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January 28th - 29th 2020 - Valletta, Malta

Jonathan Holmes, Carol Agius, Joep Crompvoets

Workshop Report

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"3rd International Workshop on Spatial Data Quality (SDQ 2020)"

joint workshop of EuroGeographics, EuroSDR, OGC, ISO TC 211, ICA

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3rd INTERNATIONAL WORKSHOP ON SPATIAL DATA QUALITY (SDQ 2020)

joint workshop of
EuroGeographics, EuroSDR, Open Geospatial Consortium (OGC),
International Organisation for Standardisation Technical Committee 211 (ISO TC 211),
International Cartographic Association (ICA)

January 28th - 29th 2020 - Valletta, Malta

Workshop Report and Contributions

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1 INTRODUCTION

Demands for spatial data are ever increasing, outstripping the capabilities of the methods by which they have traditionally been provided. New capture methods, improved technology and an increasingly diverse customer base are driving the geospatial industry forward at an alarming rate. Consumers of data recognise the importance of location and expect geospatial information to be readily available, accurate, trustworthy and free.

This fast-evolving landscape necessitates that data quality and quality management must evolve to embrace the new technologies, methods of data capture and date use. To maintain their long-standing role of providers of trusted official data, National Mapping and Cadastral Agencies (NMCAs) have to keep up with these evolving needs and trends.

The international workshops on Spatial Data Quality are organised specifically to bring together producers, users, academia and software suppliers into one event to provide innovative and original contributions to the ongoing debate on spatial data quality. They are organised and hosted by two not-for profit entities: EuroGeographics, the association for Europe's National Mapping, Cadastral and Land Registry Authorities, and EuroSDR, the network of European geographic information organisations and research institutes.

Following previous successful workshops in 2015 and 2018, EuroGeographics and EuroSDR, in conjunction with OGC, ISO and ICA, organised a third workshop on spatial data quality in Valletta, Malta in January 2020. The workshop was sponsored by 1Spatial.

The topics presented at the workshop were many and varied, as demonstrated by the papers and abstracts provided in this publication. The richness of the discussion and debate is illustrated by the broad scope of the topics and subject matter of these papers. Quality issues are varied and must be considered from different points of view. EuroGeographics and EuroSDR are proud of the range of themes covered in this publication.

Highlights include examples of how national data providers are meeting the challenge of managing quality from multiple suppliers and how new methods are enabling them to do so. Several papers cover these areas. Users are interested in locating and using data and we have examples of how data suppliers can communicate this information to end-users in new and informative ways. Authoritative data and its provenance are discussions close to the hearts of both national geospatial data providers and users as demonstrated in two papers presented here. Also included are case studies of good practice in implementing quality at the heart of production, whilst other papers provide an overview of data quality perspectives in e-Government. No discussion covering spatial data quality is complete unless it touches on standards, the topic here being the motivation for revising ISO 19157:2013 Geographic Information – Data Quality.

These papers are provided as an illustration of the rich and broad conversation around quality which is engaging data providers, researchers and users of geospatial data. We hope that their publication will contribute to the ongoing debate around spatial data quality and how best to measure it.

Jonathan Holmes – SDQ 2020 Conference Chair

and

Carol Agius – SDQ 2020 Organising Committee

2 CONTRIBUTIONS

Topics presented during the workshop were:

1. Evaluation of Height Models
2. Motivation and the Need for the Revision of ISO 19157:2013
   Geographic Information – Data Quality
3. Data Quality for Use: A Linked Data Approach
4. Data Quality in an e-Government Perspective
5. Building Register – Basis for 3D Cadastre
6. Rebuilding the Cadastral Map of The Netherlands, overall Concept & Communication on Geometric Quality
7. The Quality Control Column Set: An Alternative to the Confusion Matrix for Thematic Accuracy Quality Controls
8. Count Based Quality Control of "As Built" BIM Datasets using the ISO 19157 Framework
9. Solutions for Encouraging Spatial Data Producers to Co-Operate in Harmonizing National Topographic Data
10. Evaluating Quality of Spatial Data Coming from Multiple Suppliers
    Case Finnish National Topographic Database
11. Understanding the Importance of Provenance from the Perspective of a Geospatial Decision-Maker
12. Collaborative User Oriented Metadata Production on EuroSDR Geometadatalabs Platform
13. Authoritative Geospatial Data and its Quality
14. Ohsome – OpenStreetMap data quality analysis
15. Thematic accuracy and completeness of topographic maps
16. Data Maturity – Geo data growing up
17. Creating Data Quality Models
18. The Malta experience
19. New common method for declaring data quality in Denmark

For the first 13 presentations a paper or an (extended) abstract is included in this report.

All 19 presentations are available for download at http://www.eurosdr.net/workshops/3rd-international-workshop-spatial-data-quality.

Evaluation of Height Models

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Abstract

Height models are a basic requirement for spatial data. For qualified use, it is necessary to have information about the geometric data quality. Several investigations of height models exist, but only very few are really qualified. It is not enough to determine just the accuracy for a terrain up to a threshold of 10% or 20% slope and above it, also shifts of the height model in X, Y and Z are required as well as more complex accuracy dependencies, higher degree systematic errors and the morphologic quality. Standard commercial programs usually do not allow a detailed analysis.

Several height models, based on LiDAR, aerial images, satellite images and satellite based Interferometric Synthetic Aperture Radar (InSAR) have been evaluated with specially developed programs. Reference height models with the same or a better accuracy have been used. The required detailed analysis and the achieved results for some typical height models are described.

Keywords: evaluation, DSM, DTM, accuracy functions, systematic errors

1. Introduction

The quality of height models cannot be described just by one or two accuracy numbers. At first, different accuracy numbers are available, as Root Mean Square (RMS), standard deviation of the height (SZ), Median Absolute Deviation (MAD) and Normalized Medium Absolute Deviation (NMAD) and Linear Error with 90% (LE90) or 95% (LE95) probability; secondly, the accuracy depends on the terrain inclination and other parameters; at third, systematic errors exist, as constant height shifts and more complex systematic errors and at fourth, the relative accuracy – the accuracy of a height value in relation to the neighbored one – may not be the same as the absolute accuracy. In addition, also the horizontal accuracy of a height value has to be respected. In addition to the location accuracy, horizontal shifts of the height models are common. A height model may be a Digital Surface Model (DSM), describing the height of the visible surface or a Digital Terrain Model (DTM), describing the bare ground. A Digital Elevation Model (DEM), as general term for a height model, may be based on a raster of height data with optionally additional information as break lines or it may be based on randomly distributed height values, handled as Triangulated Irregular Network (TIN). The morphologic quality, describing the local variation of the terrain is important; it depends on the relative accuracy and the point spacing.

Nearly worldwide covering height models are available free of charge or commercially; their evaluations have been published. Especially the SRTM height model, based on InSAR, is used today as standard for several applications; it was investigated in detail, e.g. (Rodriguez et al. 2003, 143 pages). Also the improvement of SRTM to 1 arcsec point spacing (~30m) was analyzed (Mukul et al. 2016). The ASTER GDEM2 DSM, based on all stereo combinations of the optical satellite ASTER, was investigated by (Tetsushi et al. 2011, Gesch et al. 2016). A strong improvement came with the ALOS World 3D (AW3D), based on all usable optical stereo combinations of ALOS PRISM having 2.5 m GSD (ALOS World DEM, http://alosworld3d.jp/en/). This was investigated by Tadono et al. (2014) and Takaku et al. (2014). From the commercial version AW3D with 5 m point spacing the free of charge version AW3D30 with 1 arcsec point spacing – approximately 30 m at the equator –

is available and was analyzed by Tadono et al. (2014) and Takaku et al. (2014). As for the other height models a gap filling has been made with other height data. (Jacobsen 2016) gives an overview about the preceding listed height models and (Aldosari, Jacobsen 2019) are including also the following height models. The most homogenous and really worldwide height model is now available from the TanDEM-X InSAR which is commercially distributed as WorldDEM; it has been investigated in detail by the German Aerospace Center (DLR) (Rizolli et al. 2017, Wessel et al. 2018) and (Baade and Schmullius 2016). A reduced version of this is freely available as TDM90 with 3 arcsec point spacing (~ 90m).

DEM generation from aerial imagery is a standard process, described very often, so a naming of all references is not possible. As in all other areas of DEM generation the pixel wise Semi Global Matching (SGM) (Hirschmüller 2005 is used more often (Haala 2014)), especially in built up areas.

An overview about the ISPRS/EuroSDR benchmark test about the use of penta-cameras for 3D-evaluation is given in Gerke et al. 2016. The use of penta-cameras is growing. The complex matching of images with quite different view directions usually is based on Scale Invariant Feature Transform (SIFT) (Lowe, 2004). Penta-cameras often do not have very stable camera geometry, requiring an image orientation with self calibration for a satisfying ground coordinate determination (Jacobsen and Gerke 2016).

Similar it is with the Unmanned Aerial Vehicles (UAV), they also require a proper camera calibration and the matching usually is based on SIFT (Bakula et al. 2018). With UAV only small areas can be mapped opposite to the other methods. Commercial programs should be used for the orientation, allowing a block adjustment with self calibration and ground control points.

The height model determination by airborne LiDAR is a standard procedure based on calibrated systems with post-processing by commercial programs to compensate orientation uncertainties by overlapping flight lines and ground control points (Davidson et al. 2019).

InSAR from space allows the generation of height models for large area up to global coverage. The Shuttle Radar Topography Mission (SRTM) in 2000 was the first attempt to reach height accuracy, better as available for several national survey administrations by the classical methods. Now with the TanDEM-X Mission, available as commercial WorldDEM or with reduced spacing freely as TDM90, the accuracy and morphologic quality has been strongly improved (Rizolli et al. 2017, Wessel et al. 2018).

A number of benchmarks about DEM generation with the different methods exist (Bakula, Mills, Remondino, 2019).

2. Horizontal Accuracy and Improvement

Before the analysis of the vertical accuracy, the horizontal location of the height model has to be checked.

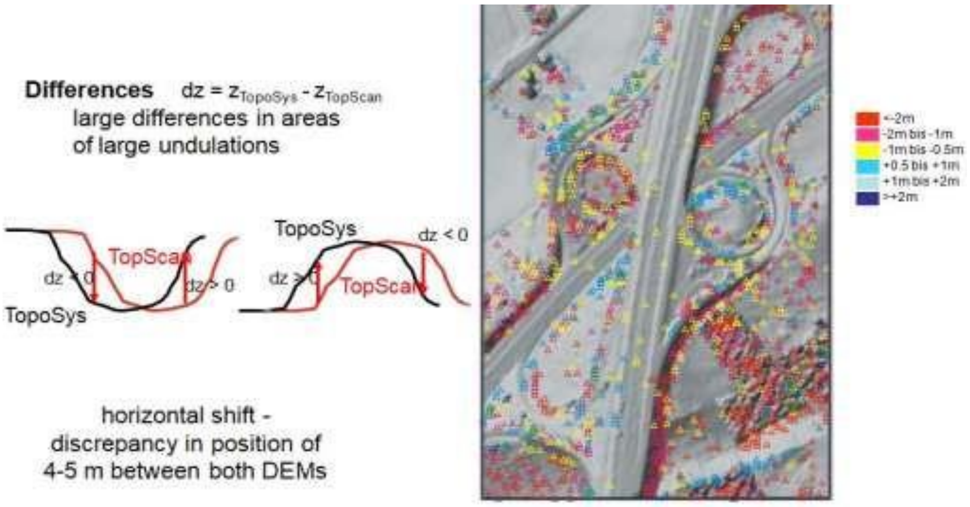


Figure 1: Horizontal shift between LiDAR height models

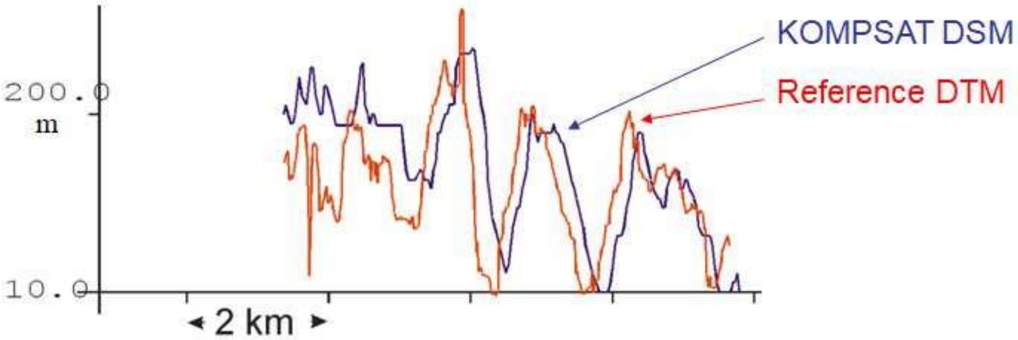


Figure 2: Horizontal shift between a DSM based on Kompsat-2 and the Turkish DTM

Horizontal shifts between height models are typical. In figure 1 a horizontal shift between two aerial LiDAR DTMs is shown. The horizontal shift of 4m up to 5m can be seen in inclined areas. The shift corresponds to DX=DZ / tan ax respectively DY=DZ / tan ay, with ax=slope in X-direction and ay=slope in Y-direction. Figure 2 shows a height profile of a DSM generated by images of the optical satellite Kompsat-2 (1m GSD) and the national Turkish DTM. On right hand side the height profile is not influenced by vegetation, while on left hand side the area is covered by forest. Nevertheless the Hannover program DEMSHIFT determined the horizontal shift correctly in X with 48m and in Y with 195m. Such large shifts are caused by datum problems of the Turkish reference. The DEM shift reduces the RMSZ from 27.09m to 10.35m. Also a tilt of the height models can be detected by this investigation.

3. Accuracy figures

Different accuracy figures are in use. The RMSZ is influenced by the bias (constant shift in Z), which is split of for the standard deviation. The Median Absolute Deviation (MAD) is the median of the height differences and corresponding to this it has 50% probability. For comparison with the standard deviation MAD is multiplied with the relation of the normal distribution for 68% to 50% probability the factor 1.4828, resulting to NMAD (Höhle and Höhle 2009). Under the condition of normal distributed height differences NMAD is identical to SZ. SZ is based on the square mean of the differences, while NMAD is a linear value. Very often the height discrepancies of a DEM against a reference DEM are not normal distributed and larger discrepancies are more frequent as corresponding to the normal distribution (figure 3, left, frequency distribution > |14m|). This is enlarging SZ more as NMAD.

Abbreviation	**Accuracy figures**
RMSZ	Root mean square height differences
SZ	Standard deviation of height differences (based on discrepancies minus bias), 68% probability
MAD	Median absolute deviation for height (median value of absolute differences), 50% probability
NMAD	Normalized median absolute deviation for height (MAD × 1.4826), 68% probability
LE90	Threshold including 90% of absolute values of discrepancies (90% median), 90% probability
LE95	Threshold including 95% of absolute values of discrepancies (95% median), 95% probability

Table 1: Accuracy figures

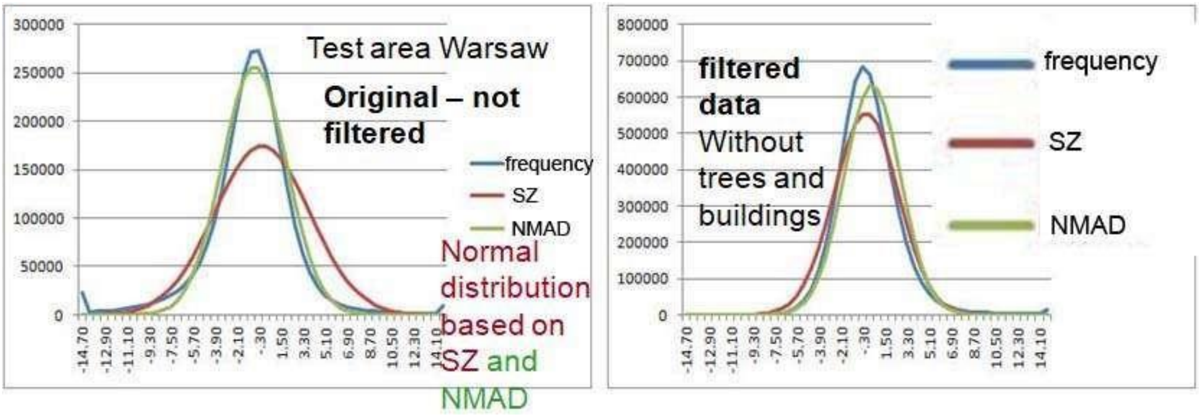


Figure 3: Overlay of frequency distribution and normal distribution based on SZ and NMAD Cartosat-1 DSM – national DTM, east of Warsaw

	Whole area **not filtered**	Open area **filtered**	Not filtered / filtered
RMSZ	3.77m	2.56m	1.47
bias	0.61m	0.50m	
SZ	**3.72m**	**2.51m**	1.48
MAD	1.75m	1.53m	1.14
NMAD	**2.59m**	**2.27m**	1.14
LE90	5.43m	4.09m	1.33
LE95	7.65m	5.21m	1.47

Table 2: Accuracy numbers corresponding to figure 3

In figure 3 and table 2 the analysis of a Cartosat-1 (2.5m GSD) DEM with a precise reference DTM based on the Hannover program DEMANAL is shown. On left hand side of figure 3 the not filtered DSM with influence of small forest parts and buildings can be seen, while on right hand side the Cartosat-1 DSM was filtered to a DTM. The influence of the small forest parts and buildings is obvious at the higher number of large discrepancies (left side of figure 3, blue line). Corresponding to this, NMAD with 2.59m is clearly below SZ with 3.72m. The filtered data (right hand side of figure 3) are closer to a normal distribution. Nevertheless also here NMAD with 2.27m is still smaller as SZ with 2.51m. In both cases the normal distribution based on NMAD (green line) is closer to the frequency distribution (blue line) as the normal distribution based on SZ. This is a typical result – in most cases the normal distribution based on NMAD is closer to the frequency distribution as the normal distribution based on SZ. This justifies the use of NMAD instead of SZ as accuracy criteria. Safe information of NMAD requires a satisfying high number of discrepancies, if only a limited number of discrepancies are available, SZ should be preferred.

Often also LE90 or even LE95 (90%, respectively 95% probability) are used. They are just based on the threshold of the largest 10%, respectively 5%, of the differences. Of course if a higher security for the height values is required, there is a reason for these threshold numbers, but they are presenting only 10%, respectively 5%, of the differences and not the large number of discrepancies, so LE90 or LE95 should not be used as the only accuracy criteria.

4. Filtering from DSM to DTM

By automatic image matching DSMs with the height of the visible surface are generated. Often a DTM with the height of the bare ground is required. In addition it is not correct to compare a DSM with a DTM, this would be dominated by the height of vegetation and buildings. Also the comparison of a DSM with a reference DSM is not as simple due to the fact that a DSM is changing faster as a DTM. In case of InSAR based on C- or X-band the canopy height is slightly below the height based on optical stereo pairs. Long wave length radar, as the L-band, is penetrating the vegetation, but there are only few L-band SAR-data available – it has also the disadvantage of a lower ground resolution.

Manual elimination of the height point groups not belonging to bare ground may be very time consuming, requiring programs for automatic filtering. Nevertheless by automatic filtering not all elements belonging to vegetation and manmade constructions can be removed. The elimination of buildings is not a problem if the GSD is not too small, but if in a forest no points are on the bare ground, the height of the bare ground cannot be estimated correctly. It has to be respected that the canopy height is equalizing the ground height and at the forest borders the trees are not as large as in the center, limiting the possibility to get the ground height just by subtracting an average tree height from the canopy height. Despite these limitations, in operational use by a large photogrammetric company the required time for the generation of a DTM based on a DSM could be reduced by 90% with the Hannover program RASCOR (Pasini, Betzner, Jacobsen 2002). This includes the manual measurements of break lines in few cases.

5. Analysis of height models

5.1 Dependency on terrain inclination

Under usual conditions the accuracy of the height models depends on the terrain inclination corresponding to formula (1).

$$SZ = A + B * \tan(slope) \qquad NMAD = A' + B' * \tan(slope) \qquad (1)$$

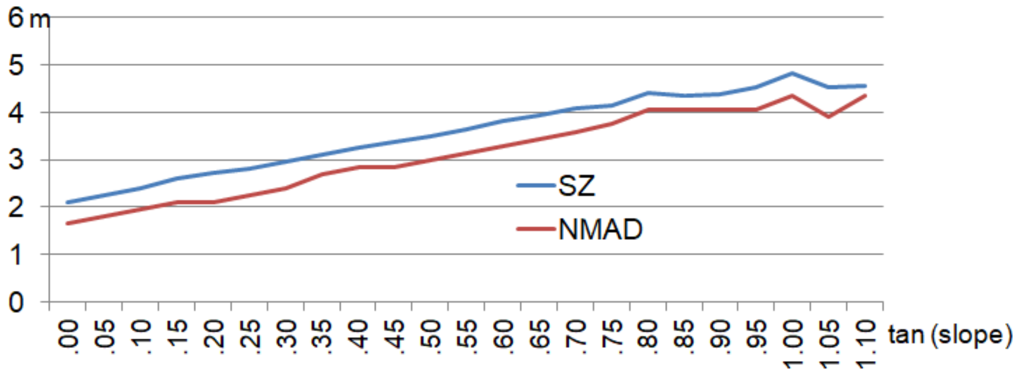
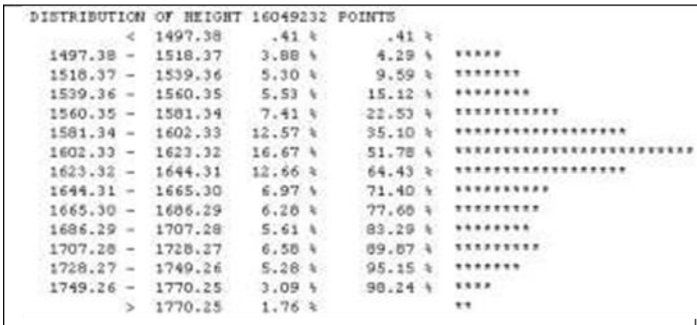


Figure 4: SZ and NMAD depending on slope groups Cartosat-1 DSM against AW3D30

Figure 4 shows the clear linear functions of SZ and NMAD on the tangent of the terrain slope for the comparison of a Cartosat-1 (2.5m GSD) DSM and AW3D30 in an area without forest and buildings (open area). The small uncertainties at higher slope are caused by the smaller number of compared points. In total 383 000 points have been compared. In the flat area approximately ~35000 points and in the steepest part ~ 700 points are in the slope groups. The adjusted function on the terrain slope is for SZ = 2.70m+1.48m*tan(slope) and for NMAD = 2.25m + 1.49*tan(slope). The linear dependency of the accuracy from the tangent of terrain slope is typical for all height models.

Due to this reason the accuracy of a height model should not be determined against ground control points (GCPs). Usually the terrain around GCPs is flat and open, leading to too optimistic results for steeper terrain.



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DISTRIBUTION OF HEIGHT 16049232 POINTS
          <  1497.38    .41 %     .41 %
  1497.38 -  1518.37   3.88 %    4.29 %  *****
  1518.37 -  1539.36   5.30 %    9.59 %  *******
  1539.36 -  1560.35   5.53 %   15.12 %  ********
  1560.35 -  1581.34   7.41 %   22.53 %  ***********
  1581.34 -  1602.33  12.57 %   35.10 %  *******************
  1602.33 -  1623.32  16.67 %   51.78 %  **************************
  1623.32 -  1644.31  12.66 %   64.43 %  *******************
  1644.31 -  1665.30   6.97 %   71.40 %  **********
  1665.30 -  1686.29   6.28 %   77.68 %  *********
  1686.29 -  1707.28   5.61 %   83.29 %  ********
  1707.28 -  1728.27   6.58 %   89.87 %  *********
  1728.27 -  1749.26   5.28 %   95.15 %  *******
  1749.26 -  1770.25   3.09 %   98.24 %  ****
          >  1770.25   1.76 %            **
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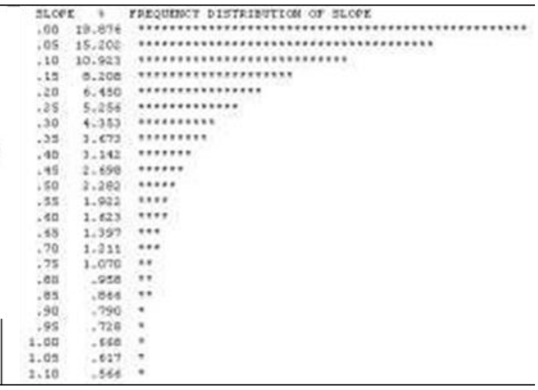

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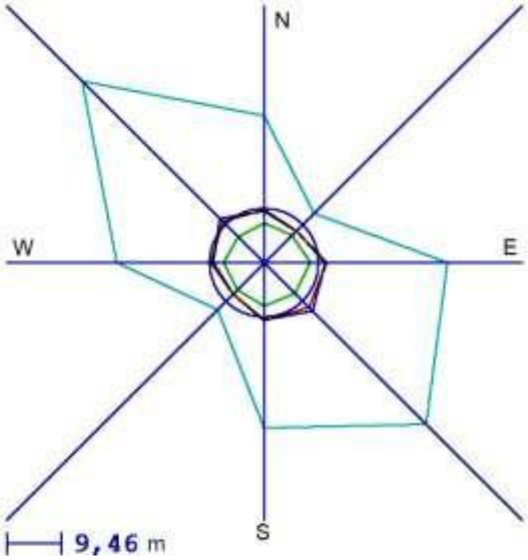
SLOPE   %    FREQUENCY DISTRIBUTION OF SLOPE
 .00  19.876  ***************************************************
 .05  15.202  ***************************************
 .10  10.923  ****************************
 .15   8.208  *********************
 .20   6.450  *****************
 .25   5.256  **************
 .30   4.383  **********
 .35   3.673  *********
 .40   3.142  *******
 .45   2.690  ******
 .50   2.282  *****
 .55   1.922  ****
 .60   1.623  ****
 .65   1.397  ***
 .70   1.211  ***
 .75   1.070  **
 .80    .958  **
 .85    .866  **
 .90    .790  *
 .95    .728  *
1.00    .668  *
1.05    .617  *
1.10    .564  *
```

Figure 5: Frequency distribution of height values
Percentage for height group + accumulated

Figure 6: Frequency distribution of
terrain slope

Cartosat-1 DSM against AW3D30 DSM, Nairobi

Aspects include the information about height accuracy as function of the slope direction (figure 7). Due to radar layover InSAR has a lower accuracy in inclined parts perpendicular to the satellite orbit. This causes larger standard deviations in the north-west and south-east direction. Especially the factor B in formula (1) – the accuracy dependency on the slope – is quite larger in this direction. For the average SZ the dependency on the slope direction is not as large, but it is still visible, it is ~ 10% larger as the overall accuracy, while it is in the north- east and south-west direction ~ 10% below the overall accuracy. In this case the data acquisition was made from descending satellite orbit (from north-north-east to south-south- west).



From center to outside Standard deviation of height:

Green line: for slope = 0.0
Red line: for average inclination
Dark blue line: mean value
Dark blue circle: SZ
Light blue-green line: factor for
multiplication with tangent (slope),
B in formula (1)

above = north direction

Mountainous area at Black Sea coast north- west of Istanbul

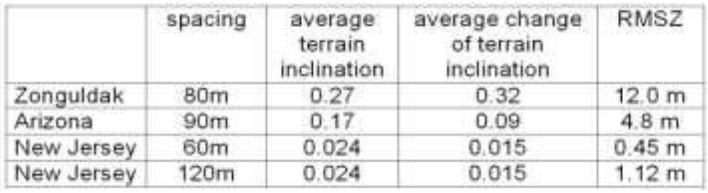
Figure 7: Aspects – SRTM against LiDAR reference

Not in any case the dependency on the aspects is so clear, but especially InSAR shows this effect in mountainous areas, while a height model based on digital images does not show this.

5.2 Point spacing and terrain roughness

The statistic about the height values (figure 5) and the frequency distribution of the terrain slope (figure 6) are supporting the analysis.

The loss of accuracy by interpolation is shown for some examples, based on SRTM in table 3. Zonguldak is a rough mountainous area, partially covered by not dense forest, Arizona is smoothly mountainous, without vegetation, and New Jersey is flat, partly with buildings and few trees. The roughness of the areas can be identified at the average change of the terrain inclination from one point spacing to the next (cα) (table 3, figure 8). The influence of the interpolation was determined by interpolation between the left and the right neighbored points and compared with the height of the center points. As a rule of thumb, the loss of accuracy by interpolation usually is reduced by the factor 4 if the point spacing is reduced by factor 2; in other words, it depends usually approximately on the square of the point spacing.



	spacing	average terrain inclination	average change of terrain inclination	RMSZ
Zonguldak	80m	0.27	0.32	12.0 m
Arizona	90m	0.17	0.09	4.8 m
New Jersey	60m	0.024	0.015	0.45 m
New Jersey	120m	0.024	0.015	1.12 m

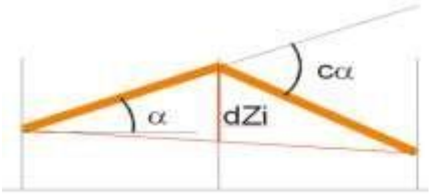
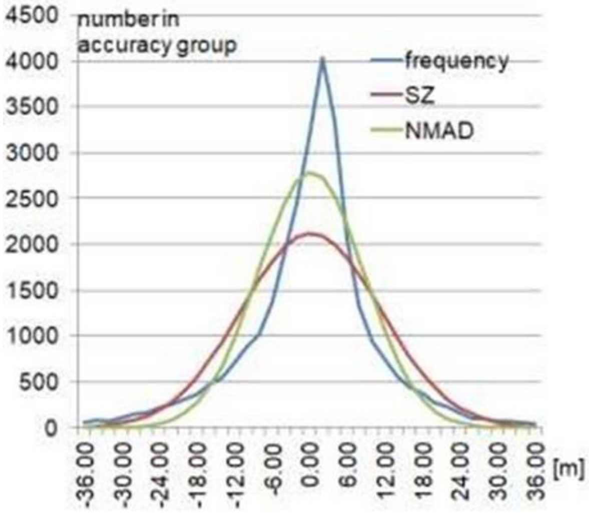


Table 3: Loss of accuracy by interpolation Figure 8: Height value interpolation

With α = terrain inclination, cα = change of inclination, dZi = Z-discrepancy caused by interpolation

5.3 Frequency distribution

Figure 9 shows the frequency distribution for all height discrepancies (SZ=11.1m, NMAD=7.3m), while figure 10 shows the frequency distribution of the same data set, but only for the height points with slope < 10% (SZ=7.7m, NMAD=5.0m). The characteristics are not so different, with the exception that the overlaid normal distribution based on SZ and on NMAD are closer to the frequency distribution. In both cases NMAD is clearly smaller as SZ and the normal distribution based on NMAD is closer to the frequency distribution. In the partly rough area larger discrepancies may be caused by the interpolation of TDM90 (~90m point spacing), while the DSM based on SPOT-6 (1.5m GSD) has just 4.5m point spacing.



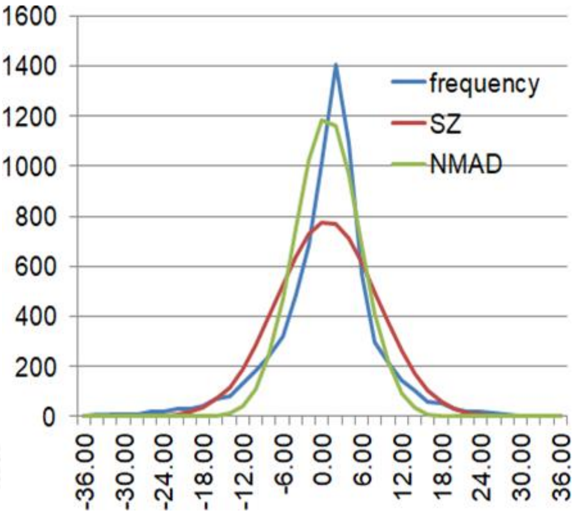


Figure 9: Frequency distribution all data Figure 10: Frequency distribution for slope<0.1
SPOT-6 DSM against TDM90 – Bolivia, Sajama – mountainous, no vegetation

The frequency distribution and the overlaid normal distributions are indicating if a group of height differences are not belonging to the same population, as it is the case if a DSM with points on top of trees and buildings is compared with a DTM, including points only on bare ground. A tendency can be seen in figure 9 where the frequency distribution has more points on the left hand side as on the right hand side.

5.4 Color coded presentation and systematic errors

A visual interpretation of the height discrepancies is important. The comparison of a WorldDEM DSM (12m point spacing) with a LiDAR DSM (SZ=3.45m, NMAD=2.96m), shown by color coded height differences in figure 11, clearly indicates larger differences in the northern part. This is caused by forest, which has been eliminated by a forest layer (figure 11, right). The LiDAR DSM describes the canopy height different to InSAR based on X-band. In the open area without forest the differences are clearly smaller (SZ=2.50m NMAD=2.00m, NMAD= 1.55m + 5.76m * tan(slope)). The strong dependency of the accuracy from the slope is typical for InSAR height models, for DEMs based on optical images it is smaller.

The color coded height differences may highlight also systematic DEM-errors as tilts or more complex deformations. As shown in figure 12, the height differences of LiDAR DSM against WorldDEM DSM have some systematic errors. In this case the influence is not too high, but also not negligible. Such systematic errors may be caused by image orientations or not optimal system calibrations. The determined systematic effects in relation to the reference DEM can be removed by adjusted linear functions (figure 12) of X, Y or Z, or even with the smoothened functions as shown in figure 12. The degree of smoothening can be chosen. X and Y may be correlated with the corrections in Z, requiring an iterative improvement.

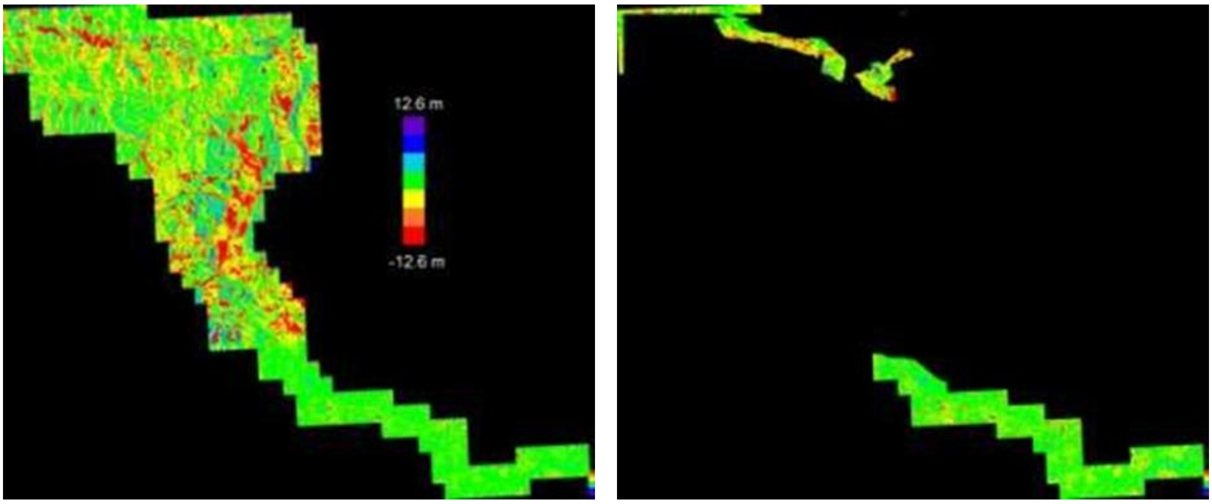


Figure 11: LiDAR DSM – WorldDEM, all points LiDAR – WorldDEM without forest area
Dücze, Turkey, 25 km x 21 km

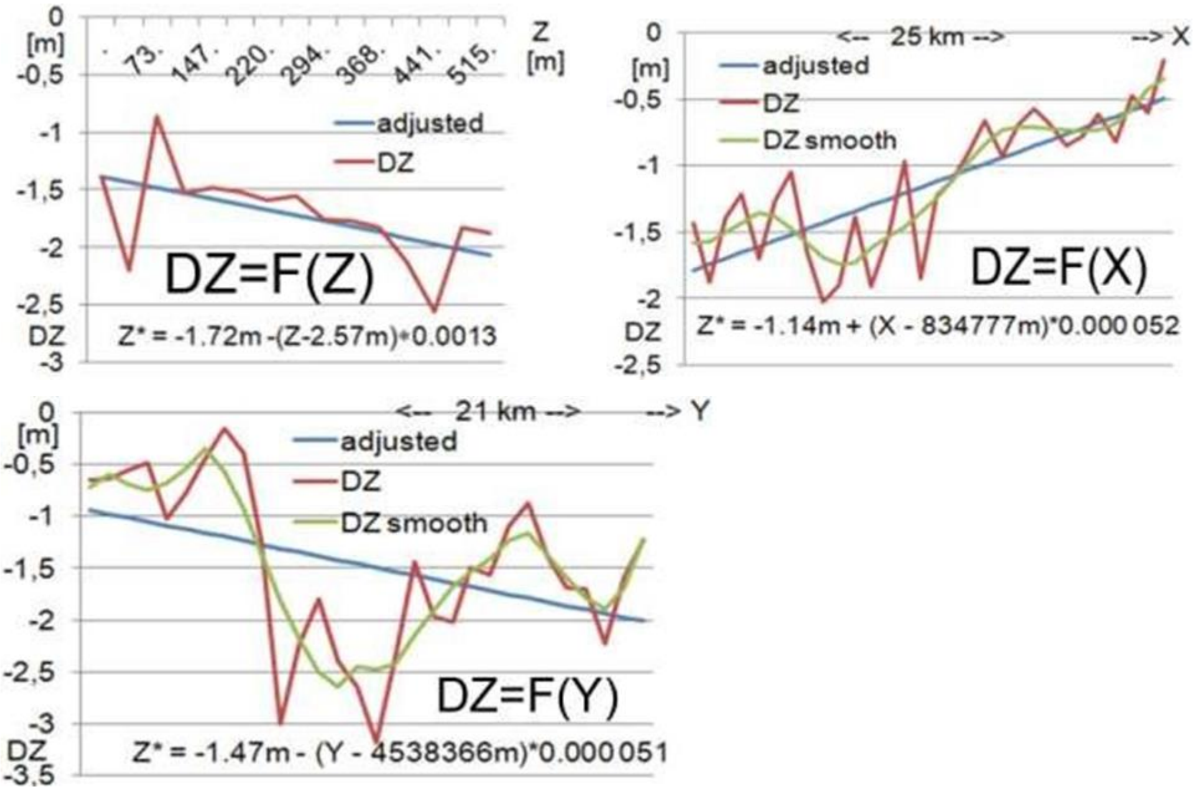
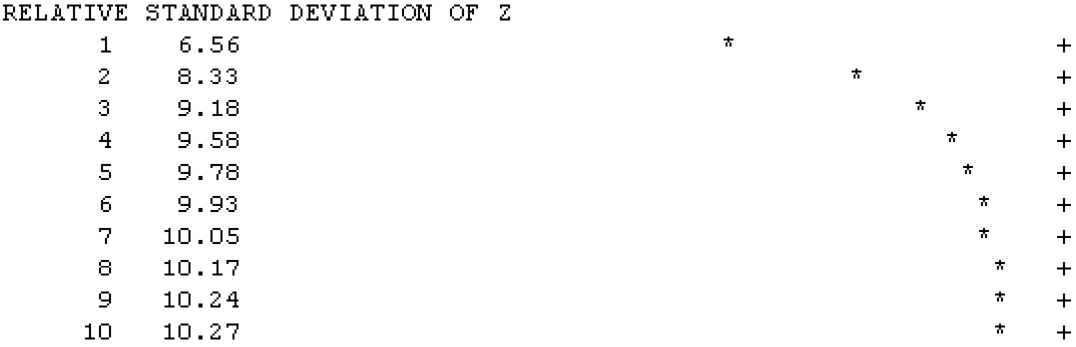


Figure 12: Systematic height errors as funktion of Z (upper left), X (upper right) and Y (lower left)
together with linear functions of DZ depending on Z, X, respectively Y
LiDAR DSM – WorldDEM, all points, Dücze, Turkey

Height models may have a good relative accuracy, but a limited absolute accuracy due to systematic problems of the images, as it is the case for CORONA height models where the GSD of 2m allows a high morphologic quality, but systematic image errors influence the absolute height values. With a comparison of the high absolute accuracy of TDM90, having limited morphologic details due to the point spacing of 90m, with a CORONA height model the systematic height errors can be determined and corrected without loss of the morphologic details of the CORONA height model.

5.5 Relative accuracy and morphologic quality

Closely neighbored points are correlated, causing the relative standard deviation of Z (RSZ) to be better as the absolute accuracy (figure 13), (2). For larger distances between height points the correlation is smaller, causing that RSZ will reach SZ. This fact influences the morphologic quality which is based on the relative accuracy.



```
RELATIVE STANDARD DEVIATION OF Z
      1     6.56                              *                +
      2     8.33                                      *        +
      3     9.18                                          *    +
      4     9.58                                            *  +
      5     9.78                                             * +
      6     9.93                                              *+
      7    10.05                                              *+
      8    10.17                                               *+
      9    10.24                                               *+
     10    10.27                                               *+
```

Figure 13: Relative SZ as function of the point distance [m] – SPOT-6 DSM against TDM90
+ = SZ * = relative SZ; distance of point groups = 80m (to be multiplied with line index)

$$RSZ = \sqrt{\frac{\sum DZi - DZj}{2 * nv}}$$

(2) Relative standard deviation (RSZ)

with nv = number of point combinations in the distance group
and DZi, DZj = closely neighbored height points

With the analyzed DEM contour lines can be generated. They are optimal for morphologic analysis. Of course with a point spacing of 5m and the high accuracy of LiDAR the corresponding contour lines (figure 14 left) are more detailed as for data sets with 27m point spacing (figure 14, 2nd and 3rd from left). AW3D30 has with 1 arcsec the same spacing as SRTM, nevertheless there are more morphologic details in AW3D30 and it is closer to the LiDAR contour lines. Even with 90m spacing TDM90 is close to the details of SRTM (figure 14, right).

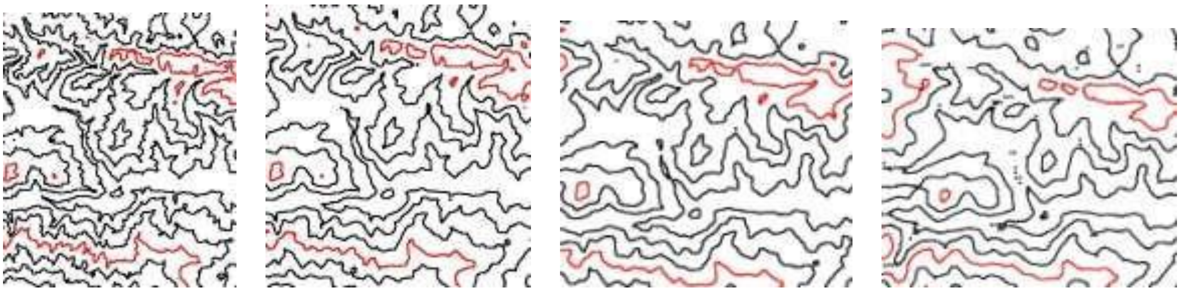


Figure 14: Contour lines with 50m equidistance, 6km x 5km, with different point spacing
LiDAR 5m AW3D30 ~27m SRTM ~27m TDM90 ~90m

Gross errors in a height model cannot be avoided. They may influence the accuracy numbers strongly. Due to this a threshold for the respected height differences has been used. The threshold has to be realistic to avoid a manipulation of the results – at least it should be 5 times SZ or better even 10 times SZ.

DEM-generation from aerial images is a standard procedure supported by GCPs and GNSS-coordinates of the projection centers avoiding orientation problems. Large format digital cameras today have only limited systematic image errors; this was not always the case (Spreckels, Schlienkamp & Jacobsen, 2007) are reporting about not negligible model deformations caused by systematic image errors. Special additional parameters were required for the UltraCam-D. This problem still exists today for mid-format cameras which have to be handled with self-calibration by additional parameters. Stepwise scanning cameras are not resulting in the required geometric quality of height models.

6. Conclusion

As mentioned in the introduction, the accuracy and quality of a height model is more complex as just to be described by one or two accuracy numbers. The analysis of a DEM has to be done by comparison with another DEM. The use of a limited number of ground control points instead of a reference DEM should be avoided. Ground control points are located on flat ground and do not present the DEM properly by avoiding rough and inclined area, so the analysis results would be too optimistic.

The evaluation has to be made in the same coordinate and datum system. Shifts between the reference and the compared DEM have to be determined and respected - in few cases also tilts are available.

The correct accuracy number has to be used – the Hannover program DEMANAL computes all above listed accuracy numbers and quality criteria. The threshold values CE90 or CE95 do present only the accuracy of the 10%, respectively 5% largest differences; nevertheless they can be used as quality criteria.

The evaluation cannot be based on the comparison of a DSM with a DTM – such results would be dominated by the height of the vegetation and the buildings. If a DTM is required from an original DSM, it has to be filtered and closed forest areas have to be excluded from the analysis, optimally made by a layer indicating the forest area. The comparison of a DSM from optical images or InSAR with a LiDAR DSM has limitations in forest areas due to different definition of the canopy height.

The evaluation should include the dependency of the accuracy from the terrain slope. Especially for InSAR-data in mountainous areas aspects have to be computed. An analysis of the frequency distribution of the height differences and a rough estimation of the influence of point interpolation should be included as well as the determination of the relative accuracy. The latter influences also the morphologic quality what can be checked with the generation of contour lines. In general a color coded presentation of the height differences is required; it shows areas with problems and may indicate systematic DEM errors. Systematic errors as Function of X, Y and Z have to be analyzed and may be respected by iteration.

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Motivation and the Need for the Revision of ISO 19157:2013 Geographic Information – Data Quality

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ISO 19157:2013 Geographic information – Data quality (ISO 19157) is the standard published by the International Organization for Standardization (ISO) and its Technical Committee 211 on Geographic information/Geomatics (ISO/TC211). The purpose of this standard is to provide framework for defining, measuring and reporting spatial data quality (ISO, 2013). For each standard ISO/TC executes a systematic review at least every five years, and for ISO 19157 a ballot has been opened in the period between October 2018 and March 2019. As a result, from all national standardization bodies or liaisons eligible to vote, 19 confirmed the standard, 3 suggested to revise it, and 14 abstained from voting on standard's revision process. In most cases, such result would not lead to a revision of a standard, but the reasons given in the three suggestions for revision convinced the ISO/TC211 committee to put the ISO 19157 up on the agenda for the project management group (PMG) during the plenary meeting week in Maribor in May/June 2019. Based on PMG's suggestion, the *ISO/TC211 has resolved to revise ISO 19157 and started a new ISO/NP 19157-1 Geographic information – Data quality – Part 1: General requirements* in July 2019.

One of the main reasons iterated through various comments supporting the call for revision, was the need to update the definition and the use of standard's terminology. Terms such as accuracy, uncertainty and correctness seem to have confusing definition, and use throughout the standard, and other terms, such as 'trustworthiness' or 'trueness' were suggested for consideration. Interestingly, a comment has been made that the main term from ISO 19157's title – data quality – has never been defined in the standard, and suggestion has been made that it should be included. However, perhaps it is now time to discuss whether the very term 'data quality' and related evaluation framework sufficiently covers the need of the main spatial exchange currency: the 'spatial resource'. Spatial resources are spatial data and metadata (e.g. found through spatial data portals), spatial services (e.g. used in cloud-based spatial applications), sensors for spatial observations and measurements (e.g. deployed in sensor observation networks), or other spatial things published to the web in the form of spatial vocabularies, spatial ontologies, linked spatial data.

Hence, one of the most important work during the revision will be the terminology harmonization. In this respect, the project team will not only be reviewing information resources available within ISO, such as ISO 8000-2:2018, ISO/IEC 98-3:2008 or ISO/IEC 25000 series (ISO, 2018; ISO/IEC, 2008; ISO/IEC, 2019), but we will also reach for related standardization efforts among ISO's direct liaisons and outside ISO. Among the most prominent of these efforts are: the World Wide Web Consortium (W3C)'s Data Quality Vocabulary (W3C, 2016) and Open Geospatial Consortium (OGC)'s Geospatial User Feedback (OGC, 2016).

But the terminology is not the only aspect of the revision. We aim at reviewing ISO 19157's ability to support the best practices in publishing resources on the web (van den Brink et al., 2019) and approaches to define and assess quality of these web resources (Debattista et al., 2016; 2017; Zaveri et al. 2016). Moreover, we aim at critically revise the 'usability' of ISO 19157 both, the term 'usability', which is currently defined too briefly and, at the same time, too widely (which impedes its applicability), and also documented 'usability' of the standard itself , for instance as demonstrated by OGC's Testbed 13 experiments (OGC, 2018a; 2018b).

In this presentation we will summarize the main reasons for revision of the ISO 19157 and provide participants with the outline and timetable for the revision. During the discussion we hope to elicit participants view and opinion about current state of ISO 19157 and receive valuable suggestion to include into the list for consideration during the initial phases of this standard's revision.

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Data Quality for Use: A Linked Data Approach

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Introduction

Quality has a long standing history, mainly from product engineering (such as automotive) and is a broad concept. Literature and practitioners have a tendency to focus on intrinsic quality, which is more or less demarcated and measurable. But in addition to intrinsic (product) quality, there are two other notions of quality. Firstly, there is process quality, which deals with organizational aspects such as maintenance processes. Secondly, there is quality in practice, i.e., quality as observed/experienced within the use of a concrete application.

Organizations such as Kadaster, have a tendency to focus on intrinsic quality, but this focus can be questioned. Juran, one of the quality guru's, defined quality as "Fitness for use". Following this definition, one would expected a focus on quality in practice. Unfortunately this is less demarcated, especially when compared to the focus on intrinsic quality. One explanation for the lack of focus on quality in practice is that this notation makes quality situation-dependent. For example, when quality in practice is applied to datasets, this means that a dataset can have a high quality in one usage scenario, yet a low quality in another usage scenario.

In this paper we look into this more situational notion of quality in practice.

Quality related Problems for Datasets

Within the practice of being one of the main suppliers of open governmental data in the Netherlands, Kadaster has identified the following two main quality-related problems for its datasets.

1. (Spatial) datasets cannot be found

One main quality issue is that open governmental datasets, while published under an open license, cannot be easily found by developers and other potential users. As a result, open governmental datasets are not currently used to their full potential. Let us take the Key Register Topography (in Dutch abbreviated as BRT) as an example case: it is the authoritative dataset about topography in The Netherlands, and contains many object types, such as schools, churches, castles, and many others. A user who searches the Dutch National Geospatial Register (in Dutch abbreviated as NGR) for schools, churches, or castles will not find the BRT, even though it is one of the most comprehensive dataset for churches in The Netherlands. The reason for this is that the object types that are present in the BRT dataset are not mentioned in the metadata description of the BRT. In general, concepts that occur within geospatial datasets are currently not (automatically) part of the dataset metadata.

Because of the above described issues, a user will only find the BRT dataset if she searches for the title of the dataset (e.g., "BRT"). This means that Kadaster datasets are typically found by people who are already aware of their existence, but not by people who are searching for concepts that appear within Kadaster datasets. What is more, one could argue that many potential users of Kadaster data will not start their search at the National Geospatial Register for Datasets at all, but will be searching from a generic search engine and/or will use a voice assistant for information about schools, churches, castles, etc.

This situation is not unique for Kadaster. The idea that geospatial datasets should be exposed through, and searched for on, a special geospatial platform is more or less the INSPIRE vision and approach.

It is our belief that a new user, unaware of the name of the dataset but with a specific and articulable need for (geospatial) data, will start his search using a popular web browser or a personal voice assistant. A more advanced user may use a dedicated, dataset-specific search engine like Google Dataset Search or a national data portal (e.g., https://data.gov.uk or https://data.overheid.nl). Ideally, when a user searches for churches in The Netherlands, he will find the BRT among the top results of his search operation. From these search results, the user will dive directly into the NGR page that specifically describes the BRT dataset. While we recognize that there are many different users with different competencies and capabilities, we believe that what we describe above will be the 'happy flow' that a large number of users that are not being served today will follow.

Unfortunately, the current situation is very far removed from what the 'happy majority flow' that we describe above. Many of the open datasets published by Kadaster today are not found at all in popular and generic search engines. Even in search engines that specifically focus on datasets, like Google Dataset Search, authoritative Kadaster datasets like the BRT cannot be found. we find several outdated copies of our data (by commercial organizations, or universities), but not the authoritative source. From user perspective a big quality issue.

We here enumerate the three sub-problems that can be distinguished with respect to the findability of spatial datasets:

Metadata descriptions for datasets often contain insufficient detail (e.g., the BRT cannot be found when searching for churches in The Netherlands).

Governmental agencies focus on search from within dedicated portals, but users use generic search engines.

Spatial datasets published in dedicated portals are often not findable through generic search engines.

2. Fitness for Use is Unclear

When we apply the definition of fitness for use, we need to know the use case in order to make the quality assessment to find out if the datasets is "fit" for this intended usage. However in the context of our role as publisher of open geospatial data, we most of the time do not know the usage of open data. What is more, the stated purpose of open data is that new users that are currently unknown to the data publisher should be able to use data in different contexts and in originally unanticipated ways.

However, if a data supplier does not know how their (open) data is being used, then it logically follows that they cannot define fitness for use (and therefore the practical quality) of a dataset either. Indeed, when a data supplier assigns quality statements or labels to its datasets, its potential users may misinterpret these static quality indicators as fitness for all use cases, but the latter may not be correct.

Solutions

We present three solutions for the issues identified in the previous section.

1. Attitude change

We need an attitude change (mind shift) from quality as a static concept that is determined by data publishing organizations, to a dynamic concept that is ultimately determined by the data consumer. Quality is always situational: for a certain user, within a certain use case, working from within a certain context. While it may still be useful to formulate and implement generic data quality metrics, such generic metrics can never capture dataset quality in its totality.

In practice we often notice that dataset owners hold on to a Boolean notion of dataset quality, resulting in two unrealistic 'all or nothing' attitudes. One extreme attitude is that the dataset already has good quality: the dataset is published in a governmental (geospatial) data portal and fulfills the currently formulated quality requirements. The fact that the dataset is not often used in practice is sometimes lamented, but is not recognized as a dataset quality problem. The other extreme attitude is that the dataset does not yet have good quality. The fact that the dataset is not often used by others is by design: the users must wait for a new version, a new data model, or a data cleaning initiative. Only once those have been completed will the dataset be ready for use.

Our notion of practical dataset quality opposes both views. A dataset publisher may believe that their dataset has good quality, but if a dataset is not often used then this is an indicator that the dataset may not be fit for use. Similarly, a dataset publisher may believe that their dataset does not yet have good quality, but a data consumer may disagree with this, and may already be satisfied with the dataset as it currently is.

2. Quality Dashboards

We need transparency, and the first step is publishing quality dashboards, which many organizations – including Kadaster – have been doing for quite some time. In the early days, custom dashboard applications were developed within the organizations. Since this is a relatively expensive process, such an approach is only feasible when the intrinsic notion data quality is used.

In recent years we have noticed an increasing need to change and redesign quality dashboard. This reflects a change in the notion of quality that is embraced by the organization: one that is based on a changing practical need. With this more fluid notion of quality for use, it becomes more economical to use standard Business Intelligence (BI) tools like Tableau to create quality dashboards.

Another generic trend is that static reports (often in the form of PDF documents) are slowly being replaced by interactive dashboards. In the near future this will be merged with quality dashboards, into one integrated dashboard, containing a viewer, data model, quality, use case descriptions etc.

3. Transparency

In the absence of a static notion of intrinsic quality, it does not make sense to advertise dataset quality in absolute terms. Instead, we want datasets to anticipate the fact that users will make use of the dataset in different and potentially unanticipated ways.

In order to achieve the latter, a dataset must seek to transparently communicate its potential for use. A dataset must communicate its potential for use in a multi-faceted and pluriform way, so that individual users are able to determine for themselves whether the dataset is fit for their use.

In the context of Kadaster, Linked Data is used in order to express the multi-faceted potential for data use. Linked Data offers a wide variety of off-the-shelf metadata vocabularies that can be utilized for this purpose. Furthermore, the open-endedness of Linked Data allows new metadata aspects and new vocabularies to be formulated, not replacing but augmenting existing initiatives.

Examples of Linked Data vocabularies that are used to express data quality aspects at Kadaster include:

- Dublin Core: allows generic dataset properties like creator and creation data to be specified.
- DCAT: allows more detailed dataset properties to be specified, including the temporal range covered by a dataset, the spatial range, the update frequency, and the accuracy of its measures.
- PROV: allows a detailed specification of how the dataset was created, curated, and published; including the specific sequence of data operations that was taken.
- Schema.org: allows an increasingly large number of metadata properties to be communicated in a format that is processed by a large number of search engines, web crawlers, and other web- based tools.
- OGP: similar to Schema.org, but mostly focused on metadata that can be used in social media platforms.
- BRT: in addition to the above existing vocabularies, Kadaster datasets introduce their own Linked Data vocabulary. For example, the BRT vocabulary describes the types of objects it contains, including schools, churches, and castles.

Since Linked Data is a web-native metadata paradigm, descriptions of data quality for use can be published online, as part of regular web pages (using JSON-LD snippets). Furthermore, popular web search engines like Google actively look for and index such metadata properties. This allows a wider range of users to determine for *themselves* whether a dataset that Kadaster publishes on the web is fit for *their* use.

Kadaster is currently experimenting with exposing its dataset metadata using the above Linked Data vocabularies. Early results already show that the Linked Data approach allows Kadaster datasets to become better findable on the generic web, i.e., outside of (spatial) data portals.

Conclusion

In this paper we propose a shift of focus in the quality domain. In addition to a different attitude and more quality dashboards, we propose is to put more effort in publishing metadata that follows modern web standards. This results in a higher level of transparency and fosters insight into data practical quality for use. The result will be that in the future more people will be able to find datasets on the web, and can make a quality assessment that is more tailored towards their specific use case.

Data Quality in an e-Government Perspective

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Abstract

Data sharing and reuse is one of the key prerequisites for digitalization of public administration (e-Government). In order to reuse data, one needs to know which data already exist, the meaning of the data, whether it is open or restricted access to the data, and last but not least, the quality of the data. As a first step towards more data sharing and reuse across the public administration and with the private sector, we have established a national data catalog which gives an overview of the datasets that the public administration collects and produces.

In this paper we will present our approaches to cope with the major challenges that we met when establishing our national data catalog, regarding 1) making available standardized and machine-readable data quality descriptions and 2) ensuring unified understanding of the data quality descriptions across the public administration.

Introduction

Quality of data is becoming increasingly important, also accelerated by digitalization of public administration (e-Government).

Norway's *National geospatial strategy towards 2025* ([1]) states that "Society needs good, up-to-date data in private and public activities, within all the specialist areas and sectors. Data must be available in ways that meet the needs. The data must have known coverage and a quality adapted to the needs of the various actors, so that it can support their specific applications and be part of the relevant decision-making processes."

The Norwegian Government white paper *Digital agenda for Norway* ([2]) emphasizes a user-centric and efficient public administration. Both *Digital agenda for Norway* and the follow-up *Digitalization strategy for public sector 2019-2025* ([3]) also emphasize the importance of sharing and reusing data across the public administration and with the private sector. Using and reusing correct and updated information is crucial for the provision of seamless public services across the public sector and for the exercise of authority. Using correct information increases the quality of the public services and strengthens the rule of law for citizens. Public services can be improved and automated through access to quality-controlled information from all public authorities.

The quality of data may affect how suitable the data is for other uses than first intended. Documentation of data quality is therefore useful in the process of evaluating whether a dataset is fit for purpose, thereby increased ability for potential users to reuse the dataset. The Norwegian government *Guidance on sharing and reuse of public administration's data* ([4]) therefore requires that the quality of the data should be documented and known challenges should be explicitly described.

As a first step towards more data sharing and reuse across the public administration and with the private sector, we have established a National data catalog ([5]), which contains not only descriptions of open data but also descriptions of data with restricted access. The national data catalog is actually a portal of catalogs that are interlinked. It consists currently of a catalog of *datasets*, a catalog of *concepts*, a catalog of *APIs* and a catalog of *information models*. It gives an overview of the datasets that the public administration collects and produces (datasets), the meaning of the datasets (concepts), the distribution of the datasets (APIs) and how the datasets/concepts are modeled (information models). If needed, more catalogs may be included in the catalog portal in the future. In addition to the aspects as the purpose of the datasets, the meaning of the data elements in the datasets, the legal basis for non-disclosure or disclosure of the datasets, distributions of the datasets etc., the data catalog also contains descriptions of the quality of the datasets.

In this paper we will present the challenges that we met in achieving standardized and machine-readable data quality descriptions in our national data catalog, and our approaches and solutions to cope with those challenges.

Standardized and machine-readable descriptions of data quality

When we started to develop our national data catalog in early 2016 regarding the inclusion of descriptions of data quality into the data catalog, the first challenge that we met was the lack of suitable standards. Our national data catalog is based on a distributed architecture. The national data catalog should be able to automatically harvest data descriptions provided by various sectors and agencies. One crucial aspect is thus standardized and machine-readable descriptions.

The national data catalog is in compliance with the national *Standard for description of datasets and data catalogs DCAT-AP-NO* ([6]) which is based on *DCAT-AP* ([7]), a European application profile of the W3C recommendation *DCAT (Data Catalog Vocabulary)* ([8]). Using the same standard, the national data catalog automatically harvests from other sources, e.g. the national portal for metadata of geospatial data ([10]) which is in compliance with the INSPIRE legislation ([9]) (as for member states of the European Union).

However, except for a few data quality aspects, current versions of DCAT from W3C and DCAT-AP from the European Commission, do not yet specify or recommend specifically how to describe quality of data in a machine-readable way. As presented at the 2nd International Workshop on Spatial Data Quality by Borrebaek and Buskerud ([11]), a national working group got the mandate to establish suitable standards for machine-readable descriptions of data quality, based on the needs from the Norwegian public administration. The working group delivered a *Specification for description of quality of datasets* ([12]). The working group concluded to extend our Norwegian application profile *DCAT-AP-NO* with relevant parts of *DQV (Data Quality Vocabulary)* ([13]) from W3C. DQV provides a framework in which the quality of a dataset can be described, whether by the dataset publisher or by a broader community of users.

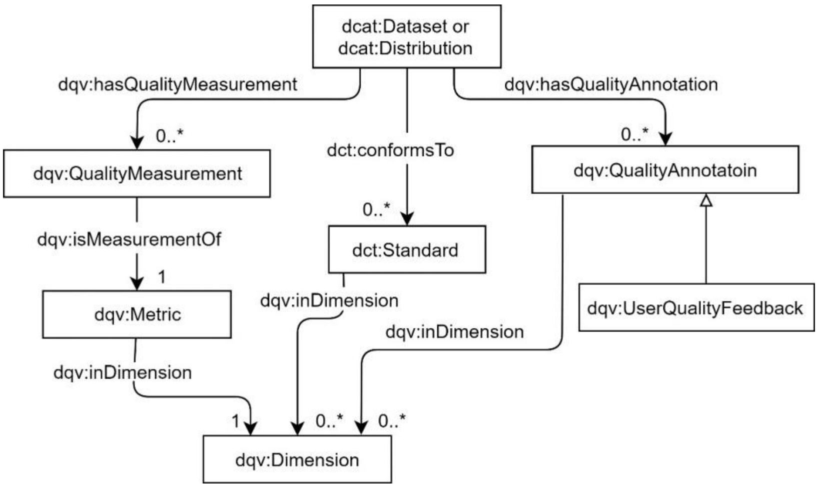

Figure 1: Simplified data model for extending DCAT-AP-NO with DQV for describing quality of datasets.

As shown in Figure 1, the working group suggested to start with the following types of quality descriptions based on the needs that were identified:

Description of quantitative data quality: One or more quantitative data quality measurements (dqv:QualityMeasurement) may be included in the description of a dataset (dcat:Dataset) using the property dqv:hasQualityMeasurement. Furthermore, using dqv:isMeasurementOf, one may specify which data quality metric (dqv:Metric) the data quality measurement is a measurement of, and using dqv:inDimension one may specify which quality dimension (dqv:Dimension) the data quality metric is within. E.g., “2%” as a measurement of the metric “rate of missing objects” in the quality dimension “completeness”.

Description of data quality that conforms to given quality standards or specifications: Using the property dct:conformsTo one may specify that the quality of a dataset conforms to one or more given standards or specifications (dct:Standard). Similarly, using dqv:inDimension one may relate a standard/specification to one or more quality dimensions (dqv:Dimension).

Description of data quality in plain text: Using dqv:hasQualityAnnotation one may include one or more plain text descriptions of data quality in the description of a dataset, and relate the description to a quality dimension (dqv:Dimension) using dqv:inDimension. E.g. “2% missing objects” as a plain text description in the quality dimension “completeness”.

Plain text user feedback on data quality: This is considered as a special case of plain text description mentioned above. The plain text description here is given by a user of the dataset, instead of the publisher of the dataset in the previous case.

The working group also identified the need to divide a quality dimension into “subdimensions”, e.g. to divide the quality dimension “completeness” into “over-coverage” (“commission”), “under-coverage” (“omission”) etc. “Subdimension” is not explicitly defined as a class in DQV but is possible to implement using DQV.

DQV is currently not yet a recommendation from W3C but a “Working Group Note”. DQV is however the best specification that we found for machine-readable data quality descriptions covering the requirements from different domains. Nevertheless, based on the needs from Norway and several other European countries who are also using DQV, DQV is now indeed explicitly included in the upcoming European application profile of DCAT for base registries BRegDCAT-AP[1] ([14]).

Our national data catalog has already partially implemented DQV for describing quality of datasets.

Common definitions of data quality dimensions, quality subdimensions and quality metrics

The Data Quality Vocabulary (DQV) provides a generic framework, a vocabulary, for describing data quality. “The goal of the Data Quality Vocabulary is not to define a normative list of dimensions and metrics.” ([13])

The second challenge that we met concerning data quality descriptions, was thus how to ensure that we have a unified understanding of the data quality descriptions in the data catalog, in order to achieve and increase semantic interoperability across the public administration.

The Norwegian geospatial community has assigned quality information to spatial datasets for several years, based upon *ISO 19157 Data Quality* ([15]) and *ISO 19115-1 Metadata* ([16]), the latter according to the European directive of *INSPIRE*. In the early days before we had international

[1] At the time of submitting this paper, BRegDCAT-AP is not yet finalized but a “stable draft”.

standards suitable for this purpose, we used a simple quality assignment in the form of measurement method (horizontal and vertical), positional accuracy (horizontal and vertical) and a rough statement on the visibility of the features from a photogrammetric point of view.

Other government agencies in Norway have been using standards such as *ISO/IEC 25012:2008 Data quality model* ([17], [18]) and *ISO/IEC 25024:2015 Measurement of data quality* ([19]). Some government agencies have similar quality elements specified in other specifications and regulations, such as *Eurostat's RAMON* ([20]), *Regulation (EC) No 223/2009* ([21]) of the European Union.

In 2019, we had a working group with the mandate to establish a set of common definitions based on ISO standards and other relevant standards and specifications, and to map the resulting definitions into the framework of DQV. The focus was standardized quality metrics. Since quality metrics should be related to quality dimensions, the working group had also the mandate to establish common definitions of the relevant quality dimensions and subdimensions.

The working group used the following criteria to decide what to define:

1. The mandate for the working group was to define metrics (dqv:Metric), i.e., only quantitative quality descriptions are included in the work.
2. Quality metrics that are only relevant for the data production phase are not included in the work, because it is about the quality of the datasets that are made available for reuse. E.g. metrics like "punctuality" are not included in the work.
3. Quality metrics that are already defined in existing standardized vocabularies are not included in the work. Examples of metrics that are already defined elsewhere and thus not included in the work are: "frequency at which dataset is published" (dcat:accrualPeriodicity) and "spatial/geographical coverage" (dct:spatial).
4. Sector specific quality metrics are not included in the work. Later in the process we became aware of that according to recommendations from ISA[2], geospatial should not be considered as sector specific, but generic.
5. Only inherent data quality metrics ([17], [18]) are included in the work. E.g. quality metrics like "accessibility" are not included in the work.

As shown in Table 1, the working group established a set of common definitions of quality metrics within the quality dimensions "completeness", "currentness", "consistency" and "accuracy". The definitions of the mentioned quality dimensions, quality subdimensions and quality metrics, with examples, are listed in Appendix B of this paper. The definitions together with a guideline for how to use them, have been through a broad national commenting process.

[2] Interoperability solutions for public administrations, businesses and citizens, https://ec.europa.eu/isa2/home_en

Quality dimension	**Quality subdimension**	**Quality metrics** (with data type)
completeness	under-coverage	missing objects (boolean)
		number of missing objects (integer)
		rate of missing objects (percentage)
		number of objects with missing value for a given property (integer)
		rate of objects with missing value for a given property (percentage)
	over-coverage	excess objects (boolean)
		number of excess objects (integer)
		rate of excess objects (percentage)
	imputation	number of objects with imputed value for a given property (integer)
		rate of objects with imputed value for a given property (percentage)
currentness	delay	overall time difference (xsd:duration)
consistency	consistency within the dataset	rate of objects with inconsistent properties (percentage)
		rate of objects with inconsistency between given properties (percentage)
accuracy	identifier correctness	number of objects with incorrect identifiers (integer)
		rate of objects with incorrect identifiers (percentage)
	classification correctness	number of incorrectly classified objects for a given property (integer)
		rate of incorrectly classified objects for a given property (percentage)

Table 1: Quality dimensions, quality subdimensions and quality metrics defined by the working group.

Summary and future work

One of the key prerequisites for digitalization of public administration (e-Government) is data sharing and reuse. In order to reuse data, one needs to know which data already exist. Furthermore, quality of data is one of the aspects that is important for potential users of a dataset, to evaluate whether the dataset is reusable or not.

As a first step towards more data sharing and reuse, we have established a national data catalog which contains standardized and machine-readable descriptions of datasets that are collected and produced by the public administration. Among of the aspects that are described in our national data catalog is the quality of datasets.

As illustrated and summarized in Figure 2:

- In order to have standardized and machine-readable data quality descriptions in our national data catalog, we have chosen to incorporate Data Quality Vocabulary (DQV) into our national standard for description of datasets and data catalogs (DCAT-AP-NO).
- In order to ensure unified understanding of the quality descriptions across the public administration, we have chosen to establish common definitions of quality dimensions, quality subdimensions and quality metrics.

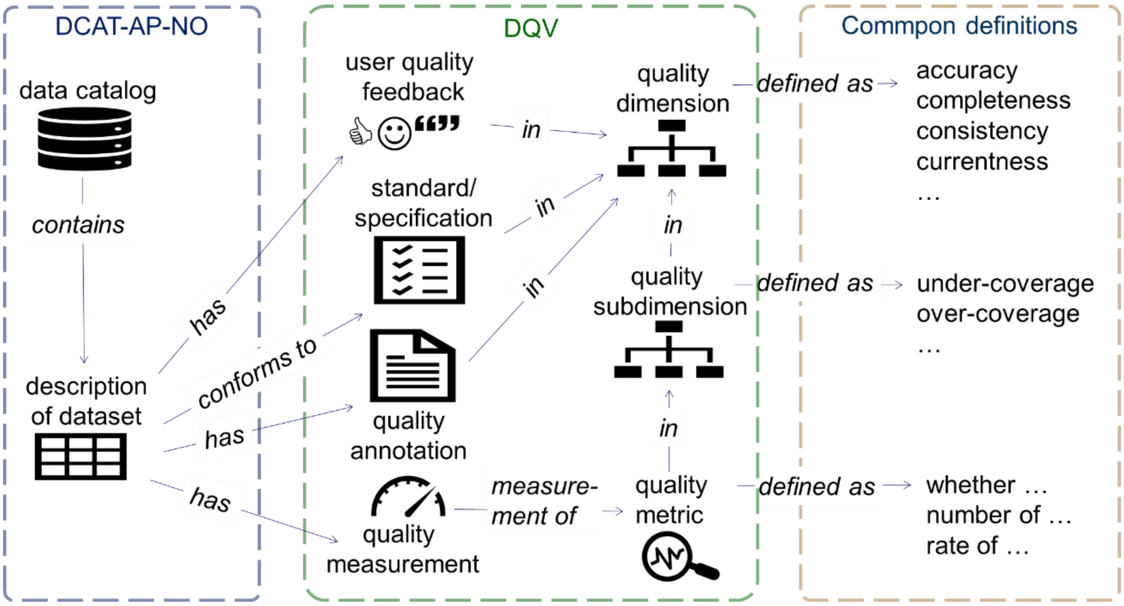

Figure 2: Incorporating DQV into DCAT-AP-NO for describing the quality of datasets, referring to common definitions of quality metrics, quality subdimensions and quality dimensions.

Future work

- Our national standard DCAT-AP-NO will be revised (probably during spring 2020), with DQV explicitly incorporated, and aligned with DCAT-AP which was recently revised.
- The definitions from the working group will soon be published, with the preferred terms and definitions in both Norwegian and English, also in machine-readable formats (e.g. RDF).
- When and if needed, more definitions will be established and published bilingually and machine- readably. Geospatial quality is among the domains that will be prioritized.
- When and if needed, we will also establish a solution for making accessible and machine-readable sector specific metric definitions.

References and links to online resources

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[6] (title freely translated from Norwegian) *Standard for description of datasets and data catalogs (DCAT-AP-NO)*, https://doc.difi.no/dcat-ap-no/ (in Norwegian).

[7] DCAT Application Profile for data portals in Europe (DCAT-AP), https://joinup.ec.europa.eu/solution/dcat-application-profile-data-portals-europe

[8] *Data Catalog Vocabulary (DCAT)*, https://www.w3.org/TR/vocab-dcat-2/

[9] INSPIRE Legislation, https://inspire.ec.europa.eu/inspire-legislation/26

[10] Map Catalogue, the national portal for metadata of geospatial data, https://www.geonorge.no/en/

[11] Morten Borrebaek and Magni Busterud, *From quality on spatial data to data quality vocabulary (DQV) for the Semantic Web – the Norwegian experience of aligning ISO 19157 Data Quality to DQV*, https://eurogeographics.org/wp-content/uploads/2018/06/11-ISO19157.pdf.

[12] (title freely translated from Norwegian) *Specification for description of quality of datasets*, https://doc.difi.no/data/kvalitet-pa-datasett/ (in Norwegian).

[13] *Data on the Web Best Practices: Data Quality Vocabulary* (DQV), https://www.w3.org/TR/vocab-dqv/

[14] *Specification of Registry of Registries*, https://joinup.ec.europa.eu/solution/abr-specification-registry-registries/news/stable-draft-bregdcat-ap

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[16] ISO 19115-1:2014 *Geographic information — Metadata — Part 1: Fundamentals*, https://www.iso.org/standard/53798.html

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[18] ISO 25012, ISO 25000 Portal, https://iso25000.com/index.php/en/iso-25000-standards/iso-25012

[19] ISO/IEC 25024:2015 *Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Measurement of data quality*, https://www.iso.org/standard/35749.html

[20] EuroStat *RAMON - Reference And Management Of Nomenclatures*, https://ec.europa.eu/eurostat/ramon/index.cfm?TargetUrl=DSP_PUB_WELC

[21] *Regulation (EC) No 223/2009 of the European Parliament and of the Council*, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009R0223

[22] BLUE-ETS, BLUE-Enterprise and Trade Statistics, http://www.pietdaas.nl/beta/pubs/pubs/BLUE-ETS_WP4_Del2.pdf

[23] (title freely translated from Norwegian) *Standards for Geographic Information – Geodata quality*, https://kartverket.no/globalassets/standard/bransjestandarder-utover-sosi/geodatakvalitet.pdf (in Norwegian).

Appendix A – Prefixes used in this paper

Table 1: Prefixes used in this paper.

Prefix	Namespace	Name of the vocabulary
dcat	http://www.w3.org/ns/dcat#	Data Catalog Vocabulary
dct	http://purl.org/dc/terms/	(Dublin Core) DCMI Metadata Terms
dqv	http://www.w3.org/ns/dqv#	Data Quality Vocabulary
oa	http://www.w3.org/ns/oa#	Web Annotation Ontology
xsd	http://www.w3.org/2001/XMLSchema#	XML Schema

Appendix B – Quality metrics and the relevant quality subdimensions and quality dimensions that are defined

Note: At the time of submission of this paper, the definitions listed in this appendix are not yet publicly published. There might therefore be some minor changes in the final published version.

Table 2: Definitions of quality metrics and the relevant quality subdimensions and quality dimensions.

Quality dimension	**Quality subdimension**	**Quality metric** (with data type)
completeness the degree to which subject data associated with an entity has values for all expected attributes and related entity instances in a specific context of use (ISO 25012, [18])	**under-coverage** data absent from a dataset (ISO 19157,[15]) *Alternative term: omission*	**missing objects** (boolean) whether objects are missing in the dataset (based on ISO 19157, [15]) Example: “false” (the dataset contains all buildings)

Quality dimension	**Quality subdimension**	**Quality metric** (with data type)
		number of missing objects (integer) number of objects that are not present in the dataset but are expected to be (based on ISO 19157, [15]) Example: “2” (Two buildings are missing in the dataset)
		rate of missing objects (percentage) number of missing objects in relation to the number of objects that should be present in the dataset (based on ISO 19157, [15]) Example: “0.02%” (0.02% of buildings are missing in the dataset)
		number of objects with missing value for a given property (integer) number of objects in the dataset with missing value for a given property (our own definition) Example: “2” (Two buildings in the dataset do not have value for the property “usable area”)
		rate of objects with missing value for a given property (percentage) number of objects with missing value for a given property in relation to the number of objects in the dataset (our own definition) Example: “0.02%” (0.02% of buildings in the dataset do not have value for the property “usable area”)
	over-coverage excess data present in a dataset (ISO 19157, [15]) *Alternative term: commission*	**excess objects** (boolean) whether there are objects incorrectly present in the dataset (based on ISO 19157, [15]) Example: “true” (some buildings in the dataset are not supposed to be there)
		number of excess objects (integer) number of objects in the dataset that should not have been present (based on ISO 19157, [15]) Example: “3” (Three buildings in the dataset are not supposed to be there)

Quality dimension	**Quality subdimension**	**Quality metric** (with data type)
		rate of excess objects (percentage) number of excess objects in the dataset in relation to the number of objects that should have been present (based on ISO 19157, [15]) Example: “0.03%” (0.03% of the buildings in the dataset are not supposed to be there)
	imputation entering a value for a specific data item where the value is missing or unusable (EuroStat RAMON, [20])	**number of objects with imputed value for a given property** (integer) number of objects in the dataset with imputed value for a given property (our own definition) Example: “4” (Four buildings in the dataset have imputed value for the property “year of construction”)
		rate of objects with imputed value for a given property (percentage) number of objects with imputed value for a given property in relation to the number of objects in the dataset (our own definition) Example: “0.04%” (0.04% of the buildings have imputed value for the property “year of construction”)
currentness the degree to which data has attributes that are of the right age in a specific context of use (ISO 25012, [18])	**delay** age of the dataset described as the difference between two points in time (our own definition)	**overall time difference** (xsd:duration) length of time between data availability and the event or phenomenon they describe (EuroStat RAMON, [20]) Example: “24 days” (On average there will be 24 days from a building is completed or demolished, to it is included in or excluded from the dataset)
consistency the degree to which data has attributes that are free from contradiction and are coherent with other data in a specific context of use. It can be either or both among data regarding one entity and across similar data for comparable entities. (ISO 25012, [18])	**consistency within the dataset** the degree to which there is consistency between the properties in the dataset (our own definition)	**rate of objects with inconsistent properties** (percentage) number of objects with inconsistent properties in relation to the number of objects in the dataset (our own definition) Example: “0.03%” (0.03% of the buildings have inconsistency between some properties)
		rate of objects with inconsistency between given properties (percentage) number of objects with inconsistency between given properties in relation to the number of objects in the dataset (our own definition) Example: “0.03%” (0.03% of the buildings in the dataset have “usable area” larger than “gross area”)

Quality dimension	**Quality subdimension**	**Quality metric** (with data type)
accuracy the degree to which data has attributes that correctly represent the true value of the intended attribute of a concept or event in a specific context of use (ISO 25012, [18])	**identifier correctness** the degree to which the objects in the dataset have the correct identifiers (based on BLUE-ETS, [22])	**number of objects with incorrect identifiers** (integer) number of objects in the dataset with incorrect identifiers (our own definition) Example: "1" (One building in the dataset has wrong identifier)
		rate of objects with incorrect identifiers (percentage) number of objects with incorrect identifiers in relation to the number of objects in the dataset (our own definition) Example: "0.01%" (0.01% of the buildings in the dataset have wrong identifiers)
	classification correctness comparison of the classes assigned to features or their attributes to a universe of discourse (e.g. ground truth or reference data) (ISO 19157, [15])	**number of incorrectly classified objects for a given property** (integer) number of objects in the dataset that are incorrectly classified for a given property (based on ISO 19157, [15]) Example: "1" (One building in the dataset is classified with wrong occupancy code)
		rate of incorrectly classified objects for a given property (percentage) number of objects that are incorrectly classified for a given property in relation to the number of objects in the dataset (based on ISO 19157, [15]) Example: "0.01%" (0.01% of the buildings in the dataset are classified with wrong occupancy codes)

Building Register – Basis for 3D Cadastre

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Keywords: building register, 3D cadastre, land registry

SUMMARY

Cadastral systems need to be designed and supported from three-dimensional spatial perspectives.

To create the 3D cadastre, a building register is needed. Development of the building cadastre can be based on the records of state surveys, spatial units registers, land registers, records of local and regional self-government units, data from construction files according to special regulations in the field of spatial planning, records kept by building managers, and other sources.

The most significant element of the 3D cadastre is comprised of buildings and separate parts of buildings, followed by public utility infrastructure and complex spatial real-life situations (bridges, tunnels, overpasses, underpasses, overlapping of constructed objects with natural facilities, large shopping malls with more underground and overhead floors etc.).

This paper investigates important steps in establishing the building register. We propose how to upgrade the building register into the 3D cadastre, based on examples from Croatian land administration system. The most significant use cases in 3D cadastre are shown in this paper as well.

1. INTRODUCTION

In the last couple of decades, there has been an increasing demand for property development in urban areas, resulting in the division of property ownership so that different owners can own delimited space on, above or below ground surface. Under 3D cadastre, the 2D cadastre management of data cannot meet the real land management of the three dimension space aspect and property. It is essential to introduce the 3D cadastre (Choon and Seng, 2013).

The limited advances in full 3D cadastre implementations throughout the world might be explained by the fact that the implementation of the 3D cadastre requires close collaboration between legal and technical experts in an empirical environment to understand the impact of each other's domain (Stoter et al. 2012).

In the Republic of Croatia (and other countries where cadastre was established a long time ago), many registers and official databases on land and interests were created where certain overlaps between some segments are evident. These were most often established independently and therefore contain a lot of redundant data. However, their interaction can be used to gain new values and establish Multipurpose Land Administration Systems (Vučić et al., 2017).

A 3D object in the 3D cadastre is defined as such a geometry that has vertical faces enclosing a 3D space with roofs and floors. A 2D object (parcel in the current cadastral system) is a special case of a 3D object which has the coincident roof and floor, and collapses into a polygon. A 3D object termed '3D property' refers to a spatial envelope containing the construction built with the land space, rather than a space of land rights because the current laws and regulations cannot give a clear and explicit statement about the spatial extent of the rights and it is impossible to describe the spatial extent of those rights (Guo et al 2011).

Cities are increasingly adopting 3D city models. Providing further value and additional utility over 2D geo-datasets, 3D city models are becoming ubiquitous for making decisions and for improving the efficiency of governance. Local governments use 3D city models for urban planning and environmental simulations such as estimating the shadows cast by buildings, investigating how noise from traffic propagates through a neighbourhood, and predicting how much solar irradiation the roof of a building receives in order to assess whether it is economically feasible to install a solar panel (Biljecki 2017).

In the Republic of Croatia, the new State Survey and Real Property Cadastre Act stipulates the establishment of a new register called the "Building Register".

This paper is organized as follows. Section 1 is introduction. Section 2 analyses Croatian LADM profile. Section 3 describes process of registering buildings in the Croatian land administration system. Section 4 describes elements for establishing the Building register and quality control of 3D cadastre data. Section 5 describes spatial data quality in 3D cadastre. The paper ends with conclusion.

2. CROATIAN LADM PROFILE

The first version of the Croatian LADM profile was developed in 2012. New classes, attributes, and types were added in the code list. For the attributes added in classes HR_SpatialUnit: HR_UsageTypeLand and HR_UsageTypeBuilding (Figure 1), the corresponding code list was created according to the Regulation on Land Cadastre and according to the Regulation on the Content and Form of Real Property Cadastre Documentation (Figure 2). The code list was also created for HR_OwnerType, HR_MonumentMaterial, HR_BoundaryType attributes, in accordance with the current State Survey and Real Property Cadastre Act.

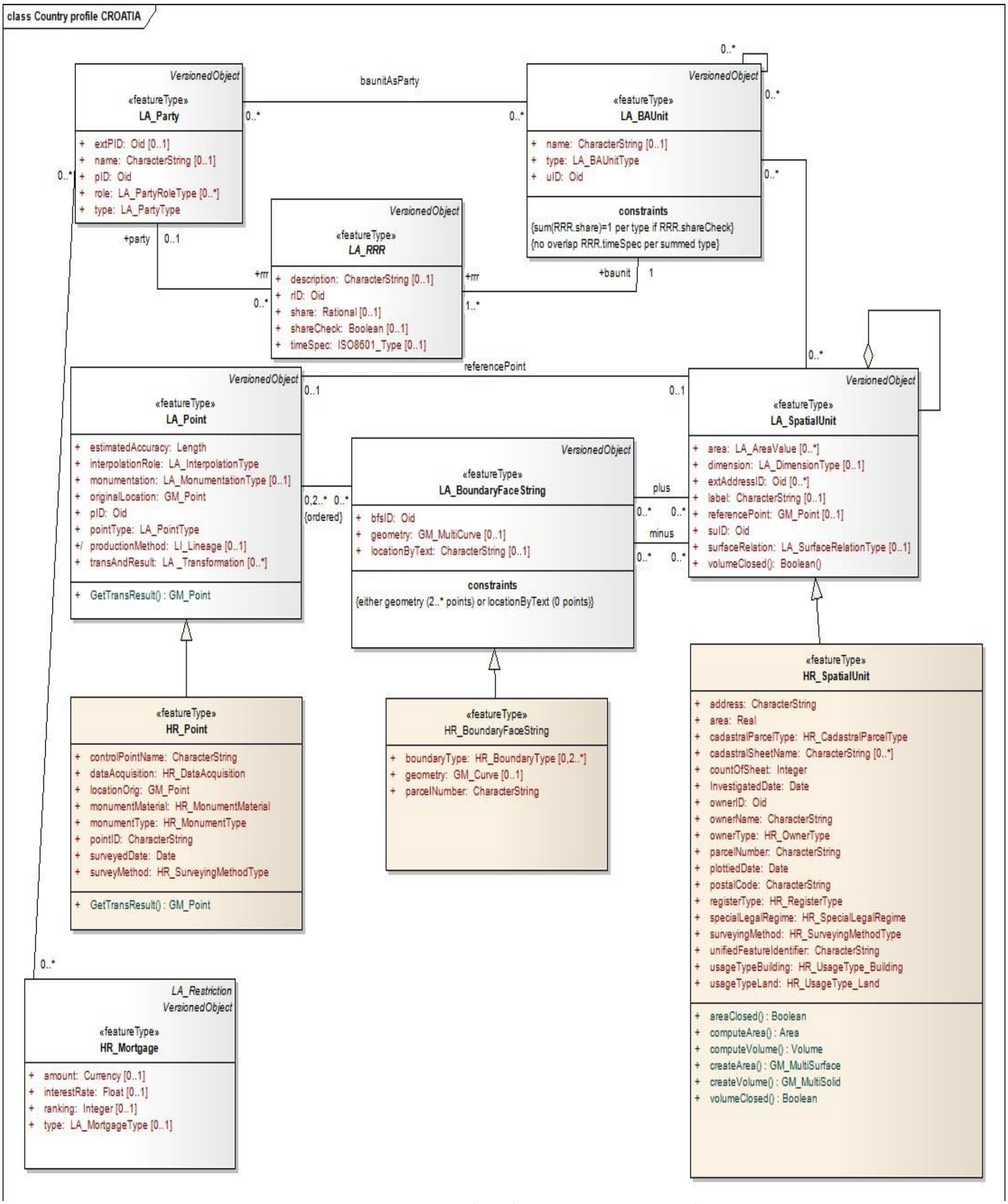
Another important contribution to the development of the 3D Cadastre in the Republic of Croatia is the introduction of the unique identifier of special parts of real property, proposed to be implemented in the State Survey and Real Property Cadastre Act and the Land Registration Act (Vučić 2015).

The unique identifier of special parts of real property is a solution for all objects that are needed for the development of 3D Cadastre (buildings of various purposes, underpasses, overpasses, tunnels, bridges, viaducts, underground buildings, etc.).

The unique identifier could be used for denotation of separate parts of buildings, such as flat, apartment, business space, where each separate part gets a unique identifier in the Croatian land management system.

The unique identifier of a special part includes:

- identification number of the cadastral municipality
- number of land registry file
- number of land registry sub-file


class Country profile CROATIA
VersionedObject
«featureType»
LA_Party
+ extPID: Oid [0..1]
+ name: CharacterString [0..1]
+ pID: Oid
+ role: LA_PartyRoleType [0..*]
+ type: LA_PartyType
baunitAsParty
0..*
0..*
0..*
VersionedObject
«featureType»
LA_BAUnit
+ name: CharacterString [0..1]
+ type: LA_BAUnitType
+ uID: Oid
constraints
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+ description: CharacterString [0..1]
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+ originalLocation: GM_Point
+ pID: Oid
+ pointType: LA_PointType
+/ productionMethod: LI_Lineage [0..1]
+ transAndResult: LA _Transformation [0..*]
+ GetTransResult() : GM_Point
0,2..*
0..*
{ordered}
VersionedObject
«featureType»
LA_BoundaryFaceString
+ bfsID: Oid
+ geometry: GM_MultiCurve [0..1]
+ locationByText: CharacterString [0..1]
constraints
{either geometry (2..* points) or locationByText (0 points)}
plus
0..*
0..*
minus
0..*
0..*
VersionedObject
«featureType»
LA_SpatialUnit
+ area: LA_AreaValue [0..*]
+ dimension: LA_DimensionType [0..1]
+ extAddressID: Oid [0..*]
+ label: CharacterString [0..1]
+ referencePoint: GM_Point [0..1]
+ suID: Oid
+ surfaceRelation: LA_SurfaceRelationType [0..1]
+ volumeClosed(): Boolean()
«featureType»
HR_Point
+ controlPointName: CharacterString
+ dataAcquisition: HR_DataAcquisition
+ locationOrig: GM_Point
+ monumentMaterial: HR_MonumentMaterial
+ monumentType: HR_MonumentType
+ pointID: CharacterString
+ surveyedDate: Date
+ surveyMethod: HR_SurveyingMethodType
+ GetTransResult() : GM_Point
«featureType»
HR_BoundaryFaceString
+ boundaryType: HR_BoundaryType [0,2..*]
+ geometry: GM_Curve [0..1]
+ parcelNumber: CharacterString
«featureType»
HR_SpatialUnit
+ address: CharacterString
+ area: Real
+ cadastralParcelType: HR_CadastralParcelType
+ cadastralSheetName: CharacterString [0..*]
+ countOfSheet: Integer
+ InvestigatedDate: Date
+ ownerID: Oid
+ ownerName: CharacterString
+ ownerType: HR_OwnerType
+ parcelNumber: CharacterString
+ plottiedDate: Date
+ postalCode: CharacterString
+ registerType: HR_RegisterType
+ specialLegalRegime: HR_SpecialLegalRegime
+ surveyingMethod: HR_SurveyingMethodType
+ unifiedFeatureIdentifier: CharacterString
+ usageTypeBuilding: HR_UsageType_Building
+ usageTypeLand: HR_UsageType_Land
+ areaClosed() : Boolean
+ computeArea() : Area
+ computeVolume() : Volume
+ createArea() : GM_MultiSurface
+ createVolume() : GM_MultiSolid
+ volumeClosed() : Boolean
0..*
LA_Restriction
VersionedObject
«featureType»
HR_Mortgage
+ amount: Currency [0..1]
+ interestRate: Float [0..1]
+ ranking: Integer [0..1]
+ type: LA_MortgageType [0..1]

Figure 1. LADM profile for the Republic of Croatia

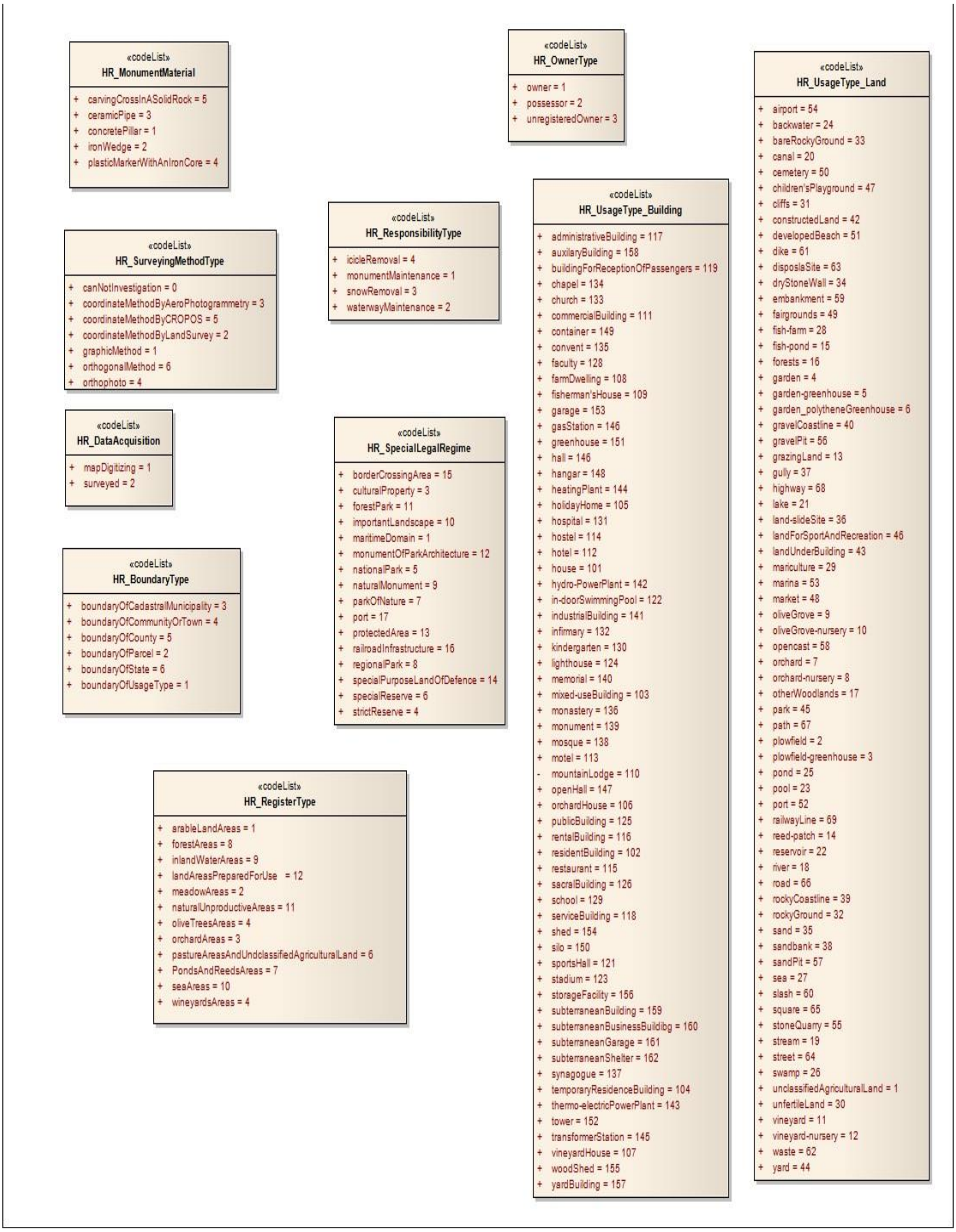

Figure 2. LADM profile for the Republic of Croatia – code lists

3. REGISTERING BUILDINGS IN THE CROATIAN LAND ADMINISTRATION SYSTEM

Data about buildings are entered into land books based on information delivered to the land registry by the cadastral office. Ownership of a particular part of real property (e.g. an apartment or office space) is realized through registration in the land registry. Such separate parts may be registered if they constitute independent units of use. Separate parts may include balconies, terraces, basements, and attics, under the condition that they serve exclusively a single particular part and are clearly separated from other parts of the real property. Land book registration of particular parts of real property is not possible without a partition of real property. The same procedure is commonly used in the land registry to formally consolidate land which was often publicly owned with buildings constructed on that land. Partition of real property serves to establish ownership of particulars part of real property (apartment, office space, garage, etc.) that become associated with the proportionally shared part of real property (Vučić et al. 2013).

Fair relationship in financing the maintenance of buildings is furthermore made possible by establishing ratios of each party’s ownership in the real property and, hence, each party’s proportional share in the shared ownership of common parts.

The elaborate on condominium partition of real property establishes the size and shape of the common and separate parts of a single real property (apartment, office space, etc.) and draws connections for reference purposes against the real property as a unit. Additionally, data about particular parts must be technically processed providing drawings of particular and common parts with the required labels and areas of particular parts. A shared ownership contract must also be provided.

4. ELEMENTS FOR ESTABLISHING THE BUILDING REGISTER

The standard attempts to assign standardized classes to generally differentiate grades of 3D data. The geometric detail and the semantic complexity increase with each level (Figure 3). This LOD categorisation is well known in the 3D GIS community (Biljecki 2017).

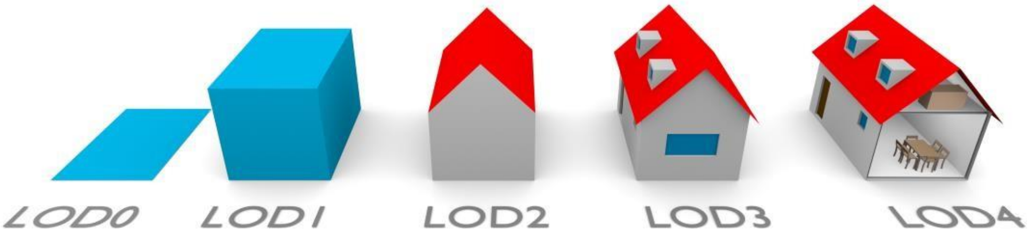

Figure 3. The five LODs of the OGC CityGML 2.0. (Biljecki 2017)

The attributes of the objects are:

- **building** (identification code of the building, identification code of the cadastral parcel, address of the building, footprint of the building, 3D building model, parameters of positional and height accuracy, real use of the building, land area under the building, altitude of the building (minimum, terrain, maximum), height of the building, number of floors, number of the ground floor, number of apartments/business premises in the building, building permit, level of construction, condition of property, year of construction, year of facade renovation, year of roof renovation, electricity, sewerage, water supply, gas, energy certificate, type of investors, type of foundation, material of bearing structures)
- **floor** (identification code, footprint of the floor, type of floor (underground/above ground), number of the floor, altitude of the floor, height of the floor)

- **roof** (footprint of the roof, ridge of the roof)
- **building unit** (identification code, address, land registry file, owner, real use of the building unit, area, method of determining area, building manager, number of rooms, bathroom, toilet, kitchen, year of the renovation of installations, energy certificate)
- **part of the building unit** (identification code, footprint of the part of the building unit, 3D model, parameters of positional and height accuracy, real use of the part of the building unit, area, energy certificate, type of heating)
- **rooms** (real use, area)

4.1 Data about buildings

Buildings are registered in the cadastre on obligatory request of a party. A geodetic report prepared by an authorized surveying company must be supplied with this request. The responsible cadastral office must review and confirm the report. Surveying companies have at their disposal many surveying methods, including the modern GNSS surveying method, while field surveying must be performed with minimally the same accuracy as cadastral surveying or technical supervision used for preparing the cadastral record for the cadastral municipality where the relevant building stands. Buildings are registered in the cadastre with the following attributes: area, intended building use, building name, and house number.

Additional information (attributes) needs to be recorded in the building register such as: footprint of the building, 3D building model, altitude of the building, height of building. Table 1 proposes the basic attributes necessary for efficient land administration.

Attribute	**Description**	**Obligation**	**Code list**
identification code of the building:			
• code of cadastral municipality		YES	code list of cadastral municipality
• the number of the building within the cadastral municipality		YES	numerical value from 1 to n
identification code of the cadastral parcel		YES	defined in the Land Cadastre
footprint of the building	maximum outline of the building or building point	YES	polygon or point
3D building model	building volume	NO	building volume
land area under the building	land area under the building recorded in the Land Cadastre or obtained in some other way (measurement, calculation from the building footprint, ...)	NO	numerical value from 1 to n
real use of the building	code from the National Classification of types of construction	YES	code list
address of the building	address structured from the Spatial Units Register	NO	defined in the Spatial Units Register

altitude of the building (minimum, terrain, maximum)	altitude of the building: - minimum (altitude of the lowest point of the building) - terrain (altitude of the terrain adjacent to the building) - maximum (altitude of the highest point of the building)	NO	numerical value between -200 and 2500
height of the building	height difference between the lowest and highest point of the building	NO	numerical value between 0 and 1000
number of floors		YES	numerical value from 1 to 100
number of the ground floor		YES	numerical value from 1 to 100
year of construction		YES	year between N and today's date
building permit	the data are already included in the Joint Information System of Land Registry and Cadastre (JIS)	NO	alphanumeric value

Table 1. Data about building

The object Building is linked to the Land Cadastre (particle or a building that already exists in the JIS), topography, address, building part, building unit, floor and roof.

Features of the building:

- building is associated with one or more cadastral parcels,
- building is associated with one or more buildings in the topography, each building has a minimum of one floor,
- each building has at least one building part,
- each building has at least one building unit,
- each building can have one or more addresses.

4.2 Collecting information on buildings

To complement those already registered in the cadastre and land registry, information can also be collected by aerial imaging (stereo restitution) or LIDAR scanning.

With stereo restitution, the height of the surface near the building is collected, the highest point of the building, the main ridge of the roof, and the height and layout of the outer edge of the roof. Based on these data, a simple 3D model consisting of the building with a roof can be created and on the basis of measured heights, the height of the building can be calculated.

Collecting the building layout data and its height is also automatically recorded by characteristic contours of the building using LIDAR data. Use of the automatic classification of LIDAR data is the easiest way to create point clouds of buildings. With software applications, characteristic contours of the buildings can be created, which can be used for the establishment of the initial building register.

4.3 Proposed separate parts to be entered in the building register

Along with the attributes entered in cadastral records for over two centuries, new, additional attributes need to be collected for establishing the cadastre of buildings, as detailed in Table 2.

Attribute	**Description**	**Obligation**	**Code list**
identification code of the building:			
• code of cadastral municipality		YES	code list of cadastral municipality
• the number of the building within the cadastral municipality		YES	numerical value from 1 to n
identification code of the cadastral parcel		YES	defined in the Land Cadastre
footprint of the building	maximum outline of the building or building point	YES	polygon or point in RoC
3D building model	building volume	NO	building volume in RoC
land area under the building	land area under the building recorded in the Land Cadastre or obtained in some other way (measurement, calculation from the building footprint, ...)	NO	numerical value from 1 to n
real use of the building	code from the National Classification of types of construction	YES	code list
address of the building	address structured from the Spatial Units Register	NO	defined in the Spatial Units Register
altitude of the building (minimum, terrain, maximum)	altitude of the building: - minimum (altitude of the lowest point of the building) - terrain (altitude of the terrain adjacent to the building) - maximum (altitude of the highest point of the building)	NO	numerical value between -200 and 2500
height of the building	height difference between the lowest and highest point of the building	NO	numerical value between 0 and 1000
number of floors		YES	numerical value from 1 to 100
number of the ground floor		YES	numerical value from 1 to 100
year of construction		YES	year between N and today's date
building permit	the data are already included in the JIS for object BUILDING:	NO	alphanumeric value
year of the facade renovation		NO	year between N and today's date
year of the roof renovation		NO	year between N and today's date
electricity	the existence of electrical networks	YES	code list
sewerage	the existence of sewerage system	YES	code list
water supply	the existence of water system	YES	code list

gas	the existence of the gas infrastructure	YES	code list
identification number of the energy certificate	data are taken from the records of the Ministry of Construction and Physical Planning	NO	take the code list of the identification number of the energy certificate
energy certificate (document)	data are taken from the records of the Ministry of Construction and Physical Planning	NO	the scans
the level of construction	the level of construction of the building	NO	code list
type of investors		NO	code list
condition of property	maintained / neglected / .. or other criteria that will determine the Tax administration? (How will it determine should prescribe the Ministry of Construction and Urban Planning)	NO	code list
number of apartments in the building	derived data	NO	numerical value from 1 do 1000
number of business premises in the building	derived data	NO	numerical value from 1 do 1000

Table 2. Data about separate parts of real property

Shared owners of real property remain herewith in a shared ownership over the common parts, while each person becomes an individual owner of separate parts (e.g. apartment or office space). The method of registering elaborates on condominium partition of real property (Figure 4) was introduced in 1996. There are many real properties in Croatia which have not yet been registered according to that method.

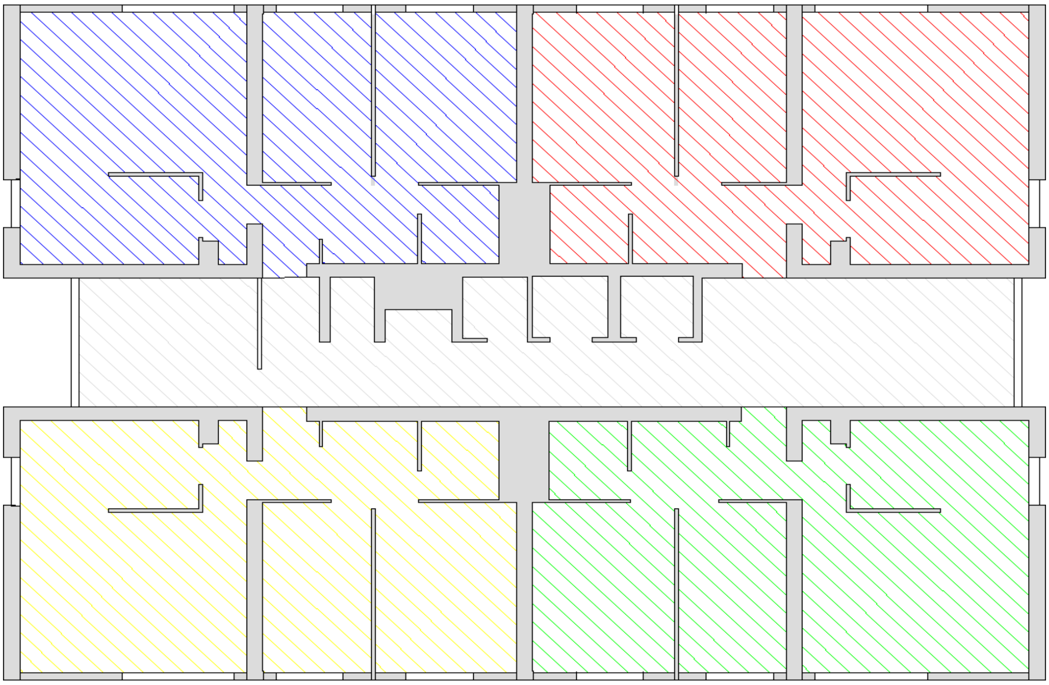

Figure 4. Part of an elaborate on condominium partition of real property (first floor)

Models have been made from the 2D building plans that are used for elaborate on partition of real property (Figure 5). In that elaborate there is an original 2D measurement data of every floor and by heights we can also easy calculate a volume of every separate part of property.

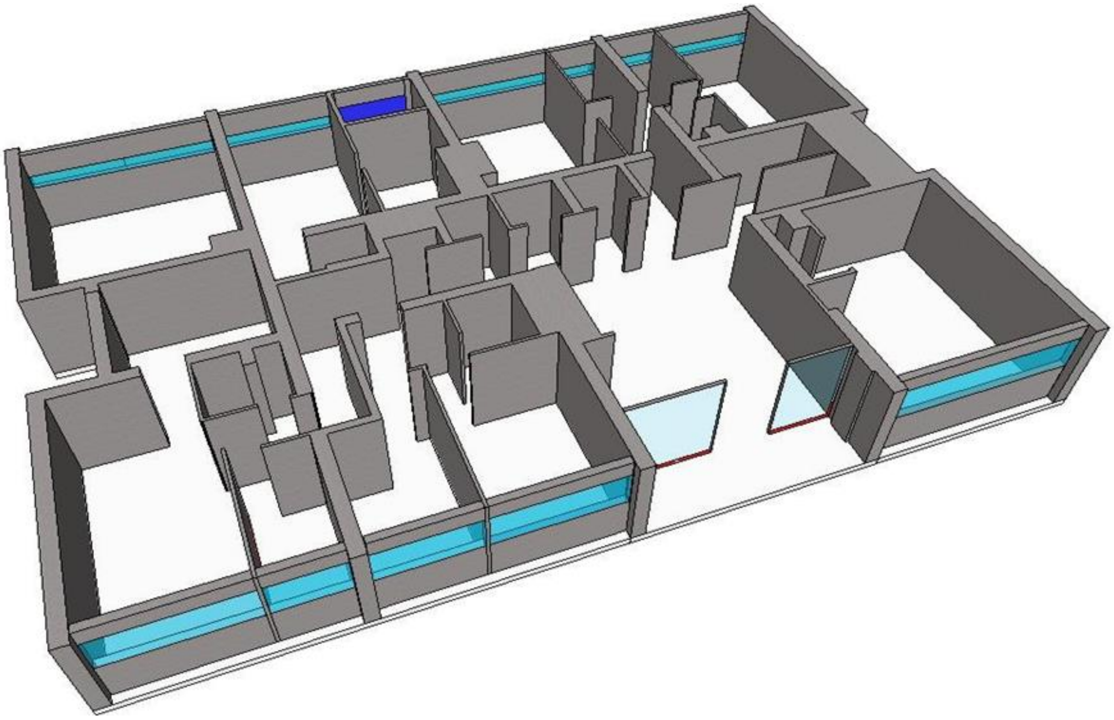

Figure 5. Residential building (3D model of a floor)

Today's computer technology provides advanced methods of registration in official registers. For the purpose of implementing a building register the 3D models can be used (Figure 6). This model can be linked to the Unified Feature Identifier of particular part of real property or to the number of cadastral parcel in the database and also integrated (by coordinates) with matching 3D cartographic view developed within the national land administration system (Vučić et al. 2013).

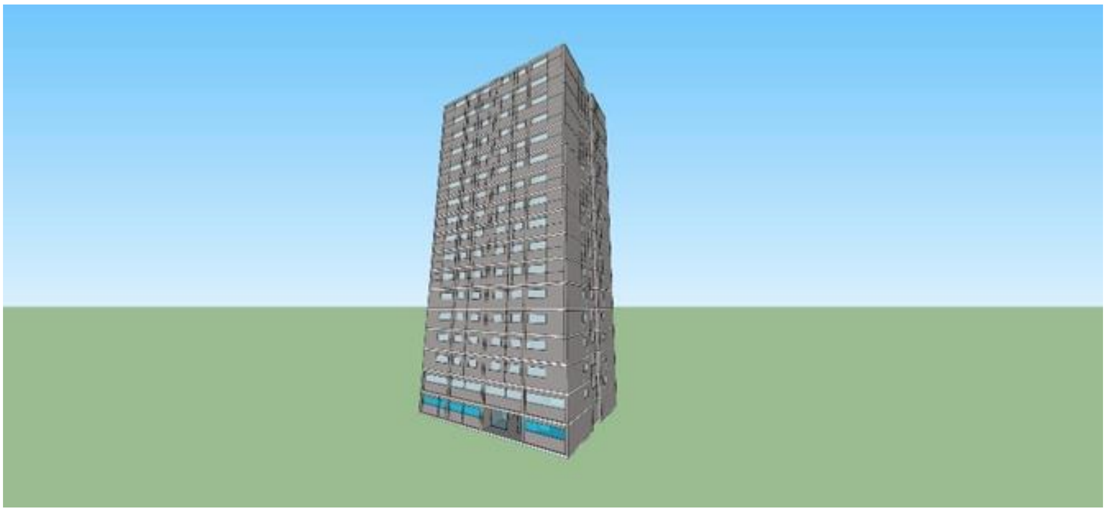

Figure 6. Residential building (3D model)

5. SPATIAL DATA QUALITY IN 3D CADASTRE

In 2009 Karki et al. investigate about data validation in 3D cadastre. Validation is initially approached to answer questions such as: " what is validation? why it is necessary to validate?, and how do we validate?". Limiting the scope to the 3D geometry or spatial representation of a 3D cadastre, their paper takes a novel approach in identifying the various aspects of validation of a 3D cadastral parcel and identifies the critical validation factors (Karki et al. 2009).

For the area of Republic of Croatia in 2019 Moharić et al. present an overview of some of the most important on-going activities in the cadastral system of the Republic of Croatia in this respect, as well as the historical cross-section of a unified digital cadastral database establishment activities and the transition towards digital cadastre (Moharić et al. 2019).

Step towards 3D cadastre also requires the processing of data inside a building on all apartments and office spaces within a single building. There are not many complex real-life 3D situations in the Republic of Croatia (such as tunnels, bridges, complex underground buildings, overlapping bulidings etc.), and the formation of a 3D cadastre is mostly reduced to the registration of the third dimension as well as to the registration of special parts of buildings.

Spatial data quality in the 3D cadastre is based on the appropriate processing of 3D data, respectively in the alignment of the graphic data of the floor plans of special parts of buildings with the written data on the surfaces of special parts. It is possible to introduce the volume of special parts of a building as a collected or calculated data. In order to control the quality of the data it is necessary to perform additional field measurement with affordable handheld laser distance meter. To achieve higher level of accuracy quality control can be integrated on the application level, e.g. applications responsible for cadastre management and maintenance.

6. CONCLUSION

Implementation of the Building Register project in the Republic of Croatia, as a new part of the real property register, is essential for the establishment unique register of buildings. This register will served as a platform for developing a good, complete and fair basis on which property tax can be established, for improving management of real property and resolving legal issues in multi-residential buildings, for better management of spatial and construction planning and housing policy, promoting the development of community and infrastructure planning, providing a better overview of apartments and office spaces, allowing better application, as well as providing a systematic statistical list. The biggest problem in establishing the building register is the large number of buildings unregistered in the cadastre and land registry, as well as the large number of apartment buildings where a partition into condominium units has not been conducted. The project of establishing the building register should, among other things, resolve this problem.

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Rebuilding the Cadastral Map of The Netherlands, overall Concept & Communication on Geometric Quality

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Keywords: cadastral map, communication, (visualization of) geometric quality, automation

SUMMARY

The Dutch Cadastral Map has been around since the early 19th century and fits the designed goal perfectly: it is a complete and topological correct index to the cadastral registration. However, the so-called graphic quality of about half a meter doesn't show on the map and it doesn't seem to be enough in a future where people want to use it as a map and zoom in and establish the exact location of their boundaries themselves. The related uncertainty of the parcel size is also an issue. Therefore Kadaster defined a wish for a cadastral map with better geometric quality and clearer communication about its quality.

It quickly became apparent that to be able to create such a map the original field documents must be used. Technically and financially it is a very big challenge to automatically digitize these documents. After a market survey we started a research project in 2017 where many different aspects (legal, communication, geodetic, organizational, etc.) were studied. The focus however was first on the most critical aspect: the question whether the millions of original analogue field documents could be read automatically. Two companies realized a proof of concept in which they proved that it is possible, but not 100% automatically. We continued by contracting experts from both companies who, together with our own staff, succeeded in building a prototype that is able to both read the documents and connect them together to a new geometry of a cadastral map. The solution is based on artificial intelligence.

Field documents

A field document contains the surveyors sketch of the measurements. The content of a field document is very complex, it is usually handwritten and with a flexible map scale. Extracting structured information from such documents demands different steps for an automatic algorithm: image improvement, line detection, point definition, recognition and reading of measurement numbers and the link between these numbers and two points (begin & end). The result of this process is a digital drawing on scale with structured measurement data. In this process manual checking and correction is still needed.

Geodetic concept

A second large process is the positioning of this line pattern in the national reference system and the connecting of the different field results to each other. The geodetic concept is based on the Delft method of testing where quality control is performed in all steps of the process. This starts with the adjustment and testing of the measurements of the many small survey projects individually, of which the measurements are stored in the field documents. After georeferencing the survey projects grow together by connecting them using corresponding points in the overlap between the projects. These corresponding points are often cadastral stones, iron pipes or corners of buildings. All measurements are weighted and the so-called idealisation precision is accounted for in relation to the type of point. With every newly added project the redundancy improves, the network is re-adjusted, and the measurements are statistically tested. In this way the geometric base for the new cadastral map is being built while errors in the measurements are eliminated.

The main challenges in building the geometric base for the new cadastral map are: the large number of field documents and the variability of their content, the relatively large number of errors in combination with an average redundancy in individual survey projects that is quite low, and how to cope with the limitations in network size as a nation-wide integral adjustment is not feasible.

Currently we are in the middle of a pilot project in which we will produce about 5 to 10 thousand digitized field documents to create a new cadastral map geometry in order to get decision support information. We are already busy preparing a new infrastructure to store the new geometry called Reconstruction Map (not yet being the current cadastral map).

Communication with the public

Now that the technical solution is in the making, the next step is to coach the public in using and understanding the current cadastral map and the new reconstruction map properly, so making the public understand the geometric quality of the data shown. This poses a big risk of damaging the public confidence in the Kadaster. Because although we are improving on the quality of our data in this project, the public for the first time will become aware of the quality of the data and therefore might perceive it as a quality loss. Therefore a good communication strategy plays a key-role in this process.

The legal and communication aspects are being examined at this moment. We are developing an introduction process with a public awareness campaign and legal answers to difficult questions with the change of parcel sizes as the most delicate one. Also the concept of do-it-yourself reconstruction is developed. At the moment we are moving from research to decision making, so we are still in the process of describing all the benefits for society.

Communication on geometric quality

Explaining geometric quality to the public is not easy because it is the result of a mathematical process. The challenge is to make clear what the result of your actions is, to explain it as simple as possible while still using correct descriptions. De-mythification of the used methods is therefore needed.

A simple example of explaining is by using a reliability strip: a zone in which the searched boundary can be found. For the current cadastral map such a strip is half a meter wide in urban areas and one meter in rural areas. This way you have an easy story for connecting the boundary representation on the current cadastral map to the real life situation. For the newly built and improved cadastral map it is important to explain what quality can be expected. We know the standard deviation (σ) of the absolute position (compared to the national coordinate system) is at least 5cm. This means a strip of 2σ = 10 cm minimum, and with a 95% reliability (4σ) even 20 cm!

What we want the public to understand, is that people should expect a 10 cm strip and not 1 cm or even better quality. While this may disappoint some persons, we feel strongly that open communication on this subject will be appreciated in the end. As a preparation for that we already show more metadata about the geometric quality in the current map.

Besides the reliability strip, we are currently designing a system of classification of the quality so the public can have a better overview of the geometric quality. This classification will be derived from the quality aspects that are stored to individual points. We already developed some default schemes to describe difficult situations in an easy way.

As the examples above show, there are many ideas on communicating the cadastral data quality, but this is still an ongoing process. Although these strategies are being developed specifically for this project, they can also be used on other spatial Key Registers in the Netherlands, because the same issues with understanding data quality exist there as well.

The Quality Control Column Set: An Alternative to the Confusion Matrix for Thematic Accuracy Quality Controls

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Introduction

A classification may be considered accurate if it provides an unbiased representation of the reality (agrees with reality), or conforms to the “truth”. Thematic accuracy is defined by ISO 19157 as the accuracy of quantitative attributes and the correctness of non-quantitative attributes and of the classifications of features and their relationships. Classification correctness is defined by the same standard as the comparison of the classes assigned to features or their attributes to a universe of discourse (e.g. ground truth or reference data). Classification correctness is a main concern in any remote sensed derived product (e.g. land cover, fire and drought incidence maps, etc.) and, in general, for any kind of spatial data (e.g. vector data such as cadastral parcels, road networks, topographic data bases, etc.). The main components for a thematic accuracy assessment are (Stehman and Czaplewski, 1998): i) the sampling design used to select the reference sample; ii) the response design used to obtain the reference land-cover classification for each sampling unit; and iii) the estimation and analysis procedures. But for a proper classification correctness assessment, a classification scheme is also needed. A classification scheme has two critical components (Congalton and Green, 2009): i) a set of labels, ii) a set of rules for assigning labels. From our point of view, the two previous aspects must be considered from a more general perspective of the production processes of spatial data, and from this perspective, the first thing to consider is a specification of the product (e.g. in the sense of ISO 19131). This specification should contain the classification scheme but also a specification of the level of quality required for each category (e.g. at least 90% of classification correctness for category A), and grade of confusion allowed between categories (e.g. at most 5% of confusion between categories A and B). These quality grades must be in accordance with the processes' voice (capacity to give some quality grade) and the user's voice (quality needs for a specific use case).

The confusion matrix is currently at the core of the accuracy assessment literature (Foody, 2002) and, as stated by Comber et al. (2012), the error matrix has been adopted as both the *“de facto”* and the *“de jure”* standard, the way to report on the thematic accuracy of any remotely sensed data product (e.g. image derived data). Of course, the same tool can be used for any kind of data directly originated in a vector form.

A confusion matrix and the indices derived from it are statistical tools for the analysis of paired observation. When the objective is to compare two classified data (by different processes, different operators, different times, or something similar), the observed frequencies in a confusion matrix areassumed to be modelled by a multinomial distribution (forming a vector after ordering by columns,for instance). The indexes derived, like overall accuracy, kappa, producer’s and user’s accuracies and so on, are based on this assumption (multinomial distribution) and they make sense due to the complete randomness of the elements inside the confusion matrix. However, this inherent randomness, that is the assumption of the underlying statistical model falls down when a true reference data is available. Suppose the reference data is located by column. If the reference data are considered as the truth, the total number of elements we know that belong to a particular category, can be correctly classified or confused with other categories, but always there will be located in the same column but never in other different column (category). This fact implies that inherent randomness of the multinomial is not possible now. However, we can deal with the available classification by considering a multinomial distribution for each category (column) instead of the initial multinomial distribution which involved all the elements in the matrix. For this reason, we will call this approach as Quality Control Column Sets (QCCS). Therefore, the goal of this paper is to present the basis of this new approach and to give an example of its application.

Quality control column set

A confusion matrix, or error matrix, is a contingency table, which is a statistical tool for the analysis of paired observations. The confusion matrix is proposed and defined as a standard quality- measure for spatial data (measure #62) by ISO 19157. For a given geographical space, the content of a confusion matrix is a set of values accounting for the degree of similarity between paired observations of k classes in a controlled data set (CDS), and the same k classes of a reference data set (RDS). Usually RDS and CDS are located by columns and by rows, respectively. So it is a $k \times k$ squared matrix. The diagonal elements of a confusion matrix contain the number of correctly classified items in each class or category, and the off-diagonal elements contain the number of confusions. So a confusion matrix is a type of similarity assessment mechanism used for thematic accuracy assessments.

$$CM(i,j) = [\#items\ of\ class\ (j)\ of\ the\ RDS\ classified\ as\ class\ (i)\ in\ the\ CDS] \qquad (1)$$

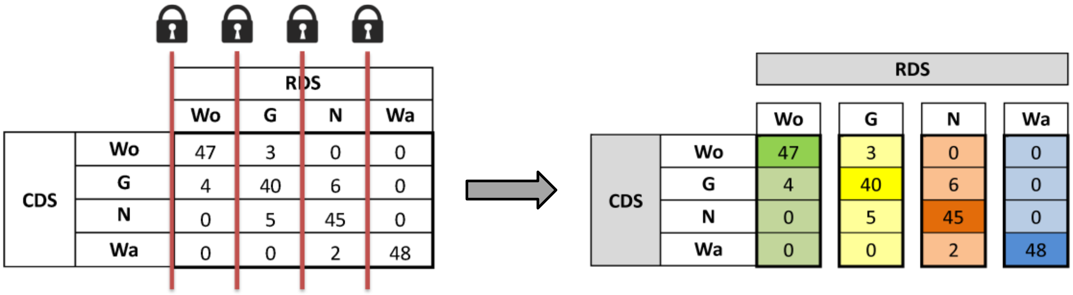
A confusion matrix in not free of errors (Congalton and Green, 1993; Foody, 2002), and for this reason a quality assurance of intervening processes is needed; e.g. the proposal of Shehman and Czaplewski (1998) can be considered in this way (in order to apply a statistically rigorous accuracy assessment). As pointed out by Smits et al. (1999), obtaining a reliable confusion matrix is a weak link in the accuracy assessment chain. Here a key element is the RDS, denoted sometimes as “ground truth”, which can be totally inappropriate and, in some cases, very misleading (Congalton and Green, 2009) and should be avoided. As pointed out by several studies, RDS often contain error and sometimes possibly more error than the CDS. Here, the mayor problem comes from the fact that classifications are often based on highly subjective interpretations. The problem of lack of quality in the reference data is still current (Congalton et al. 2014), and the thematic quality of products derived from remote sensing still presents problems. We understand that this situation is due to the fact that in most cases the RDS is simply another set of data (just another classification) and not a true reference (error free or of better quality).

The above mentioned situation does not occur in the quality assessment of other components of spatial data quality; in this way, compared to positional accuracy there is a clear lack of standardization. For example, in the case of positional accuracy, the ASPRS standard (ASPRS, 2015) establishes the following requirement: “The independent source of higher accuracy for checkpoints shall be at least three times more accurate than the required accuracy of the geospatial data set being tested”. This situation is directly achievable when working with topographic and geodetic instruments, but it is not directly attainable when working with thematic categories because of the high subjectivity of interpretations. However, we believe that this situation should guide all processes for determining the RDS of an assessment of thematic accuracy.

In order to actually achieve greater accuracy for the RDS some quality assurance actions need to be deployed in order to reduce the subjectivity of the interpretations, for instance: i) using a group of selected operators, ii) designing a specific training procedure for the group of operators in each specific quality control (use case), iii) calibrating the work of the group of operators in a controlled area, iv) supplying the group with good written documentation of the product specifications and the quality control process, v) helping the group with good service support during the quality-control work and socializing the problems and the solutions and, finally vi) proceeding to the classification based on a multiple assignation process produced by the operators of the group, achieving agreements where needed. In this way Yang et al (2017) propose that validation sampling units be reviewed by 9 experts and to adopt a label requires a consensus of at least 6/9 among these experts. All these actions are quality assurance actions and must be deployed, paying special attention to improving trueness (reducing systematic differences between operators and reality), precision (increasing agreement between operators in each case) and uniformity (increasing the stability of operators' classifications under different scenarios).

If the RDS does not have the quality to be a reference, the confusion matrix can be understood as a complete multinomial. From this perspective, the analyses based on the confusion matrix are correct (e.g. overall accuracy, kappa, users' and producers' accuracies, and so on). But if the RDS does have the quality to be a reference, it is not correct to work with the complete confusion matrix because the inherent randomness in the matrix falls down. Now we can manage the data under a new approach: separating the matrix in columns (one for each category) and redefining a multinomial distribution for each category (column). Within this new approach we propose a category-wise control that allows the statement of our preferences of quality, category by category, but also the statement of misclassifications or confusions limited between classes. These preferences are expressed in terms of minimum percentages required in well-classified items and maximum percentage allowed in misclassifications between classes within each column.

In order to illustrate the application of the above with an example, Figure 1 shows a confusion matrix with results from the accuracy assessment of the classification of a synthetic data set with four categories. Now let us consider that the RDS used in this assessment does have the quality to be a reference. Therefore, the data from Figure 1 cannot be understood as a complete multinomial but rather a set of four multinomials, one for each category (column). Figure 2 illustrates this fact with locks that symbolize that the marginal of the columns are fixed and therefore the new structure "quality control column set" (QCCS) has to be considered instead of the classical method based on the confusion matrix.



		RDS			
		Wo	G	N	Wa
CDS	Wo	47	3	0	0
	G	4	40	6	0
	N	0	5	45	0
	Wa	0	0	2	48

		RDS			
		Wo	G	N	Wa
CDS	Wo	47	3	0	0
	G	4	40	6	0
	N	0	5	45	0
	Wa	0	0	2	48

Figure 1. The new structure called "quality control column set" (QCCS) applied to data with the structure of a confusion matrix. The locks symbolize that the marginal of the columns are fixed. For clarity, each column is presented in a different colour, highlighting the number of correctly classified items. (Wo = Woodland, G = Grassland, N = Non-vegetated, Wa = Water)

Once the QCCS structure is considered our proposal allows us to consider a set of quality specifications in the following manner: for each category, a classification level could be stated but also misclassification levels with each other category (or group of them). In Table 1 we have summarized an example of quality specifications for the category Wo of Figure 1. We have indicated, the minimum percentage required for well-classified items, but also the maximum percentage allowed in misclassifications. This possibility of merging categories offers a more flexible quality control analysis. By this way, the quality specifications conform what we call quality control hypothesis set (QCHS). Each column of a QCHS allows the complete definition of a multinomial model for a category (e.g. Table 1). A QCCS supplies the observed data and a QCHS the specifications modelled by a set of multinomial, so a complete definition of a quality control has been performed and can be tested by means of an exact test based on the multinomial distribution function.

Category	Specification ID	Description
Woodland	SpWo#1	95% of minimum percentage required in well-classified item (≥95%)
	SpWo#2	4% of maximum percentage allowed in misclassifications with Grassland (≤4%)
	SpWo#3	1% of maximum percentage allowed in misclassifications with both Non-vegetated land and Water (≤1%)
Note: these specifications are only by way of example		

Table 1. Example of specifications: quality levels required for each category and the percentage of misclassifications allowed between classes within each category.

Conclusions

A new approach for thematic accuracy quality control is presented. It is based on the assumption that the RDS is a reference, and this fact makes available a more powerful and complete method for thematic accuracy quality control than those based on a confusion matrix or on global indices. This method allows a class by class quality control, including some degree of misclassifications or confusions between classes. It is a very flexible procedure because it provides the possibility to merge classes, which means the possibility of varying the dimension of the underlying multinomial and it also allows us to test simultaneously the quality levels for a set of categories.

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Count Based Quality Control of “As Built” BIM Datasets using the ISO 19157 Framework

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From an informational point of view, a Building information model (BIM) is digital model based geometric information, enriched thematically, semantically and relationally that, managed by the right software tools, allows a smarter management of buildings and facilities. The corner stone of BIMs is to understand the relationships between materials, objects, assemblies and projects. All these elements are managed by a BIM tool as objects, in the sense of object-oriented programming. That means that materials, objects, assemblies and projects have properties, methods, events and relationships. In reality, a BIM tool is little more than a database management system with a graphical user interface. From this point of view, BIM models are directly linked to Geographic Information Systems (GIS) and BIM data to spatial data (geographic information).

Data quality of BIM datasets (BIMDS) is relevant and the BIM Comunity (www.bimcommunity.com) has developed a publication series which includes a guide centered on quality assurance of BIM projects (COBIM, 2012). This document proposes and develop several quality controls mainly devoted to check logical consistency issues and the use of software is proposed for examining clashes between building elements. Automatic routines for quality control of BIM has been proposed by Cheng (2018) and many others authors, also there are several software tools for this propose, e.g. iTWO by RIB (www.rib-software.co.uk), Solibri by Solibri (www.solibri.com); BIM Tree Manager by Agacad (www.aga-cad.com) or Verity by ClearEdge (www.clearedge3d.com). All these controls are based on aspects of logical consistency that, in most cases, can be automated.

Neither of the previously mentioned documents or tools develops or proposes a statistical method for a statistical quality control. Nor is there any mention of quality control standards from the industrial field (e.g. ISO 2851 or ISO 3851 series). The situation described above indicates the existence of several aspects that require research attention. One of them is that all aspects whose quality must be controlled in BIM datasets must be formalized, and another, that an appropriate method must be available so that the acceptance/rejection of BIM datasets is carried out on a statistical basis when a sampling is needed (e.g. as built perspective). In this work proposals are made in these two lines. Thus, our objective is to propose how to adequately formulate a quality control of BIM datasets and how to approach a statistical control.

BIM data quality and ISO 19157

BIM data are very similar to spatial data because they must be integrated into a geographical framework (the actual location of the building), integrated into its environment (the surrounding geographical-topographic reality), and collect the presence, dimensions, positions and exact attributes of the elements of interest. This resemblance is both conceptual (data models), and factual (e.g. capture and processing procedures), as well as exploitation (thematic, topological, temporal consultations, modeling, etc.). This proximity allows an advantageous approximation since in the field of geographic information there is a greater experience related to data quality. For instance, Sun et al. (2018) show the close links between spatial data and BIM data and review of the standards and methods currently used for ensuring quality in spatial data and BIM in Sweden (mainly), and internationally. For this reason, we adopt this international standard as the base for our proposal.

The International Standard ISO 19157 (ISO 2013) establishes the principles for describing the quality of spatial data. This is achieved by defining data quality elements, data quality measures, a general procedure for assessing and reporting data quality.

As a way of handling diverse perspectives of data quality, ISO 19157 proposes the so-called data quality elements (DQE) (e.g. absolute positional accuracy, relative positional accuracy, classification correctness, etc.). A DQE relates to a specific aspect of data quality that can be measured and evaluated through different measures and methods. DQEs can be organized into categories which are logical groupings of DQE (e.g. DQEs related to logical consistency conform a category).

Before executing quality control, the population of elements of interest must be defined, and this is carried out by means of a scope. The scope is a filter based on time, location, classification, attributes… or, in general, in any other criteria that establish an element selection rule. The scope is usually defined by a category of elements of interest (e.g. windows, walls, pipes, etc.), but it can also be defined by a set of categories of elements of interest that share some aspect of common interest (e.g. windows and doors and walls, when our interest is the correction of the finish color). We call this set of categories of elements of interest the category of interest (CoI). The joint of a CoI with a DQE is known as data quality unit (DQU) in ISO 19157 terminology. So the same CoI can be linked to different DQE in order to control several perspectives of the data quality (e.g. those of all the DQE). Also, the same DQU can be assessed by means of different DQM (data quality measures) and by different evaluation methods (EM). ISO 19157 defines more than 70 standardized data quality measures (see Annex C of ISO 19157) but only a general EM. The last is not problematic because ISO 19157 allows the use of whatever evaluation method considered adequate for the assessment purpose, e.g. ISO 28590 (ISO 2017), ISO 3951 (ISO 2007), etc. Finally, quality control of a product is a statistical decision on the acceptance or rejection of a product with respect to its specifications, for this purpose a quality level (QL), or conformity level, must be established. This QL must be expressed in the same way and units as the DQM used for the DQE being considered. By this way, a quality control is well defined if a DQU (=DQE + Scope) and its corresponding QL (=DQM) and EM are properly stablished. These are the elements that must be managed to unequivocally establish quality control when using the ISO 19157 framework.

Count-based quality control

Products are defined by specifications, so that a nonconformity is the non-fulfillment of a specified requirement: e.g. a specification can be that 95% of the instances of a BIMDB must carry correct attributes in relation to reality. The presence of nonconforming/defective items is then quantified and a decision is made about the compatibility of this amount with respect to the conformity level. If sampling is required, e.g. in an “as built” BIM quality control, this decision must be taken in a statistical context in which the risks of the parties are controlled. The appropriate statistical tool for this is the hypothesis testing framework. Thus, adopting a hypothesis (distribution and value) on the behavior of the nonconforming items, by taking a sample (of a given sample size n), this statistical technique allows a decision to be taken where the producer's risk (Type I error), and the user's risk (Type II error) are bounded. The appropriate statistical models for working with proportions are: the binomial and hypergeometric models for working with one single class, in an infinite or finite population, respectively, and the multinomial and multivariate hypergeometric models for working with multiple classes, in an infinite or finite population, respectively.

Thus, the procedure is:

- Take an independent sample for each DQU.
- Count the number of nonconforming items found in the sample of each DQU.
- Calculate the corresponding p-values for each DQU.
- Check whether or not the global H0 hypothesis is accepted or rejected according to a MHTM correction.

Example of application

As an example of the application of the proposed method, the case of a BIMDB control corresponding to the delivery of an ended project ("as built") will be considered. It is a building with 4 floors (basement, F0, F1 and F2); with garages in the basement, two commercial premises in F0 and 4 apartments distributed between F1 and F2, that is, two per each floor.

Group	**Categories of interest**	**Cases (N)**	**Group**	**Categories of interest**	**Cases (N)**
Elements	C1=Doors and windows	119		C8=Slabs and paving	25
	C2=Bathrooms and Kitchens	14		C9=Pillars	105
	C3=Balconies and terraces	29		C10=Sales unit	6
	C4=Other rooms	18		C11= Interior walls	200
	C5=Living rooms and bedrooms	16	Facilities	C12=Electricity installation	7
	C6=Common zones	6		C13=Heating and air conditioned installations	7
	C7=Enclosures (walls)	179		Total	731

Table 1 Categories of interest in the BIMDB

In relation to the DQU for the control, Table 2 summarizes their configuration, population and sample sizes. Sample sizes have been set arbitrarily with the criteria set forth above (≈10%), except for case C2, for which a size that assumes a proportion is adopted of the population.

Data quality units	**Cases in the population (N)**	**Sample size (n)**	**Quality control**	**Data Quality Measure and ID***	**Conformity level (Maximum proportion of defects)**
DQU1=Completeness of elements DQE = Commission + omission CoI = C1+C2+ ··· + C10	511	50	QC1	Rate of excess items (ID=3) + Rate of missing items (ID=7)	1%
DQU2=Completeness of facilities DQE = Commission + omission CoI = C11+ C13	182	40	QC2	Rate of excess items (ID=3) + Rate of missing items (ID=7)	3%
DQU3= Shape Fidelity DQE = Fidelity in shape CoI = C1+C2+ ··· + C10	1605	160	QC3	Rate of unfaithful items (ID=**)	5%
DQU4=Attributes of elements DQE = Correction of non-quantitative attributes CoI = C1+C2+ ··· + C10	462	50	QC4	Rate of incorrect attribute values (ID=67)	10%

DQU5=Attributes of installations DQE = Correction of non-quantitative attributes CoI = C12+ C13	491	50	QC5	Rate of incorrect attribute values (ID=67)	10%
DQU6= Shape Fidelity of walls DQE = Fidelity in shape CoI = C11	200	20	QC6	Rate of unfaithful items (ID=**)	80%, 15%,5%***
Total	**3451**	**350**			
(*) The ID is the identifier for this measure given in Annex D of ISO 19157. (**) This measure is not included in Annex D of ISO 19157. (***) This proportions are linked to good, acceptable and unacceptable cases.					

Table 2 Definition of data quality units to be considered for the control (cases in the population and sample size) and the quality controls by means of the data quality units and the conformity levels

Prior to the control and by agreement between the parties, QL must have been established. For this example, the specifications are those presented in Table 2. When indicating completeness, we refer to both omissions and commissions, considering both types of error as equivalent for error counting proposes. Finally, it should be noted that the QLs are themselves an order of the importance of the different aspects considered in the control. Naturally, these values must be determined based on the experience and the requirement of greater or lesser rigor for the BIM application. By this way, as indicated by Eq (4), the global control on the BIMDB means that: QC1 is passed AND QC2 is passed AND QC3 is passed AND QC4 is passed AND QC5 is passed AND QC6 is passed.

Defect case counts are computed (Table 3). From them, applying the functions (*pbinom* and *phyper*) (R Core Team, 2019), the p-values that appear in Table 3 are obtained. As can be seen, the hypergeometric model has been considered for the case QC2, in the rest of the cases the binomial model is applied. Here a MHTM is needed, and we apply Bonferroni by its simplicity. Since $\alpha = 5\%$ was adopted, the global null hypothesis should be rejected if any p-value were less than 0.05 / 6=0.0083. Given that the lowest obtained p-value is 0.0004 <0.083, it is possible to reject the hypothesis that the BIMDB complies with the specifications imposed by Table 4 since the observed data give evidence of this.

Quality control	**Number of nonconforming items**	**Sample size (n)**	**p-value**		
			Binomial	**Hypergeometric**	**Multivariate Hypergeometric**
QC1	0	50	1.000		
QC2	5	40		0.0004	
QC3	11	160	0.179		
QC4	5	50	0.569		
QC5	2	50	0.966		
QC6	7,1(*)	20			0.0236
(*) The number of items per class is: 12 (good), 7 (acceptable), 1 (unacceptable)					

Table 3 Results of the defective count and p-values by quality control

Conclusions

The quality of BIMDB is an issue of great importance but, so far, it is not acquiring the appropriate relevance compared to the current boom of its applications. The quality of BIMDB is not fully formalized, but directly applicable knowledge can be transferred from the field of geospatial data. The framework established by ISO 19157 (ISO 2013) has already been proposed for its application to BIM data due to its great similarity with geographical information. This paper has presented the statistical basis of a method of global quality control of BIMDB with multiple DQUs, which means different scopes and diverse DQEs. The method has a valid, affordable and known statistical formulation as it is based on known distribution functions that are applied in the field of quality control. The main contributions of this work are two, first the proposal and example of use of ISO 19157 data quality framework to BIM data, and second the statistical approach formulation including an example of use on how to handle the joint control of several types of errors with different quality specifications for each of them.

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Solutions for Encouraging Spatial Data Producers to Co-Operate in Harmonizing National Topographic Data

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National Land Survey (NLS) has developed digital services that aim to advance harmonization of spatial data in Finland. The Geospatial Platform started during 2017 and it consists of a number of digital services to support the national SDI in Finland. One of the main goals of the platform is to encourage data producers to adopt common conceptual models defined in the project in collaboration with various stakeholders. Data quality is an important component in harmonizing national spatial data because while having a multi-producer environment reduces overlapping work, it also means that all of the data producers have their own methods of producing their data which again makes national data regionally different in terms of quality.

This paper highlights answering to a number of challenges faced in involving data producers in the effort of making national spatial data harmonized, i.e. interoperable in Finland. New development ideas, the Quality Rule Catalog and Quality Map are presented. To advance the national SDI, it is very important to utilize various communicational methods along with developing technical solutions to meet the user needs. Common solutions, definitions and services are required to make it certain that data producers have the capability to deliver high quality interoperable data to the national supply. That is why I believe that it is important to develop both the technical things as well as methods to listen and to involve key stakeholders in the development work.

Data producers import their data using the Data Upload Service which allows integrating spatial data in various schemas and formats to the Geospatial Platform and importing them to the national database. Data Upload Service transforms interoperable data to a data model following common conceptual models.

QualityGuard is an automated spatial data quality solution that evaluates data quality of all data that are imported to the national database. It has been in trial use for over a year now. Users which are primarily municipalities and regions at the moment receive a logical consistency report describing which of the imported features conflict with quality rules regarding the theme of the imported data. Quality rules are meant to reveal issues that are not logically consistent with the common conceptual models.

A central challenge is to motivate municipalities and regions to try the services and provide feed- back on them during their beta phase so that they could be developed to reach the user needs to a higher degree before entering production. Communicating a clear and reachable vision is imperative in motivating data producers to participate in the effort. Bombastic headlines will certainly bring attention to the cause across the board but claiming the promises and making them reality is an entirely different challenge that requires expertise in many fields.

A promising path to success seems to be a combination of creating co-operation by working intensively with key stakeholders and delivering high-quality digital services that meet the user needs as well as possible. Motivated or not, data producers may not necessarily have the means to do anything regardless of how excited they would be about the vision. Developing the data to be nationally interoperable and making the methods for data collection to be less error-prone requires work, GIS professionals and money. This also requires building commitment among the municipal policy makers.

Implementation work of the demonstration services of data importation service and QualityGuard has had a rather sluggish start. This is due to various reasons and the problem field is diverse. Currently there are 40 user organizations that have been granted access the Geospatial Platform. Most of these are municipalities and regional alliances interested in importing their data. Regional alliances maintain and deliver regional plans using a common data model. Having a common data model makes it effortless to integrate these services to their data production process. Municipalities deliver building data but in this case the data production methods are different for each data producer. This leads to building data being different for each producer, making it more awkward to integrate with the data and to reach for national interoperability. Larger municipalities have more resources and often have their own GIS department but smaller municipalities may have out- sourced all of their GIS work if there even is any relevant spatial data available.

Understanding and supporting the users in adopting the services has a big role in the implementation work. Data producers need individual support in adopting and using the services. Geospatial Platform has answered to this need by establishing a number of supporting activities. Implementation support team is responsible for taking care of the data producer once they have applied for access rights to QualityGuard and to the Data Upload Service until the data can be successfully imported to the Geospatial Platform services. This requires granting access and creating configurations for the data to be imported and dealing with any issues until successful runs have been made.

The data producer’s capability to integrate their data will be evaluated with technical personnel before implementation. In case of issues or worries about the services or the data, they can contact the support using email or telephone. NLS also arranges promoting sessions (skype meetings and face to face meetings) with municipalities where the data producers can discuss about integrating their data with experts. Communicating actively with the data producers has an essential role in developing the support services and also the applications because it is an excellent method of reaching a sufficient understanding of the users needs and their problems. However, communication is not enough to support the user in this task and there should be a good repository of online support material available.

Data Quality Catalog is an online collection of quality rules added with detailed instructions and guiding visuals on how to fix the data. A basic version of the Catalog containing just the quality rule definitions will be online this fall to be evaluated by users of the Geospatial Platform services. The fully featured version has been recognized to hold great value and the development is expected to begin next year. It is meant to deliver assistance on a platter to the users trying to understand and find ways how to fix their data relying on the quality information provided by QualityGuard's error dataset. Having an online repository of quality rules is an essential resource that makes fixing quality issues easier and greatly reduces the need to guide data producers individually. In many cases it can completely eliminate the need to contact the Geospatial Platform support organization and this is again very beneficial because there is always a threshold in reaching for help.

One of the ideas that we are planning to implement to support the users, Quality Map is a web map that visualizes data quality across the nation. Visualizing data quality across the nation on a web map could also be very useful for implementation work but also for the end users of the data. Making things visible would display which data producers are delivering their data and putting an effort in improving and developing their data towards national interoperability. This would bring data quality transparent to the ecosystem and hopefully make data producers to compete with each other in developing their data. On the other hand, end users could see if the data is available and interoperable across administrative region borders, which would improve usability of the data by helping users decide whether or not the data is suitable for their use case.

Harmonizing national topographic data is a big effort which requires common rules, models and processes regarding the data, building motivation and commitment among the data producers as well as implementing high quality digital services that meet the user needs. We believe that resort- ing to legislation is far from being the only way to reach commitment and hope to see the rise of an innovative spatial data ecosystem around interoperable data in Finland.

Evaluating Quality of Spatial Data Coming from Multiple Suppliers
Case Finnish National Topographic Database

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The Finnish National Topographic Database (NTDB) is a centralized database for topographic data of Finland. It consists of buildings (2.5D and 3D), road links, other manmade structures and addresses. The NTDB consists of data coming from multiple suppliers: governmental organizations and municipalities. Different suppliers use varying systems in gathering and storing spatial data among each other's (Lundvall 2019). Because the systems vary greatly, also the data supplied comes in many different forms in regard of their format and quality. In effect, large diversity of data is the biggest challenge in collecting national data into a centralized database.

To overcome the versatility of data, schema transformation and quality check must be implemented on every data import. Data validation is based on quality specifications formatted as *quality rules*. Quality rules are derived from INSPIRE and current national topographic database norms, quality rules produced by European Location Framework project (ELF) and international and national standards. Quality rules are divided into three ISO 19157 quality elements: format consistency, domain consistency and topological consistency (ISO/TS 19157:2014). This paper focuses on implementing quality rules on spatial data: what is being tested before importing data into the NTDB and how quality rules are implemented.

Before a data supplier can import data into the NTDB, a corresponding schema transformation document is created into the automated data import system called *Quality Guard and Data Upload Service*, of which schema transformation is an integrated part of. During schema transformation, attribute names and values are converter to the ones used in the NTDB. After the schema transformation, data is compatible with the data model used in the NTDB and with the quality rules.

In Quality Guard and Data Upload Service, there are fifteen individual rule types (fig 1) and 351 different quality rules. Besides rule type, each rule consists of rule identifier, attribute it is targeted on, feature type that is being validated, severity, description and rule parameters. Rule parameters contain detail-leveled information of what is being validated, whereas rule type guides how a rule is tested. Based on feature type and attribute, correct quality rules can be targeted to appropriate features. The most crucial rules, such as geometry validity, empty geometry and attribute data types are tested on all features passing Quality Guard and Data Upload Service.

Rule type	**What is tested?**
Not null	Attribute has a value
Character length	Value consists of certain amount of characters
Geometry type	Geometry is the right type (area, point, or line)
Value range	Value belongs in a predefined range of values
Belongs in a set	Value belongs in a predefined set of values
Data type	Data type is correct (integer, double, numeric, boolean, string, timestamp or date)
Distance	Distance between features (features that are linked to each other's can only have certain distance between them)

Compare	Value must be bigger, smaller or equal compared to another value
Overlaps	Features must not overlap more than defined ratio
Geometry validity	Geometry meets OGC SFSQL standards
Empty geometry	Feature has a geometry
RegEx	Value is consistent with a given regular expression
Within	Feature is within a given area
Name list	Value is found on a list (used to find out misspellings in address names)

Fig 1. Quality rule types implemented in building imports.

Depending on a quality rule, not passing a quality check causes either a warning or an error. All rules related to geometry validity cause an error. Instead, attribute rules usually only cause an error when data type is not correct. A feature causing error will not be inserted into the NTDB, but a feature causing warning will. On the both cases, failed feature will be added in automatically constructed quality rapport data supplier receives in case warnings or error are discovered. Quality rapport is a shapefile where every failed feature is represented as a point marking failed feature’s center point. However, if error relates to geometry invalidity, the point is in the invalid spot. Besides error location, quality rapport also includes rule description, identifier, severity and original value. In the case a rule compares a value to another, also compared value is represented in the quality rapport.

Having correct results in data validation depends fully on correct schema transformation. Because quality rules expect input data to be in a certain schema, schema transformation is actually the most crucial part of data validation in Quality Guard and Data Upload Service. Moreover, schema transformation document is created manually, which makes it prone to mistakes. In the case schema transformation is not done correctly, in addition to having false errors, data upload process usually fails when starting to write features into database because of mismatches between NTDB and input data.

Both, schema transformation and data validation, are being implemented in FME based application. FME is a versatile and effective platform for building ETL (extract, transform & load) workflows. Workflows used by Quality Guard and Data Upload Service are parametrized, making the application dynamic and automated. FME offers a great number of built-in tools to test, route and manipulate data. Also, many spatial data tools, such as spatial filtering and geometry validation, are available. In case FME’s built-in tools do not offer solution, Python, TCL and SQL can be used. For example, overlap and distance rules are executed by Postgis functions instead of built-in tools, because queries are more efficient compared to built-in functions (fig 2).

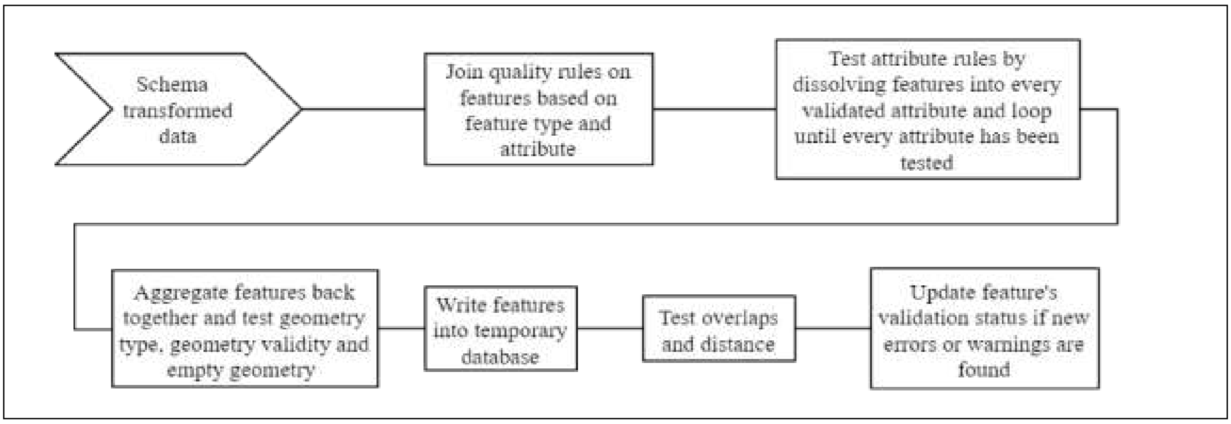
Schema transformed data
Join quality rules on features based on feature type and attribute
Test attribute rules by dissolving features into every validated attribute and loop until every attribute has been tested
Aggregate features back together and test geometry type, geometry validity and empty geometry
Write features into temporary database
Test overlaps and distance
Update feature's validation status if new errors or warnings are found

Fig 2. Data validation process in Quality Guard and Data Upload Service

To conclude, NTDB can be built on data that is versatile in format and in quality. However, schema transformation and data validation are crucial parts in the process. Either cannot be skipped, when building a centralized database that uses diverse data sources and only includes high-quality data. Furthermore, such a process should be as dynamic as possible, since dynamic process often lead to easy maintainability.

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Understanding the Importance of Provenance from the Perspective of a Geospatial Decision-Maker

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Keywords: Provenance, Decision-making, Usefulness

Abstract

Information derived from geospatial sources are used in decision-making in various sectors such as in defence (Franklin et al. 2013; Roy et al. 2017), in government (Harding 2006; Sutanta et al. 2016; Scott and Rajabifard 2017) and in non-government organisations (Crooks and Wise 2013; Quill 2018). However, decision-makers do not always have an easy way to decide whether to make use of the given information in their decisions – and if so, how much can they rely on them. A factor that may influence reliance on information for decision-making is well-documented provenance[1] of the information (Ma et al. 2014). Provenance is defined as the "*information about entities, activities, and people involved in producing a piece of data or thing, which can be used to form assessments about its quality, reliability or trustworthiness*" (W3C 2010). It is frequently referred to as lineage, pedigree, parentage, genealogy and filiation (Buneman et al. 2001; Simmhan et al. 2005). There is thus a specific interest in whether presenting important factors of provenance alongside the delivered information, can assist decision-makers to be able to make informed decisions. This abstract presents the preliminary results of an investigation into this aspect of provenance [2].

A core challenge in evidence-based decision-making is to prevent information overload. It is thus important to find out what provenance factors are required, providing the decision-makers only with sufficient context without over-burdening them with excessive details. The first step of any approach to tackle this challenge includes developing a better understanding of related concepts – what is provenance, and what are the current factors suggested as being an important component of provenance. Research shows that data quality and metadata factors are of high importance to make provenance information more useful. This in turn leads to the development of a theoretical framework to underpin work on identifying which data quality and metadata factors are potentially relevant to decision-makers interested in the provenance of their data.

The analysis of the related concepts indicates that although provenance does not entirely correspond to metadata, these concepts (provenance and metadata) are usually linked (W3C 2010). Provenance is often described as the process to detect the lineage and the derivation of data (Alkhalil and Ramadan 2017). Yue et al. (2011) state that lineage and provenance often overlap, with both being used to

[1] Provenance information can answer to questions such as who created the information, when it was created, why it was created, when it was updated, who own the information.

[2] The presented work has been ethically approved by the UCL Research Ethics Committee until 15th July 2020.

describe the same information. Provenance also evaluates the data quality and reproduces processes (Simmhan et al. 2005; Moreau and Foster 2006; Chen et al. 2014; Closa et al. 2017).

Interoperability of diverse environments thus can be increased (W3C 2013). The level of detail described in provenance can determine how much quality can be assessed (Simmhan et al. 2005). Provenance can also identify relationships between different objects, trace them back, providing thereby the big image of a situation (Chen et al. 2014). Therefore, it can help a user to assess fitness for purpose for a specific application, by providing a description of the origin of the data as well as the processes implemented to bring data in the current form (Closa et al. 2017).

However, much of the work cited above relates to a producer centric view of provenance. To develop a more user-centric view of the problem – and address issues relating to information overload due to the complexity of current standards, interviews have then been conducted to further understand the decision-maker perspective on this challenge as well as their actual needs. For these semi-structured interviews, participants are selected from various sectors amongst the geospatial network of the research study. The selected stakeholders represent a wide range of sectors of decision-makers, making use of geospatial information products (geospatial decision-makers). Each interview was around 40 minutes long and covered topics including geospatial information, metadata and presentation techniques.

Once the interviews were transcribed, thematic analysis was selected as a user-friendly method of qualitative data analysis (Braun and Clarke 2012). This involves a six-phase approach (proposed by Braun and Clarke, 2012), including code generation and theme identification. The outputs of the analysis are examined in the NVIVO software, which supports the annotation and coding of qualitative data and presented through reports as well as scatter diagrams and other graphical representations. Preliminary findings include a set of factors identified as important, several suggestions to present them through provenance and additional challenges that can influence decision-makers' trust.

These preliminary results highlight the importance of taking into account the decision-makers' needs when presenting provenance information and will help develop a focus on the important factors that should be presented as provenance accompanying the received information. Based on this results, online surveys will be distributed to a larger number of participants that is not possible to participate in the interview study, providing immediate data validation and faster response rates (Sue and Ritter 2012; Díaz De Rada and Domínguez-Alvarez 2014). This information - i.e. the usefulness of the provenance information for information derived from geospatial information – will thus form part of an enhanced provenance framework, with the next stages of the work focussing on usability and trust. A number of low and high-fidelity prototypes will be then developed to present provenance information according to the decision-makers' preferences. The developed prototypes will be also evaluated through usability tests where the stakeholders will have to interact with several tasks, trying to assess if the provenance information is presented in a usable way as well as if their trust level is increased.

Acknowledgments

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Collaborative User Oriented Metadata Production on EuroSDR Geometadatalabs Platform

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Geographical metadata have initially been designed for the management of geographical data in a production environment and for the exchange of geographical data between a provider environment and a user application. These metadata were to be processed in contexts belonging to the general domain of expertise of geographic information (GI). In the past twenty years, geographical metadata standards stemming mainly from the GI community have been elaborated, in particular ISO19115 to describe geographical data series. Metadata datasets have been produced to describe authoritative databases, in particular in the context of the European spatial information infrastructure, INSPIRE. On-line catalogue services were developed to exploit these metadata and exchange them metadata conforming to the CSW standard.

Geographical metadata may also be needed in contexts not belonging to the general field of GI expertise. In the early century, the Web has been widely adopted as an open distributed architecture. In an open distributed architecture, no restriction should be set on the potential users of a given data service and metadata should support not only data exchange but also data discovery and reuse in domains possibly far from the data specific domain. Users who may not have been trained to use complex geographical data could benefit from spatial data infrastructure like INSPIRE. To achieve this, current GI catalogues must be improved to be usable not only from GI specialists but also from novice users. Since ten years, efforts have been devoted by the GI community to reach new users by adopting new formalism and standards outside the GI field of expertise. For example the DCAT metadata standard is used to produce geographical metadata more legible outside the GI community.

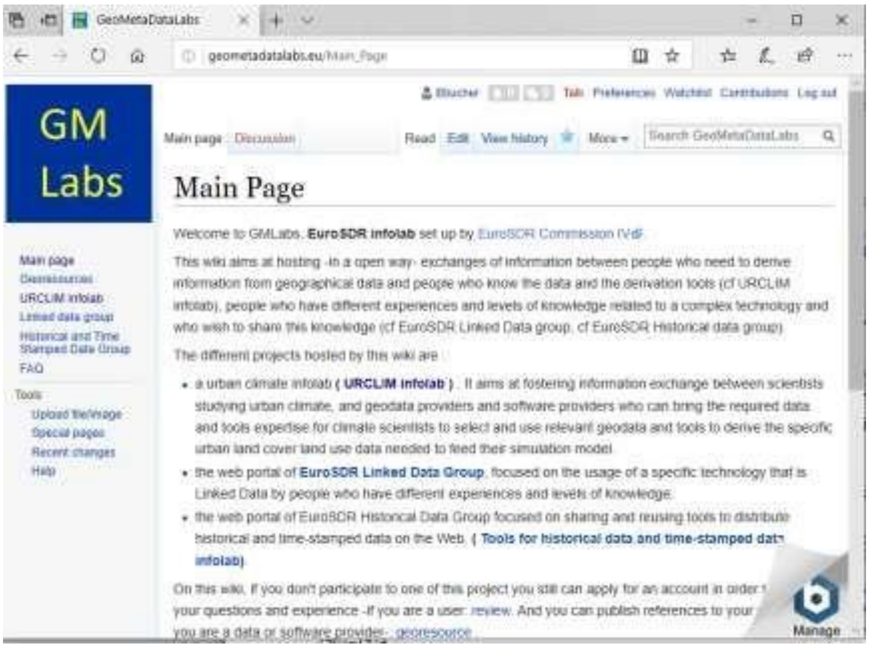
The work presented here targets the identification and production of geographical metadata to improve the capacities of existing GI catalogues and make them more usable for novice users of geographical data. We wish to remove from the user perspective existing silos between data technologies and funding programs that he currently has to cope with when he searches for geographical data. Our research hypothesis is that this identification and this production can be organized through a collaborative platform connecting representative users and experts of the different relevant GI components, geographical data and geographical software or services to pre- process the raw geographical data for the user application. Our approach is to foster the analysis by the requirements of a chosen application. For this application, we analyze what metadata are required for users to retrieve and use geographical data and are currently missing. Then we experiment a process to produce these missing metadata on a collaborative platform, in a way compatible with standard models so that the produced metadata content can eventually feed existing catalogues.

To implement our approach and evaluate our research hypothesis, a first step was to design a collaborative platform accessible from representative users of an application domain and from experts in geodata or geosoftware.

This platform is the EuroSDR Geometadatalabs platform. Geometadatalabs was designed to support the identification of missing metadata by eliciting user requirements and connecting them with existing metadata, more precisely querying existing catalogues based on their requirements and presenting them the results. A strong constraint from our perspective was to support user- centered access to data and to mobilize geodata experts who may be reluctant to interact with different platforms. We implemented Geomatadatalabs as a unique platform that will host different projects depending on the user community. These use-oriented projects are called infolabs, as illustrated on

Figure 1. The user sees the specific infolab dedicated to his usage whereas the geodata provider can have an access centered on his geodata and transversal to all thematic infolabs.

Geometadatalabs was also designed to support the production of missing metadata. With this respect, it must be capable of supporting collaborative production of whatever constitutes metadata in today's context: textual comments, structured data more and more to be organized as linked data and images. Mediawiki engine was chosen mainly because it powers the successful collaborative project Wikipedia which demonstrates that its editing interface can be learnt by anyone. Besides, it supports the edition of textual and semi-structured information. It can integrate RDF data and hence interact with more structured and GI oriented catalogues powered by Geonetwork for example as well as yield structured data for these catalogues.



Main Page

Welcome to GMLabs. **EuroSDR infolab** set up by EuroSDR Commission IV.

This wiki aims at hosting -in a open way- exchanges of information between people who need to derive information from geographical data and people who know the data and the derivation tools (cf URCLIM infolab), people who have different experiences and levels of knowledge related to a complex technology and who wish to share this knowledge (cf EuroSDR Linked Data group, cf EuroSDR Historical data group)

The different projects hosted by this wiki are :

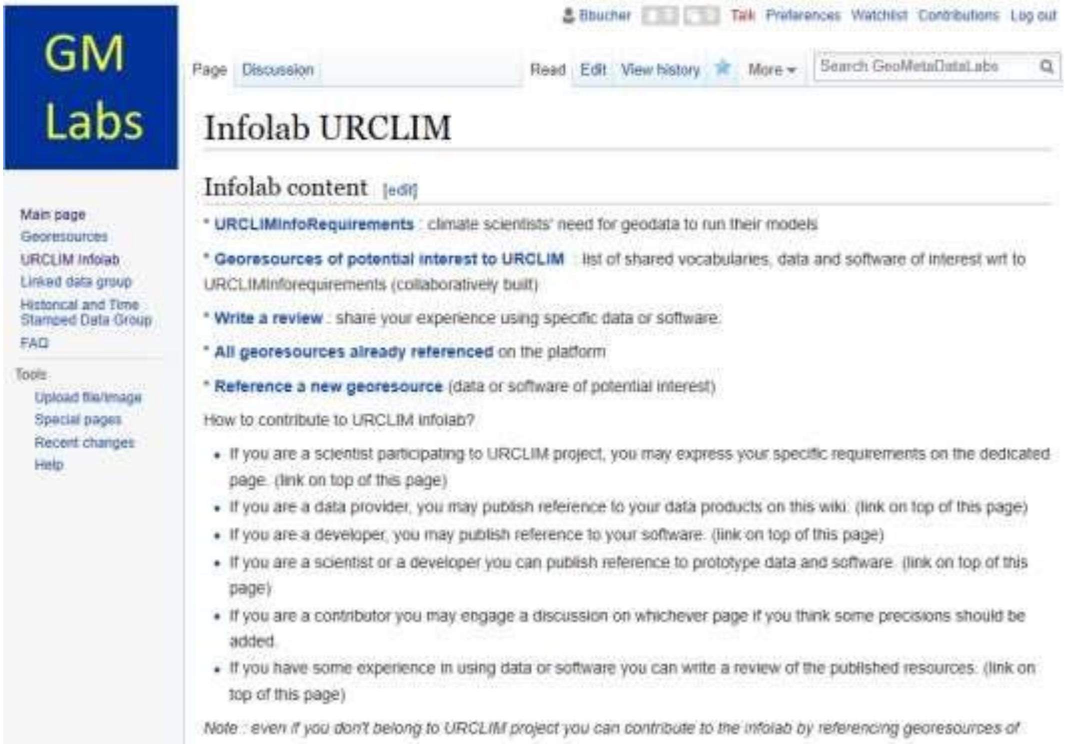
- a urban climate infolab (**URCLIM infolab**) . It aims at fostering information exchange between scientists studying urban climate, and geodata providers and software providers who can bring the required data and tools expertise for climate scientists to select and use relevant geodata and tools to derive the specific urban land cover land use data needed to feed their simulation model
- the web portal of **EuroSDR Linked Data Group**, focused on the usage of a specific technology that is Linked Data by people who have different experiences and levels of knowledge
- the web portal of EuroSDR Historical Data Group focused on sharing and reusing tools to distribute historical and time-stamped data on the Web. (**Tools for historical data and time-stamped data infolab**)

On this wiki, if you don't participate to one of this project you still can apply for an account in order t your questions and experience -If you are a user: review. And you can publish references to your you are a data or software provider- georesource

Figure 1. Geometadatalabs, a collaborative platform hosting specific infolabs dedicated to exchanges between GI experts and a specific users community, on this page URCLIM infolab for the urban climate community to connect with experts in geodata and geosoftware relevant for their needs.

The next step is to select an application domain for this research and experiment our approach on this domain, i.e. our capacity to identify missing metadata and to collaboratively document them. The criterion to select an application domain is the fact that representative users are motivated to engage in our experiment.

Our first proof of concept is developed within the application domain of urban climate modelling. Scientists studying urban climate design canopy models to simulate interactions between meteorological phenomena (wind, moisture, temperature) described at a given scale and the surface of earth described at a finer scale in order to calculate finer meteorological phenomena. To obtain land data required to feed these canopy models, this community has developed a common strategy: 1) agree on common formal specifications of such land models (a.k.a Local climate Zones) (Bechter et al. 2015), 2) design production procedures of such land data affordable by the community itself (Ching et al. 2018). This strategy has been successfully applied to produce low resolution land model out of Landsat imagery on the World Urban Databased and Access Portal Tools project (http://www.wudapt.org/). In order to account for local phenomena like for instance urban heat islands or air pollution, more resolute climate models are needed. To design these models, scientists need more resolute land data describing the city morphology and land use (Masson et al. 2019). The purpose of the URCLIM project is to design local urban climate models on a set of European cities – Paris, Toulouse, Ghent, Brussels, Helsinki, The Randstadt, Bucarest- reusing local open data, and local data which falls into the scope of the Public Sector Information Directive, i.e. which may not be open at the start of the project but that have a good probability to become open in the near future. The URCLIM infolab has been developed on Geometadatalabs platform to connect climate scientists and data specialist to identify and reuse relevant geo- resources to produce land models to feed urban canopy models at a high resolution (Bucher and Van Damme 2018). Its main page is visible on Figure 2.



Infolab URCLIM

Infolab content [edit]

* **URCLIMInfoRequirements** : climate scientists' need for geodata to run their models

* **Georesources of potential interest to URCLIM** : list of shared vocabularies, data and software of interest wrt to URCLIMInforequirements (collaboratively built)

* **Write a review** : share your experience using specific data or software.

* **All georesources already referenced** on the platform

* **Reference a new georesource** (data or software of potential interest)

How to contribute to URCLIM infolab?

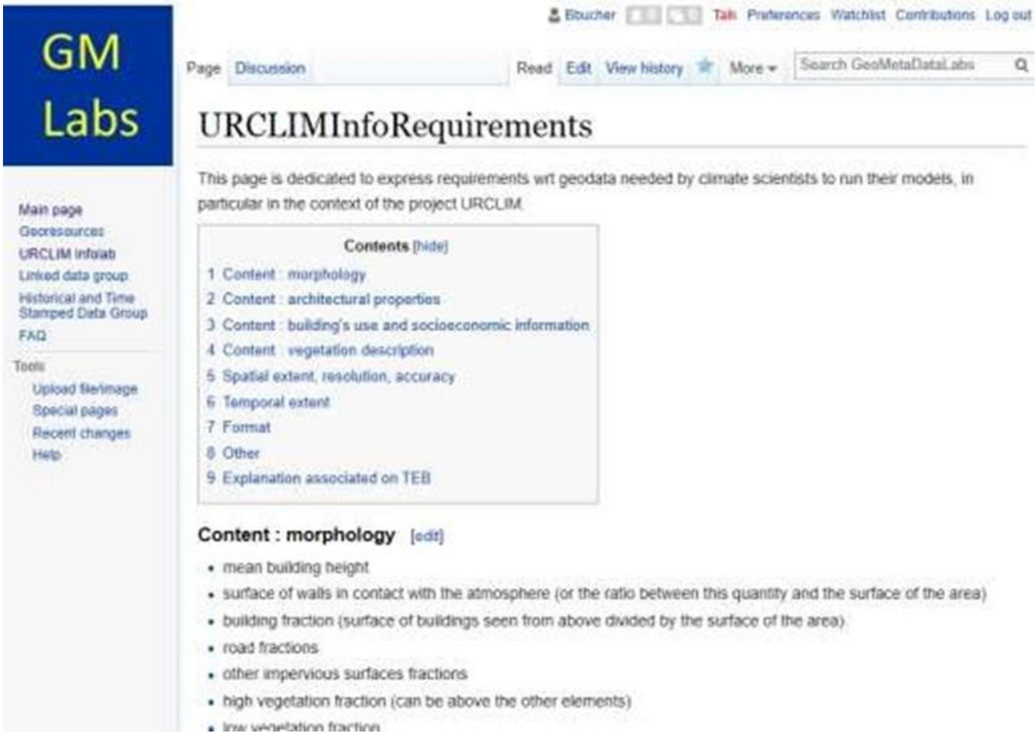
- If you are a scientist participating to URCLIM project, you may express your specific requirements on the dedicated page. (link on top of this page)
- If you are a data provider, you may publish reference to your data products on this wiki. (link on top of this page)
- If you are a developer, you may publish reference to your software. (link on top of this page)
- If you are a scientist or a developer you can publish reference to prototype data and software. (link on top of this page)
- If you are a contributor you may engage a discussion on whichever page if you think some precisions should be added.
- If you have some experience in using data or software you can write a review of the published resources. (link on top of this page)

Note : even if you don't belong to URCLIM project you can contribute to the infolab by referencing georesources of

Figure 2. Infolab dedicated to urban climate research hosted on Geometadatalabs.

The identification of missing metadata was performed by decomposing the retrieval process step by step, using the platform to share the expression of user requirements and the presentation of metadata results and discussions on data relevance. We identified the following missing metadata.

- To improve the expression of a user need, more alignments between existing ontologies must be established and maintained to connect user domain with geo-data domains. INSPIRE schemas are a very useful asset to perform these alignments. Similarity measures are needed, firstly to assess if comparable data are available on a different city, and second to support the query extension.
- To improve the retrieval of resources and evaluate their relevance, multi-lingual metadata are needed as well as data samples. Similarity measures are needed to compare datasets. More metadata about derivation processes are needed than metadata about the different software projects –users do not want to contribute to the software but rather to preprocess their data-. In this specific step, Geospatial user feedback from similar users is especially relevant. Cross-references between similar data and similar software or services are missing.
- During the exploitation of the data, for users to be able to question the results, they need legible provenance documentation (the entities involved, their expertise, the technologies). Besides, there is a need for a technology neutral way to describe uncertainty.



URCLIMInfoRequirements

This page is dedicated to express requirements wrt geodata needed by climate scientists to run their models, in particular in the context of the project URCLIM.

Contents [hide]

Content : morphology [edit]

- mean building height
- surface of walls in contact with the atmosphere (or the ratio between this quantity and the surface of the area)
- building fraction (surface of buildings seen from above divided by the surface of the area)
- road fractions
- other impervious surfaces fractions
- high vegetation fraction (can be above the other elements)
- low vegetation fraction

Figure 3. Elicitation of user requirements for geographical information on URCLIM infolab.

Further work must address the production of cross references between data set in the different cities of the project and n the documentation of derivation process to process the raw datasets and yield the required information layer.

This work is developed in the context of EuroSDR commission on information usage and has been funded by EuroSDR. It also benefited from fruitful exchanges with Eurogeographics Quality KEN and INSPIRE KEN. It has been partly funded by ERA4CS, an ERA-NET initiated by JPI Climate with co-funding from the European Union (Grant n° 690462) for the URCLIM project (www.urclim.eu).

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Authoritative Geospatial Data and its Quality

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1. INTRODUCTION

Societies are increasingly digitalising more and more aspects of daily life. A basic building block for digitalisation is data. This data is being integrated within and across public administrations, but also across borders and across the public, private and not-for-profit sectors. High quality data is a necessary criterion to ensure the quality of both public and private digital services and to drive innovation (Debruyne et al., 2017; European Commission, 2016).

The recognition and organisation of data as *authoritative* should be vital not only for ensuring the data quality, but also to foster trust between public sector organisations, between different sectors and across borders (European Commission, 2017). Especially in the context of geospatial data, the exchange and integration of authoritative data has advanced significantly. Important challenges however still need to be addressed (Cravens & Ardoin, 2016).

Authoritative is a term that one often hears when someone is describing geospatial data. Many public mapping, cadastral and land registration agencies promote their geospatial data as authoritative or as created from authoritative sources. Although *authoritative data* sounds impressive, it is important to understand what it really means.

In a geospatial context, land surveyors were probably the first to use the term *authoritative geospatial data* and they have been producing authoritative data for some time. Surveyors define *authoritative* as data that contains a surveyor's professional stamp and that the data can be used for engineering design, determination of property boundaries and permit applications. In essence, the term carries a certification of positional accuracy (Plunkett, 2014).

For decades, if not centuries, national mapping, land registries and cadastral authorities (NMCAs) have been recognised as the official source of geographic information. They were established by states to collect and distribute geospatial (mapping) and map-related data, often for some defined public purpose, such as defence, taxation or protection of property rights. The data provided by these public authorities were habitually presented as authoritative data.

Today, NMCAs are not the only ones providing geospatial data, information and related services. A growing number of different producers and providers of geospatial data, information and services are entering the market, serving different purposes and needs vis-à-vis the users, who are both private and publicly oriented. These new data, information and service producers/providers come from the public, private and community sectors. With this development in mind, there is a need for setting a clear understanding of what is meant by *authoritative*. When exploring the meaning of the term authoritative geospatial data, issues related to legislation, trust, and (quality) certification emerge. The term might be applied only to data that is legislated or regulated. If it is necessary to differentiate data supplied by government agencies from other sources of data, then it is suggested that the discussion should be about trusted data, and what gives rise to such trust. The validation of this type of data might be part of the certification of authoritativeness. For most practitioners, the term usually somehow refers to data that was produced or is approved by some authority.

Besides the meaning of the term, there is also no proper understanding what is the added value of authoritative geospatial data in Europe. It is also not fully clear how the term is applied and interpreted across Europe. Under different national conditions 'authoritativeness' can be defined in various ways. Moreover, the link with spatial data quality is also not fully understood. This paper aims to fill these gaps. Therefore, the main objective of this paper is to provide a better and more comprehensive understanding of the definition, nature, governance and future of authoritative data and the links to spatial data quality in Europe.

An online survey was undertaken in the summer of 2018 to get an overview of the definitions, characteristics, governance and future of authoritative data across Europe. A questionnaire was sent to all members of EuroGeographics, who are the national mapping, land registry and cadastral authorities (NMCAs) of Europe. The first results were presented at the General Assembly of EuroGeographics in Prague (October 2018). During the General Assembly, focus group meetings in the form of roundtable discussions were organised that built on the findings of the survey and delved into the definitions, importance and opportunities of authoritative data. This paper presents the results of the online survey as well as the focus groups meetings.

After this introduction, the followed methodologies of the online survey and focus group meetings are described in Section 2. In Section 3, the results of the online survey and focus group meetings are presented. Finally section 4 provides the main conclusions.

2. METHODOLOGY

A two-step methodology was applied:

1. An online survey with the members of EuroGeographics was undertaken to get an overview of the definitions, characteristics, goverance and future of authoritative geospatial data across Europe.
2. Focus groups meetings in the shape of roundtable discussions with the members of EuroGeographics were organised that built on the findings of the survey and delved into more detail regarding the definitions, importance and future of authoritative data.

This two-step methodology allowed to have a more comprehensive and detailed view on the topic of authoritative data across Europe.

2.1 Survey

As this research aims to create an overview of the different positions taken by the network members of EuroGeographics, it was decided to conduct an online survey during the 2018 summer. Questions were created on the basis of the insights provided in the academic literature, as well as the specific context in which EuroGeographics and its members find themselves. All members are known to have a strong knowledge concerning geospatial data and relevant policy making. These competences were taken into account when approaching the concept of "authoritative data". The survey therefore included both closed and open questions serving a double goal. On one hand, it allowed the researchers to collect data based on existing views presented in the academic literature, whereas the open questions gave the possibility to gather more specific information on the positions taken by the respondents and the organisations they represent.

Besides some introductory questions, such as the name of the respondent, the name of the organisation and the country, the following 9 main questions were asked:

1) What is the definition that your organisation applies with regards to authoritative geospatial data (sets)?
2) What is your opinion about the tentative definition of authoritative geospatial data (sets) presented at the beginning of the survey?

3) The notion of authoritative can relate to different objects (e.g. a specific category of data, a specific data point, an entire data set) and subjects (e.g. an organisation). In your country, does authoritative point to one of the following situations?
4) What are the conditions which define geospatial data (sets) as authoritative?
5) What geospatial data (sets) should always be/remain authoritative?
6) Are there quality management programs within your organisation that manage the authoritative geospatial data (sets)?
7) Which organisation(s) is/are responsible for the validation of authoritative geospatial data (sets)?
8) Is your organisation restricted by any of the following issues related to practical management of authoritative geospatial data (sets) in your country?
9) How would your organisation like to see authoritative geospatial data (sets) being developed in the next five year?

The questionnaire was sent to the 63 Permanent Correspondents (organisations in 46 countries) of the NMCA members of EuroGeographics.

The data was cleaned and a simple analysis was executed, based on a number of qualitative and quantitative analysis techniques.

2.2 Focus group meetings

A focus group meeting is a good way to gather together people from diverse backgrounds or experiences to discuss a specific topic of interest. In our case, we gathered executives of national mapping, cadastral and land registration agencies in Europe to discuss issues related to authoritative data including definitions, importance and future developments. A focus group is a small but diverse group of people whose reactions are studied in guided or open discussions about a specific topic – in our case a guided discussion about authoritative data – to determine the reactions that can be expected from a larger population (Marshall & Rossman, 1999). This qualitative research approach complements with the survey results and provide more detail. Participants were asked about their perceptions, opinions, beliefs, and attitude towards the topic. Questions were asked in an interactive group setting where participants were free to talk with other group members. In our case the group setting was based on a roundtable construction in which each person was given equal right to participate. The discussion was led by a moderator who was familiar with the topic. During the discussion, another person either took notes or recorded the vital points he or she was getting from the group. Beforehand, a set of discussion questions were prepared. These questions were mainly derived from the survey results that needed further explanation/understanding. The following preparatory questions formed the basis for the roundtable discussions:

1. What is authoritative data for you?
2. How important is it for you that your data is labelled as ‘authoritative’?
3. Do you think that there is a future for authoritative data? If yes, then what needs to be done to sustain the usage of authoritative data in the future?

The focus group meetings took place in the afternoon of 8 October 2018 as part of the annual General Assembly of EuroGeographics. An important event in which the executives of most European national mapping, cadastral and land registration agencies participate. Before the focus group meetings, the topic authoritative data was briefly introduced and the preliminary survey results were presented. In total, 94 people participated in one of the 10 arranged roundtable discussions. All the notes of each roundtable were collected and analysed afterwards.

3. RESULTS

The results are presented in the following two sub-sections: 3.1 Survey and 3.2 Focus group meetings.

3.1 Survey

3.1.1 Response and organisational characteristics

The online survey was launched on 26 June 2018 and remained open until 25 October 2018. A first reminder was sent in the week of 25 July 2018, and a second one in the week of 9 August 2018. In addition, an oral reminder was given during the General Assembly of EuroGeographics (8 October 2018) followed by a fourth reminder that was sent 12 October 2018. In parallel, several Members were individually reminded. Overall, 37 responses from 31 countries were received. In terms of organisations, the response rate was 37/63 (59%). In terms of countries, the response rate was 31/46 (67%). In comparison with similar online studies, these responses rates are very high.

The countries that responded were: Croatia, Cyprus, Czech Republic, Denmark (2), Estonia, Finland, France, Georgia, Germany (2), Hungary, Iceland (2), Ireland, Italy, Latvia (3), Lithuania, Luxembourg, Macedonia (FYROM), Moldova, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, and United Kingdom (3). Between brackets the number of responding organisations per country can be found in case that two or three organisations per country responded.

3.1.2 Definitions

Four survey questions referred to the definition of authoritative data and their coverage.

Respondents were asked the following question: *'What is the definition that your organisation applies with regards to authoritative geospatial data (sets)? (Q1)'* From the 37 respondents, 21 respondents were able to give a definition (60%). From the 21 definitions, 13 definitions made reference to legal/official aspects of authoritative data, 12 definitions made reference to the provision by a public authority, and 3 definitions referred to reference data. 4 definitions were exactly the same as the definition presented in the introductory text of the survey. Only 5 respondents mentioned that their given definitions were officially approved by their organisation.

At the start of the survey, a tentative definition for authoritative data (sets) was presented: "Data provided by or on behalf of a public body (authority) which has an official mandate to provide it". This definition was introduced in the European Location Framework (ELF) project. In this context, the following was question was asked: '*What is your opinion about the tentative definition of authoritative geospatial data (sets) presented at the beginning of the survey? (Q2)'*. From the 35 responses, 30 (strongly) support the tentative definition (86%).

The next survey question was the following: *The notion of authoritative can relate to different objects (e.g. a specific category of data, a specific data point, an entire data set) and subjects (e.g. an organisation).* '*In your country, does authoritative point to one of the following situations? (Q3)'* The respondents could tick all the relevant options. From the answers, it appears that authoritative data can relate to a variety of objects and subjects within and across countries. For almost half of the respondents, it is the data or part of the data in the dataset (44%). For more than half of the respondents (56%), it relates to the dataset as a whole. For almost 60%, it relates to all data that is collected and/or managed by the authoritative organisation. The results clearly indicate that authoritative data cover different objects and subjects and so the coverage is not straightforward.

The fourth question referred to *'the conditions which define geospatial data (sets) as authoritative (Q4)'*. Respondents were in the position to tick all the relevant options. Concerning the conditions which define data as authoritative, almost all respondents indicate input legitimacy as a prominent factor (i.e. 'Supplied by a recognised public authority' (94%) and 'Derived from a trusted source' (71%). 'Having a high quality' (47%), 'Being institutionalised' (44%), and 'Existence of licensing agreements' (38%) are indicated by a significant number of respondents, while all other conditions appear of less importance.

3.1.3 Characterisation of Authoritative datasets

Two survey questions referred to the characterisation of the key authoritative datasets (being type and quality). Respondents were asked to answer the following question: *'What geospatial data (sets) should always be/remain authoritative? (Q5)'* Respondents were allowed to tick all the relevant options. Many members agreed on a wide set of necessary authoritative datasets, with 'Cadastral parcels' (94%), 'Administrative boundaries' (92%), and 'Addresses' (92%) as the most listed datasets. In addition, it is notable that the percentage for each of the presented datasets was above 50%.

The next question was: *'Are there quality management programs within your organisation that manage the authoritative geospatial data (sets)? (Q6)'*. Most respondents answered this question with 'Yes' (82%). This strongly indicates that quality is a very important aspect in the management of authoritative geospatial data. If the answer was 'Yes', then the respondents were able to comment on their response. A number of comments provided by the respondents were the following:

- 'Data coming from the private sector are automatically verified and randomly tested. Quality indexes are produced and continuously monitored. Several projects to enhance quality are ongoing';
- 'We run quality checks continuously';
- 'Applying validation rules that can be expanded';
- 'The Centre of Registers validates the data (vertex points of surveyed land parcels) provided by surveyors before entering in the cadastral map';
- 'Compliance with standards for data updating and validation';
- 'Each provider is responsible to manage the quality of their data';
- 'Specific requirements are included in law regulations'.

3.1.4 Governance

The next two questions are associated with issues related to the governance of authoritative geospatial data. The first governance question was the following: '*Which organisation(s) is/are responsible for the validation of authoritative geospatial data (sets)?* (Q7)'. Most respondents answered that it is the authority defined in the law or mentioned the name of their own organisation. A few respondents explicitly referred to the organisation that provides the data (sets). In most federal countries, the responsibilities are allocated to authorities operating at different levels of administration.

The next governance question was: *'Is your organisation restricted by any of the following issues related to practical management of authoritative geospatial data (sets) in your country?* (Q8)'. From the results it was clear that the organisations face a variety of restrictions in the practical management of authoritative data. 56% of respondents point out 'National security', while 47% indicate 'Privacy' and 'Licensing' as a restriction. Other factors (e.g. IPR (41%), Funding (35%), Access (35%), Quality (32%) , Authority (18%)) are much less prominent.

3.1.5 Future developments

The last survey question dealt with the future developments of authoritative geospatial datasets: *'How would your organisation like to see authoritative geospatial data (sets) being developed in the next five years?* (Q9)' Respondents had to answer this question both from their country as well as the European perspective. The responses at the country level were diverse, some respondents had no specific expectations for the developments in the next five years whereas others referred to a number of potential developments. The most frequently mentioned answers referred to developments related to data quality, data quality management control, legislation, governance (in terms of strategy development, structure, coordination, and responsibilities), open data, data accessibility, standardisation/harmonisation and user-centricity. The responses towards the potential developments at the European level were less diverse. A similar picture as the one at country level appeared. The answers of those who have clear expectations were however less diversified. Developments related to data harmonisation/standardisation, governance (in terms of a coordination body or cross-border management), and INSPIRE implementation/usage stood out. A few respondents referred to developments related to data quality, data accessibility, open data, and legislation.

3.2 Focus group meetings

After an introductory session about authoritative data (including the presentation of the preliminary survey results), a number of focus group meetings in the shape of roundtables were organised in Prague at the EuroGeographics General Assembly on 8 October 2018. In total, 10 roundtables were set up whereby 94 participants joined the discussions. Most of the participants were executives of national mapping, cadastral or land registration agencies across Europe.

The participants came from the following countries: Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia & Herzegovina, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Iceland, Ireland, Italy, Kosovo, Latvia, Lithuania, Macedonia (FYROM), Moldova, Netherlands, Norway, Poland, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, and United Kingdom.

Before the discussions started the procedure was explained and the discussion questions were introduced. The duration of the focus group meetings was around 1.5 hours.

3.2.1 Question 1: What is authoritative data for you?

A similar question was asked in the online survey. From the survey it became clear that authoritative data needs somehow to be linked to the provision of data by a (public) authority which is legally binding. In some countries, the term *reference data* is used as an alternative. The discussions in focus groups complemented the answers of the survey as the outcomes give a much more comprehensive and detailed picture about the meaning of authoritative data.

From the discussions, numerous characteristics of authoritative data emerged. These include: legally binding, accountability, uniqueness, mandatory use, liability, (public) authority provision, trusted, standardised, continuity, high quality, quality management system, certified, traceability, maintained, and accessibility. Each of the terms will be briefly introduced and/or explained. It is worth noting that the terms legally binding, accountability, uniqueness, mandatory use, liability refer somehow to the legal aspect of authoritative data. Meanwhile high quality, quality management system, certified, traceability and maintained refer to the quality aspect. In addition, it is good to mention that authoritative data cover most of these characteristics but does not necessarily have these all at the time. Moreover, there are strong dependencies among the characteristics. One characteristic could be a vital condition for another.

Legally binding

Many participants strongly stated that authoritative data has to be legally binding. According to several participants, the term authoritative should only be applied to data that is legislated or regulated. It has to be officially recognised by a reference in law. If authoritative data is not embedded in legislation, it can never be labelled as authoritative. Many participants stated that authoritative should mostly be produced and collected by legal obligation. In addition, several participants mentioned that the usage of authoritative data should be legally regulated enforcing stakeholders to use it. This legally binding characteristic is a vital condition for authoritative data that to become trusted by society.

Accountability

Some participants referred to the need that there is somehow an organisation that is legally accountable for the data production, provision, high quality, and/or maintenance of authoritative data. Few participants stated that organisations should be accountable but not necessarily be liable.

Uniqueness

The uniqueness refers to the authoritative data as an object as well as the role performed by the organisation which provides the data. According to the respondents, a dataset that stands out from other datasets by its characteristics is 'unique'. Unique is also the provision of authoritative data by giving one organisation the sole rights to produce and/or provide for a wide use

Mandatory Use

This characteristic refers to the mandate that other (public) authorities (and other stakeholders) are legally obliged to solely use authoritative data and no other data. As such, authoritative data has been given a higher usage priority.

Liability

The participants did not fully agree if liability is a full characteristic of authoritative data. Most of the participants agreed that authoritative organisations should be accountable for the data production, provision or maintenance. The participants are less clear about the liability issue. Some participants strongly stated that their organisations are liable for their 'authoritative' actions and products with all the consequences, meanwhile others are not. The implementation of quality management systems enhances the assurance of liability in many organisations. In this context, few participants underlined that authoritative data is not about quality but more about liability.

(Public) Authority provision

Authoritative data refers to data provided by or on behalf a (public) authority body. A few participants added that authoritative data should be also produced, maintained and/or certified by the authority body. It is hereby however not fully clear if authoritative data also has to come from a public entity or not. Some participants stated that authoritative data could be also provided (produced, maintained) by private companies (e.g. by means of outsourcing), however private companies are not in the position to officially certify data as authoritative data. Moreover, many participants agreed that not every dataset provided (produced, maintained) by a public entity should be labelled as authoritative. Some participants asked themselves if the discussion should be about the necessity to differentiate the source of data provision (production, maintenance) by public agencies from other sources of data.

Trusted

Although trust did not appear in the online survey, it formed an important topic in the roundtable discussions. Trust is a rather vague topic that is difficult to grasp in its full extent. In order to be widely used in society and to be applied in essential public tasks, it is important that the authoritative data can be trusted. Several characteristics that have already been mentioned are a key condition to reach trust (e.g. characteristics such as legally binding, accountability, off, authority provision, standardised, high quality, accessibility of authoritative data). It is crucial to provide data that can be trusted by the users in the long term or to build a lasting organisational trust. However, this is a long and complicated process that has to address validation and correction of existing data, implementation of standards and quality control instruments in the collection, production, maintenance and updating processes as well as securing access to the data in future.

Standardised
In order to enhance trust and usage, it is important that authoritative datasets are harmonised and the production and maintenance processes/procedures/protocols are specified according to international standards that are defined in relevant regulations.

Continuity
It is important that authoritative data has a long lasting trust. This could be achieved by having building up a tradition in the production, maintenance and/or provision of highly qualitative data that are backed up by legislation. Many datasets of NMCAs have been successfully institutionalised during the years. This recognition can be a guarantee that the NMCAs are able to produce, maintain and provide authoritative data well.

High Quality
It is assumed to be one of the critical attributes of authoritative data that the quality of authoritative data is higher than the quality of competing data and that correct data enhances the appetite for more quality of data. Data quality is a wide topic and includes issues related to geometric accuracy, precision, updates, and reliability. All these issues have to be taken into account when dealing with the high quality and reliability of authoritative data. Users need reliable data to sue in the business processes. They need to have a guarantee that the data used is good or certified for their activities and/or products. Moreover, users do not want to be liable for their data and prefer to shift the responsibilities to recognised authorities as they are obliged to keep the data updated and accurate. Finally, it is important that the quality of authoritative data is defined in the relevant regulations (e.g. frequency in delivering updated versions).

Quality management system
It is important that the validation of high quality of authoritative data is assured as authorities are often liable for their data produced, provided or maintained. This could be achieved by establishing a quality management system specifically developed for securing validation processes of certain authoritative datasets. These validations must be part of the certification of authoritativeness and should be made as transparent as possible.

Certified
Authoritativeness is a kind of status. Therefore, this authoritativeness needs to be defined and validated. When data are produced by third parties, the data needs to be validated on the basis of a set of standardised criteria. As a recognition that all the criteria are achieved, the dataset can be certified as authoritative.

Traceability
According to several participants, an important condition for data to be labelled as authoritative is that the data generation has to be fully traceable with clear documentation of the process of how the data has been created and/or maintained. It is an important quality specification.

Maintenance
Several participants strongly stated that the data does not only need to be produced by a (public) authority but also needs to be maintained in order to fully receive the label of authoritative data. It is therefore crucial to communicate how the authoritative data are maintained and how it is updated in the future.

Accessible
In order to provide trusted data, participants mentioned that authoritative data also needs to be accessible to users. When the authoritative data is accessible, the usage of the data could be significantly increased and become more trusted. Accessibility could be enhanced by providing

authoritative data via geoportals or other relevant platforms. Important to underline is the fact that the participants gave very conflicting responses on whether or not the data needs to be open and/or free.

3.2.2 Question 2: How important is it for you that your data is labelled as 'authoritative'?

One roundtable described "authoritativeness of data" as a label meaning that an organisation is granted a legal mandate to collect and maintain certain information which serves a concrete purpose or a task within the public administration. This relates to several responsibilities of public authorities, including: securing legal rights and ownership of lands, proper and actual addressing, zoning and planning, administrative divisions, public infrastructure and other aspects that have to be taken into consideration in the decision-making processes within the public administration. In other words, authoritative decisions can be (only) made based on authoritative data.

According to most participants, it is very important that some of their data is labelled as authoritative. NMCAs might lose part of the 'market' if their data is not labelled as authoritative. In general, it can be assumed that the user will likely give higher credits for authoritative data, compared with other data; e.g. the use of authoritative data would potentially lead to the avoidance of conflicts by citizens as they are/feel more (legally) secured. In order to be labelled authoritative data, agreed (quality) rules and/protocols need to followed and independent entities need to check if these rules and/or protocols are respected. It is very likely that governments will invest more in updates and other kind of support related to authoritative data than to data that are not labelled as authoritative. This all means that data labelled as authoritative will likely be more used by public authorities and other stakeholders and that their demand will be higher when the data are not labelled authoritative. In this context, investments in the improved accessibility of data is a must to facilitate the usage of the authoritative data.

3.2.3 Question 3: Do you think that there is a future for authoritative data? If yes, then what needs to be done to sustain the usage of authoritative data in the future?

The participants strongly stated that there is definitely a future for authoritative data, but only for a limited number of datasets (at least for addresses, cadastral and administrative boundaries). If NMCAs would have no future, then they do not have a purpose. Authoritative geospatial data are core business and a unique selling point of NMCAs. There will likely always be a need for public authorities to provide and use authoritative data as they are the only ones required to be used in numerous key public policy and delivery processes. It is likely that authoritative data will become even more important when more public processes will be more automated in which there will be less opportunity to intervene in the processes. This means that data in these automated processed will strongly depend on standardised, high quality and legally binding datasets – so authoritative data.

The participants also indicated that there might be a need to distinguish two types of authoritative data; a core set of datasets that always have to remain authoritative (e.g. for military or national security reasons) vs. a set of associated datasets. This set of core datasets can only be provided by public institutions. To a certain extent, topographic data can be collected by companies or citizens, however the authoritativeness of topographic data can be important when associated with (administrative) boundaries.

Some of the key responsibilities of modern welfare states include military, social welfare, justice, or spatial planning tasks. These tasks strongly demand authoritative data and moreover, citizens assume that these public tasks are simply executed by default, but they will however not be executed (correctly) if there is no authoritative data.

Authoritative data have a cost for data acquisition, collection, storage, maintenance and distribution, and cannot simply compete with data provided by private companies. A question that does arise is the conflict that arises when public authorities are required to sell their data to third parties. The participants underlined that there is no such conflict as it is just a discussion of funding policy. In this context, it is also important to underline that non-public authorities are able to provide authoritative data, see PSMA in Australia [1]. It is as such not the sole tasks of public authorities.

In response to the second part of the question, participants gave a set of recommendations to sustain the usage of authoritative data in the future. The first recommendations refer to the legally oriented recommendations:

- Authoritative data needs to be registered in laws and regulations in order to ensure that this data is available into the future and is not manipulated. If someone would like to change it then they need to legally challenge and/or question it.
- Ensure the legally binding aspect of authoritative data. A citizen can decide if he/she uses data from the state, or another source, but if a judge needs to make a verdict he will always refer to authoritative data, because the law states it.
- Validate crowdsourced data by an expert in order to be certified as an authoritative source.

Several recommendations also refer to trust as an important future element.

- Open authoritative data in order to enhance public transparency and allow users to give feedback;
- Focus on the public values of authoritative data serving the general public interest;
- Do not focus only on the possible profits;
- Be persistent in order to guarantee that the data will be kept available and provides continuity.

It is also strongly recommended to make the existing authoritative data to be used as widely as possible to ensure it meets future needs. This could be achieved by opening the data and by improving its accessibility, for example via popular platforms and/or one-stop shops.

Other given data quality-oriented recommendations were:

- Invest in the high quality of authoritative data (in terms of accuracy, frequent updates);
- Have a strong data quality management control system in place in order to ensure the data integrity.

3. Conclusion

The main objective of this paper was to provide a better and more comprehensive understanding of the definition, nature, governance and future of authoritative data and the links to spatial data quality in Europe.

To better understand authoritative data, this study applied a two-step methodology, making use of an online survey, and focus group meetings based on roundtable discussions, both with the members of EuroGeographics. Both steps were followed by a triangulation with the academic literature surrounding the subject. The focus group meetings confirmed the main conclusions of the surveys and provided complementary information about authoritative data in Europe. The focus groups underlined that several additional conditions and characteristics of authoritative data were added to the (existing) organisational conditions for authoritative data mentioned in the survey: Legally binding, accountability, uniqueness, mandatory use, liability, (public) authority provision, trust, standardisation,

[1] Although PSMA Australia Limited is a company, it has to be underlined that it is owned by all the governments of Australia.

continuity, high data quality, adequate quality management system, certification, traceability, and maintenance.

The results of this paper underline the need for a systematic and harmonised approach towards authoritative data. The survey revealed that there is a variety of definitions and approaches applied by the different member organisations of EuroGeographics, as well as different opinions on which data should be considered as authoritative. Through the focus groups, the results of the survey were corroborated and several additional elements could be added on the topic of authoritative data.

The research shows that spatial data quality is an important element to be included in a definition for authoritative data but is not the most prominent one. Based on the findings of this this research, we have tried to integrate all relevant elements and aspects into one single overarching definition: "Data likely provided by or on behalf of a public body (authority) which has an official mandate to provide and sustain it, that is based on a set of known criteria to ensure (inter alia) high data quality, and that is required to be used or aimed towards extensive use and reuse within the public sector and society as a whole". This new proposed definition could be the basis for further discussion on the meaning of authoritative data.

Other conclusions of this paper are that NMCAs underlined that data that is validated as authoritative data is considered to be of very high quality. This does, in turn necessitates adequate resources for ensuring data quality and up-to-dateness. The paper also underlined that the obligation to use authoritative data depends on the situation at hand. More effort should be put in making authoritative data available and recognisable by other public organisations as well as private actors. Finally, the participating NMCAs underlined that there is a need for organisations within the public sector to take up a central role in the governance of authoritative data.

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