoral changes and at 4 points/m² in populated areas for deriving urban applications, for example the analysis of the solar potential of the buildings (see Figure 6).

Figure 6 – Application to provide the solar potential of buildings based on LiDAR data

2.3 Dissemination of 3D data

Nowadays ICGC data can be accessed through a portal, used through geoservices and downloaded in several vector formats, as SHAPE, DGN, DXF or KMZ, and also raster formats. LiDAR data are available in LAZ format. By the moment data is mainly used for 2D applications, and, although there is a huge potential of city model applications (urban planning, telecommunications, energy, environment, smart cities, simulations, etc.), visualization is the most common while the other ones are not yet enough developed.

For the visualization of 3D datasets, ICGC is currently studying a 3D viewer based in Cesium technology and the first prototypes are in test phases. The WebGL Cesium library allows the presentation of 3D graphics in web pages, and taking advantage of the acceleration provided by the user computer, achieves an excellent quality and speed from the web browser.

Finally, to facilitate and to spread the use of city models, an ongoing project analyses in depth the requirements related to the use of ICGC data for 3D city modelling in architecture projects, and an specific user profile is being implemented to provide ICGC data better adapted to this professional field. The plans for the next future are to analyse in depth other fields.

3 THE SWEDISH EXPERIENCES ON A COMMON NATIONAL 3D VISUALISATION

Lantmateriet - the Swedish mapping, cadaster and land registration authority - was in 2013 commissioned by the Government to investigate the possibilities for the provision of mapping and image information in 3D. The user needs assessment conducted during the investigation found that there is growing demand for geodata in 3D to do better visualizations, analyzes and plans in areas such as urban and infrastructure planning as well as in climate adaptation work.

Existing data themes in 2D should over time be provided and displayed in 3D. The aim should be that existing data themes from Lantmateriet along with data themes from other authorities gradually should build up a common 3D landscape model that meet society's basic needs. As part of this work a common framework for 3D should be developed in collaboration with other authorities as well as a test platform for the visualization of spatial data in 3D.

Work has begun with the Geological Survey of Sweden, the Swedish Maritime Administration, the Swedish Transport Administration, Swedish forest agency and the municipalities. Experience to date shows that (see Figure 7):

1. The existing elevation models in 2.5D from different agencies can be displayed in a common application after some editing and knowledge on quality. The models tested together are DTM, DSM, a seabed model and a bedrock model. It is possible to set up these height models as WCS services at the responsible authority for real-time delivery.
2. It is possible to use existing 2D WMS services at each responsible authority to drape on the different height models for 2.5D in real-time. Water, transportation, land cover and orthoimagery is draped on the DTM. Hill shading on the DTM and seabed. Forest polygons on the DSM. Soil and groundwater on the bedrock.
3. There is currently no good standard services to provide 3D objects for visualization like buildings, power lines, wind turbines, boreholes and other artificial 3D objects that are above and below the ground surface. These objects are at the moment stored and delivered by the application provider. Lantmateriet collects buildings in-house for rural areas and in cooperation with municipalities for urban areas. The buildings are measured in-house in 2.5D with photogrammetry and roof edges are stored in a 2.5D database. The

municipalities use photogrammetry or terrestrial measurements to collect in different 2D or 3D models. There is a collaborative project between Lantmäteriet and the Swedish municipalities regarding a new information model for 3D building to be used for national data exchange. The new model is based on the old model, CityGML LoD0-3 and INSPIRE.

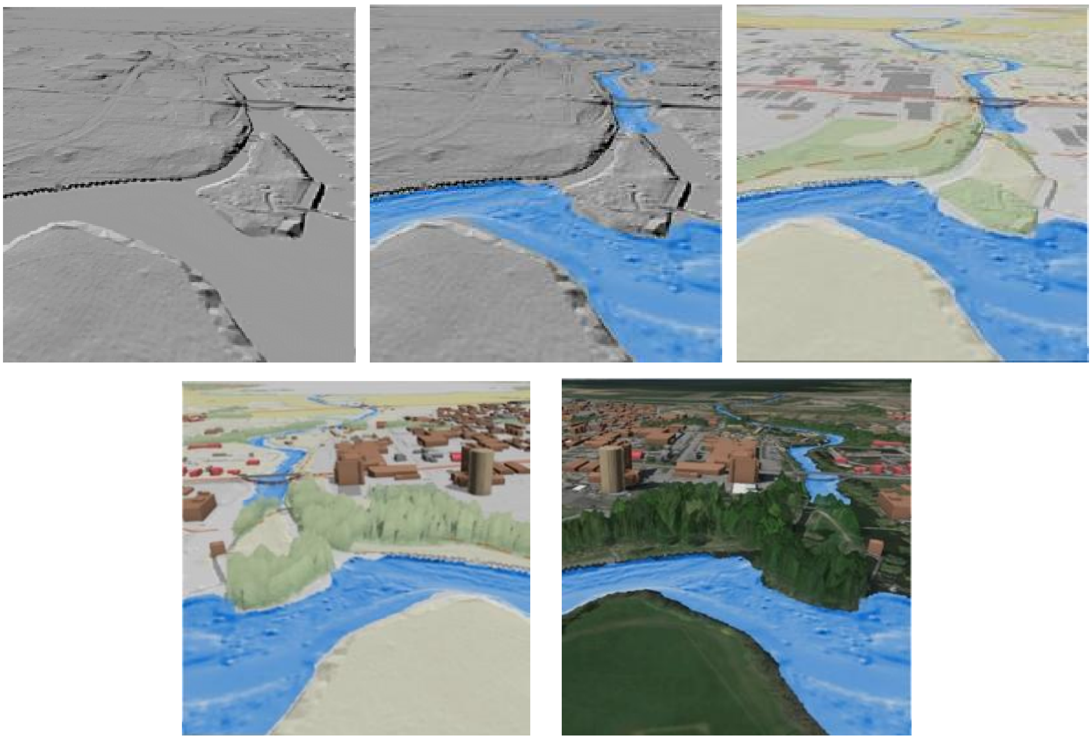

Figure 7 – 2.5D landscape model with buildings (below) of Lantmateriet

4 3D MAPPING AT GUGIK, POLAND

On November 19th 2015, the Head Office of Geodesy and Cartography (GUGiK) has begun implementation of the CAPAP project (Public Administration Center for Spatial Analysis) where one of main tasks is to set up 3D building models database for the entire country in LoD2 CityGML standard together with procedures and tools to keep it updated. It is planned to use ALS (4-12 points/m²) and 2D outlines of buildings from Topographic Objects Database as a main data source. Whole process of production is going to be outsourced, quality control will be conducted mainly by external contractor however final verification will take place in-house.

Terms of Reference are being prepared in close cooperation with defined customers. In 2014 GUGiK conducted a survey regarding customers needs and received feedback from 650 public and private organizations followed by dedicated meetings with further 92 organizations in a second step of consultations.

First 3D data will be available in second half of 2017 and whole dataset will be ready for use before end of 2018. GUGIK considers to distribute 3D database as an open dataset which will potentially strengthen application of data and economic grow in sector of geo-bussines in Poland. In addition to 3D database it is planned in CAPAP initiative to implement analytical environment for customers facilitating utilization of 3D data as an extension of geoportal.gov.pl environment. To meet customers expectations GUGiK is in testing procedure of 3D web viewer with analytical functionalities (see Figure 8).

Figure 8 – 3D webviewer of GUGiK

5 3D MOBILE MAPPING AT IGN FRANCE

Mobile mapping consists in the dynamic numeration of the environment at very high spatial resolution from a mobile terrestrial platform. Mobile mapping systems are of utmost interest in the context of fine scale 3D mapping of urban areas and have been a fast growing trend for the past decade. This has several reasons. At first the resolution of airborne sensors has reached its limits, so the only possible improvement is getting closer to the scene. One possibility is with UAVs (that have also known a great boost recently), the other is with ground based platform. While fixed platforms are extremely limited in productivity, mobile mapping is the only ground alternative allowing for the coverage of an entire city in reasonable time. Another reasons for the increase interest in mobile mapping is that both the storage size capabilities and processing power keep growing. An increase in spatial data resolution implies a similar increase in data size. That aspect is all the more visible in the rise of a strong international BigData community.

Because of that trend, specific sensors (image, LiDAR, georeferencing) have also emerged, favoring the growth of mobile mapping. Importantly, the Google StreetView web service has much popularized mobile mapping (Anguelov et al., 2010). There is now an abundance of private mobile mapping operators (Here, Cyclomedia, StreetMapper from 3DLaserMapping, TopCon, Apple) often equipped with fully packaged systems (Optech, RIEGL VMX-450, Trimble MX8, Siteco). In parallel, research initiatives have seen the emergence of more and more precise systems: VISAT (El- Sheimy, 1996), GPSVan (Grejner-Brzezinska, 1996), Lara3D (Goulette et al., 2006), Roamer (Kukko et al., 2007), Photobus (Gontran et al., 2007), RoadScanner (Gandolfi et al., 2008), Stéréropolis (Paparoditis et al., 2012), or the Kitti initiative (Geiger et al., 2012).

The main challenge of mobile mapping is that of integrating and synchronizing image, LiDAR and georeferencing systems from the mechanical, electrical and software point of view so as to provide images and point clouds precisely georeferenced in a geographical reference system. Its main challenges can be divided into:

- Quality of the georeferencing: because of the high data resolution, many applications also call for a very accurate absolute geo-positioning (below 10cm accuracy) which can only be obtained in good GPS visibility but not in dense urban cores. Some academic papers and commercial tools propose to use external data sources (tie points, 3D object locations) to improve the accuracy of the geo-positioning system in GPS denied environments.
- Scene complexity: compared to aerial acquisitions, the sensor is within the scene. That scene cannot be analysed in 2.5D but only with true 3D tools. This is quite a new paradigm in a geospatial community more used to 2D tools (orthophotos, digital elevation models, 2D vector data, …)
- The specific acquisition geometry induces a much more anisotropic and variable resolution as in the aerial case where all objects lie at a rather similar distance from the sensor. Occlusions are also much more important.
- Dynamics: from the ground point of view, dynamic objects such as cars compose an important part of the scene and can hardly be neglected.
- Radiometric issues (reflexions, shadows, …) in images are much more important and hard to correct.
- Data size (roughly 1Tbyte per day of acquisition) is very challenging for processing and visualization tools.

Despite these challenges, mobile mapping also offers huge improvements above traditional mapping techniques. Because of the proximity to the scene, mobile mapping unlocks numerous data production possibilities that are inaccessible to airborne acquisitions:

Facade analysis and reconstruction

Precise road mapping (lanes separation, road/sidewalk separation, road marks/signs detection and reconstruction, road surface analysis and defects detection, gutters localization, ...)

Urban objects detection and reconstruction (trees, urban furniture, poles, …)

Fine grained change detection

Some of these new products can have important applications for NMAs because related to national legislation, including building accessibility to the disabled and accessibility diagnostics and localization of underground networks. Other important applications for local collectivities include urban furniture inventory and degradation diagnostic (including road signs, road marks and road surface quality); car park usage monitoring; assessment of conformity of new constructions with the provided plans; mapping of vehicle and pedestrian flow. Finally, such data can support numerous services such as 3D monitoring from the office (based on a street view interface); mapping for autonomous navigation; and pedestrian itinerary computations and planning.

Most aspects listed above are still very prospective and are active fields of research. Therefore it is often hard for NMAs to define a position towards this field in constant developments. IGN France has chosen to maintain an expertise that initiated in its research laboratories by developing a production vehicle operated by a production service specialized in highly specific metrologic surveys (see Figure 9). The aim is not only to develop such services but also to maintain an expertise, thus a legitimacy to advise local collectivities regarding mobile mapping, and to qualify the accuracy of private operators. Even if several large cities (including Paris) have been covered by mobile mapping acquisition, a nationwide coverage is not the target as the corresponding investment is too high. Mobile mapping is a promising technology that opens the door to numerous new applications of geospatial data, but the challenges it still faces makes it hard to deploy at large scale, and the amount and specificity of the collected data still calls for specific processing and interaction tools before being really exploitable by end users.

Figure 9 – The mobile mapping system of IGN

6 3D MAPPING AT NLS FINLAND

The National Land Survey of Finland is responsible for national topographic data production in Finland. The current topographic data production is mostly based on aerial images and LiDAR data.

LiDAR data (minimum 0.5 points/m^2) is used for the DTM production. The final product is 2meter grid. The feature collection is done by using stereo workstations. The height information for features is derived from the LiDAR based DTM i.e. current topographic data is 2.5 D.

Topographic data is available as open data from the portal https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en NLS has started a program to create a new National Topographic Database (NTDB) in beginning of 2015. First new version should be available in 2019. One of the change is to support 3D data. Plan is to follow CityGML level of details (LoD) classification. The production is divided to three classes:

Class A: A city center, features are represented in LoD2 (or better if available from construction plans).

Class B: Other densely populated area or industrial area, features are represented in LoD2. Class B may also contain shore areas with recreational activities.

Class C: Other area, features are represented in LoD1 or LoD2.

There is separate ISPRS paper with more detailed description of the NTDB.

7 3D MAPPING AT SWISSTOPO, SWITZERLAND

Referring to Switzerland from a land survey view means dealing with large elevation differences, pronounced terrain variations in the Alps, dense population and infrastructure in the mid lands and an increasing legal interest in claiming the air, the ground and the subterranean space. In 2008 the Swiss Federal Office of Topography (swisstopo) consequentially switched its land survey from a 2D map based approach to the straightforward 3D acquisition of the digital Swiss Topographic Landscape Model TLM (Schmassmann et al., 2010), see Figure 10.

Figure 10 – Representation of swissTLM3D elements near the City of Interlaken

The 3D database is the nationwide primary geometric reference with a precision of better than 1m for all elements, captured either directly from aerial or satellite scanner data by photogrammetric techniques and/or data integration from authorities and organisations. Today most of the TLM elements are already built up and are subject to a regular update process, namely the digital terrain model swissALTI3D, roads and paths, the public transportation network, administrative boundaries swissBOUNDARIES3D, the name dataset swissNAMES3D, single prominent objects and lakes. The buildings swissBUILDINGS3D are expected to be accomplished in 2018 followed by the land cover features, the areas of specific use and the hydrographic network in 2019 (swisstopo, 2016).

swissALTI3D is a continuous terrain model in a 2m mesh, based on LiDAR flights up to 2000 altitude and photogrammetrically extracted heights from aerial flights above. The model is updated in a regular circle using automatically extracted point clouds and manually measured break lines and contains even precise bathymetric information of the larger lakes. Swisstopo initiated a successive renewal of swissALTI3D based on new LiDAR flights over the next seven years to end up with a surface model and a more accurate 1m terrain model.

The roads and paths and the public transportation network, surveyed in true 3D, are represented by network axes and attributes such as width, type, usage and more. The network is updated on a regular base. Arising discrepancies of the network altitude and the elevation data are revised immediately in the coupled data acquisition process of both, an approach valid for all the other TLM elements too. In contrast land cover, areas of specific interests and the hydrographic network are mapped in 2D and draped over the terrain model, resulting in 2.5D objects. swissBUILDINGS3D is the 3D vector data set representing over 3 million buildings of Switzerland. The roofs are manually acquired in 3D from aerial digital images with a precision of better than 50 cm in all dimensions and complemented with attributes. The additional building elements (facades, footprints and roof overhangs) originate from automatic procedures (only where third party information is missing). Swisstopo fosters actually a big national effort which will allow for a simultaneous use of the geometric 3D data of swissBUIDINGS3D, the statistical information about households and living from national surveys and the legal and local information from the cantonal cadastral services: in the near future the swisstopo buildings and the cadastral building entities will refer both to the unique national statistical building identifier.

7.1 National 3D data viewer of Switzerland

All public 2D governmental data of Switzerland is currently published on the federal geoportal (geo.admin.ch, 2016). In order to make better use of the 3D geo-data from swisstopo and to foster the dissemination of the data, swisstopo is pushing to expand the geoportal with 3D capabilities. Currently a preliminary viewer (see Figure 11) is available for the public, capable to show 2D information layers draped over an adapted terrain model (map.geo.admin.ch). swisstopo will start to add first 3D elements such as buildings, trees and structures over the coming month in order to comply with a true 3D viewer.

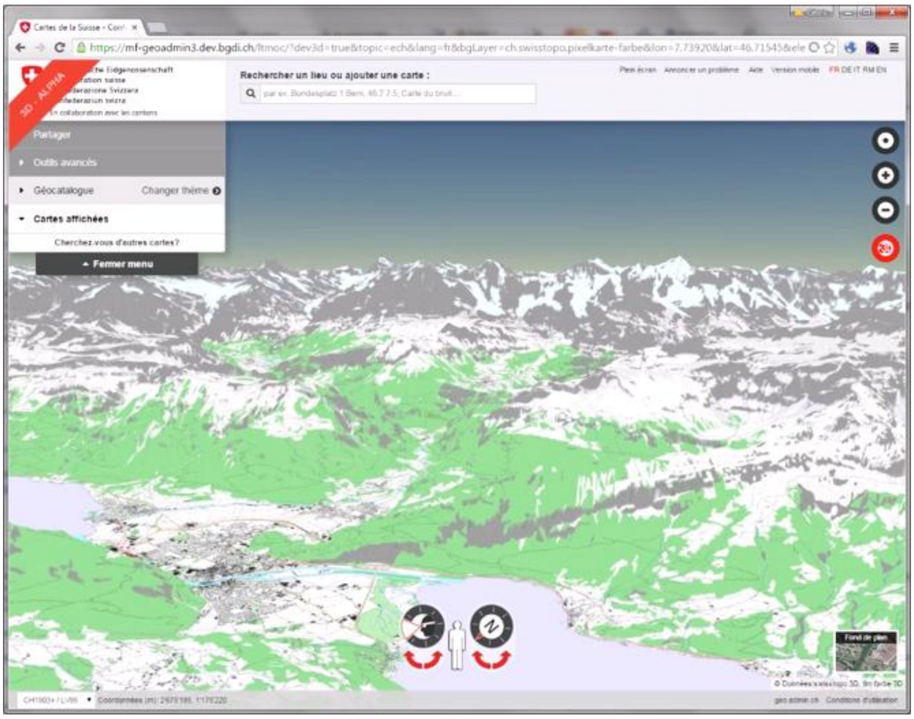

Figure 11 – Preliminary 3D viewer on the federal geoportal of Switzerland

8 3D NATIONAL MAPPING IN THE NETHERLANDS

For several years, 3D mapping at the national level has got attention in The Netherlands. This is driven by a growing need for 3D data in applications such as noise calculation, flooding simulation, solar potential analysis, maintenance of dikes.

For that reason, the standard for large scale topography (IMGeo: Information Model Geography) is modelled as an Application Domain Extension of CityGML (Van den Brink et al, 2013a; 2013b). The standard was established in 2012. All organisations responsible for collecting large scale topography are obliged to provide such data according to the IMGeo standard from 2016 onwards. The 2D part is mandatory; the 3D part is optional. In sequential research, we are investigating several issues to further develop towards a base 3D data provision.

8.1 A national 3D data portal

At first we are investigating how we can publish governmental 3D data (which can be 3D IMGeo, but also other 3D data like cables and pipelines, 3D data bout the geological underground etc) via a national portal. 2D data is being published via a national portal called Publieke Dienstverlening Op de Kaart (www.pdok.nl). In a testbed we will investigate with the community what the best options are for the interactive visualisation of 3D data via the Internet. Candidates for testing are Cesium, i3S (the open standard developed by Esri that contains an Indexed 3D Scene delivery format and the Scene Layer Package definition both encoded using JSON, Esri, 2016). We also plan to investigate the recently established 3D Portrayal Service from the Open Geospatial Consortium. The main challenge will be to publish both semantics and geometry at the same time and preferably directly from the database, without the conversion to other formats.

8.2 3D data reconstruction at national coverage

A second item for research is the national wide 3D data reconstruction.

The extension of IMGeo towards 3D is the responsibility of individual organisations and thus not ready yet to provide a countrywide 3D data set. Therefore, in 2014 a countrywide 3D dataset has been generated from the object-oriented data at scale 1:10k (the largest scale as maintained by the Netherlands' Kadaster) in combination with high-resolution airborne LiDAR data (10+ points/m^2, available as open data). The 3D model was reconstructed in a consortium composed of Kadaster, the Delft University of Technology, the Twente University and the Free University of Amsterdam. For the 3D reconstruction the opensource tool was used developed by (Oude Elberink and Vosselman, 2009a; 2009b; Oude Elberink et al, 2013). The tools reconstruct a surface representation for each class in the 2D map by the integration of the 2D data and high resolution LiDAR data. For the volumetric objects (buildings and plant cover) the 3D reconstruction has until now been limited to LoD1 (block models). The reconstruction is driven by rules that prescribe how to process the LiDAR data, how to model specific object types, and how to connect neighbouring objects in 3D (Oude Elberink and Vosselman, 2009a; 2009b).

The lessons learnt from the reconstruction of 3D TOP10NL data are currently being used to develop a 3D reconstruction tool for 3D IMGeo (i.e. at more detailed level), based on 2D IMGeo data and height points (see Figure 12).

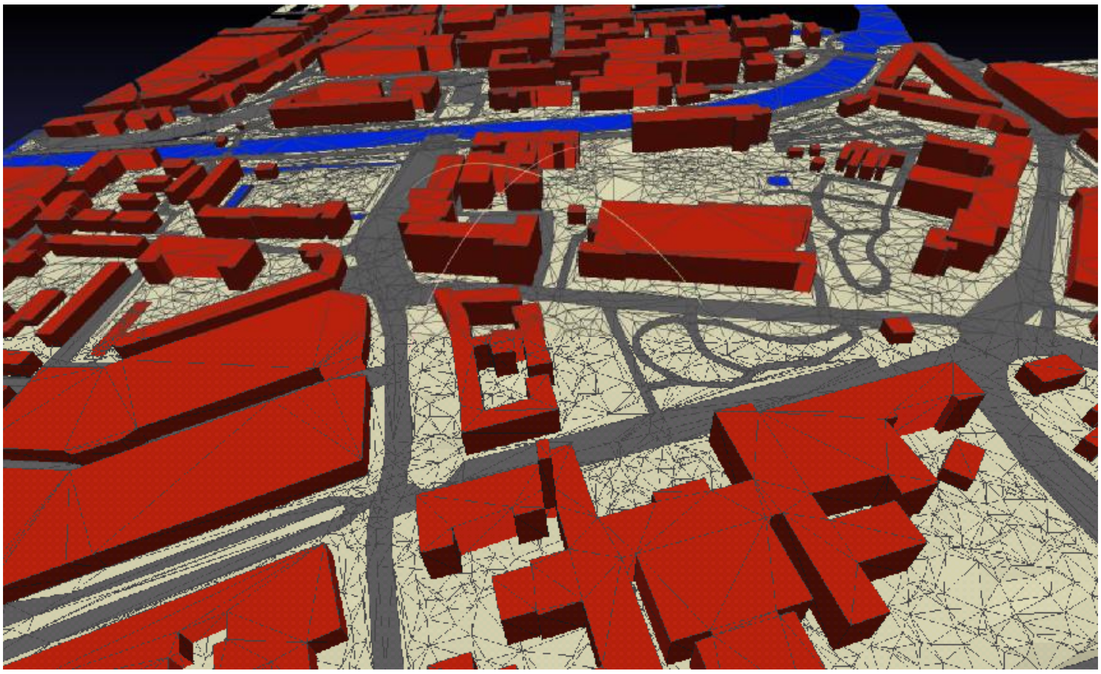

Figure 12 – 3D IMGeo data, automatically reconstructed from 2D IMGeo data and height points

Since the 2D source data set contains significantly more 2D features at higher detail, and since the original process was computational expensive (several fitting of planes with leastsquare adjustment), we are currently investigating simpler alternatives to assigning elevations to the features. Each feature, or part of a feature, would be "lifted" to 3D by using rules such as lowest within a given area (e.g. for water) or by using a certain percentile of all elevations points within an area. This will allow scaling the process to the whole country easily. For the buildings, we plan to decompose each footprint into parts whose elevation is similar. For this we will use the methodology of Commandeur (2012).

To use more updated height data than the LiDAR data (which is acquired every 5-6 years), the Netherlands' Kadaster are also investigating the use of height data obtained from dense image matching.

8.3 Create 3D-proof workflows for governmental organisations

For several governmental workflows it is known that an integrated 3D approach will provide a more efficient way of working. However, this requires a change of work processes as well as additional agreements between different departments and organisations. Therefore, we will select one or two of such workflows and make an integrated 3D approach optionally possible. At first we look at workflows that already make full use of 3D, but that could be more efficient with an integrated approach, such as carrying out a noise study or the process to apply for a building permit. Such cases will show the added value of working in 3D. In addition, they prepare governmental organisations to make the step towards 3D. Enabling a building permit to be submitted and checked in 3D requires that each step in that process supports such data. This workflow operates on the edge between BIM and GIS domains and detailed agreements are needed to make the workflow possible. In addition, an integrated approach to 3D noise studies, from the preparation of the 3D input data, and calculation of noise levels in 3D to dissemination and visualisation of the 3D output data of noise simulation studies, requires a change in the existing work processes. The cases will provide insight into what it takes to perform this work in 3D, starting with countrywide 3D data, including agreements on the relevant 3D data ideally laid down in standards.

8.4 3D cadastre

A related issue on national 3D mapping is 3D cadastre. A 3D cadastre should provide insight into complex ownership. In The Netherlands, like in many other countries, the ownership to real estate is established via 2D parcels. Multi-level ownership is established via limited real rights on the parcel such as easement, right of long lease and right of superficies. Although it is possible to legally establish 3D rights, until recently it was impossible to visualise these 3D rights. However, with the recently established acceptance of digital deeds, the registration of a 3D visualisation of multi-level rights in the form of a 3D PDF has become possible (Stoter et al, 2014). In March 2016, the Dutch Kadaster has registered the first 3D visualisation of the multi-level ownership of a building complex as a 3D PDF (see Figure 13).

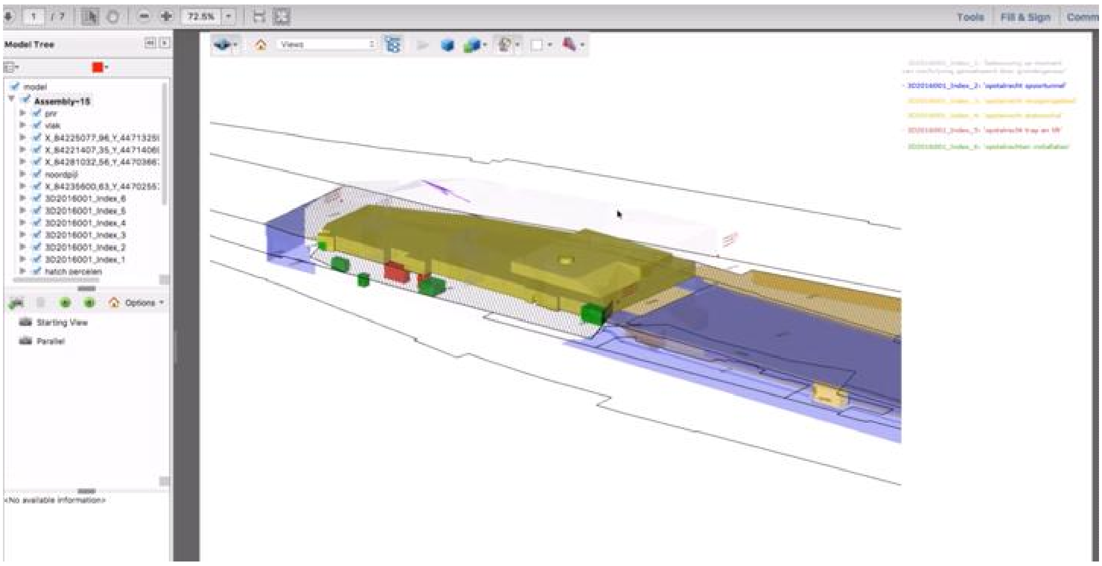

Figure 13 – 3D PDF, official document that visualises rights of multilevel ownership in 3D. It concerns the underground railway station in Delft

The combined structure of the new city hall and the station of Delft, including the underground railway station and railway tunnel, as well as the underground bicycle parking place is the first to be registered in 3D in this way. The construction contains rights of three parties that come together in a compact amount of space: the municipality of Delft as owner of the land, NS Real Estate as holder of the station with shops and installations, lifts and stairs and ProRail / Railinfratrust as holder of the tunnel and the underground station.

For the 3D registration, the Kadaster has worked closely together with the city of Delft and the 3D Geoinformation group of TU Delft. The 3D visualisation was designed by Mecanoo Architects based on the BIM data generated in the design and construction phase. The notary Houthoff Buruma has issued the certificate for the deposit in the Land Registry.

Based on the experiences the registration of a 3D visualisation of complex ownership rights will be further developed and regulations may be adjusted accordingly.

9 CONCLUSIONS AND FUTURE WORK

In this paper we summarised recent developments on national 3D mapping for a selection of NMAs. It shows that NMAs are making significant steps to collect, maintain and provide 3D data to serve a wide variety of applications.

Despite the potentials of 3D, all NMAs observe an underuse of the 3D data they produce. To better understand the mismatch between the availability of 3D data and the use of it (beyond visualisation), the EuroSDR 3D SIG has started a research project on the identification of economic value of 3D geo data. The project is funded through "crowdfunding": eleven National Mapping Agencies (NMAs) and EuroSDR as 12th partner each contribute financially. The results of the project will give the participating NMAs understanding in the business case of 3D data: In what applications does 3D give added value?; What are the required 3D data for these applications?; What are the costs and benefits to collect and maintain these 3D data nationwide? The project has started early 2016 and is expected to run for one year.

Another related activity is the development of common specifications for 3D mapping. The objective of this shared specification for 3D mapping is to define how objects in existing 2D map databases at NMAs could be represented geometrically in 3D. It builds on existing concepts like the Levels of Details, commonly used in CityGML and semantic data specifications of INSPIRE. These common specifications for 3D mapping will support joining 3D experiences and efforts in different countries. In addition they will enable to build on each other's developments and to articulate 3D mapping needs to industry, academia and standardization organisations and initiatives like OGC and INSPIRE.

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EuroSDR – THE PAN-EUROPEAN NETWORK FOR MAPPING AGENCIES AND ACADEMIA

With 7 figures

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Abstract

EuroSDR (http://www.eurosdr.net/) is a non-profit organisation that provides a pan-European network that brings together mapping / cadastre agencies and academia for the purpose of applied research, and securing timely, research-based knowledge that allows the agencies to play their role as content providers and government competence centres for geographic information and spatial data infrastructures.

EuroSDR is the recognised provider of research-based knowledge to a Europe where citizens can readily benefit from geographic information. Its mission is to develop and improve methods, systems and standards for the acquisition, processing, production, maintenance, management, visualization, and dissemination of geographic reference data in support of applications and service delivery.

EuroSDR delivers advanced research-based knowledge. Its value is generated by facilitating interaction between research organisations and the public and private sector with the aim of exchanging ideas and knowledge about relevant research topics; by facilitating and contributing to research projects; and by transferring knowledge and research results to real world applications.

The paper gives an overview about EuroSDR research principles, research alliances, objectives and action plans of each of the technical commissions.

Acknowledgement

The authors would like express their gratitude to all the current and former members of the EuroSDR network for their long and sustainable contribution to the development of our domain.

1 INTRODUCTION

EuroSDR can look back on a very long and successful history of 56 years. On 12 October 1953 the Organisation Européenne d'Etudes Photogrammétriques Experimentales (OEEPE) was established, "... to increase the accuracy, quality and efficiency of aerial surveys by speeding up the development and improvement of photogrammetric methods ...".

The research- and development work within the Organisation has covered all the relevant topics concerning photogrammetry during the past fifty years, including films and cameras, photogrammetric scanners, image co-ordinate measurement, aerial triangulation, digital terrain modelling as well as the manual and automated production and updating of topographic and orthophoto maps and databases.

Thus the Organisation and its members have made a significant contribution to the production of topographic maps and databases in Europe. During the past twenty years the technology has developed rapidly, with new sensors and platforms as well as the development of digital data processing. The Organisation also widened its field of activity in the late 1990's so that it now covers, "… Research- and development of methods, systems and standards for the acquisition, processing, production, maintenance, storing, and dissemination of core geospatial data and information ...", as is recorded in the Agreement on the Formation of the European Spatial Data Research (EuroSDR) in 2003.

Today EuroSDR is a non-profit organisation that provides a pan-European network that brings together mapping / cadastre agencies and academia for the purpose of applied research, and securing timely, research-based knowledge that allows the agencies to play their role as content providers and government competence centres for geographic information and spatial data infrastructures.

This is achieved by a network of delegated from European national mapping and/or cadastral agencies and academia, who initiates and conducts corporate research projects and benchmark projects in the field of geoinfomation and their application. With this close and institutional collaboration between practice and research EuroSDR is unique in Europe.

The field of research, development and education of EuroSDR covers the whole technical field of data acquisition, modelling and processing, updating and integration, information usage, business models and operations, and knowledge transfer of geographic information. The research activities of EuroSDR are carried out through projects and workshops. These can be executed by EuroSDR alone or in collaboration with other organisations and companies.

2 EUROSDR VISION, MISSION AND VALUE PREPOSITION

2.1 Vision

EuroSDR is the recognised provider of research-based knowledge to a Europe where citizens can readily benefit from geographic information.

2.2 Mission

To develop and improve methods, systems and standards for the acquisition, processing, production, maintenance, management, visualization, and dissemination of geographic reference data in support of applications and service delivery.

To be the European research platform for National Mapping and Cadastre Agencies (NMCA's), Academic Institutes, the Private Sector, Industry and User Groups, on issues related to the implementation of technology developments with respect to optimising the provision (collection, processing, storage, maintenance, visualisation, dissemination and use) of spatial information (data serving as a reference framework for organisations involved in monitoring, management and development) in a Geoinformation Infrastructure (GI) context.

2.3 Value proposition

EuroSDR's value is generated by facilitating interaction between research organisations and the public and private sector with the aim of exchanging ideas and knowledge about relevant research topics; by facilitating and contributing to research projects; and by transferring knowledge and research results to real world applications. The products and services offered by EuroSDR are

- Network for members
- Workshops
- Benchmarks
- Project setup facilitation
- Project results
- Contribution to standards
- Guidelines and best practices

- Education
- Publications (including EuroSDR web-page)

3 OPERATION

EuroSDR aims to prioritize activities that generate researchbased knowledge that give maximum cost benefit to its stakeholders. The organization considers cooperation between mapping / cadastre agencies and academia as well as related geo-associations and industry as important elements in its operation. The strategic objectives will be achieved through the following means:

- Delegates meetings
- Workshops
- Research projects
- Publications
- Educational activities

3.1 Delegates meetings

The Board of Delegates consists of representatives of the EuroSDR member countries and is the supreme decisionmaking body of EuroSDR. It meets twice per year and handles scientific matters, such as the research plan, projects and results as well as other relevant scientific, technical and administrative matters, which are discussed and necessary decisions are made. It consist of keynote presentations and focussed discussions on sharing best practise and mastering new challenges. The Board of Delegates it the central medium for communication, decision and networking of the members.

Figure 1 – Board of Delegates meeting (Leuven, 2014)

3.2 Workshops

Workshops are dialogue-based events where real world problems, industry achievements and developments are discussed amongst experts and researchers. Workshops present the state-of-the-art in a particular field, may result in identification of research topics and may also be used for planning and dissemination of information on research activities. These workshops are documented and information is available for members.

Figure 2 – EuroSDR/ISPRS workshop 'Efficient capturing of 3D objects at a national level: with a focus on buildings and infrastructure', 27 - 28 november 2014 (Ordnance Survey, Southampton, UK)

3.3 Research projects

EuroSDR's supports especially the interaction between research organisations and the public and private sector with the aim of exchanging ideas and knowledge about relevant research topics; by facilitating and contributing to research projects; and by transferring knowledge and research results to real world applications.

The research activities are carried out through projects. The projects can be executed by EuroSDR alone or in collaboration with other organisations and companies. Typical research projects last for a limited time (1-3 years), are multi-site approaches with experiments using data acquired/provided by the participants, support the knowledge transfer through active participation of member and nonmember organisations and are the results are published in the official EuroSDR series.

3.4 Publication

The EuroSDR web-page is the prime vehicle for information dissemination from EuroSDR. Reports including results from research projects and workshops, annual reports and newsletters containing information about activities of EuroSDR are in addition published by other media, such as the official publications series of EuroSDR.

3.5 *Educational activities*

Specific E-learning courses are offered to facilitate the transfer of outcomes from EuroSDR's research activities. The educational activities will complement the research and workshop reports and address the issue of capacity building and competence development amongst stakeholders.

4 RESEARCH

EuroSDR delivers advanced research-based knowledge. Its value is mainly generated by facilitating interaction between research organizations and the public and private sector with the aim of exchanging ideas and knowledge about relevant research problems; by facilitating and contributing to research projects; and by transferring knowledge and research results to the production domain.

4.1 *EuroSDR Research principles*

The research activities of EuroSDR have the following principles:

- EuroSDR delivers advanced research-based knowledge.
- Research activities of EuroSDR are carried out through projects and workshops.
- Research activities address one or more of the technical fields of data acquisition, modelling and processing, updating and integration, information usage, business models and operations, or knowledge transfer of geographic information.
- Research activities are reported on the EuroSDR website and final reports of a EuroSDR project are compiled, edited and peer-reviewed in order to become an official EuroSDR publication.
- EuroSDR will provide educational activities ensuring the dissemination of the research-based knowledge gained.
- Research activities are be executed by EuroSDR alone or in collaboration with other organizations and companies.

4.2 *EuroSDR Research alliances*

To ensure a global perspective and participation EuroSDR will actively seek to intensify cooperation and collaboration with sister organisations at the European level and beyond. As such EuroSDR has active cooperations with:

- the association of the European National Mapping, Cadastre and Land Registry Authorities (EuroGeographics),
- the International Society for Photogrammetry and Remote Sensing (ISPRS),
- the International Cartographic Association,
- the International Association of Geodesy (IAG),
- the Fédération Internationale des Géomètres / International Federation of Surveyors (FIG),
- the Global Spatial Data Infrastructure Association (GSDI),
- the International Organisation for Standardisation (ISO),

- the Comitè Europèen de Normalisation / European Committee for Standardisation (CEN),
- the Open GeoSpatial Consortium (OGC),
- the World Wide Web Consortium (W3C),
- the European Space Agency (ESA),
- and others.

5 EUROSDR COMMISSIONS

The research of EuroSDR covers the whole geoinformation management cyle, ranging from the raw data acquisition to the end user of this information, with a focus on methods, systems and standards for the acquisition, processing, production, maintenance, management, visualization, and dissemination of geographic reference data.

The Commissions serve as a catalyst between the research projects and the EuroSDR network. The Commissions give a report on the relevant activities at every Board of Delegates meeting.

EuroSDR has the following six commissions:

• Commission 1: Data acquisition

• Commission 2: Modelling and Processing

• Commission 3: Updating and Integration

• Commission 4: Information Usage

• Commission 5: Business Models and Operations

• Commission 6: Knowledge Transfer

The network of the commission's work and the interaction of

the commission is expressed in Figure 3.

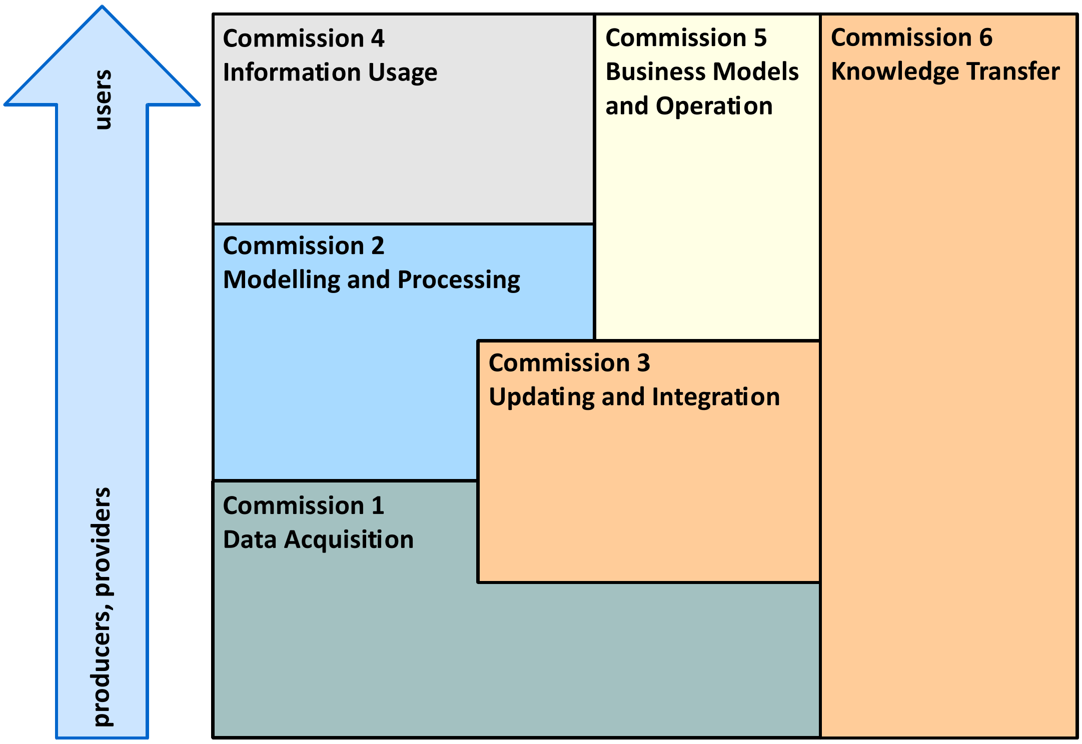

Figure 3 – Network of the commission's work and interaction

The following chapters describe the objectives and action items of each EuroSDR Commission.

5.1 COMMISSION 1: DATA ACQUSITION

EuroSDR Commission 1 focuses on the initial phase of the entire mapping pipeline, i.e. data acquisition. The main objective of Commission I is to explore, test and validate platforms, sensors and algorithms used to acquire geo-spatial data, with emphasis on accuracy, reliability and standardization of data processing procedures. The research activities of the commission therefore touch platforms and sensors (satellite, oblique and nadir cameras, RPAS, mobile mapping, etc.) as well as geo-referencing, matching and positioning algorithms. Some of these topics are clearly overlapping with other commissions (e.g. Commission 2 and 3) showing how commissions and activities are interlinked.

The ongoing and recently closed Commission 1 activities includes:

- EuroDAC – EuroSDR network on Digital Camera Calibration and Validation (Cramer, 2008);
- Medium Format Digital Camera (Grenzdoerffer, 2008; 2010);
- Radiometric Aspects of Digital Photogrammetric Images (Honkavaaraa et al., 2009);
- RPAS/UAV (Everaerts, 2009);
- Oblique aerial imagery / Multi-platform photogrammetry (Remondino and Gerke, 2015).

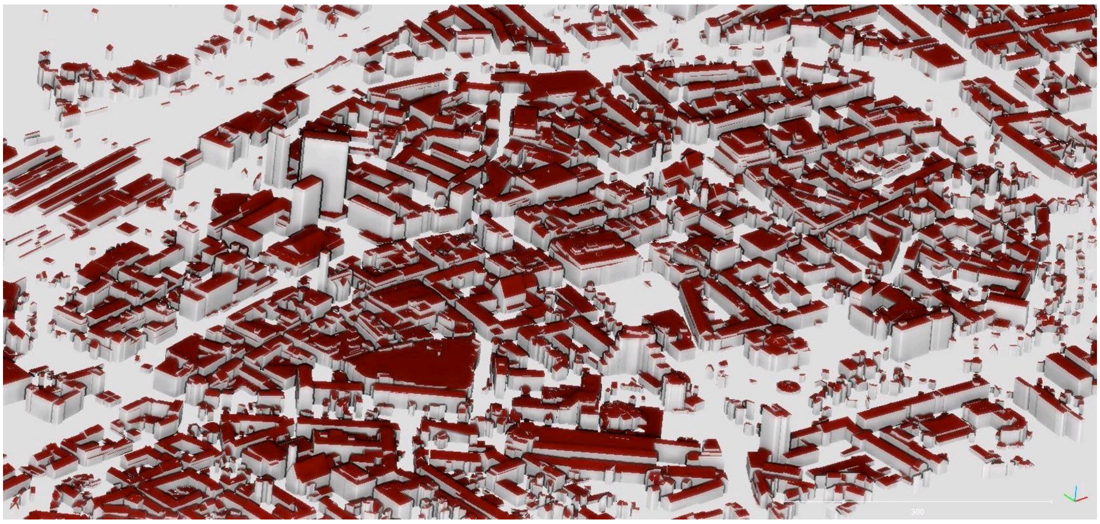

Figure 4 – 3D building blocks (LOD2) automatically generated from oblique imagery

In particular, the oblique imagery activity (see Figure 4) started in 2013 to evaluate potentials and limitations of this technology and continuously update EuroSDR members on the ongoing developments in sensors and software. Within the activity, an international workshop was held in Southampton with more than 100 participants from R&D, companies and mapping agencies (http://www.eurosdr.net/workshops/eurosdrisprsworkshop- oblique-cameras-and-dense-image-matching).

A potential new activity under consideration deals with mapping from high-resolution satellite imagery for mapping purposes.

5.2 COMMISSION 2: MODELLING AND PROCESSING

Commission 2 focuses on advanced ways of modelling and processing 2D and 3D spatio-temporal data: How to structure such data which can be in any form and hence very heterogeneous and massive (i.e.”big”): points clouds, object oriented data sets, at different levels of detail (i.e scale), above and underground, collected for different applications; How to maintain and update the large amount of heterogeneous data? How to process the 2D/3D data and how to distribute the 2D/3D spatial information via the Web?

Topics of this commission are: Data models, information models and data structures; 3D GIS, also in relation to BIM; Time; Database management systems; Multi-scale & generalisation; big data; geoprocessing; cartography (incl. web cartography); validation of spatial data and cleaning; high density image matching; and standards.

One of the activities of this commission is the activity on data modelling and model driven implementation of data distribution (with Commission 4). NMCAs and other spatial data infrastructure (SDI) content providers are facing increasing demand for making well-documented data in known data models available as standardised web-services. National egovernment initiatives require spatial data to be modelled seamlessly with non-spatial data; INSPIRE puts requirements on GML application schemas and web-service standards; and the European Location Framework (ELF) project brings the national SDIs together in a pan-European context. Data modelling as such is a mature discipline, but how best to handle a number of specific modelling issues for geo-data is still challenging. In addition, although the potential benefits of implementing an automated data distribution environment are obvious and automated generation of GML application schemas based on UML data models is widely used (e.g. in INSPIRE context), many considerations need to be taken into account when making the data models, and automatically generating database schemas. Web-services based on UML data models add even another level of complexity. The commission aims to contribute to finding solutions to these challenges, like the workshop we organised in 2015 on this topic with relevant partners (i.e. OGC. ELF, AGILE and JRC). The workshop outcomes and materials are available via the EuroSDR website (EuroSDR, 2015).

Another main research topic is automated map generalisation, i.e. the automated extraction of a less detailed map from a highly detailed map as is the traditional task of NMAs (see Figure 5).

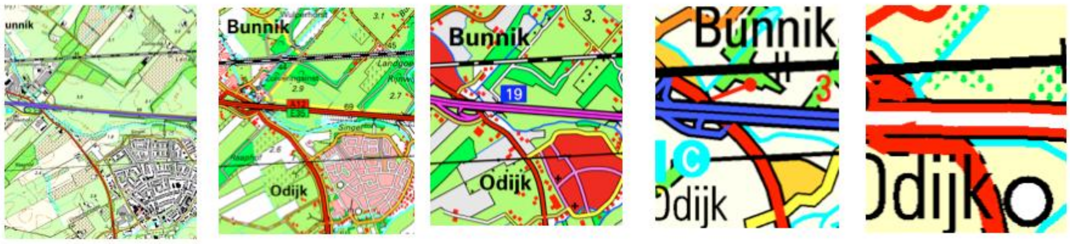

Figure 5 – Map series of Netherlands' Kadaster (1:10k, 1:50k, 1:100k, 1:250k, 1:500k)

This topics significantly benefits from the close collaboration between researchers, NMAs and industry in EuroSDR. Since decades researchers have studied the complex problem of automating a process that used to be done by cartographers. Recently, there have been several automated generalisation achievements in practice, such as the automated generalisation of OS MasterMap to OS VectorMap District in Great Britain (Regnauld, 2011) and the replacement of the manual generalisation production line by a fully automated workflow at the Dutch Kadaster of the 1:50k map series (Stoter, et al, 2014). Other examples of automated generalisation solutions have been published by Duchene et all (2014). The activities of EuroSDR on multi-scale & generalisation are often done in collaboration with the Commission on Generalisation and Multiple Representation of the International Cartographic Associations. For example, two workshop have been organised to exchange the experiences of automated generalisation within National Mapping Agencies and to identify open issues, see ICA (2013; 2015).

Another main research topic of this commission is on 3D mapping. Techniques for collecting, reconstructing and maintaining 3D information have matured and many applications make use of 3D data ranging from flooding and noise simulations to energy and urban heat island calculation. Consequently, there is an increasing need for up-to-date, countrywide 3D data. Several National Mapping Agencies in Europe are making the step from 2D to 3D mapping to produce such data or are considering to make this step (see Figure 6).

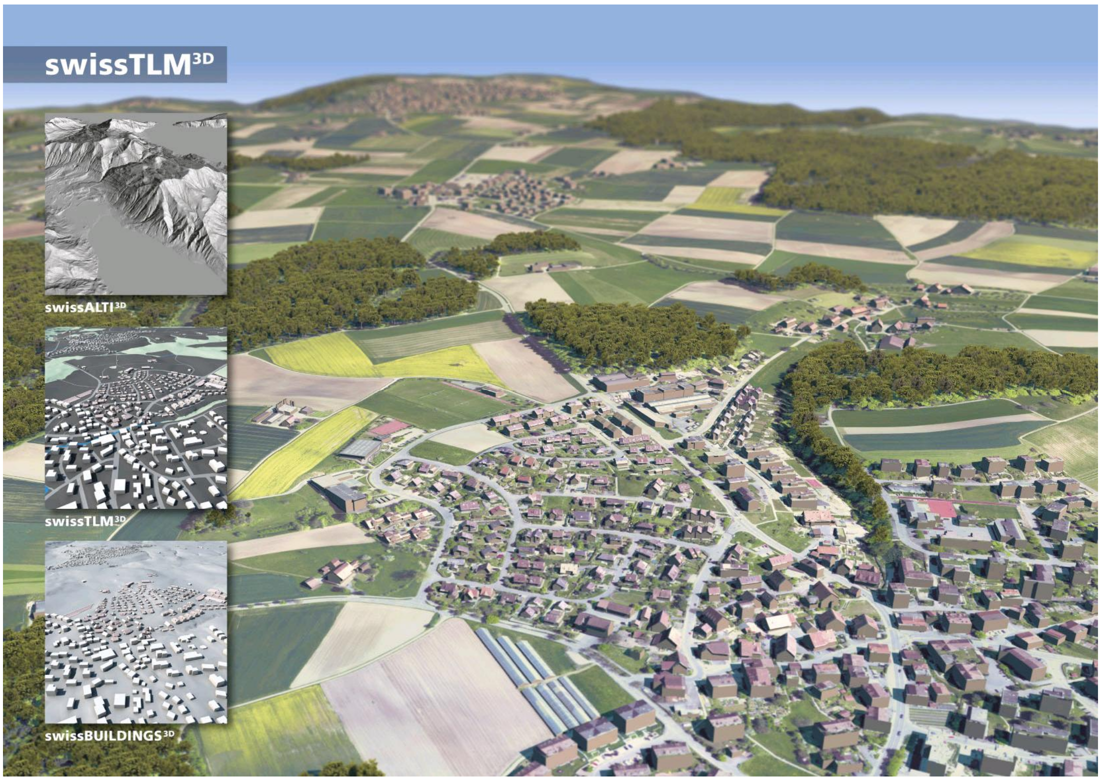

Figure 6 – 3D topographic landscape model created by swisstopo

To join experiences and pursue the research agenda for 3D mapping, twelve European National Mapping Agencies of EuroSDR have organised themselves in a 3D Special Interest Group, i.e. EuroSDR 3D SIG (Stoter et al, 2014). The group meets two till three times a year to exchange experiences and to work on the working plan of the group. The group organises workshops on open issues like on the efficient capturing of 3D objects at national level in 2014.

In addition, they are developing common specifications for 3D mapping. The objective of this shared specification for 3D mapping is to define how objects in existing 2D map databases at NMAs could be represented geometrically in 3D. It builds on existing concepts like the Levels of Details, commonly used in CityGML (Gröger and Plümer, 2012). Another activity of the EuroSDR 3D SIG was its contribution to the Quality Interoperability Experiment (QIE) on defining and validating data quality requirements of CityGML data (OGC, 2014; Ledoux, 2014). This was a joint initiative of OGC, SIG3D and EuroSDR 3D SIG. The aim of the experiments was to formally define data quality requirements for a general CityGML data specification, to provide recommended implementation guidance for 3D data, and to provide a suite of essential quality checking tools to carry out quality assurance on CityGML data. This has been accomplished by evaluating the quality of existing CityGML data as well as of CityGML sample data sets that have been specifically developed for this experiment with different quality checking tools. The report of the QIE will be published in June, 2016.

Another ongoing activity of the EuroSDR 3D SIG, is the project on "assessing the economic value of 3D geo-information", together with EuroSDR commission 5. Despite the potentials of 3D, the NMAs in EuroSDR 3D SIG observe an underuse of the 3D data they produce. The project aims at better understanding the mismatch between the availability of 3D data they produce and the use of it (beyond visualisation) to be able to address this gap. The project has started early 2016 and is expected to run for one year.

The project has started with an analysis of uses cases in which 3D gives added value. For a selection of these use cases the value chain for NMAs will be assessed. The project is funded through “crowdfunding”: eleven National Mapping Agencies (NMAs) and EuroSDR as 12th partner each contribute financially. The results of the project will give the participating NMAs understanding in the business case of 3D data: In what applications does 3D give added value? What are the required 3D data for these applications? What are the costs and benefits to collect and maintain these 3D data nationwide? Potential new activities of the EuroSDR commission on modelling and processing are: Mapping from high-resolution satellite imagery; Exploitation and usage of cloud processing services in NMCA and a Benchmark project on high density imaging for updating 3D data products (e.g. 3D topographical data sets).

5.3 COMMISSION 3: UPDATING AND INTEGRATION

Commission 3 concentrates on what has been a key objective of NMCAs ever since, namely the updating of geospatial information, often based on change detection. As the production environments changed from standard data flows using one type of sensor only, i.e. the aerial photogrammetric camera, to a multitude of sources, including now LiDAR, volunteered geographic information (Mooney and Morley, 2014), geodata from terrestrial mobile platforms, and satellite imagery, the integration of different data streams became important.

Update cycles for the entire topographic information used to be in the order of 5 years, but decreased in some EuroSDR member countries to 3 or even 2 years for the entire national area. Thus, the efficiency is becoming more and more a matter of concern, and this mandates the development of automated, if not completely automatic, update procedures. A continuous update stream for authorative nation-wide data is currently available for some special classes in some countries (e.g. routable road networks, cadastral boundaries). Still, this is not typical for all classes of topographic information. Nonetheless, it demonstrates future expectations.

Having finalized “map” updating in a certain area makes the old map historic data. An organized set of time-stamped data allows monitoring processes. Thus, only structured archiving of historic data secures the value of such a record. This includes notably the archiving of metadata as well.

A key challenge in updating geospatial data and the integration of different geospatial data sets is maintenance of the quality of the data.

Commission 3 thus aspires to contribute to advanced ways of updating and integration of spatial information by investigating, demonstrating, evaluating and documenting new methods.

The ongoing and recently finalized activities of commission 3 thus include projects and workshops on:

- Updating topographic databases from images (Domenech and Mallet, 2014)
- Updating topographic databases from Lidar (ongoing)
- Preparing for Sentinel-2 data
- Using mobile LiDAR in city areas, with a concentration on the accuracy of object extraction (Lin et al., 2013)

- High density aerial image matching for DSM generation
- Laser scanning in forests
- Archiving geospatial information, published as white paper (EuroSDR, 2014)
- Understanding and using historical data

Obviously, there is some overlap with topics which are also encountered in other commissions (e.g. Commission 1, on data acquisition). In order to shed more light on the activities, information on a few projects and workshops is provided below. One workshop was held on preparations for Sentinel-2 data in Europe. Sentinel-2 is a satellite observing the Earth surface with a GSD of 10m and 20m, resp., for bands in the visible and near and mid infrared. At the equator it has a revisit time of 10 days. With the planned constellation of 2 satellites, the revisit time will drop to 5 days and even less at higher latitudes. During the workshop, concerns on the orthorectification, especially for the northern European counties were raised, as well as the distribution of the massive imagery. Also the information level of NMCAs and other governmental agencies (e.g. on environment) varied considerably within Europe. On the other hand, “change alerting” has been identified as one topic of especial interest for NMCAs, which is compatible with the resolution and could probably benefit from the high revisit frequency (EuroSDR, 2014).

High density image matching was executed as a series of two consecutive benchmark projects. It included participants from industry (software vendors), academia, and mapping agencies. High resolution imagery was made available to test participants, which used their own and/or commercially available algorithms for the generation of digital surface models (Haala et al., 2013). The outcome of this workshop demonstrated the maturity of the algorithms. The method became standard in many NMCAs in the meantime.

Nation-wide generation of height data is an ongoing task within most European national mapping agencies. However, the status and requirements are quite different among the different NMA’s, and therefore it is difficult to find suitable fields for cooperation. A workshop on this topic was held in January 2016, with participants from both NMA’s and private companies. The main objective was to discuss different aspects about laser data and other sources used for generation of detailed height data at a national level (EuroSDR, 2016).

Finally, a benchmark project currently (2015-2016) running investigates using terrestrial laser scanning (TLS) in forests. Data was acquired with two standard configurations (1 central scan vs. 1 central and 4 peripheral scans) in more than 20 plots featuring different types of undergrowth (from none/sparse to dense), terrains shape, and tree distribution (in species, distance, maturity, etc.). First results are published (Liang et al., 2016), demonstrating the advantage of a multi-scan configuration and the high accuracy reached by TLS in retrieving DBH (tree diameter at breast height) and the stem curve, i.e. the change of the radius with tree height (see Figure 7).

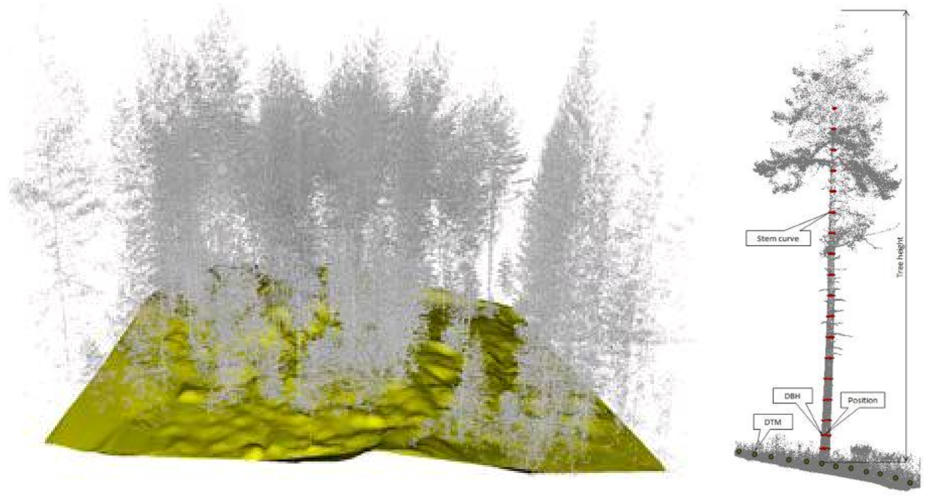

Figure 7 – TLS in Forestry benchmark, Left: extracted DTM and point cloud of trees, Right: example of reference data: DTM, DBH, tree position and stem curve (tree height not shown)

5.4 COMMISSION 4: INFORMATION USAGE

The mission of Commission 4 is to explore, demonstrate and contribute to further increase in access to authorized geodata, and contribute to improve the mechanisms for dissemination of geodata from database to end user. The Commission 4 also cover to investigate, evaluate and document developments in the technologies for data integration, service-level interoperability and delivery of all forms of geoinformation, data and services.

Following EuroSDR position paper on Linked data, an EuroSDR Linked Data seminar was organized by the Dutch Kadaster and IGN France in Paris in April 2015. The goal was to get more insight in the potential contributions and potential new needs brought by these new technologies to the domain of geo-referencing in the largest sense, i.e. location framework on the Web and for the Web. One of the conclusions was that there is a need to connect different European initiatives related to authoritative data with a location, and linked data (EuroSDR 2015b).

Based on outputs from the first seminar and on discussions at the following EuroSDR board of delegates meeting, the decision was made to adopt a perspective centered on the problems to be solved rather than on the technology. IGN France and Dutch Kadaster framed a new event aiming at reaching a common ground between people with different backgrounds in location framework on the web, practically Linked data believers and people attached to GI science unsolved issues. It was organized in February 2016, jointly with the meeting of the Spatial Data on the Web working group of W3C and OGC.

5.5 COMMISSION 5: BUSINESS MODELS AND OPERATION

This is a new commission (founded in 2015) as research issues related to the businesses become more relevant for NMCA's (see United Nations Committee of Experts on Global Geospatial Information Management, 2013). This does not mean that this topic was fully ignored in the past (see for example projects on INSPIRE (Vanden Berghe et al., 2011; De Vries et al., 2011), crowdsourcing (Mooney and Morley, 2014) and preservation of the geographic information production process. With business models we refer to definition of Al-Debei et al. (2008): 'Abstract representation of an organization (in particular a NMCA), be it conceptual, textual, and/or graphical, of all core interrelated architectural, cooperational, and financial arrangements designed and developed by an organization presently and in the future, as well as all core products and/or services the organization offers, or will offer, based on these arrangements that are needed to achieve its strategic goals and objectives'. This definition indicates that value proposition, value architecture (the organizational infrastructure and technological architecture that allows the movement of products, services, and information), value finance (modeling information related to total cost of ownership, pricing methods, and revenue structure), and value network articulate the primary constructs or dimensions of business models (Al-Debei and Avison., 2010).

The main objective of this Commission 5 is to contribute to the development and implementation of business models describing the rationale of how NMCA's can create, deliver, and capture value, in economic, legal, social, governance, cultural or other contexts. As such, the scope of this commission is wider than the one according to the definition of Al-Debei et al. (2008).

Commission 5 also takes into account issues related to governance (such as coordination structures, policy management and partnerships) and legalisation (such as privacy, liability, licensing, security, IPR) as they form key contextual factors for shaping appropriate business models.

Commission 5 has the ambition to initiate projects and workshops on topics such as: business modelling for spatial data infrastructure, Geographic information valuing, Geospatial brokering, Governance modelling for geographic information management (incl. structures, Roles, Task allocations), (Marine) spatial data infrastructure concepts and implementations, and Open data business models.

Since the foundation of Commission 5 has already co-organised a workshop 'Tutorial on Cost Benefit Analysis in the context of Geospatial Information' (Paris, 9 March) together with OECD, NASA and USGS, wrote a discussion paper on NMCAs' adaptations to alternative sources for the EuroGeographics General Assembly 2015 (Crompvoets et al., 2015), relaunched the second phase of the 'Crowdsourcing and National Mapping' project, and initiated projects on 'Coastal spatial data infrastructures' to seamlessly integrate marine and terrestrial data as well as 'Business models for open data of NMCA data' to review relevant business models, identify the implications for applying these business models.

5.6 COMMISSION 6: KNOWLEDGE TRANSFER

The main purpose of the newly established commission is to support the transfer of knowledge from EuroSDR research projects to NMCAs, academia and industry and to fulfil specific NMCAs demands for knowledge update. Its activities cover educational services and dissemination of methodologies, developed tools and research reports in the form of EuroSDR official publications and via the EuroSDR homepage. The commission works in close collaboration with the commissions 1-5 (see Figure 1).

Since 2002, EuroSDR annually offers four two-week e-learning courses combined with a two-day pre-course seminar on topics that are basically generated from the EuroSDR research projects (Fritsch et al., 2012). This fact makes the EuroSDR educational service (EduServ) unique in the sense that it reflects the newest developments in the field of geoinformation science and technology and at the same time it meets requirements of NMCAs personnel for knowledge update in this field. In average, EduServ is yearly attended by thirty participants from NMCAs, academia and industry, mostly from European countries.

As a new educational activity built on the EuroSDR network, an intensive one week residential course in gravity and height for national mapping and geodetic surveying was arranged by Dublin Institute of Technology (DIT) in spring 2015. Collaboration among specialists from DIT, the Swedish Lantmäteriet, the Dublin Institute of Advanced Studies and Ordnance Survey Ireland resulted in the design of a 5 ECTS course open to staff of NMCAs, public authorities and Master/PhD students interested in height determination and maintenance. Continuation of this new model of cooperation among EuroSDR members in education and capacity building is currently in discussion.

In order to strengthen its network in academia and especially to attract young scientist, EuroSDR has established an award for the best PhD thesis that has significantly contributed to the development of geoinformation science in the context of national mapping and cadastre. Starting from 2016, the awarded candidates will be invited to present their work at the autumnal board of delegates meeting.

Looking to near future, in addition to on-going activities the commission would like to establish a closer collaboration on organizing short courses or on development of e-learning materials with related associations (e.g. ISPRS, ICA, AGILE).

6 CONCLUSION

EuroSDR is a non-profit organisation that provides a pan- European network that brings together mapping / cadastre agencies and academia for the purpose of applied research, and securing timely, research-based knowledge that allows the agencies to play their role as content providers and government competence centres for geographic information and spatial data infrastructures.

EuroSDR is since more than 50 years a recognised provider of research-based knowledge to a Europe where citizens can readily benefit from geographic information. Its mission is to develop and improve methods, systems and standards for the acquisition, processing, production, maintenance, management, visualization, and dissemination of geographic reference data in support of applications and service delivery.

The network delivers advanced research-based knowledge. Its value is generated by facilitating interaction between research organisations and the public and private sector with the aim of exchanging ideas and knowledge about relevant research topics; by facilitating and contributing to research projects; and by transferring knowledge and research results to real world applications.

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