3D Modelling with National Coverage: Bridging the Gap Between Research and Practice

Commission II, WG II/2

Jantien Stoter, Carsten Roensdorf, Rollo Home, Dave Capstick, André Streilein, Tobias Kellenberger, Eric Bayers, Paul Kane, Josef Dorsch, Piotr Woźniak, Gunnar Lysell, Thomas Lithen, Benedicte Bucher, Nicolas Paparoditis and Risto Ilves

Abstract 3D technologies are becoming mature and more and more organisations are investing in 3D models for their areas. For National Mapping and Cadastral Agencies (NMCAs), that have a long history in collating and maintaining countrywide 2D-datasets, the major challenge is how to best adopt a 2D base into 3D environment with an established process of continuous incremental update, and making best use of available resources. To identify best and common practices, as well as remaining research challenges, since 2013 ten NMCAs work together in the

J. Stoter (✉)
Kadaster & TU Delft, Delft, The Netherlands
e-mail: j.e.stoter@tudelft.nl

C. Roensdorf · R. Home · D. Capstick
Ordnance Survey, Southampton, UK

A. Streilein · T. Kellenberger
Swisstopo, Wabern, Switzerland

E. Bayers
IGN, Brussels, Belgium

P. Kane
Ordnance Survey, Dublin, Ireland

J. Dorsch
LDBV, Bavaria, Germany

P. Woźniak
GUGIK, Warszawa, Poland

G. Lysell · T. Lithen
Lantmateriet, Gävle, Sweden

B. Bucher · N. Paparoditis
IGN, Paris, France

R. Ilves
NLS, Helsinki, Finland

M. Breunig et al. (eds.), *3D Geoinformation Science*,
Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-12181-9_13

European Spatial Data Research (EuroSDR) 3D Special Interest Group. This paper reports about an inventory that has been made on the state-of-the art of 3D products and plans that these NMCAs have as well as the challenges they face. The 3D modelling of buildings is explored in more detail, since buildings are prominent features in 3D city and landscape models. In addition, together with road objects (traffic infrastructure), building objects change often and therefore these require efficient update processes.

Keywords 3D city and landscape modelling · 3D object reconstruction with national coverage · 3D updating · 3D building modelling

1 Introduction

Traditionally the design of georeferencing frameworks, be they geodetic or topographic, has made accommodation for 3D elements. Traditional representation of the third dimension is done through the definition of ellipsoids for geodetic frameworks, the production of reference points and interpolation methods for altitudes, and the representation of height of some features such as buildings, by an attribute. Yet, the encoding of geographical data that constitutes topographical frameworks has always favoured two dimensions because of several reasons. First, the importance of visualisation, on paper or screens, has necessitated the definition of planar projection and representation of the third dimension with 2D features. Second, available technologies for data acquisition were more adapted to 2D. Finally, the methodologies for modelling in 2D, which evolved, have proven to be already very rich for most geo-applications and become entrenched.

The last few years we have witnessed the rapid evolution in 3D visualisation which has put a spotlight on the value of 3D visualisation in raising awareness, particularly of complex phenomena, and promotion, of for example a territory. The growing awareness for our intensively used environment makes 3D information increasingly important, not just in describing the physical environment, but also for modelling abstract features such as flood dynamics, pollution spread and urban analytics in an intuitive and accessible manner.

Besides the many initiatives focusing on generating and using city models, National Mapping and Cadastre Agencies (NMCAs) are also extending their traditional 2D maps into the 3rd dimension. For NMCAs that have a long history in collating and maintaining countrywide 2D-datasets, the major challenge is how to best adopt a 2D base into 3D environment with an established process of continuous incremental update, and making best use of available resources. The ability to retain consistency with the original source is an imperative.

Many NMCAs have made or are making the step towards 3D mapping, although several issues remain on how to generate appropriate 3D data in most effective manner, to the *appropriate* specification, maintain it accordingly, and use it in a wide variety of applications. Ten NMCAs have joined forces in the European Spatial Data Research (EuroSDR) 3D Special Interest Group (3D SIG) to address these issues since they see it as important to further develop in the 3D domain, with help of universities and companies. The NMCAs of the EuroSDR 3D SIG are: GUGIK (Poland), Swisstopo, Ordnance Survey Ireland (OSI), Ordnance Survey UK (OSUK), IGN France, IGN Belgium, Bavarian Agency for Digitisation, High-Speed Internet and Surveying (Germany), Lantmateriet Sweden, NLS Finland and Dutch Kadaster. The purpose of the established EuroSDR 3D SIG is to coordinate the long term research on 3D based on own experiences and developments in both research and industry, by means of describing best practices (e.g. for 3D modelling of buildings), defining a joint research plan, conducting research projects in areas of common interest (e.g. 3D object reconstruction for large areas based on 3D source data that is typically available at NMCAs) and the organization of a workshop series on relevant topics. This paper presents the progresses made in 3D of the ten EuroSDR 3D SIG members. It updates and extends the paper that analysed five of these NMCAs in 2013 (see Stoter et al. 2013a).

The paper provides insights into how results from research are adopted in practice and what further research is required to be able to map complete countries in 3D as part of mainstream spatial information flows. The paper is based on an inventory, the compilation of which is presented first in the methodology. After listing the main research challenges for several aspects of 3D, ranging from data collection, modelling, maintenance to dissemination, specific attention is paid to the approach and issues for modelling and updating 3D building features. Buildings are prominent features in 3D city and landscape models and these features change the most (together with traffic infrastructure). The paper ends with conclusions.

2 Methodology

To see the progress and plans of the ten NMCAs, an inventory was made in February 2014. The aim of this inventory was to identify areas of commonality and divergence of 3D approaches of NMCAs. The inventory consisted of two parts. The first part is product-oriented and meant to identify existing and planned 3D products, including the ‘issues’ associated with getting there. It also focused on current or planned 3D research that is directly related to a product development.

The second part focused on collecting issues that cross 3D products. From both inventories a generic research agenda was defined from the programs that the NMCAs have. This research agenda is currently being further developed after having been discussed at meetings with the NMCAs in March and June 2014.

3 Existing and Planned 3D Models

This section presents an analysis of the outcomes of the first part of the inventory, i.e. on existing and planned 3D models.

The available countrywide 3D data produced by NMCAs can be divided into two main products: field data (Digital Terrain Models, Digital Elevation Models, Digital Surface Models, point clouds) and object-oriented data, i.e. topographic features. This latter data can be both 3D (mostly buildings) and 2.5D (surfaces for features like terrain, land use, vegetation, water, road).

Field data is produced by all concerned NMCAs using various methods; see Fig. 1 for the DTM example of OSUK. Storage and dissemination is also done in various formats, such as LAS files (in DBMS), GeoTIFF, TIN, ESRI ASCII Grid, ESRI File Geodatabase 10.1, ASCII X,Y,Z single space, GML (contours).

Field data can be considered as raw data. In contrast, object oriented data can be considered as interpreted data. Several NMCAs produce such 3D object data:

The Regional Mapping and Cadastre Agency of Bavaria produces LOD1 and LOD2 building models for their 8.1 million buildings, see Fig. 2. The bases of these buildings consist of cadaster building outlines. LOD1 buildings are generated automatically from Lidar data and updated twice a year with new cadaster data and standard heights derived from number of floors where the Lidar data are not updated. LOD1 buildings are available for all 8.1 million buildings (since 2010). A German-wide LOD1 model will be offered in 2015 via the Working Committee

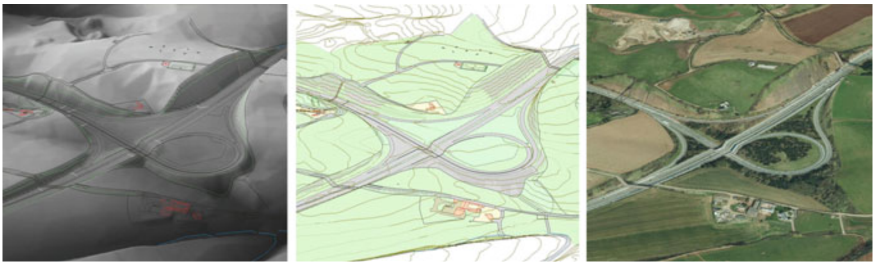

Fig. 1 DTM produced by OSUK

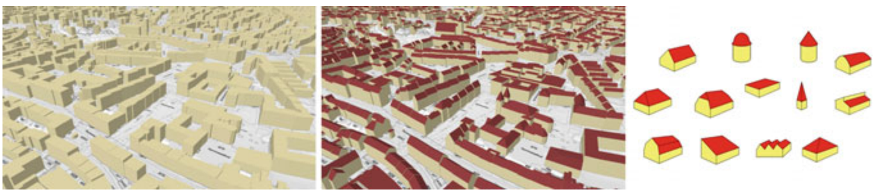

Fig. 2 Buildings from Bavaria: LOD1 (*left*); LOD2 (*middle*); 13 standard roof shapes from ALKIS®-object catalog for LOD2 buildings (*right*)

of the Surveying Authorities of the States of the Federal Republic of Germany (AdV) in a common CityGML standard.

The LOD2 buildings with roof shapes are also generated from Lidar data using an object catalog with 13 different roof shapes (see Fig. 2, right). Image matching point cloud is used (4 points/m^2) for missing buildings in Lidar data. LOD2 buildings are available for 25 % of the buildings and are expected to be complete in 2016. The LOD2 shapes are created with semi-automatic processing and interactive post-processing using the LOD2 reconstruction software "BuildingReconstruction" (company virtualcitySYSTEMS in Berlin).

The update process of LOD2 is being developed using a modified version of the LOD2 reconstruction software. Basis for update information is the terrestrial measurement of buildings by cadaster offices. The semi-automatic update process will start in 2015.

Storage

Storage format is CityGML and the buildings are stored in the 3D CityDB implementation of the Technical University of Berlin (Oracle).

Distribution

LOD1 buildings are distributed in formats CityGML, KML/KMZ and Shape (with attribute height). German-wide distribution of LOD1 buildings is done by the ZSHH in Cologne (central office for house coordinates and outlines). The LOD2 buildings are distributed in formats CityGML, KML/KMZ, 3D Shape, dxf, and 3ds. The use of a web service for distribution (WFS2.0) for LOD2 is being studied.

IGN, Belgium maintains its classical midscale product Inventaire Topo Géographique—Topo Geografische Inventaris (ITGI) in 2.5D: i.e. every x, y-coordinate contains a z-coordinate derived from the 20 m DTM (Fig. 3). The data is created with stereo-restitution, field survey, ortho-interpretation and image correlation (DTM). It was first acquired from 1992 to 2008 and is being updating since 2009.

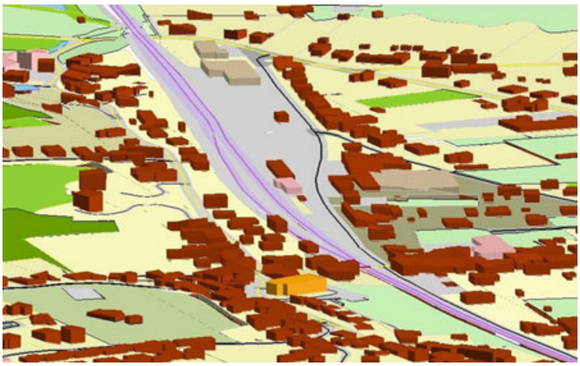

Fig. 3 The 3D topographical data set of IGN, Belgium

The data is interactively edited with various software: Intergraph geomedia + ISSG, ArcGIS, Inpho (Match-AT, Match-T), DTM Master, FME, Radius Studio.

Storage is done in Oracle/ESRI Enterprise geodb (SDE).

Distributed via:

- Top10 vector (derived standard product)
- Testbed WMS services (see www.ngi.be)
- Cartoweb WMTS service (see www.ngi.be)

Other NMCAs

The 3D data products of swisstopo, Kadaster, IGN France and Ordnance Survey were described in detail (Stoter et al. 2013a). In summary, **swisstopo** maintains their large-scale data in 3D since 2010, while the 2D maps are derived from the 3D swissTLM^{3D} database (O'Sullivan et al. 2008). **The Netherlands** has established a national 3D standard extending CityGML for large-scale data (to be captured at the municipal level), see Stoter et al. (2013b). In addition, the **Netherlands Kadaster** is currently creating a 3D version of their 1:10 k topographic database, using high resolution Lidar data and 2D topography (Oude Elberink et al. 2013). Several possible 3D products are in research at **Ordnance Survey UK (OSUK)**, these are listed in the next table:

	Datasets
New elevation models	DTMs (complete)
	DSMs
Ground heighting of existing 2D datasets	Topographic features
	Road network
	Hydrology network (complete)
	Rail network (complete)
	Tracks and paths network
	Address points
Additional capture for elevated features	Building heights (LOD1)
	3D buildings and structures (LOD2)
	Vegetation

In addition, in 2014, OSUK released a new product called Building Height Attribute, which attributes 25 million buildings in OS Mastermap with height information (update released in June 2014). The heights are calculated by a fully automatic process that uses remotely sensed data, including aerial imagery and digital surface and terrain models (the same that are used to produce the OS Terrain 5 and 50 products). Attribution is provided for the ground level, the base of the roof (which can be thought of as being similar to eave height) and the highest part of the roof for each building.

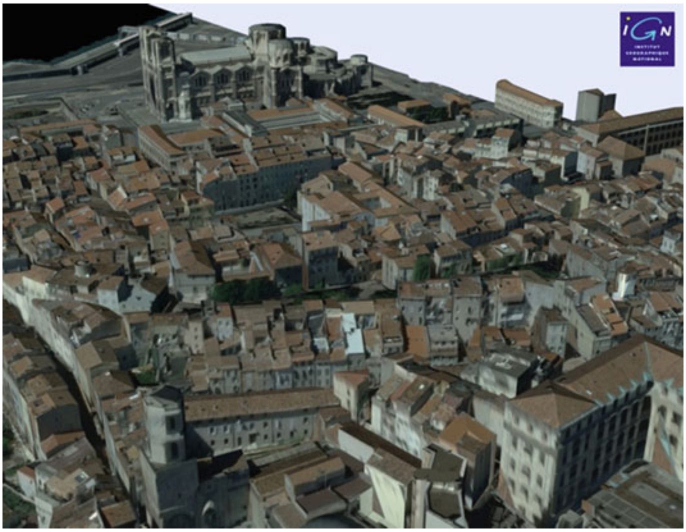

Fig. 4 Marseille old downtown Bati3D

IGN France launched the BD Topo product in 1994. This product provides a LOD1 model of buildings as part of a 2.5D geographic information framework, the Référentiel à grande échelle (RGE, for large scale reference framework). The nationwide coverage was completed in 2007. In late 2007 IGN-F launched an innovation project which industrialized research results pertaining to 3D data automated extraction, and chose to primarily rely upon CityGML and a pivot format in this venture. This innovation project was completed by the end of 2009, and resulted in an automated workflow currently used for two production activities:

- Creation of high resolution DTMs from dedicated aerial coverages in rural areas (25 cm ground pixel size, typically 4,000–10,000 km^2)
- Creation of 3D city models (LOD 2 level) with texturation extracted from images, from higher resolution and denser aerial coverages, called Bati3D product (Fig. 4).

More recently, IGN-F has launched a project to define national specifications for 3D product, together with users, so that 3D data produced at local level according to these specifications can be integrated in a nationwide 3D referencing framework. These specifications are defined considering the state of the art 3D modelling techniques and standards as well as user expectations. IGN-F has gained experience about user expectations with respect to 3D data through the participation of some of its researchers to the COST action TU0801, Semantic cities and 3D models (Cost 2014). In this action, user requirements were elicited between researcher's specialists of data production, cartography and GIS and researchers in different application domains like urbanism, landscape scenery assessment, or serious games.

4 Open Research Issues

In the second part of the inventory, the NMCAs were asked to describe the open issues that they face in their 3D product developments. The mentioned challenges can be categorised in eight types and are further detailed in the remainder of this section:

- Open issues regarding field data
- Product enhancement and 3D object reconstruction
- 3D standards and data modelling
- Maintenance, storage and update
- 3D dissemination and portrayal
- Integration, fusion and consistency
- Tooling
- Users and Customers

4.1 Open Issues Regarding Field Data

The challenges that the NMCAs face for collecting and distributing field data are several:

- Managing and documenting the uncertainty during data capture to produce reference data.
- Integrating various products (points clouds, aerial images, terrestrial images, 2D topographic DB)
- Integrating field data with object-oriented data, e.g. breaklines in DTM with roads or rivers in the topographic data set to ensure consistency between both products
- Update of the DTMs, DSMs and DEMs
- Development of the DTM to support the creation of 2.5D and 3D products
- Integration of surface change detection algorithms to improve the manual update process
- Modelling of 3D hyper surfaces as part of the DTM (such as sheers, overhangs, faults, arcs)

4.2 Product Enhancement and 3D Object Reconstruction

NMCAs are seeking better ways to reconstruct (and interpret) 3D representation of objects such as: buildings, networks, vegetation, structures (distinct to buildings, and include features such as tunnels, bridges and piers), hydrography, power lines etc.

The primary focus of the mentioned issues relates mostly to the reconstruction of building features. For example, more building attributes (including roof type attribution) are required as well as accuracy statements. In addition, complex building footprints and large footprints give problems in automated reconstruction processes. A big challenge for buildings remains the question of how to generate roof structures from point-cloud data while keeping consistency with the footprints maintained in the 2D database?

Different production methods may result in different models, i.e. walls projected from the roof edges (typical for airborne techniques) result usually in larger volumes than the walls extruded from true locations of the footprints (common in terrestrial and oblique techniques). None of them violates the LOD2 specification, but they are considerably different from each other (Biljecki et al. 2014).

For the reconstruction of 3D objects represented with surfaces (mostly triangulated surfaces), the following issues are mentioned:

- How to model bridges (i.e. non-equal crossings) and subsurface elements (e.g. tunnels, caves, etc.)?
- How to support vertical faces (triangle) in the TIN (for example to represent curbs)?
- How to model 3D hyper surfaces such as sheers, overhangs, faults, arcs?

For NMCAs that traditionally have to model large areas, a specific question is how to make capturing of 3D objects on a national level affordable? "As automated as possible" might not always be the most efficient solution, i.e. guaranteeing a valid 3D object output for 60 % of the objects could be preferable over a solution that targets a higher percentage but requires higher levels of human verification. Therefore, besides object reconstruction processes, it is important to be able to identify (i.e. validate) which objects have correctly been generated.

4.3 3D Standards and Data Modelling

A main issue for 3D data modelling is that common agreements on the content of 3D data are missing. Even within this group of NMCAs active in 3D, there is no common agreement on terms as 3D, 2.5D, LOD, 3D building, 3D model, 3D data etc. nor on how to model 3D topography like building, roads and water.

The establishment of the 3D standard "CityGML" by the Open Geospatial Consortium (OGC) in 2008 was an important step in the standardization of 3D data, 3D features and their use. The standard resulted in increased 3D datasets, in tandem with the range of applications to which 3D is being applied, e.g. solar mapping, noise modelling, cadastre, etc. (OGC 2012).

However, the CityGML standard is meant as a generic standard and allows an implementation freedom. An issue for wide implementation of CityGML is that it does not offer sufficient guidance on how to uniformly and unambiguously implement the standard: while conformance requirements do exist, they do not cover checking the integrity of CityGML geometries. Furthermore, implementation specifications for CityGML hardly exist, with some exceptions such as the Dutch implementation specification for CityGML (Geonovum 2013) and the modelling handbook published by the German 3D Special Interest Group—data quality working group (SIG 3D 2013a, b). In short, CityGML requires further attention to be able to produce consistent and high-quality 3D geo-information encoded in CityGML. This is currently taken up by the CityGML Quality Interoperability Experiment of OGC (2014).

The NMCAs mentioned the following remaining issues for 3D standards:

- Defining a common, international vocabulary for 3D concepts that all NMCAs use, both for geometry and themes and in line with existing standards (INSPIRE, CityGML, national models and approaches).
- Establishing standards for nationwide 3D models in coherence with 2D data models and preferably based on international agreements, considering user needs and considering complementarities with other industries than GI software (typically the BIM industry).
- Defining specifications for complex structures (canopies etc.) and object types at different levels of details, other than buildings (e.g. trees).
- Defining more advanced 3D spatial data models (vector, voxel, CSG, tetrahedrons, curved surfaces, hyper surfaces etc.)
- Reporting of LOD1 and LOD2 buildings for INSPIRE-monitoring of Annex III theme “Buildings”
- Solving the technical problems with respect to the implementation of the CityGML standard, e.g. current industrial solutions limit flexibility.

Also concerning the foundation principle of CityGML, i.e. Levels of Details, the NMCAs mentioned several open issues:

- How do scale and resolution relate to LOD? A common vocabulary on scale and LOD is missing (beyond the existing conceptual and global vocabulary).
- How to derive 2D from 3D data? How to derive LOD(n − 1) from LODn?

4.4 Maintenance, Storage and Update

Maintenance, storage and updating is important for NMCAs to make 3D data useful and reliable.

Database Management Systems (DBMSs) nowadays support 3D geometries. Still the NMCAs mention a need for improved storage and maintenance models and solutions for 3D geodata, i.e. vector, voxel, CSG, tetrahedrons, curved surfaces, hyper surfaces, network, vertical surfaces in a TIN etc. In addition, the consistency with 2D data was also mentioned with respect to storing 3D data. Finally, the storage of massive constraint TINs (i.e. the TriangluatedSurface of CityGML) in coherence with the breaklines (i.e. 2D topography) requires further research.

Several issues were mentioned by the NMCA concerning updating such as efficient updating processes, updating via heights points obtained from dense image matching, and change detection in 3D (see also the next section).

4.5 3D Dissemination and Portrayal

Nationwide modelling is traditionally the focus for NMCAs. How can the resulting Big 3D data products be distributed via web services? Are OGC Web Feature Services appropriate? Can the OGC draft specification "Web 3D Service (OGC 2010)" be used? How can 3D data be integrated in existing Web viewers? What are the best formats for the dissemination of 3D data as products?

4.6 Integration, Fusion and Consistency

Fusing 3D data brings specific challenges and many issues are still unsolved. The NMCAs mentioned the following open questions:

- What are the main consistency issues in data fusion?
- How to fuse 3D data with other 3D data and how to fuse 3D data with 2D data, i.e. buildings, elevation models, roads, water, vegetation, 3D vector and raster/points?
- How to keep 3D data consistent with 2D data and vice versa?
- How to keep 3D vector data and 2.5D DTM data consistent and 3D vector data with the underlying raw data?
- How to maintain consistency between 3D objects (buildings, roads, bridges, water, vegetation) and terrain?
- What technologies allow automatic establishment of consistency between different data sets?
- Some topics define the landform (e.g. water, roads, bridges, tunnels). How is their relation with a DTM best maintained?
- How to combine terrestrial (cadastral) building footprints with roofs from other sources?
- How to integrate near subsurface buildings?
- How to integrate above and below surface data?
- How to integrate 3D geo-data with 3D data from other domains (Building Information Models, Gaming, 3D Land Administration Model)

4.7 Tooling

Tooling for 3D data is required to be able to process the data. What are the frameworks for representing 3D spatial relationships, for 3D spatial analysis and simulation and for 3D navigation and interpolation algorithms?

4.8 Uses and Customers

When making the step from 2D to 3D, an important question for NMCAs is what is the business case for 3D, i.e. what are the benefits for an NMCA that justify the investment in 3D? Regarding the value of 3D data, several issues for NMCAs exist:

- What are the Best Practices on added value of 3D above 2D?
- What is the best pricing policy for 3D data (for example open data?)
- How to strengthen the awareness of 3D data? Several NMCAs identified that their 3D data is underused.
- How to determine the economic value of 3D (the value to the economy, or public good)? Thus, what business opportunities can be realised through the application of 3D data?
- What are the required 3D data content, formats and quality?
- For 2.5D and 3D data a related question is "what is the specific task of NMCAs to produce such data and what should be left to the market?" Should an NMCA provide a 3D model of the complete country or produce 3D data on demand? What LOD's should an NMCA provide: basic LOD or more (multi-LOD, texture, UUID/linked data)? Should an NMCA provide photorealistic products in 3D, (as today provision of orthos in 2D) which can range from a 3D-point cloud (+classification + RGB) and a 3D-image model (DSM + texture) to 2.5D/3D-GIS map (DTM + volume + texture).

5 Focus on Buildings

The previous section listed the main 3D issues for the participating NMCAs. This section elaborates on one of them, which is the modelling and updating of 3D building features. These features are most prominent features in a 3D city and landscape models and require the most effort to model in 3D. In addition, these features are most frequently updated (together with traffic infrastructure) and therefore buildings are traditionally important objects within topographic data sets that NMCAs produce.

For a selection of the involved NMCAs the modelling approach for buildings are explained. At the end of this section, research issues for maintenance and update of building data are detailed.

5.1 Building Modelling Approaches

Switzerland

swisstopo captures roofs of buildings on the base of aerial stereo imagery (Fig. 5). XYZ (coordinates and height) are stored for every single roof or roof element. For these roofs a library of possible roofs is used (different than in Bavaria). The footprints are automatically or manually deduced, while walls are automatically generated.

Swisstopo does not map all buildings, since the target scale for the data is approximately 1:10 k. Instead, the building (or element) should have minimum dimensions:

- A roof top line is mapped from 1 m height difference
- Minimal diameter of tower-like buildings is 4 m
- Minimal dimension of mapped buildings is 24 m^2 area. The minimal length of one side has to be 8 m or larger.
- Minimal dimension of «Gauben» (roof side add-ons) is 8 m

At this moment almost 600,000 buildings have been captured of the 3 million buildings to be mapped. The mapping speed of an employee is one building per 2 min (including all attributes).

Bavaria

The way of building modelling in Bavaria was already explained in the second section [see also Arlinger et al. (2013) and Bavaria (2014)]. Interestingly, in the 2D process important height information is already captured, see Fig. 6. The 2.5D information for footprints in the cadaster enables an update process of 3D buildings via terrestrial field survey.

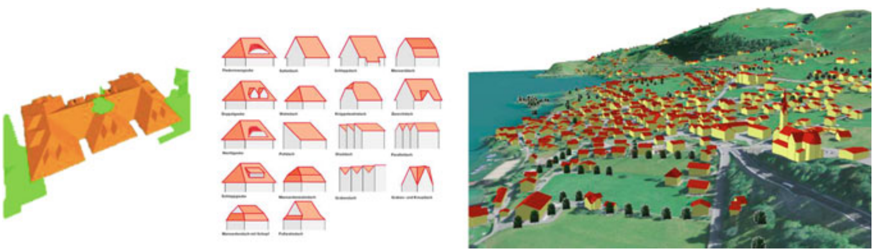

Fig. 5 Mapping of 3D buildings by swisstopo

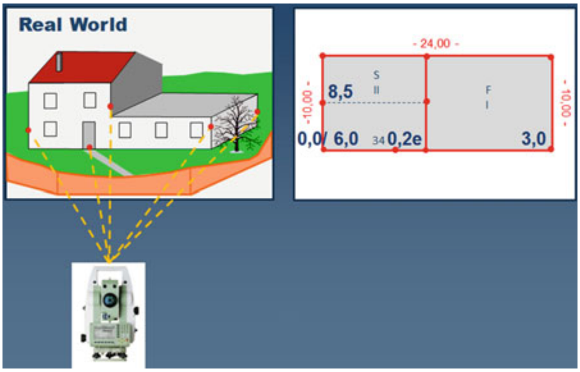

Fig. 6 Capturing 3D characteristics in 2D data collection process in Bavaria

The automation of LOD2 3D modelling is high (50–85 %). Even though each building model is interactively checked, the output per day per employee is 200–500 LOD2 building models. Bavaria uses minimum requirements for the 3D characteristics of buildings to be mapped in 3D: for buildings smaller than 13 m^2, flat roofs are generated. Minimum height of buildings is 1.8 m. Buildings with missing Lidar data get a standard height, for buildings smaller than 25 m^2 the standard height given is 3 m and buildings larger than 25 m^2 get a standard height of 9 m. In the next years these standard heights will be replaced by roofs from image matching point clouds.

Sweden

Lantmateriet, Sweden collects buildings in-house for rural areas and in cooperation with municipalities for urban areas. The buildings are measured in-house in 2.5D with photogrammetry and roof edges are stored in a 2.5D database, see Fig. 7a. The municipalities use photogrammetry or terrestrial measurements to collect in different models. Some municipalities have adopted CityGML or the Norwegian standard SOSI/FKB for photogrammatry, see Fig. 7b. The Norwegian standard supports four levels of detail of buildings depending on user's needs. 3D models can be generated on demand using 2.5D building representations and the DTM. FME and manual labour or data services are used for transfer municipalities' data to Lantmateriet. In Sweden about eight million buildings need to be mapped over an area of 450,000 km^2.

Belgium

IGN, Belgium captures roofs from stereography and stores the 2.5D geometries in a DBMS. The buildings are part of the digital landscape model, see second section. The 3D characteristics that are captured are shown in Fig. 8.

France

IGN France has been conducting researches to improve the modelling of buildings for more than 15 years. 3D modelling is not a research domain driven by obvious users. Hence the overall research strategy in 3D at IGN-F has also been to acquire and distribute innovative 3D data with a concern for cost, quality and performances

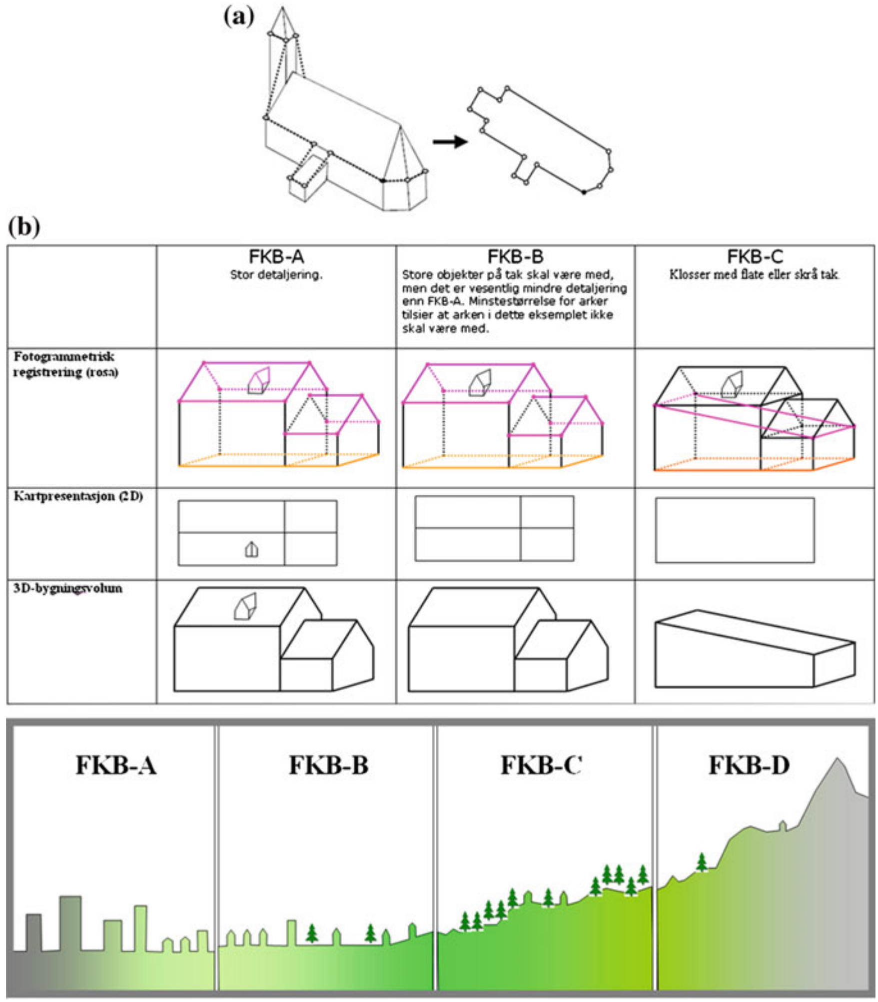

Fig. 7 **a** Buildings captured in the 2.5D by Lantmateriet, Sweden. **b** 3D modelling approach for some municipalities in Sweden; adopted from Norwegian standard SOSI/FKB

(research led at MATIS lab and LOEMI lab) and to improve GIS and cartography capacities considering these next generation data (research led at COGIT lab).

In the domain of instrumentation, in the late years, contributions have addressed innovative sensors to capture 3D data: photogrammetric cameras (Souchon et al. 2010) and wireless sensor networks to provide ground truth for researchers simulated models for pollution.

In the domain of remote-sensing and photogrammetry, contributions are a mobile mapping systems integrating optical cameras with lidar sensors to achieve a

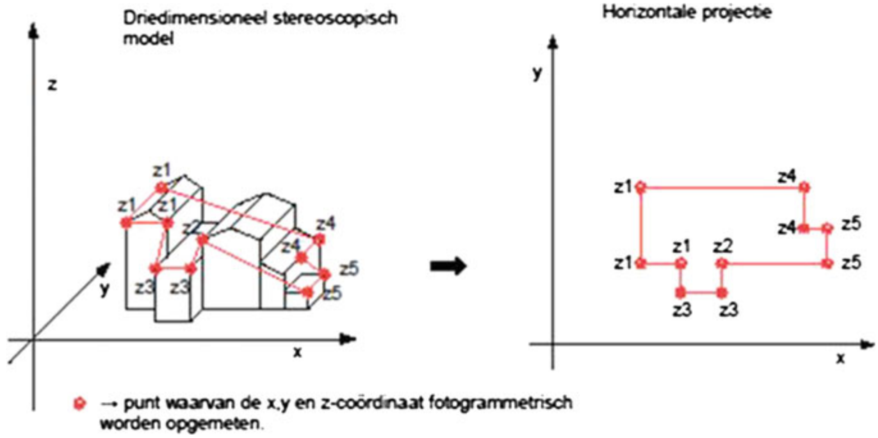

Fig. 8 3D characteristics of buildings captured in the 3D modelling process by IGN, Belgium

very high precision (Paparoditis et al. 2012). Chehata et al. (2014) studied sensors specifications for urban 3D model design in order to assess which frequencies are useful in an urban super spectral camera to measure pollution typically. The performance of building reconstruction, edition and quality checking has also been improved (Vallet et al. 2001; Brédif et al. 2013). Current research directions comprehend the enhancement of the quality of automatic modelling with superstructures and cadastral parcels splitting, the qualification of 3D models and the integration of data acquired from mobile mapping systems. 3D model enhancement is also addressed thanks to these mobile mapping systems data. Challenges currently tackled are: registration of laser and 3D model, 3D model texturation with ground imagery and photorealistic 3D façade modelling with deformable grids (Demantké et al. 2012, 2013).

In the domain of GIS and cartography, contributions to building modelling are a library of geometric data structures for 3D spatial operators, work to compare different 3D specification (extruded BDTopo® and Bati3D®) to compute some urban indicators, work with thematic researchers to assess which features, properties and relations have to be derived from the state of the art reference data (3D and 2D and time series) for their application. Brasebin et al. (2011) have proposed an extension of CityGML and specific operators to perform automatic checking of building conformance with urban rules, as well as a methodology to analyse the consequences of urban rules on urban fabric dynamics. Specifically he proposes two models: one for visualisation and one for calculus. Last Bucher et al. (2012) have proposed a vocabulary to describe relations and properties relevant to users of 3D buildings models and to GI modelling experts.

5.2 Open Issues for NMCAs to Update and Maintain Building Features

This section explains the specific issues of updating buildings features by NMCAs (which may also be valid for other mapping organisation). The first reconstruction process of a 3D building model (LOD2) is expensive. NMCAs see updating as a unique selling point for the 3D building model produced by NMCAs because regular updates guarantee the long-term maintenance of value and these will avoid a growing inconsistency between 2D and 3D information. Up to 1 % of the buildings are subject to changes every year and existing data sources can be used for the update process.

Three update types for 3D buildings can be distinguished, i.e. a geometric update (building falls away, change of the building, new building), a semantic update (new building function, change in address, roof type name adjusted, number of floors changed, last date of update check change) and updates because of updates in others sources (update of DTM).

Approaches for updating can be a bottom-up approach based on exact 2D footprints. A new building in the 2D database triggers a change in 3D. The 3D geometry can then be acquired via for example terrestrial measurements. Updates in a top-down approach are based on cyclic remote sensing data (new LiDAR data or images for dense image matching). These new data will detect building changes and roofs can be modelled in 3D accordingly. Updating can also be done by a combination of both: new 2D footprints trigger changes of building; intersection of footprints with new 3D data from remote sensing can be used for 3D modelling of single buildings. A significant difference between the two approaches is that the first approach (bottom up) assures consistency between the footprints of 3D buildings and the footprints in the 2D data set, while the second (top down approach) does not.

From the inventory and discussions, we have identified a list of issues for updating 3D building models by NMCAs, which are often also valid for other object types.

These issues are:

- What triggers change in 3D data?
- What is the most efficient updating process (with respect to quality and economy)?
- What requirements should be laid down for the source data?
- What is better given the state-of-the-art: automatic approaches or semi-automatic approaches with post-processing?
- Can heights obtained from dense image matching be used as alternative for Lidar data when updating buildings?
- What are the customer requirements regarding updating, taking into account that change detection with image matching will result in update cycles of 1–3 years and updates via cadastre makes it possible to update in weeks of building modelling in Bavaria was already explainedor months?

  - do users require 100 % consistency between 2D and 3D?
  - do users require the same actuality for 3D data as for 2D data?

- What are the effects of the updating process to the data management?
- How can inconsistencies between 3D data and 2D data be reduced, i.e. in time (different update cycles), in geometry (different scale and data sources) and in semantic information?
- Do we need archiving of 3D buildings and their elements for future 4D applications and how to model these in the database?
- How do all these questions apply to the update of facades and roof textures?

6 Conclusion

This paper provides an overview of the 3D modelling activities within a selection of European NMCAs and the challenges they face to build 3D data products within their traditional tasks as geo-information producers. For NMCAs the specific challenge is to map large areas, to assure actuality of the data, to establish a reliable update process and to find a positive business case for 3D data that justify the investments of NMCAs in addition to other organisations that collect 3D data such as municipalities and companies. For one issue, i.e. the modelling and updating of buildings, the current approaches and existing challenges were further detailed.

From this paper it can be concluded that NMCAs have made the step to produce 3D data, while some challenges still need further attention such as maintaining large 3D data sets in DataBase Management Systems; dissemination of the 3D data via web services and via user-friendly formats; automated reconstruction of 3D data (not only buildings); integration of different 3D data and of 2D and 3D data; standardisation in 3D modelling; and, underuse of the 3D data.

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