Integration of 3D city models in a country wide covering 3D basemap

A case in The Netherlands

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1 Introduction

Nowadays large-scale topography maps are indispensable in the daily use for both the private and the public sector. These topographical maps contain geo-information about all features that appear on the Earth's surface. The features are displayed at a highly detailed level and include for example roads, buildings, borders, waterworks and land cover. Though this 2D geo-information is still widely used, also the needs and interests for topographical 3D data are increasing (Elberink and Vosselman, 2006).

A wide variety of 3D data needs have emerged in multiple domains and for many different applications. Investigations on the purposes of 3D data have been done and include applications for spatial planning, noise propagation and shadow estimation (Ho et al., 2018). The requirements the 3D data must meet depends a lot on the application it will be used for. Mapping agencies and organisations in countries all over the world are aiming more and more towards the managing of 3D topographic data. These organisations are all in a different development phase and have different approaches towards the managing and formatting of the 3D data. This has led to the emergence of a wide variety of 3D models (Stoter et al., 2017).

The Netherlands is one of the countries where a lot of experimentation with topographical 3D data has been done already. The basic registration of large-scale topography (referred to as the Dutch abbreviation *BGT*) is one of the ten basic registrations in the Netherlands, which are mandatory by law since 2016. The digital map of the large-scale topography is being collected and maintained by source holders. These source holders are each responsible for their own region and include all governments, provinces, water boards, ProRail and multiple ministries. The data is then managed by the Cadastre, who facilitates the national supply of the BGT products. Since the start of the 3D Pilot, an initiative that was set up to examine the use of 3D geo-information, the Cadastre has been working on a country-wide covering 3D topographical basemap. The resulting 3D model is based on the large-scale topographic data and the basic registrations for buildings and addresses (BAG). Height values are retrieved from both the national elevation map (AHN) as well as dense image matching from aerial imagery (Goos et al., 2011).

However, also some of the source holders have taken steps towards a 3D approach of their data management. They have been, or are currently, developing 3D city models of their own regions. These 3D city models are different from the 3D basemap of the Cadastre, but also from each other in several ways. Differences can be seen in their contents, level of detail, data quality, completeness and actuality among other things. The question now arises if an integrated approach towards topographical 3D data is possible and desirable. For this research a case study will be done on the Netherlands, in collaboration with six stakeholders that are involved in the generation of large-scale topographical 3D models.

2 Related Work

2.1 3D Modelling Urban Environment

In this section the publications that are related to the subject of this thesis will be described. Over the last 20 years, many researches and initiatives have been set up in order to examine the state of art of 3D urban models, their functionality and standards. One of these initiatives is called the Action, which took place between 2008-2012. Billen et al. (2014) elaborates on the aim of this Action, which was to explore different ways to semantically enrich 3D models and defines a city model as: "a representation of a part of the real world that encompasses urban entities and the global urban environment where they are located".

Another initiative is called the 3D pilot, a two-phases project which started in 2010. The pilot was initiated by Dutch Cadastre, Geonovum (the National Spatial Data Infrastructure executive committee in the Netherlands), The Netherlands's Geodetic Commission (NCG), and the Dutch Ministry of Infrastructure and Environment. The first phase aimed at an establishment of a uniform approach for acquiring, maintaining, and disseminating 3D geo-information. (Berntssen et al., 2012), (Berlo et al., 2011) and (Goos et al., 2011) describe the findings of respectively the 3D use cases, 3D standards and supply of 3D geo-information. The pilot resulted in a national 3D standard CityGML Application Domain Extension (*ADE*) that integrates with a new version of the national Information Model for Geo-Information (*IMGeo*) (Nl et al., 2011). The second phase of the pilot distinguishes six activities. The activity of designing a standard specification for the construction of 3D IMGeo data is defined by Blaauboer et al. (2017).

Standards are essential during and after the development of 3D data. These standards describe the management, modelling, exchange and disclose of 3D geo-information. In Delft (2016) the developments of different 3D standards are examined, focusing on the standards that are relevant to the geo-domain. Among these standards are: GML, CityGML, gITF, KLM, InfraGML, IFC and SLPK.

Borrmann et al. (2018) states that CityGML is one of the most important international standard used for 3D city models. An important concept in the CityGML standard is the use of LOD (Level of Detail). Five different level of detail are defined as shown in Figure 1. In this thesis research LOD will be mentioned several times, referring to CityGML LOD's. The LOD not only applies to buildings, also to the terrain.

Figure 1: CityGML LOD's (Delft, 2016)

2.2 Use Cases & Value

The value of topographic data, for both 2D as well as 3D, is often measured in terms of usability (Sliuzas and Brussel, 2000). Many researches have been dedicated to this topic and take up an increasingly and wide variety number of domains. Studies like this could be very useful for stakeholders and public organisations, in order to create support for 3D developments and understand the market. A recent and comprehensive study regarding the utilisation of 3D city models is done by Biljecki et al. (2015). The study mentions many challenges regarding the definition of use cases. By segmenting and categorising diverse use cases, the result is a list of use cases and applications.

Other studies have been carried out to examine the value of 3D geo-information in means of economical benefits. On of these studies is published by (Nl et al., 2011). This report demonstrates that the characteristics of 3D geo-information as an economic good must be considered during valuation and that the value of 3D GI is highly context dependent.

Ho et al. (2018) states: "However, broader public management literature has shown that while economic value is vital for justifying public investment, it is not the only driving factor and that the creation of public value is crucially and equally significant as it conveys social and political legitimacy." A study has been carried out which describes how the use of 3D geo-information may potentially manifest as different types of public value.

Research has been done on 3D city models of six cities in Finland. This study, published by Julin et al. (2018), examines different 3D models and the expectations towards their use cases. The 3D models where provided by a variety of stakeholders, both public and private. The study is done by means of data comparison and interviews with the stakeholders. During the interviews the stakeholders stated some of the barriers concerning the development of an 3D city model. These barriers included a lack of up-to-date guidelines and policies, ambiguous terminology and lack of co-ordination and leadership. The study portrays a contradiction between the realised 3D city modelling projects and the expectations towards them: models do not appear to reach the broad applicability envisioned. As a result a concept for harmonisation of the 3D city models is suggested (Julin et al., 2018).

3 Objectives

3.1 Research Questions

The main research question for this thesis is stated as following:

- *How can a variety of 3D city models be integrated in a country wide covering 3D basemap based on large-scale topography?*

In order to answer the above question, this research will be done in collaboration with the Cadastre and a variety of large-scale topography source holders in the Netherlands. Multiple resources will be deployed to study the current state of art of 3D data and the wishes and requirements of the stakeholders. These resources include surveys, meetings and an exchange of 3D data. The following sub questions will also be examined in this study.

- What is the state of art of large-scale topography data in the Netherlands? Who are involved in the collection, development and managing of the data?
- What can be considered a 3D city model? Which standards and formats apply to 3D data? What are the differences between existing 3D models in the Netherlands? What tools and software are used to generate and manage 3D data?
- Who are the potential users and what are the purposes for them to use these 3D models and therefor the data needs?
- Who are the stakeholders and what are their needs and requirements concerning the integration of their 3D data? What would be their role concerning an integral approach of a national 3D model?

3.2 Research Scope

The research focuses on 3D models of large-scale topography in the Netherlands. The data that will be used is provided by the stakeholders during the first phase of the thesis, so the outcome is based on the current state of their 3D data. Though the developments concerning the collection, generating and managing of 3D models keep evolving.

For the outcome of the thesis, the use and purposes of 3D data will be taken into account. This will be done based on the result of existing literature. Thus a study to the purposes of 3D models and their requirements does not lie within the scope of this research.

4 Methodology

In order to achieve the research goals and formulate an answer to the main question, the methodology has been split up into three components. At the beginning a literature study will be done on 3D models of large-scale topography. The current state of art and the developments of 3D data will be described. Questions about the use, requirements and different interests of 3D city models will also be examined. The second component of the methodology contains the interaction with stakeholders, which will be described in Section 4.1. The third component includes the technical part of the research: the comparing & integration of data. This component will be further explained in Section 4.2.

Stakeholder	Meeting	Contact(s)
Cadastre	04-06-2019	Vincent van Altena, Marc Post, Tony Baving
Provence of North-Brabant	19-04-2019	Stefan van Gerwen
Municipality of Amsterdam	07-05-2019	Wietse Balster
Municipality of The Hague	09-05-2019	Isabella Tonioli, Kim Langenberg
Municipality of Eindhoven	22-05-2019	Heidi van der Vloet, Mieke Pol, Mark Stals
Municipality of Rotterdam	16-05-2019	Timo Erinkveld, Christian Wisse, Erik Jansen

Figure 2: Stakeholder Meetings & Contacts

4.1 Surveys & Meetings Stakeholders

The second component of the methodology of this research contains the interaction with stakeholders. Not only the technical aspects, but also the role and wishes of the stakeholders have to be taken into account during the research. The stakeholders include all instances that manage, create or distribute large-scale topography. Some of these instance in the Netherlands have been (or are currently) using this data to generate 3D models. For this research six of these instances are contacted whom agreed to collaborate and provide their 3D data. These six stakeholders and the names of the contact(s) are listed in Figure 2. Surveys have been send out to them in order to give answers to the following questions, divided in different categories:

1. **Content** Does the data include topography and/or buildings? In what level of detail are buildings displayed? Does the model also include other objects (bridges/trees etc.)?

2. **Source Data** What data is used for the topography? What data is used to retrieve heights and generate 3D?

3. **Process** Is the generation of the 3D model done fully automatically, fully manually of both? Is this done within the stakeholders organisation or it is outsourced?

4. **Management** Is the data being managed within the organisation? What software/databases are used to store and manage the data? What is the standard format of the data used internal? Is it possible to export the data in other formats?

5. **Actuality** When was the first version of the model created? Has it been updated since then? Does the update include the complete model or only the mutated parts?

After the surveys had been send out, meetings with the stakeholders have been planned. The dates of these meetings can be found in Figure 2 and have all taken place in the first phase of the thesis. The purpose of those meetings is to gain deeper insights of the use of the 3D data and the requirements and wishes of the stakeholders. Follow-up meetings or a collective meeting will be considered at a later stage.

4.2 Data

The third component of the methodology contains the comparing, merging & integration of the different 3D test data. The test data is located in five places: Eindhoven, The Hague, Rotterdam, Amsterdam & Baarle-Nassau. For each of these locations an associating CityGML model is generated by the Cadastre.

The first step is to compare the different 3D models according to their geometries and attributes. To achieve this, the test data of each location will be merged with their associating model from Cadastre. A merged model makes it possible to visually inspect the data and check whether geometries are equal or not. The second step is to integrate both models, thus integrate the test data in their association Cadastre model. To be able to do this, three different methods are provided. The flowcharts of these methods are shown in Figure 3, 4 and 5. The chosen method depends on the formatting of the input data. If the test data is already provided in CityGML format with the right semantics (BGT attributes), method 1 (Figure 3) can be used. In this method a list of the feature id's in the test data is extracted. This list will be used to remove the feature with the same id's from the Cadastre model and replace them with the features from the test data. After the validation and possible fixing of geometries, the output will be an intregrated CityGML model.

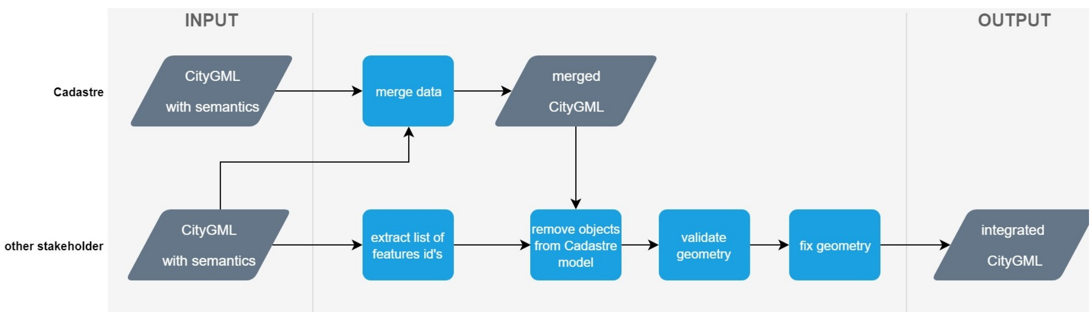


Figure 3: Flowchart Method 1

The second method (Figure 4) is used when the test data is also provided in CityGML, but without the (right) semantics. In this method the BGT containing 2D features is being clipped by the extent of the test data, in order to retrieve a list of the feature id's. Subsequently this list is used to remove the features from the Cadastre model and replace them with the features from the test data.

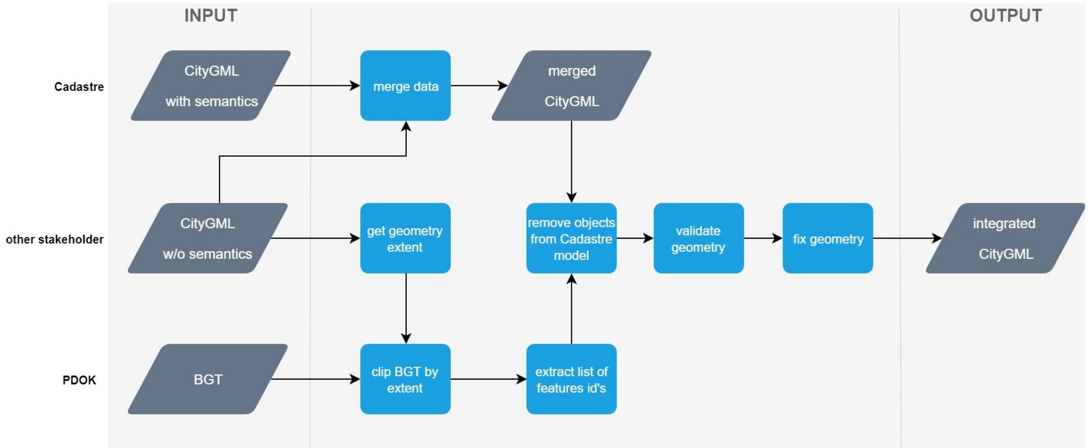


Figure 4: Flowchart Method 2

The third method (Figure 5) is used when the test data is provided in any other format than CityGML. During this method the test data gets converted to either CityJSON or CityGML format. After this the merging can be followed by the same steps as method 2.

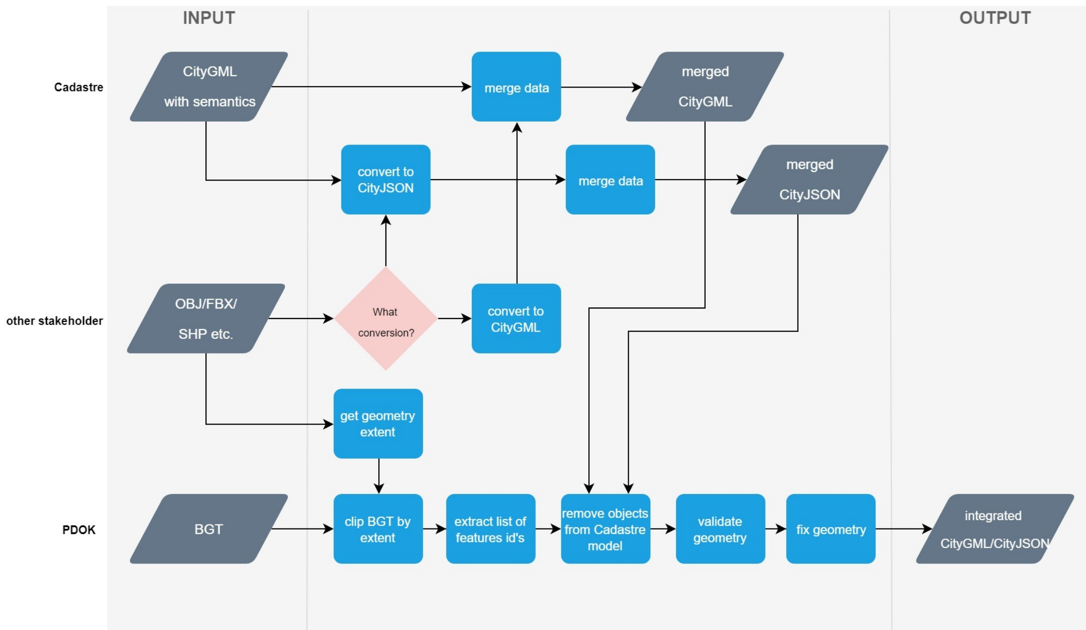


Figure 5: Flowchart Method 3

5 Time Table

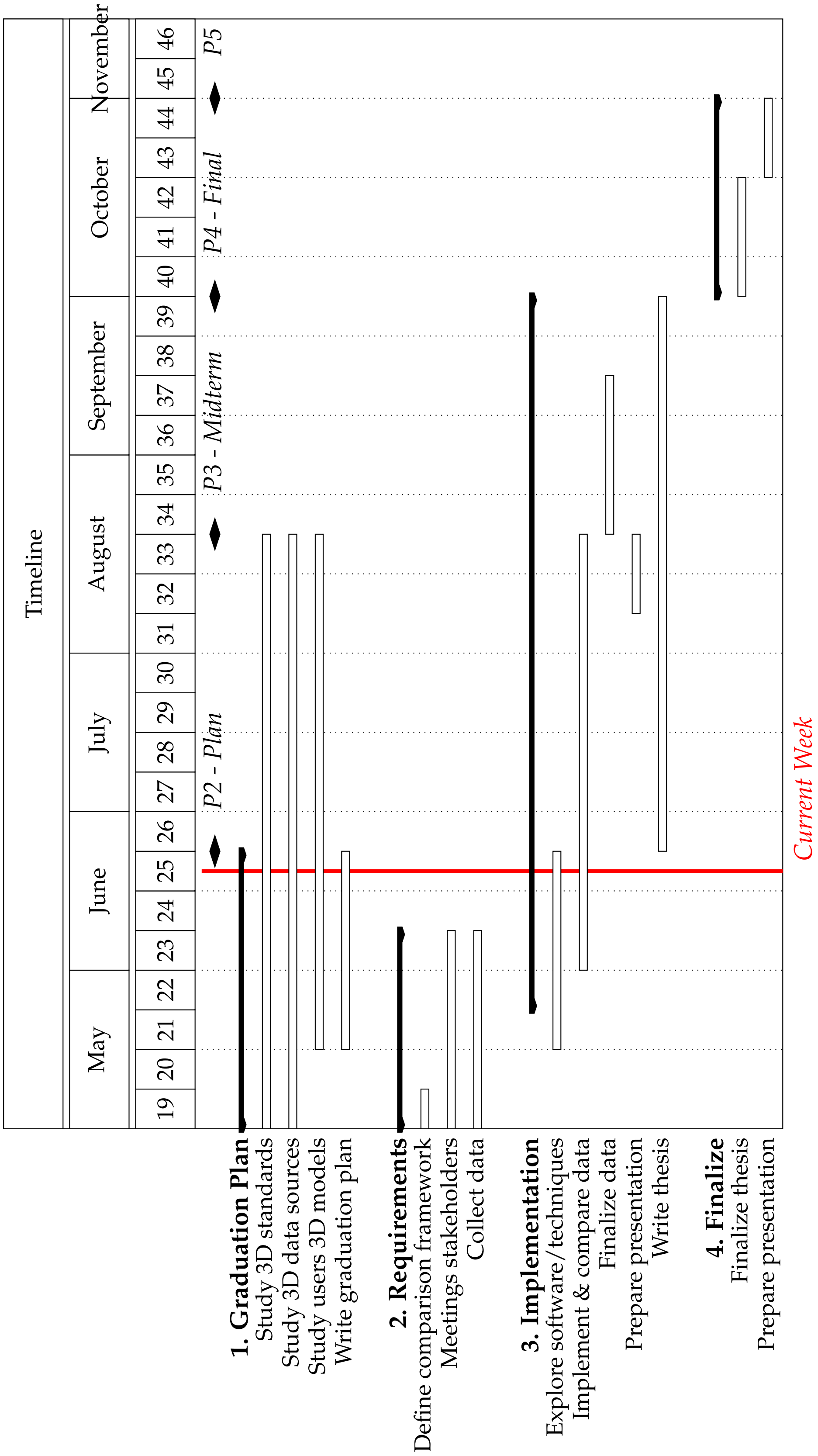
For the guidance of this thesis weekly meetings are being scheduled with the first supervisor ir. T.J.F. (Tom) Commandeur and/or the second supervisor Prof. dr. J.E. (Jantien) Stoter. A co-reader will be chosen after the P2 on June 19th. The Gantt chart on the next page distinguishes the following four phases:

1. **Graduation Plan**
   The graduation plan phase includes most of the literature study, defining the research objectives and the methodology to achieve these goals. This graduation plan will be presented June 19th during the official P2 session.

2. **Requirements**
   During the requirements phase all resources will be deployed. These resources include: surveys, meetings with stakeholders and the collection of data. Also a framework is defined in order to compare the data in the next phase.

3. **Implementation**
   The implementation phases includes the visualisation, comparison and integration of the data.

4. **Finalize**
   During the last phase, both the data outcome and thesis will be finalized for the final presentation (P5).


Timeline
May
June
July
August
September
October
November
19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
P2 - Plan
P3 - Midterm
P4 - Final
P5
Current Week
1. Graduation Plan
Study 3D standards
Study 3D data sources
Study users 3D models
Write graduation plan
2. Requirements
Define comparison framework
Meetings stakeholders
Collect data
3. Implementation
Explore software/techniques
Implement & compare data
Finalize data
Prepare presentation
Write thesis
4. Finalize
Finalize thesis
Prepare presentation

6 Tools and Data

6.1 Tools

A variety of tools and software will be used during this research. FME Software, ArcGIS Pro & QGIS will be used for the reading and visualisation of the 3D data. Other software provided by TUDelft will be considered for the integration of the different models; For the parsing and writing of CityJSON files from CityGML, **citygml4j** is available at: `https://github.com/citygml4j/citygml4j`. For the manipulation of CityJSON files, **cjio** is available at: `https://github.com/tudelft3d/cjio`.

6.2 Data

The data is generated and supplied by the different stakeholders. Figure 6 gives an overview of the test data, specifying the content and data formats. Cadastre provides CityGML subunits of 1000x1250 meter for each location shown in Figure 7.

Stakeholder	**Data**	**Format**
Cadastre	Topography incl. buildings	CityGML
Provence of North-Brabant	Topography excl. buildings	Shapefile
Municipality of Amsterdam	Buildings	OBJ
Municipality of The Hague	Buildings	Shapefile
Municipality of Eindhoven	Topography incl. buildings	DNG + CityGML
Municipality of Rotterdam	Topography incl. buildings	CityGML

Figure 6: Data Content & Formats

Figure 7: Locations Test Data

7 Preliminary Results

7.1 Summary Surveys & Meetings

In order to compare the different 3D data and approaches of the stakeholders, an overview as a result of the surveys and meetings is shown in Figure 8 and 9. The stakeholders are numbered as followed: 1 Amsterdam, 2 The Hague, 3 Eindhoven, 4 Cadastre, 5 North-Brabant and 6 Rotterdam.

		1	2	3	4	5	6
Contents	Buildings LOD1	✓			✓		✓
	Buildings LOD2		✓	✓			✓
	Terrain	✓	✓	✓	✓	✓	✓
	Trees	✓	✓				✓
	Constructions (bridges etc.)				✓	✓	✓
	Other objects						✓
Source Data	BAG	✓	✓	✓	✓		✓
	BGT	✓		✓	✓	✓	✓
	AHN2			✓			
	AHN3	✓			✓		
	Own pointcloud		✓	✓	✓	✓	✓
	DigTop		✓				

Figure 8: Comparison - Contents & Source Data

		1	2	3	4	5	6
Process	Fully automatic	✓			✓	✓	
	Automatic generation, manually corrected		✓	✓			✓
Management & Actuality	Data is managed	✓	✓	✓	✓	✓	✓
	Data is publicly available		✓				✓
	Standard data formats	QM tiles OBJ FBX	?	DNG FGDB CityGML	CityGML	IMGeo	CityGML
	First version	2019	2010	2013	<2010	< 2000	2016
	Update frequency	?	?	incidental	yearly	incidental	incidental
	Update fully/partly	full	full	partly	full	partly	partly

Figure 9: Comparison - Process, Management & Actuality

7.2 Data - Test Eindhoven

For the first test the 3D data from Eindhoven will be examined. The municipality of Eindhoven has generated two different 3D models; one of the buildings (in LoD2) of the city centre and one of the same area including the terrain. The first tests will be done with the 3D buildings of the city centre, which are provided in CityGML. Each feature has a list of attributes as shown in Figure 10.

Attributes (9)

- citygml_feature_role (encoded: utf-16)
- citygml_level_of_detail{0} (encode...
- citygml_target_uri (encoded: utf-16)
- fme_geometry (string)
- fme_type (string)
- gml_id (encoded: utf-16)
- gml_name (encoded: utf-16)
- gml_parent_id (encoded: utf-16)
- xml_type (string)

Figure 10: List of Attributes Eindhoven Model

Visualisation & Merging Data

The first step contains the visualisation of the data. In Figure 11 an image of the area in 3D is shown. Figure 12 shows the same location, zoomed in on a church. However, when the same data is visualised on a 2D map together with the BGT, differences between the building polygons from Eindhoven (*red*) and the building polygons from the BGT (*grey*) are noticeable. These 2D views are shown in Figure 13 and 14. Since the test data is provided in CityGML without the right semantics (feature id's), these features can not be automatically linked to the BGT features in the Cadastre model. Thus Method 2, as described in Figure 4, will have to be applied fur further integration of the data.

Figure 11: 3D View City Centre

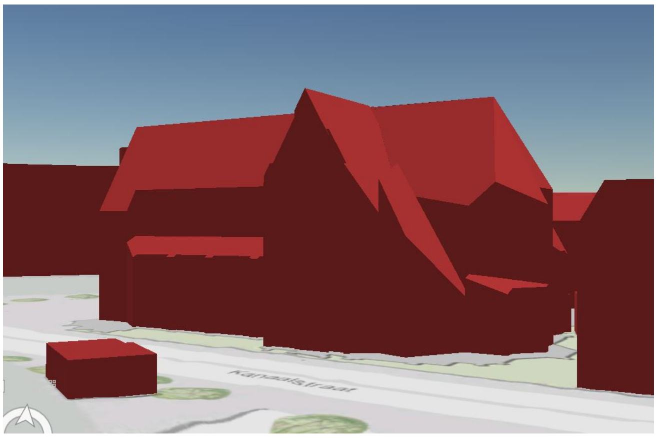


Figure 12: 3D View Church

Figure 13: 2D View City Centre

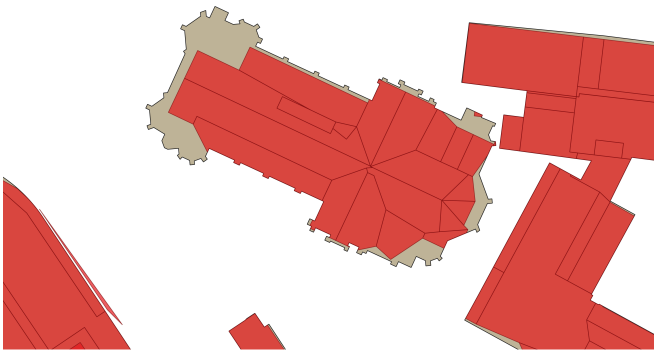


Figure 14: 2D View Church

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