MASTER

The use of 3D city models in real estate valuation and transactions

defining and developing a use case requiring 3D city models in real estate valuation and transaction applications

Toppen, T.P.

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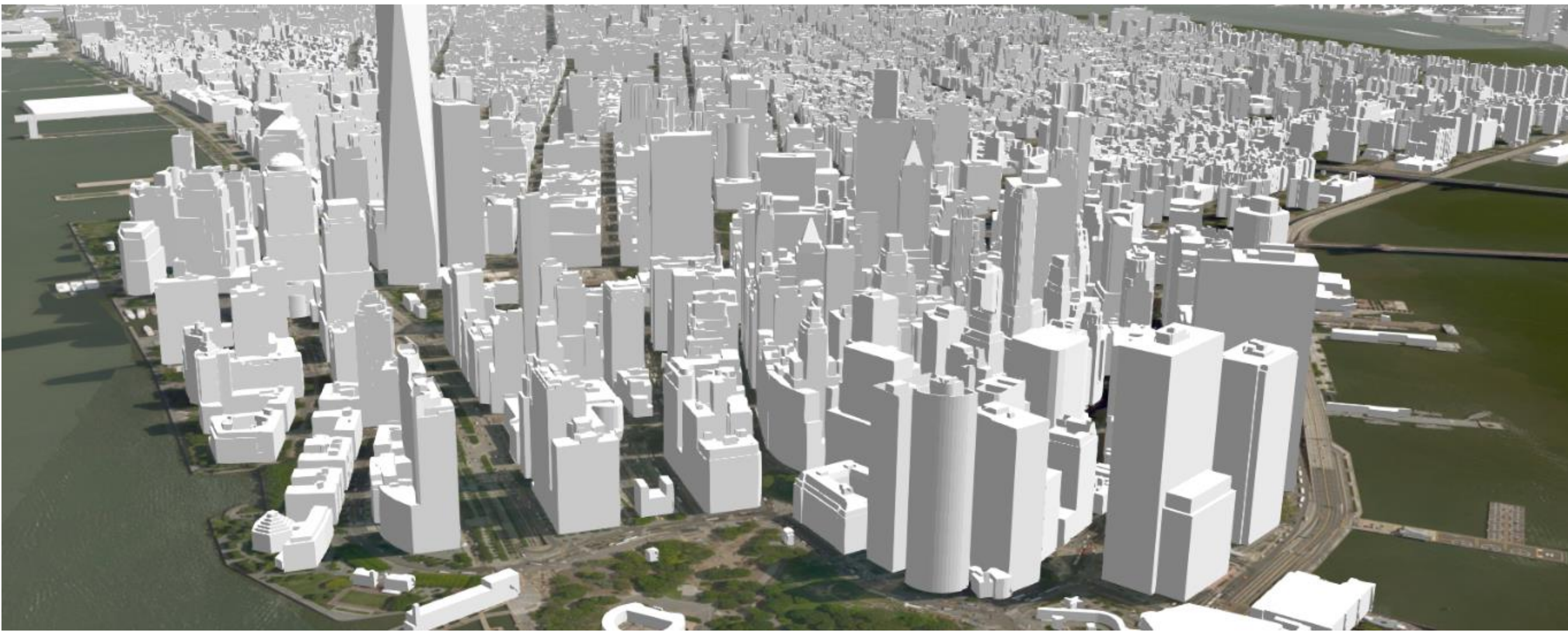

A Master thesis presented by:

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To

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Real Estate Management and Development (REMD) &

Information Systems in the Built Environment (ISBE)

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*Cover photo is derived from Cesiums 3D model of New York City (https://cesiumjs.org/NewYork/index.html).

Colophon

Title:

The use of 3D city models in real estate valuation and transaction applications

Master thesis

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Preface

The report before you concludes my two year education period at Eindhoven University of Technology. In 2014 I started off with the master Real Estate Management and Development. I soon realized that this master track alone was neither going to fulfil my ambitions nor the required skills of a future real estate specialist. Considering the many technical developments that not only the real estate industry is subject to, I was determined to include technical and computer aided technologies in my Master education. I did so by participating in different courses of the chair Information Systems in the Built Environment. Particular the developments in 3D modelling drew my attention. The capabilities of 3D modelling of buildings and cities have increased exponentially. Mainly the use of 3D modelling in the architecture, engineering and development domain became standard practise. Nowadays, even in real estate (management) related domains the use of 3D building modelling is becoming of increased use. A good example is the use within property management in which new fields are being researched that involve the use of sensor data. My personal field of interest is within the real estate development and transactions domain. I noticed that within this domain the adoption of new techniques is rather slow. During my master I therefore sought for opportunities in which using 3D information models could be of added value within this domain. By following a selection of courses in this domain and learning about the technical capabilities and relevant use cases of 3D modelling I constructed the foundation for this research.

This research has been executed between February and August 2016 and has involved a great deal of time, dedication, short nights and arguments with my laptop. However the result is worthwhile. This result however could not be achieved without the help of my tutors at Eindhoven University: Jakob Beetz and Peter van der Waerden. The same goes for Joran Jessurun who has been of great help in guiding a layman in the field of computer languages. Great support has come from my employer Cushman & Wakefield who did notice the importance of GIS and 3D modelling in the field of real estate valuation and transactions and therefore allowed me to conduct this research besides my day to day responsibilities. Internally my supervisor and GIS expert Tim van der Velden has been of great help and support. Finally I would like to give many thanks to my father Fred Toppen whom, as a layman in the field of 3D modelling and real estate, was a tremendous help in providing structure in the research design and proving me with the necessary critical side notes regarding the GIS topic but also the general layout and writing of this report. Finally I would like to thank the Dutch weather gods for making this summer feel and look like a late autumn, it provided a great motivation to keep writing and modelling behind the comfort of my desk. I hope you enjoy the result.

Kind regards,

Timco Toppen

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Summary

This research describes why and how the 3D CityGML modelling standard can be used in real estate valuation and transaction applications. A practical use case in the real estate domain that that should utilize 3D instead of 2D data models, for more efficient and effective information exchange, is missing. Subsequently the process of developing a potential use case is missing as well. Previous studies have focussed on the use of 3D models primarily in the Architecture, Engineering and Construction (AEC) domain or described the potential use for large scale governmental property taxation. In this research the potential use of 3D city models predominantly in the real estate valuation and transaction domain is studied. This is achieved by examining why (3D) Geographic Information Systems (GIS) in real estate is used, and describing the state of the art. The relevant and technical use of 3D city models is established based up on professional opinions from real estate advisors and 3D modelling experts. Using 3D city models to visualise information per building storey was found to be one of the most relevant use cases. The process of developing this use case showed different complications mainly in enhancing a CityGML of Level of Detail 2 (LOD2) with building storeys (LOD2+). Using the CityGML extension capabilities an ADE is created that defines property rights information per building and storey. The research showed that the use of 3D models in practice is a whole new development, that requires a lot of demonstrable use cases and technical developments to increase the use in the real estate valuation and transaction domain.

Key words: real estate, valuation, transactions, CityGML, 3D GIS, use case, LOD2+, ADE.

1. Introduction

The influence of data availability and computerisation on different professions is increasing. Studies already indicated that that the jobs of a real estate appraiser and broker is subject to trends in computerisation (Frey & Osborne, 2013). The jobs doe potentially become obsolete in the coming decades, or at least a shift in the job description is expected (Bowles, 2014). A practical example of data and computerisation is the Automated Valuation Model (AVM) created by Sprundel (2013). This AVM is capable of automatically appraising the value of owner occupied homes in the Netherlands with an accuracy up to 94%. In theory this AVM could make the job of a real estate appraiser obsolete since valuation is done more efficient and effective. The aim of this research however is not to make the job of any real estate professional obsolete but rather to study how data availability and computerisation trends can be part of the job activities of real estate appraisers and brokers.

1.1 Data, computerisation and GIS in real estate

Different companies in the Netherlands gather and store data on the Dutch real estate market for benchmarking purposes. This data concerns information on real estate transactions between owners and between owners and tenants. This data can be defined as "Big Data" since it concerns a vast amount of data, with great diversity, collected in a short amount of time. This data is valuable to the real estate industry (Wit, 2016). Databases can be constructed based upon Big Data that solve traditional problems real estate appraisers face such as the lack of comparable data of real estate transactions (Zhou, Shi, & Zhang, 2015). The AVM of Sprundel already indicated the potential in valuation of owner occupied homes. A new problem that arises is how to analyse and make good use of all available data (Zhou, Shi, & Zhang, 2015). Tools that have been used for data visualisations and analysis are Geographic Information Systems (GIS). Combining GIS with real estate data enables to add spatial intelligence to real estate applications and create a competitive advantage (Culley, 2010).

GIS provide powerful capabilities for spatial data analysis and visualisation and have therefore been widely used in the real estate field of valuation (Zhang, Li, Liu, & Liu, 2014). GIS is defined as "a computerised database management system used for the capture, storage, retrieval and display of locational defined data that is referenced by spatial or geographic coordinate" (Ralphs & Wyatt, 2003). From this definition important characteristics of GIS can be linked to the aforementioned computerisation trend and the real estate sector. A computerised database used for different operations with data is potentially relevant for the computerisation of jobs and the increasing amount of available data. While the characteristic "referenced by spatial or geographic coordinates" has similarities with real estate objects, since the location is essential in real estate. To quote Joseph Magnotta on the common factor of GIS and real estate: "They both place a very high importance on location" (Magnotta, 2014). This is also seen by the Royal Institute of Charted Surveyors (RICS). They noted that the use of Geospatial Information (GI) will impact surveyors as the majority of their work has some kind of geographic element (Culley, 2010). It allows for real estate advisory firms to comprehend and analyse all data applicable to an object (ESRI Nederland, 2016).

1.2 3D GIS and CityGML

So far the use of GIS for real estate applications focussed on mapping in a 2D representation. The mapping in 2D GIS is however no longer sufficient and the use of 3D applications is becoming more common. 2D models lack the capabilities to visualise and analyse data applicable to real world 3D objects such as buildings. According to different studies that already addressed this topic, 3D GIS could provide a more professional decision making tool in the real estate domain (Liu, Yu, & Zhang, 2014). Current studies on this topic focus on valuation for governmental taxation purposes and property ownership registration. Cagdas (2012) conducted a research into property valuation for taxation purposes by utilizing 3D city models. Isikdag Et al. (2015) studied the use of 3D city models for better valuation of real estate by extracting volumes from the 3D model. Liu, Yu and Zhang (2014) studied the capabilities of 3D city models in finding comparable transaction records of properties for valuation purposes. Gifford Dsilva (2009) studied how CityGML could be used for the registration of property rights that are currently defined in the 2D cadastre. Just recently a Dutch pilot project was worldwide the first to formally register property rights of a building in a 3D cadastre (SpoorPro, 2016). This is the first use case utilizing 3D models that is applied in practice. The 3D models used in these example can mostly be generated automatically based upon two Dutch datasets: Basis Administratie Gebouwen (BAG) and Algemeen Hoogtebestand Nederland (AHN).

The main 3D standard in the GIS domain is considered to be the CityGML file format (Arroryo Et al, 2015). This format is aimed at the representation of the semantic properties of 3D city models. An important feature of CityGML that lies within the scope of this research is the capability to add additional data to CityGML models. Application Domain Extensions (ADEs) have been created in the past for different requirements. With ADEs new feature types, attributes, geometries and associations can be created, as well as additions to formats of existing feature types (Cagdas, 2012). In line with the capabilities of GIS, CityGML allows for advanced analysis and visualisation for a variety of applications (Groger & Plumer, 2012).

1.3 Problem statement and research layout

GIS has been used in different real estate applications for visualisation and analysis purposes. However 2D GIS is not sufficient in all cases and the use of 3D GIS could add an extra dimension (ESRI Nederland, 2016) and could provide a more professional decision making tool in the real estate domain (Liu, Yu, & Zhang, 2014). Despite of studies indication that using 3D city models could be relevant in real estate valuation and transaction applications, only one (3D cadastre) has recently been applied. 3D information is current still being remodelled in to 2D models and solutions (Stoter, 2014 p. 9). Practical applications such as Zoning plans, BAG function mapping, property ownership registrations describe 3D information such as floors, heights and volumes but these are still presented on a 2D map. CityGML has different capabilities and technical features that would allow this standard to be used in real estate valuation and transaction use cases. This research therefore aims to answer the questions why and how 3D GIS instead of 2D could be used in the visualisation and analysis of real estate valuation and transaction information:

1)Why and to what purpose could 3D city models in CityGML instead of 2D models be utilized in real estate valuation and transaction applications and 2)how could the requirements of a relevant 3D real estate use case be technically achieved?

To answer these questions first the literature on Real estate and (3D) GIS is studied. Derived from the literature the state of the art and the purpose and added value of real estate use cases utilizing 3D City models are studied (section 2). Based upon these findings a research methodology is proposed (section 3). Then real estate professionals and experts on 3D modelling are asked to provide input on which use cases are relevant and technically achievable (section 4). These first four sections answer the "why" part of the research question. The next two sections aim to answer "how" CityGML can be used to create a relevant use case. In section 5 the capabilities of CityGML in relation to the use cases is studied. Then the process is described how CityGML could be used to create a relevant use case (section 6). In section 7 the results of this research are discussed. In the final section a conclusion on the problem statement is provided (section 8).

2. Literature review

A literature study is performed on the two main topics of this research: the relation between real estate and GIS and the use of 3D GIS in real estate valuation and transaction applications. The literature study aims to answer why GIS is used in real estate applications and to what purposes and added value 3D GIS could be used.

2.1 GIS in real estate valuation and transactions

Since the early 90's GIS' have become of increased use as a system for the analyse of spatial and thematic information of geographic objects (Stoter & Zlatanova, 2003). GIS' are extensively used in the analyses of spatial data and are part of different real estate valuation methods. The accuracy of a geographic location is of most importance to GIS' which is also the primary factor that influences the value real estate. A GIS captures and analyses data and visualises the data on map. It allows for real estate advisory firms to comprehend and analyse all data applicable to an object (ESRI Nederland, 2016). According to different studies GIS can be used for a more quantitative analysis of spatial, real estate related information (Wyatt, 1997) and to help comprehend and analyse data by visualising real estate data in a geographic environment (GuoDao, RongHua, FuLi, & HuaMin, 2013) & (Lomax, 2015). According to Wijk (2006) the traditional purpose of visualisation is to gain insight. Visualising data enables users to gain insight in data and discover information. It is however hard to quantify the added value of this gained insight (Wijk, 2006).

2.2 The shift from 2D toward 3D GIS

Multiple arguments can be found that support the shift from 2D GIS to 3D GIS in real estate applications. *1) Available models:* The availability of 3D maps is increasing (Stoter, 2014). However some 3D models are not available yet for free which might be an obstacle for companies to include 3D GIS in their processes (Almeida Et al. 2014). Therefore the use of 3D models is mostly seen as an add-on (Ujang, Azri, & Rahman, 2015). According to their research the use of 3D models will increase because of user demands and technological developments. *2) Other industries:* In the architecture, engineering and construction (AEC) industry as well as the property management industry 3D models have already been adopted in the form of a Building Information Model (BIM) (Eastman, Liston, Sacks, & Teicholz, 2011). Based upon the characteristic of a BIM, El-Mekawy, Paasch, & Paulsson (2014) concluded that a BIM could be utilized for not only visualisation applications but for spatial analyses as well. However the manual work involved in creating a BIM is found to be the main reason why BIM is not widely used for existing buildings. Isikdag Et al. (2015) state that BIMs contain valuable information for valuation of new properties but the utilization of CityGML provides opportunities in the valuation of existing real estate. *3) Usefulness:* Based upon three previous studies Liu, Yu, & Zhang (2014) conclude that 3D GIS could provide real estate professionals with a more professional decision making assistant than 2D GIS. Lomax (2015) states that 3D models are nice to look at but the practical application, usefulness and value is limited for the real estate industry if they remain just simple polygons. Only one study is found that measured the usefulness of 2D over 3D. This study found that 3D visualisations improve the mental image of a building and its influence on the surroundings (Herbert & Chen, 2015).

2.3 3D GIS in real estate

One of the main purposes of 3D city models mentioned in different studies (Biljecki Et al (2015), Fuchs Et al (2014) & Herbert & Chen (2015)) and papers (ESRI (2014) & Lomax (2015)) is visualisation. The aim of this visualisation is to gain insight in data which could otherwise not be obtained by using 2D visualisations. The other main purpose of using 3D city models is the perform analytical tasks in an automated way[1]. Also the usefulness of 3D city models for analysis could be discussed, especially when buildings in the model remain "empty shells" (Crooks, Hudson-Smith, & Patel, 2011). These two purposes are interrelated since visualisation is considered to have a key role in the successful analysis of geo-spatial information (Keim, et al., 2008). A technological approach on the value of visualisation could be adopted which is aimed at assessing the costs and benefits. Visualisation would then be measured in terms of effectiveness and efficiency. In this case the cost and benefits of using a 3D city model could be assessed (Wijk, 2005). This technical/economic point of view is supported by Fekete, Wijk, Stasko, & North (2008).

2.3.1 Creating a framework for the purpose, added value and use cases

Biljecki Et al (2015) found that it is indeed hard to categorise the purpose and added value of 3D use cases. Their research determined that the only research in the added value of 3D over 2D has been done by Herbert and Chen (2015) and that other studies in this category are rare. They found that the only suitable aspect in the taxonomy of using 3D is the visualisation aspect. They made a distinction in two types of use cases (Biljecki Et al. 2015):

1. Non-(required)visualisation use cases: Use cases in which 3D city models provide solely a digital visualisation of the built environment and do not require visualisation and/or the results of spatial operations.
2. Visualisation based use cases: Use cases that require performing computations and spatial operations that are solely possible with 3D data models and in which visualisation is very important, and the use cases that are possible with 2D/2.5D GIS data but do significantly benefit from 3D data models for the communication of information;

I would argue that within the second definition an additional distinction can be made in two sub type of use cases.

Thus three distinctions can be formed:

1. Non required visualisation use cases: these use case have no added value by **visualising** the results;
2. Visualisation use cases (1): these use cases require **visualisation** and are possible with 2D/2.5D but do significantly benefit from 3D visualisations;
3. Visualisation use cases (2): these use cases require **analysis** in terms of spatial operations and computations on the 3D model and **visualisation** is very important.

This subdivision is comparable to the fundamental distinctions made in the use of (2D) GIS for spatial analytics. GIS includes three types of analysis 1) attribute query (non-spatial), 2) spatial query and 3) generating new datasets by combining data (Raju, 2004). Zhang, Li, Liu & Liu

1 (Liu, Yu, & Zhang, 2014) (Tomic, Roic, & Mastelic Ivic, 2012)

(2014) made a similar distinction in the use and potential added value of 3D GIS. This subdivision in the types of use cases is related to the general purpose of the use cases: visualisation or analysis (figure 1). First it has to be noted that a use case is defined as being part of an application domain (for example: real estate valuation) and includes spatial operations.

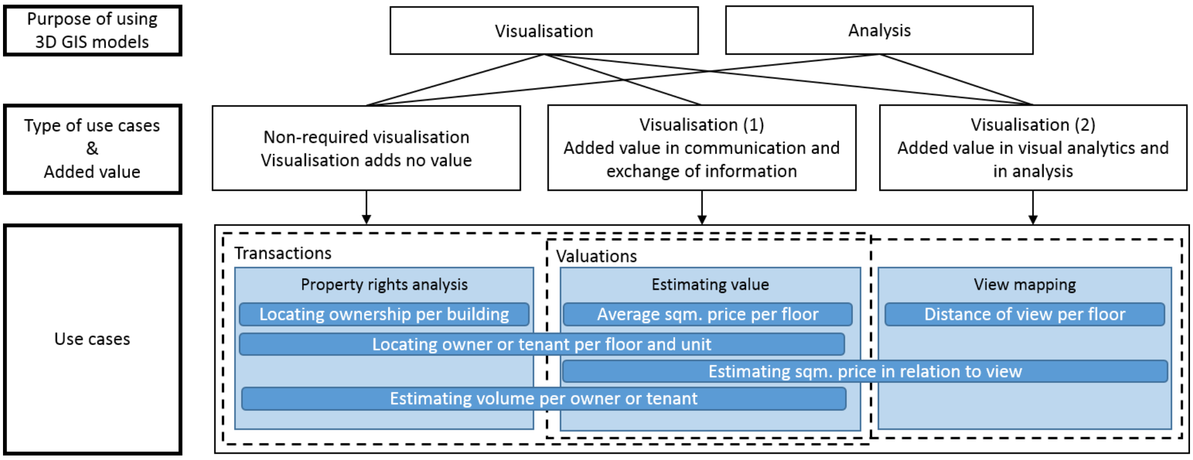

FIGURE 1: FRAMEWORK OF PURPOSE AND ADDED VALUE RELATED TO THE GROUPING OF USE CASES FROM BILJECKI ET AL. (2015): DASHED SQUARE: APPLICATION, LIGHT BLUE: USE CASE, DARK BLUE: SPATIAL OPERATION

2.3.2 Describing the state of the art.

A study of the available literature on the topic of 3D city models utilized in different applications identified multiple real estate related use cases. Six of these use cases were described within the literature or in practise to the extent that they could be used in this research (table 1).

TABLE 1: OVERVIEW OF THE REAL ESTATE USE CASE UTILIZING 3D CITY MODELS FOUND IN THE LITERATURE

Application domain	Use case	Purpose and type of use case	Source
Real estate transactions	**3D property ownership registration**	The purpose of using a 3D model in this case is to visualise information adding value with a more efficient and effective way of data exchange. Visualisation type 1	(Biljecki Et al. , 2015) (SpoorPro, 2016) & (Almeida, Liu, Ellul, & Manuel Rodrigues-de-Carvalho, 2014)
Real estate valuation	**3D zoning plans**	In GIS terms this use case requires the combination of different datasets (legislation and building models) to analyse clashes or possibilities. The purpose is both visualisation and analyses and therefore is a visualisation type 2 use case.	(Berlo & Dijkmans, 2013)
Real estate valuation	**Property valuation and taxation**	The type of use case in this case depends on the variables and operations included, calculating for variables as sun radiation on the value of property can be considered a visualisation 2 type use case.	(Biljecki Et al. 2015) & (Isikdag, Horhammer, Zlatanova, Kathmann, & Oosterom, 2015), (Cagdas, 2012)
Real estate valuation	**Mass valuation of real estate properties**	The added value is mainly in terms of efficiency by performing analysis and visualising the results which makes it a visualisation 2 type of use case.	(Tomic, Roic, & Mastelic Ivic, 2012)
Real estate valuation and transactions	**Identifying comparable sales units**	The main purpose of this use case is to analyse different data, including the 3D model. Since the use case requires the combination of datasets and visual analytics this is a visualisation type 2 use case.	(Liu, Yu, & Zhang, 2014) & (Biljecki Et al. 2015)
Real estate valuation and transactions	**Vacancy mapping and thematic data in a city**	The aim of this visualisation use case is to allow for better understanding and communication of information which makes it a type 1 visualisation use case.	(Dollner, Baumann, & Buchholz, 2006)

3. Research design

In this research the "why" and the "how" question are answered with respect to the real estate valuation and transaction use cases and the use of CityGML. Empirical research is required to further establish an answer on the "why" question. The answer on this question is interrelated to the second part of this research: how a real estate valuation and transaction use case can be developed using a 3D city model.

ESRI (2014) & Bayers et al (2015) provided different steps that have to be considered to make the shift from using 2D to 3D in real estate applications. These steps involved defining the purpose and added value of 3D. An attempt is made to define the purpose and potential added value based upon findings in the literature (figure 1). This framework is solely based upon theoretical input and therefore requires empirical testing. To establish the future needs of technical developments such as 3D city models, the relevancy of certain use cases should be indicated. The empirical part of the research therefore aims to identify which use cases are relevant according the professionals in the real estate domain. Also an indication is required of why in general 3D city models could be used and to what added value.

Other than the indications from the literature on why 3D should be used in real estate applications, the available knowledge is limited. A qualitative research approach is therefore adopted. By means of interviews with selected participants new information is obtained. From the professionals participating in this research information is required regarding their personal opinions, knowledge and experiences with 3D city models. A semi structured interview is used since prior knowledge is limited and also the knowledge of the respondents on the topic is unknown.

As mentioned by Ujang, Azri, & Rahman (2015) the developments of utilization of 3D city models is supported by two trends: user demands and technical developments. To obtain knowledge on both relevant use cases as well as technically achievable use cases two different types of experts are needed. The population in this research therefore consists of the respondents who are either in the real estate advisory business or in the technical business. From the top 10 real estate advisors in the Netherlands three are selected. Three additional participants are selected from three different more technical domains: 3D modelling, 3D software and real estate data analysis.

In the interview five topics are discussed:

- The general purpose and potential of 3D city models in the real estate industry;
- Using 3D city models for the purpose of information visualisation;
- Using 3D city models for the purpose of analysing data;
- Scoring the known and potential 3D use cases on relevancy or technical achievability;
- The general requirements of using 3D city models in real estate use cases.

To obtain the correct information, criteria and questions are formulated per topic and related to findings from the literature. The results are analysed and measured according to the pre-defined methods and criteria (Appendix 1.1). The term "measured" should be reconsidered. Interviews are chosen as a qualitative research approach and therefore does basically not allow for quantification of the results. The aim of measuring the results is to find some saturation in the answers given by the respondents therefore an indication on how this is measured is provided. The purpose is however not to quantify the results. It is the purpose to explore why 3D city models could potentially be used and to which added value.

4. Results

Interviews are conducted among three real estate advisory firms, one firm specialised in automated real estate valuation and two involved in the research and development of 3D city models and standards (appendix 1.2).

4.1 Purpose and added value

Increased insight was mentioned by all respondents as an important purpose of 3D city models. A second purpose, mentioned by three real estate professionals is using a 3D city model as a database that includes all relevant information of objects in a city. The database should at minimum include information regarding floors and units. This would allow for more transparency of data, more insight and the capability to better benchmark properties according to the respondents. This is an interesting result since 2D GIS is already capable of being used as a spatial database (Culley, 2010) but is however not used to this potential according to Lomax (2015). Different studies did already describe the use of (3D) GIS as a database tool (Zhang, Li, Liu, & Liu, 2014) & (Raju, 2004). Also indications that including floors and units would enhance the usability of 3D models are found (Arroryo Ohori Et al. 2015).

The added value of using 3D city models for visualisation is primarily seen in terms of efficiency. When these models could be used for analysis as well the added value is also seen in terms of effectiveness. When used for analysis, 3D city models can increase the speed in which analysis are performed and provide more consistency in the results.

The respondents from the real estate domain are asked to score and discuss the different use cases found in the different studies and applications and the ones found in the literature (table 2, score 1-5). The respondents from the 3D modelling domain are asked to indicate the technical possibilities of creating the use case. Their response was that in terms of the technical capabilities of 3D modelling all use cases are possible to develop and apply.

TABLE 2: AVERAGE SCORE AND COMMENTS ON MOST RELEVANT USE CASES

Use case	Average Score	Most relevant comments from respondents
Building cost approach	4,9	The construction cost pricing use case that was mainly argued by the 3D data professionals from an organisational point of view. The real estate professionals find it very relevant to use semantically rich 3D models stored in a city model to calculate the construction costs of a property. Especially to calculate the reconstruction value which is often performed for insurance companies is mentioned as relevant.
Square meter prices	4,4	The use cases with regard to average prices and cap rates per floor are found useful in the mostly larger cities as Amsterdam, Rotterdam, Utrecht and The Hague. In smaller cities the situations are often less complex and therefore do not require 3D visualisation.
3D property ownership registration	4,3	Most respondents found this use case very relevant. However one mentions that this use case is only relevant in a limited number of cases as for example Claude Debussylaan in Amsterdam. One other respondent also mentioned the organisational burden involved in making the shift from a 2D towards a 3D cadastre.
Mass valuation of real estate properties	4,3	Although the general response indicated this relevancy of this use case one respondent stated that clients as banks and institutional investors still prefer the actual valuation methods. The most important note regarding the relevancy of this and the property valuation use case was that the relevancy depends on the amount of variables that are in the use case.
Identifying comparable sales units	4,3	This use case was found relevant especially when additional variables could be used to determine what a comparable sales unit is.
BAG Function mapping	4,1	Regarding the function mapping one real estate professional stated the it is of particular interest for the entire industry to improve the current way functions are mapped (e.g. in the 2D BAG).
3D zoning plans	4,1	This use case would also require great organisational changes to be applied.

The general tendency that can be derived from the real estate professionals participating is that the relevancy of using 3D city models starts with being able to distinguish floors and units in 3D models and being able to attach information to this floors and units to construct a database that has query possibilities (mainly visualisation 1 type of uses cases).

5. Possibilities with CityGML

CityGML is selected as 3D format to be used for the creation of the use case described in section 4. In this section the characteristics and capability of CityGML are presented. In general the CityGML format is capable of representing geographic, semantic and visual aspects of a city. CityGML is considered as one of the main 3D standards in the GIS domain (Arroryo Ohori, Biljecki, Boeters, & Zlatanova, 2015). The standard was issued by the Open Geospatial Consortium (OGC) as an international standard that is aimed at the representation and exchange of semantically rich 3D city models (Kolbe, 2009). Certain capabilities of CityGML are relevant for the development of the use case.

5.1 The Level of Detail

The concept of LODs in CityGML does not only indicate the quality of the geometrical aspects of a model. The LOD also conveys the semantic quality and richness of a CityGML file. There are five different LODs ranging from LOD0 to LOD4. LOD0 consists of two and a half dimension (2.5D) and contain only a terrain. A map or image can be draped over his terrain model. LOD1 consists of extruded polygons upon a terrain surface. These extruded polygons result in block models with flat roofs. Textures can be mapped onto the block models. LOD2 basically is LOD1 embedded with textures and roof structures. Different surfaces, based upon a certain theme, can be mapped onto the model. This LOD also includes first pieces of vegetation like trees. LOD3 contains architectural details of buildings. In this LOD more detailed pieces of *vegetation* and *furniture* can be mapped ranging from trees to bikes and cars. The highest LOD is 4. At this LOD the buildings contain an interior structure such as floors, rooms, doors, windows, stairs and furniture. Considering the wish from the real estate professionals to attach information to building floors LOD4 would be required.

5.2 The structure of the standard

CityGML is an extension of the GML3 schema definition and it is an xml based format. The structure of CityGML is divided into a Core module with eleven sub-modules that each define a different aspect of a city. The core module defines the basic attributes of all other modules while each module defines additional module specific attributes. Each module has to import the CityGML *Core module*. The *building module* is considered the most importance module of the structure for both this research as well as in general (appendix 2.1). The different attributes that the *building module* can describe depend on the LOD.

5.3 Extension possibilities

An ADE can be used to extend the CityGML standard by defining new elements and attributes of a module in a separate schema. It can be used to define new object types by for example adding new attributes to a building such as the attribute "inhabitants". Another advantage of CityGML is that more than one ADE can be used in the same data model. For example: the *building module* could be extended with multiple ADEs. An ADE is defined in a separated schema definition and does explicitly have to inherited the application schemas it is applicable to. Since the ADE is defined in a separated schema definition it allows for further specification, development and re-use by the CityGML community (Groger, Kolbe, Czerwinski, & Nagel, 2012) & (Gifford Dsilva, 2009).

5.4 Developments

The importance of a 3D model that includes floors for real estate use cases is repeatedly mentioned. Recent development showed that it is possible to enhance a LOD2 CityGML model with indoor geometry (Arroryo Ohori Et al. 2015). Research from the Technical University of Delft developed a tool to do so. The output of the tool includes an xml document that defines storeys as part of the building module. This method was favoured by the researchers over the creation of an ADE or use the city *ObjectGroup* option from the CityGML standard.

6. Use case development process

Based on the results from the interviews and the capabilities of CityGML a relevant use case is described with the following requirements:

1. The use case requires data to be attached to certain parts of a building. Therefore a 3D city model is required that is capable of holding and visualising semantic information. 3D city models aimed at solely the graphic representation of building are therefore not suited;
2. The 3D city model should contain at least (two) storeys within a building. The current models that are available represent buildings as one object composed of ground, wall and roof surfaces;
3. The 3D City model should be able to hold information on ownership and leasing rights;
4. The use case should be able to be extended with additional information and datasets to use the 3D city model as a database. The development process should therefore use an approach that is repeatable and allows for extensions;
5. The users should be able to query the model via the model itself and via the dataset.

The first step in the process includes that a valid CityGML document is obtained. The municipality of Rotterdam provides dataset in the CityGML format of the entire city in LOD2. In this research the area known as "Kop van Zuid" is selected to be used. In the next step the model is enhanced with storeys. Different tools are evaluated to be used in this step. ArcGIS provides a "Split floor" function in CityEngine (Taylor, 2016). This required however that CityGML is remodelled into ESRI shape files. The CityGML Standard provides an mechanism to group object together in for example "storey" (Groger, Kolbe, Czerwinski, & Nagel, 2012). This would require that *wallsurface* polygons are split in *wallsurfaces* per floor which is rather complex. Another tool created by Arroryo Ohori Et al. (2015) from the Technical University Delft is selected. However during the process some errors occurred when executing the tool and importing the correct CGAL libraries. Therefore an output of this tool is obtained from the original authors to be used in developing a prototype of the use case. This tool is chosen since it defines a building storey as a semantic object of a building that provides possibilities to be included in the CityGML standard.

The output derived from the tool is however not in line with the CityGML standard (e.g. the denotation of elements in the document was not in line with the CityGML schema definitions). Therefore the output requires to be restructured. A Python based script is written that is capable of re-structuring the output from the tool of Arroryo Ohori Et al. (2015) into a valid CityGML document (appendix 3.2). Another problem that is found in the output is that "storey" despite of being geometrically correct is not defined in the CityGML schema definitions.

Previous studies indicated that an ADE could be used to define similar attributes as within this use case (Cagdas, 2012) & (Gifford Dsilva, 2009). Therefore an ADE is proposed that defines *storey* as a part of the building module (appendix 3.4). To allow the CityGML document to include ownership and leasing information per *building* and *storey* a second ADE is proposed (appendix 3.5). This ADE defines the different property rights attributes that can be included in the CityGML document.

This research did not completely met the fifth requirement. The information could only be queried via the tables in the viewer not via the dataset. The final result is stored in a folder according to the CityGML standard and includes the two ADEs, a valid CityGML document and the Python script in which the output from the tool from Arroryo Ohori Et al. (2015) can be restructured. The valid document only requires that the schema locations are defined in a local directory.

7. Discussion

The findings in this research are of influence on further scientific research and on further practical developments. Some of the major findings and implications are discussed in this section.

7.1 Scientific discussion

This research focussed on answering two questions regarding 3D city models: 1) To what purpose ("why") should these 3D city models be used in real estate applications and 2) how can the use case technically be achieved? Given the limited timeframe of this research, at a certain point a start had to be made with answering the second question while the first was not entirely clear yet. Given the results obtained, both questions deserve a full research to discover the potential of the use of 3D city models in real estate applications.

The first part of this research that studied the "why" question explored the potential of 3D city models for real estate valuation and transactions. The results showed several relevant and technical achievable use cases. Yet none have been applied in practice. Therefore an indication on the added value was requested from the respondents in terms of "efficiency" and "effectiveness" of using a 3D city model. As described by Collerette, Ingham, & Legris (2003) one of the factors that influence the use of a new technology is the measurable profit. Recently the Dutch cadastre includes its first 3D property right registration (SpoorPro, 2016). When more property rights are registered in the cadastre a comparison can be made between the usefulness of the 3D registration over the 2D registration. Research on the usefulness and added value is currently limited to research by Herbert & Chen (2015). I would recommend to study the time (efficiency) that it takes to correctly (effectivity) derive all property rights related to an object from a 2D map compared to a 3D model.

7.2 Practical discussion

This research found that the real estate respondents saw potential in the use of 3D city models as a database to obtain insight in information of tenants and owners on different storeys in a city. The process of how to develop this use case is also studied and described in this research. The result however was limited to one building because the application created by Arroryo Ohori Et al. (2015) did not work. It did show that the output of this tool required remodelling and the addition of an ADE to be able to be used as a database. A large scale test of the products developed in this research is required to create the database. It is therefore recommended that the tool created by Arroryo Ohori Et al (2015) is used on a larger scale for different LOD2 datasets in association with the Python script en ADEs developed in this research.

The CityGML standard does currently not define storeys within the building module (appendix 2.1). Nor does the standard provide conclusive options to properly define storeys. Therefore this research proposed an ADE that describes this storeys in line with the standard. According to findings in the literature the usability of CityGML would increase if storeys are added at LOD2 in the standard (Arroryo Ohori Et al. 2015). The literature showed that buildings which remain simple polygons or boxes are less useful within the real estate domain (Lomax, 2015) & (Herbert & Chen, 2015). A same indication was obtained from the real estate professionals participating in this research. They indicated that any application that could show information per building floor was currently missing and therefore deem the development of one relevant.

8. Conclusion

The literature on GIS and real estate showed that GIS is used in real estate applications for the purpose of data visualisation and analysis. 3D GIS, of which CityGML is considered to be the main standard, has the same capabilities as 2D GIS with certain added value. Some use cases require data visualisation in 3D since the data is applicable not only to an x, y coordinate but to a height coordinate as well. To gain insight in, and analyse this data 3D GIS can be used. According to the real estate professionals, using 3D city models could provide added value in terms of primarily efficiency. **These professionals stated that using 3D city models to visualise and store data per building floor is a use case that is currently missing.** 3D city models can be used for the same purposes as 2D GIS is used in real estate valuation and transaction applications, with the purposes of visualising and analysing data. However with 3D, an extra dimension is added that is currently missing. This is seen in different 3D use cases that have been studied. These use cases utilize 3D city models to visualise data for better understanding of data or for analytical purposes. The use cases derived from the literature and the input from the real estate professionals indicated a number of relevant use cases:

1. 3D property ownership registration;
2. 3D zoning plans;
3. Mass valuation of real estate properties based upon different variables;
4. Identifying comparable sales units on variables other than location and time;
5. Building cost approach based upon semantically rich 3D models;
6. Square meter prices per building floor;
7. BAG Function mapping in 3D.

This answers the question to what purpose and "why" 3D city models can be used in real estate valuation and transaction applications. CityGML is studied to answer "how" 3D city models can be used in a relevant real estate valuation and transaction use case. Most of the relevant use cases require that a building at least is separated into storeys. Different studies did already indicate that a building as one solid box (e.g. multiple polygons) is not useful for real estate applications. CityGML models do however not include indoor geometry and therefore storeys until LOD4. To be able to create a relevant use case a tool from the Delft University is used to obtain a CityGML file with storeys defined as "LOD2+". To be able to use this model as a database that can contain property rights information the output has to be in line with the CityGML standard. Therefore restructuring of the output is required, this can be done by using a Python script. According to the CityGML standard additional attributes, that can include property rights information, should be defined in an ADE. Therefore two ADEs are created that 1) define the storeys in buildings and 2)define the property rights of building and storeys. **Performing these steps allows for the technical creation of a relevant real estate valuation and transactions use case that utilizes 3D city models** (figure 2).

FIGURE 2: REQUIREMENTS OF A USE CASE AND THE PROCESS TO ALLOW CITYGML TO BE USED

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Abbreviations

ADE	Application Domain Extension
AEC	Architecture Engineering and Construction
AHN	Algemeen Hoogtebestand Nederland
AVM	Automated Valuation Model
BAG	Basis Administratie Gebouwen
BIM	Building Information Model
CAD	Computer Aided Design
GI	Geospatial Information
GIS	Geographic Information System
GML	Geography Markup Language
IFC	Industry Foundation Class
LOD	Level of Detail
OGC	Open Geospatial Consortium
REGIS	Real Estate GIS
RICS	Royal Institute of Charted Surveyors
RRR	Rights Restrictions and Responsibilities
SIG 3D	Special Interest Group 3D
UML	Unified Modelling Language
URI	Unique Resource Identifier
XML	Extensible Markup Language
XSD	XML Schema Definition

Chapter 1. Introduction and problem definition

This first chapter serves as an introduction on the background of this research and aims to define a problem statement. Section 1.1 describes the research context by elaborating on the new computerisation and data trends that influence real estate professionals and their use of geographic information systems. In the section 1.2 a problem statement and the general research limitations are defined. The aim of this research is defined in section 1.3. The problem statement and research aim are translated into multiple research questions and a research design in sections 1.4-1.6. The final section presents the general layout of this research report.

1.1 Research background

The aim of this section is to define a problem statement that provides the foundation for this research. It does so by first considering the future of real estate valuation and transactions applications and the developments involved. Next these developments are elaborated on, to try and establish a context in which the problem statement is addressed.

1.1.1 The future of the real estate appraiser and broker

In 2013 research by Frey and Osborne (2013), indicating that 47% of the United States employment is at risk because of computerisation, received a significant amount of attention. In their research they quantified 702 occupations by probability of being subject to computerisation. Four real estate occupations where quantified with a probability of 80% or higher of becoming obsolete due to computerisation (Frey & Osborne, 2013):

1. Real Estate Brokers (97%);
2. Appraiser and Assessors of Real Estate (90%);
3. Real Estate Sales Agents (86%);
4. Property, Real Estate and Community Association Managers (81%).

One of the reactions the research received was from Bowles (2014) providing some additional context and indicating a limitation that was mentioned by the authors as well. Bowles specifically mentioned as a research limitation that when tasks are made obsolete because of technology, time becomes available to perform new or other tasks. The result is that particular job definitions will shift in the coming decades instead of running obsolete. Bowles (2014) mentions that the debates on the implications of new technology are divided in to two camps: minimalist and maximalist. The first camp believes very little will change while the other believes everything will. The headline from the original article stating that 47% of the jobs will run obsolete in the next two decades is more provocative and the truth is perhaps a bit more nuanced. Subject to this shift in the job description are computerisation trends and development (Frey & Osborne, 2013)Vast amounts of real estate related data can be mined from public domains as well as bought from data providers. Combining this data could for example be used in creating an Automated Valuation Model (AVM) to predict to value of owner occupied housing. An accuracy up to 94% in valuation could be achieved by combining different datasets, as shown by Sprundel (2013). In theory this AVM could make the job of a real estate appraiser of owner-occupied housing obsolete. The aim of this research however is not make the job of any real estate professional obsolete but rather to study the shift of the job activities and the way these are performed, by studying new and more efficient ways of data sharing and analysis driven by computerisation.

1.1.2 Data and computerisation in real estate

The AVM developed by Sprundel is solely applicable to owner-occupied housing of which far more data is publicly available compared to commercial real estate data. However, Robertson[2] (2014) states that the commercial real estate market is "ripe for disruption". He Specifically names the increasing need for transparency of information and data, as source of the greatest disruption. The results, according to Robertson, are better transactions since brokers have access to a vast amount of data, providing them with insight in the market and trends which help them with lease and transaction negotiations.

Robertson (2014) mentions two major players in the commercial real estate data market in the USA: CompStak[3] and Tenant Rex[4]. Both providing clients with leasing data of commercial real estate. In the Netherlands different comparable businesses exist such as Vastgoeddata, Geophy (both commercial real estate) and Calcasa (primarily owner-occupied housing). Other parties such as Vastgoedjournaal, Vastgoedmarkt and PropertyNL are documenting all real estate transactions and distributing this data for analysis and benchmarking. It is evident that a vast amount of data with great diversity collected in a short time (e.g. Big Data) is ´hot´ and therefore valuable to the real estate industry according to Wit (2016). Big Data is another trend, that is however outside the scope of this research, but can be used for data mining and like in Sprundels (2013) AVM used in the assessment of real estate. Databases can be constructed based upon Big Data and data mining that solve traditional problems real estate appraisers face such as the lack of comparison data of real estate transactions (Zhou, Shi, & Zhang, 2015). Their research focussed on mining data, reducing the data and constructing a data warehouse based upon, among others: price and building data, and GIS.

As argued in the previous sections trends in computerisation, data acquisition and increasing data transparency are of potential influence on the jobs of different real estate professionals. Sprundel (2013) showed that the combination of data and computerisation techniques can be used to create an AVM for mass real estate valuation. While Zhou, Shi & Zhang (2015) stated that mining large amounts of data (e.g. Big Data) could help the process of real estate assessment. A new problem that arises is how to analyse and make good use of all available data (Zhou, Shi, & Zhang, 2015).

1.1.3 GIS in real estate applications

Geographic Information Systems (GIS) provide powerful capabilities for spatial data analysis and display and have therefore been widely used in the real estate field of valuation (Zhang, Li, Liu, & Liu, 2014). GIS is defined as "*a computerised database management system used for the capture, storage, retrieval and display of locational defined data that is referenced by spatial or geographic coordinates*" (Ralphs & Wyatt, 2003). From this definition important characteristics of GIS can be linked to the aforementioned trends and the real estate sector. A computerised database used for different operations with data is potentially relevant for the computerisation of jobs and the increasing amount of available data. While the characteristic "referenced by spatial or geographic coordinates" has similarities with real estate objects, since the location is essential in real estate. To quote Joseph Magnotta on the common factor of GIS and real estate: *"They both place a very high importance on location"* (Magnotta, 2014). The accuracy of geographic data is of most important to GIS users while location is the primary factor that influences real value property. This is also seen by the Royal Institute of Charted Surveyors (RICS). They noted that the use of Geospatial Information (GI) will impact surveyors as the majority of their work has some kind of geographic element (Culley, 2010).

Multiple studies have investigated the use of GIS in real estate applications since its emergence in the 90s. Wyatt (1997) studied the development of a GIS based property information system

2 CEO of Skyline Exchange, platform to crowdsource commercial real estate information

3 https://compstak.com/

4 http://www.tenantrex.com/

for real estate valuation. Wyatt stated that the primary factor influencing real estate value is location, but noted that this factor was traditionally accounted for by the appraisers own expert knowledge. With a GIS based approach he proposed a more quantitative analysis of spatial property related information. Based upon the assumption that location is the most important parameter in real state valuation, Din, Hoesli, & Bender (2000) studied the influence of using GIS on the different real estate price indices. Their research compared various real estate valuation models and how these take into account the different environmental variables. Zeng & Zhou (2001) conclude that the potential and value of a property is fundamentally determined by the location of a property. They therefore proposed a Real Estate GIS application (REGIS) to support decision making for different real estate applications such as valuations and transactions.

Besides an extensive amount of studies conducted in using GIS for real estate applications, GIS has been applied in practise as well, partly motivated by the increasing availability of software of among others ESRI. Using GIS in real estate applications has been adverted by ESRI[5] since it allows to add spatial intelligence to real estate applications and thereby create a competitive advantage (Culley, 2010). It allows for real estate advisory firms to comprehend and analyse all data applicable to an object (ESRI Nederland, 2016). However according to ESRI (2014) the world of urban mapping is changing fast. The evidence can be seen in the world around is where maps are just recently being used to locate and project virtual Pokémon figures upon. This game is built upon highly accurate and available maps (Lankinen, 2016). A little longer ago Google Earth already showed the capabilities of 3D projections allowing users to "fly" through a city in their 7th version[6]. The mapping in two dimensions is no longer sufficient and the use of 3D applications is becoming more common. According to different studies that already addressed this topic, 3D GIS could provide a more professional decision making tool in the real estate domain (Liu, Yu, & Zhang, 2014). In line with this statement current 2D GIS applications used for decision making in the real estate industry could be evaluated. Mainly the BAG (property functions and sizes), Zoning plans (building legislation) and Cadastre (property rights). These applications describe 3D information on a 2D map. The BAG for example denotes storeys and units with points in a 2D surface. No information can be derived that indicates which point represent a certain storey or unit. The same problem occurs within the other two applications as well.

1.1.4 GIS 3D in real estate: studies and practical applications

The use of 3D city models and the possibilities within real estate valuation and transaction applications have been studied by a number of researchers. These studies tend to focus on valuation for governmental taxation purposes and property ownership registration. Cagdas (2012) conducted a research in to property valuation for taxation purposes by utilizing 3D city models. The research mentions that physical, economic and environmental data along with a spatial representation of the 3D properties was often provided for in separate information systems. Cagdas proposed an Application Domain Extension (ADE, section 1.1.5) for CityGML which would cover the legal and administrative aspects of city objects that are required for in the process of property taxation. Isikdag, Horhammer, Zlatanova, Kathmann, & Oosterom (2015) studied the use of 3D city models for better valuation of real estate by extracting volumes from the 3D model. Their study concludes that these parameters where often obtained from various sources or estimated and that using 3D citymodels would be more efficient in this matter. El-Mekawy, Paasch, & Paulsson (2014) studied the integration of Building Information

5 Main software provider of GIS software

6 https://www.google.com/earth/

Models (BIM) and 3D real estate property information for the creation of a 3D cadastre. Gifford Dsilva (2009) studied how CityGML could be used for the registration of property rights that are currently defined in the 2D cadastre. Just recently a Dutch pilot project was worldwide the first to formally registrate property rights of a building in a 3D cadastre (SpoorPro, 2016).

Other studies did not focus on real estate valuation for governmental taxation purposes but aimed at other aspects of real estate valuation such as improving the comparable sales approach method or using 3D city models for mass valuation of properties. Liu, Yu and Zhang (2014) studied the capabilities of 3D city models in finding comparable transaction records of properties for valuation purposes. Their 3D GIS showed great benefits of using 3D compared to 2D GIS in finding comparable transaction records. Since the use of 3D allowed multiple other variables than solely time and location of a transaction. Zhang, Li, Liu, & Liu (2014) studied the use of 3D GIS for real estate mass valuation. Their research generated 3D building models using ESRI's CityEngine and utilized this model for sunlight and landscape analysis to quantify these variables and their influence on real estate value. The research showed improved accuracy and efficiency in accounting for this variables by real estate appraisers.

There are multiple studies indicating that the utilization of 3D city models are potentially of added value in different use cases within the valuation and transaction domain. However Isikdag Et al. (2015) discovered that in different countries, including the Netherlands, the property valuation and taxation has not applied the use of 3D city models. This is caused by a lack of awareness of the possibilities offered by semantically rich 3D models. The research concludes that valuation of properties could be done more efficient by extracting the right data from 3D building model geometries and adding additional data regarding the quality of the building and surroundings. Stoter (2014, p.9) states that currently most 3D information is re-modelled into 2D models and solutions. Therefore Stoter urges for a change, referring to publicly available 3D city models and the potential economic benefits in applications that require 3D Considering the increased amount of 3D city models in the Netherlands available as "open data"[7], a shift in the re-modelling of 3D data may be possible. The larger cities are working on the creation of 3D city models of their region and also sharing these data online. An example is the city of Rotterdam which created a 3D model based on the BAG[8] and the AHN. This 3D City model is being provided publicly as a CityGML file format. Along with the increasing amount of available 3D city models, the possibilities for managing, acquisition, access and usage of 3D geo information has increased exponentially in recent years (Scholten, Stoter, & Velde, 2014). In order to adopt 3D city models in business it is important to gain understanding of the benefits and shortcomings of different types of 3D models (chapter 6) (ESRI, 2014).

1.1.5 CityGML a 3D standard

The main 3D standard in the GIS domain is considered to be the CityGML file format (Arroryo Ohori, Biljecki, Boeters, & Zlatanova, 2015). This format is aimed at the representation of the semantic properties of 3D city models. The CityGML file format is capable of representing geographic, semantic and visual aspects of a city. In line with the capabilities of GIS, CityGML allows for advanced analysis and visualisation for a variety of applications (Groger & Plumer, 2012). Other file formats such as KML, X3D, Collada and ESRI Shape files purely focus on the geometrical and geographical visualisation aspects and lack semantic information. Like the increased availability of real estate data, data that allows for the modelling of 3D cities has

7 Data which is provided online and publicly available to use and re-use (Rotterdam example: http://www.rotterdam.nl/links_rotterdam_3d).

8 Main dataset in the Netherlands that holds information on properties and their function (https://bagviewer.kadaster.nl)

become publicly available as well. For example one could use the BAG data and combine it with the Algemeen Hoogtebestand Nederland (AHN[9]) to model a 3D city automatically.

Real estate valuation and transactions consider mainly existing objects of which no 3D BIM models are available. It is expected that the amount of 3D building models in the Industry Foundation Class file format (IFC) which become available will increase since it is possible, and in some cases mandatory to upload this file formats in the process of obtaining a construction permit. However considering there are roughly 8 million buildings in the Netherlands and there are approximately 30.000[10] construction permit requests per year it will take ages before 3D model of all properties in the Netherlands are available. Therefore automatically generated 3D city models in the CityGML format are used. These 3D city models are generated automatically, some are publicly available and allowed the be re-used. Compared to other file formats CityGML allows semantic representation of building models. This means that these models are more than just a geographic and visual representation. In CityGML objects can be defined as a "wallsurface" or "roofsurface" rather than being just a polygon.

CityGML is an open standard which has been developed and issued by the Open Geospatial Consortium (OGC). CityGML is the standard within the Netherlands for 3D geo-information. For the purpose of this research, 3D city models and 3D GIS are considered the same. Within CityGML five levels of detail (LOD 0 to 4, figure 1.1) are used to represent city objects, where each level contains more features of a city (El-Mekawy, Ostman, & Hijazi, 2012). A LOD0 model is the basis and contains 2.5D data in the form a digital terrain model. LOD1 consists of a model in which buildings are represented as blocks with flat roofs. A LOD2 model, the level in which the city of Rotterdam is available, contains detailed roof structures. In LOD3 more detailed roof and wall structures are defined, for example balconies and windows. A LOD4 model can also contain detailed interior aspects of buildings which makes this level closer related to BIMs.

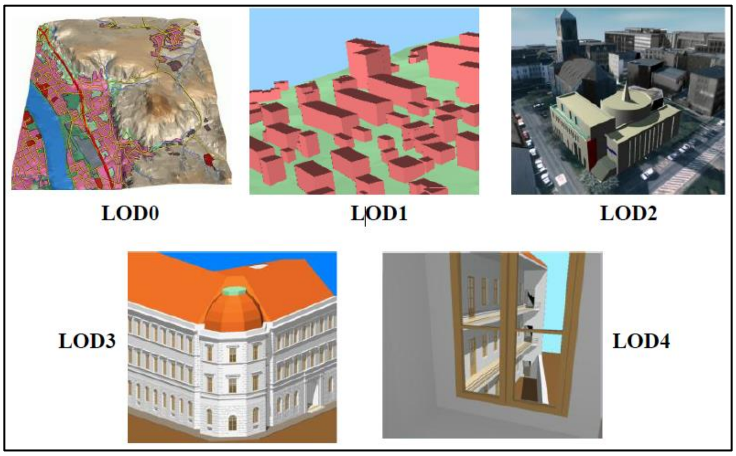

FIGURE 1.1: FIVE LEVELS OF DETAIL WITHIN CITYGML, SOURCE: (GROGER & PLUMER, 2012)

An important feature of CityGML that lies within the scope of this research is the capability to add additional data to CityGML models. Application Domain Extensions (ADEs) have been created in the past for different requirements. With ADEs new feature types, attributes, geometries and associations can be created, as well as additions to formats of existing feature types (Cagdas, 2012). Another important concept of CityGML within the scope of this research is its capability to point to the identifier of an object in an external data source by "external reference". With the external reference a link is created from a CityGML object to the same object in another information system, for example the BAG dataset (section 1.1.2.1).

9 Algemeen Hoogtebestand Nederland: dataset that contains all height levels in the Netherlands

10 www.cbs.nl, Statline 2016

1.2 Problem statement and limitations

Five topics describe the context of why (3D) GIS is used in real estate valuation and transactions. The combined conclusions per topic form the problem statement.

Section 1.1: Some real estate professions within the real estate appraisal and brokerage domain are subject to computerisation trends and developments. Therefore these professions could become obsolete or at least a shift within the job description could occur.

Section 1.1.2: The increasing amount of available data and request for more transparency of real estate data result in new techniques within real estate valuation. An example is the AVM that automatically values owner occupied homes in the Netherlands. With more available data new techniques and tools are required to comprehend this data.

Section 1.1.3: GIS could be seen as a tool that is capable of handling the increasing amount of information and the computerisation trends. GIS is used to visualise, analyse and comprehend the vast amount of data. Different studies already addressed the relation between GIS and real state and the added value that using a GIS in real estate could provide. Applied in practise GIS could provide competitive advantages to real estate professionals.

Section 1.1.4: Using 3D GIS is relevant since many data is applicable to users and owners on different floors and units at different heights and locations throughout a building. Current applications used by real estate professionals still present 3D data on 2D map. There are different studies that provide examples how 3D city models could be used in real estate valuation and transactions. However there are no use cases in practice that utilize 3D city models for real estate valuation and transactions applications.

Section 1.15: CityGML is the main 3D standard in GIS. This file format is capable of describing semantically rich 3D model of cities. These models can be generated relatively easy based on the BAG and AHN datasets.

1.2.1 Problem statement

2D GIS has been used as a tool to visualise and analyse real estate data. However not all data is applicable to only an x and y coordinate but to a height (z) coordinate as well. Different studies already described that 3D city models could be used in multiple real estate use cases. However only one has been applied so far. From the studied use cases it is unclear which are of added value and relevant to apply in practise. As a consequence it is unclear how the CityGML standard could be used to develop a real estate use case that requires a 3D city model. Therefore two problem statements are defined:

1. It is unclear in which use cases 3D City models are of added value over 2D models and which of those are relevant and technically achievable to be applied in practise;
2. A study is missing on how the capabilities of the CityGML standard allow for the development of a real estate use case and which modifications and tools are required.

1.2.2 Research limitations

This research is conducted in a limited time frame of approximately six months in which both problem statements are to be addressed and studied. Given the fact that the utilization of 3D city models in real estate applications is new, there is no market evidence supporting the use and added value of using 3D city models in specifically this sector. This is a limitation in itself with the consequence that this research is of an exploratory nature. Subject to this type of research is that it could discover many new subjects that are of potential interest. The focus remains on the topics described in the introduction (real estate valuation and transactions and 3D GIS) and their mutual relation. To prevent exceeding the given time frame the research design (section 1.6) is well bounded by precisely describing the activities that are performed.

1.3 Research goals

As two problem statements need to be addressed two research goals can be formulated. The first research goal is related to the first problem statement which states that it is unclear which of the studied and new use case utilizing 3D city models are of added value and relevant to be applied in practise or developed.

1. Provide insight in the purpose and added value of using 3D city models compared to 2D models and determine in which use cases it is relevant to utilize these 3D city models. This insight is based upon the literature on this topic and input from professionals in the real estate and 3D data modelling domain.

The second research goal is of a more technical nature. This research goal is related to the second problem statement that it is unclear what the technical possibilities are of 3D CityGML models in relation to the use cases they are utilized in.

2. Determine the technical capabilities of CityGML in relation to real estate use cases and describe the process of creating a prototype that allows CityGML to be used in a relevant use case.

Related to this second research goal is the establishment of a relevant use case. This is the result of achieving the first research goal and is described subsequently.

1.4 Research questions

To achieve the two formulated research goals, one main research question in formulated along with six sub questions. By answering the sub questions chronological, the two research goals are achieved and eventually a conclusion can be drawn answering the main research question:

Why and to what purpose could 3D city models in CityGML instead of 2D models be utilized in real estate valuation and transaction applications and how could the requirements of a relevant 3D real estate use case be technically achieved?

1. What is the relation between (3D) GIS and real estate valuation and transaction applications?
2. For what purpose and added value is 3D GIS currently used in real estate valuation and transaction applications (state of the art use cases)?
3. Which use cases utilizing 3D city models are relevant and technically achievable within valuation and transaction applications and what are the requirements?

Achieving goal 1: Defining a relevant and achievable use case.

4. What are capabilities and characteristics of CityGML as a 3D city model?
5. What are the requirements of the use case and what datasets are required to create this use case?
6. How could CityGML be used to attach the dataset to and allow its downstream use e.g. to visualise the required information from that dataset?
   - 6.1 Which LOD is required for CityGML to accurately visualise the information?
   - 6.2 How can the datasets be attached to the CityGML file or within the data structure?

Achieving goal 2: Utilizing CityGML in a real estate use case.

1.5 Research Relevance

The overall relevance of this research can be sought in the outcome of the research conducted by Frey & Osborne (2013), stating that at least four real estate related professions have a chance of 80% or more of becoming obsolete wihtin the next two decades. If not obsolete, a shift of the general job description is to be expected. It is therefore worthwhile to examine the possibilites of computer technologies in relation to real estate applications. The increasing demand for more transparancy in the commercial real estate sector contributes to the amount of data available. Besides real estate data, datasets including semantically rich 3D geographic representations of cities are becoming available since they can be generated automatically. The exchange format CityGML for 3D city models is provided for by the OGC and more 3D models in this format are becoming available (Scholten, Stoter, & Velde, 2014). Different tools can be used to analyse, comprehend and re-use this data. GIS is one of these tools and has in common with real estate that location is the most important variable. Using 3D GIS could add an extra dimension in the analysis and comprehension of real estate data and is already being studied for some valuation transaction applications but however not applied.

1.5.1 Theoretical relevance

Besides the overall relevance, conducting this research will contribute to the scientific domain as well. Current research has focused on how to integrate BIM and GIS (e.g. IFC and CityGML) and how to create city models with semantically rich building data (Ding, Luo, Ma, & Xu, 2014) (Isikdag, Horhammer, Zlatanova, Kathmann, & Oosterom, 2015) or create extensions for CityGML which contain additional information for specifically real estate valuation by government agencies (Cagdas, 2012). From a real estate valuation perspective, semantically rich building models are not necessary per se, only the basic attributes of a property and its surroundings are of importance. However research indicating the specific relevant use cases of 3D city models in the Netherlands, for real estate valuation and transaction applications, is scarce. Isikdag Et al (2015) conclude that professionals in the real estate industry are not aware of the potential of semantically rich 3D data models. Stoter (2014) states that it is time to convert 2D data to 3D because it is simply possible nowadays to create 3D models which are of value for multiple forms of use. In order to make the change from 2D towards 3D data models, a clear use case along with its requirements is needed (Bayers, et al., 2015). According to ESRI (2014) it is important to define the primary applications in which 3D data would be required and who the users of this application are. This research therefore aims at establishing the relevant use case(s) for the use of 3D city models in real estate valuation and transaction applications by identifying the users, possibilities, requirements and potential added value. This would allow future research to direct their research on more practical applications of 3D city models within a certain domain, in this case real estate valuation and transactions.

1.5.2 Practical relevance

The practical relevance of this research can be sought in the statement of Isikdag (2015) that professionals are not aware of the potential of semantically rich 3D data models. Combining the proven potential of 3D models in other industries, such as the AEC industry and potential of 3D city models seen by experts in the real estate industry, could improve the lack of awareness mentioned by Isikdag. As indicated by studies from Frey & Osborne (2013) & Bowles (2014) that some real estate related jobs are subject to computerisation within the next two decades, it would be particullary interesting to respond by studying the capabilities of new technoligies, such as 3D GIS, within the real estate domain. First, if certain use cases with 3D city models for real estate valuation and transacition applications can be defined and technically created, one would perhaps be ahead of competitors. By means of a more efficient way of data-sharing and combining, a real estate professional would contribute to the shift of his job definition because of opportunities instead of threats provided by the computerisation. Second, by describing the process of how certain use cases using CityGML and real estate data can technically be created the overall use and possibilities might increase.

1.6 Research design

An interactive brainstorm session at a Dutch real estate data provider, with most larger real estate advisory firms as a client, was held. In this session both real estate data consultants as well as data programmers were involved. During this session it was learned that the utilization and awareness of 3D city models is rather low. At Cushman & Wakefield, one of the first real estate advisory firms as a client of ESRI, 2D geographic models have been used for visualisation and analyses. The utilization of 3D models is seen as the next step (ESRI Nederland, 2016). The low awareness and limited use of even 2D GIS supports the aforementioned limitations of this research (section 1.2.2) indication the exploratory nature of this research.

Since the utilization of 3D applications and data models in the real estate industry has not yet made its full entry, hardly any practical examples or case studies are available to be studied. Therefore a qualitative and exploratory research approach is adopted. By conducting a qualitative research approach, in-depth knowledge regarding the potential and requirements of 3D data models in real estate valuation and transaction applications can be found. Therefore this research is of an applied scientific kind with both practical and theoretical input as well as output. The basic form is non experimental and consists of a qualitative research (e.g. interviews, desk-research, test cases) (Baarda & Goede, 1995).

The research is structured into three phases (figure 1.2). The first phase consists of a desk research on the main topics of this research. In the second phase input from professionals in the real estate industry and experts on (3D) data is required. In the final phase of this research the process of creating a prototype capable of holding and visualising 3D real estate data in a CityGML format is studied.

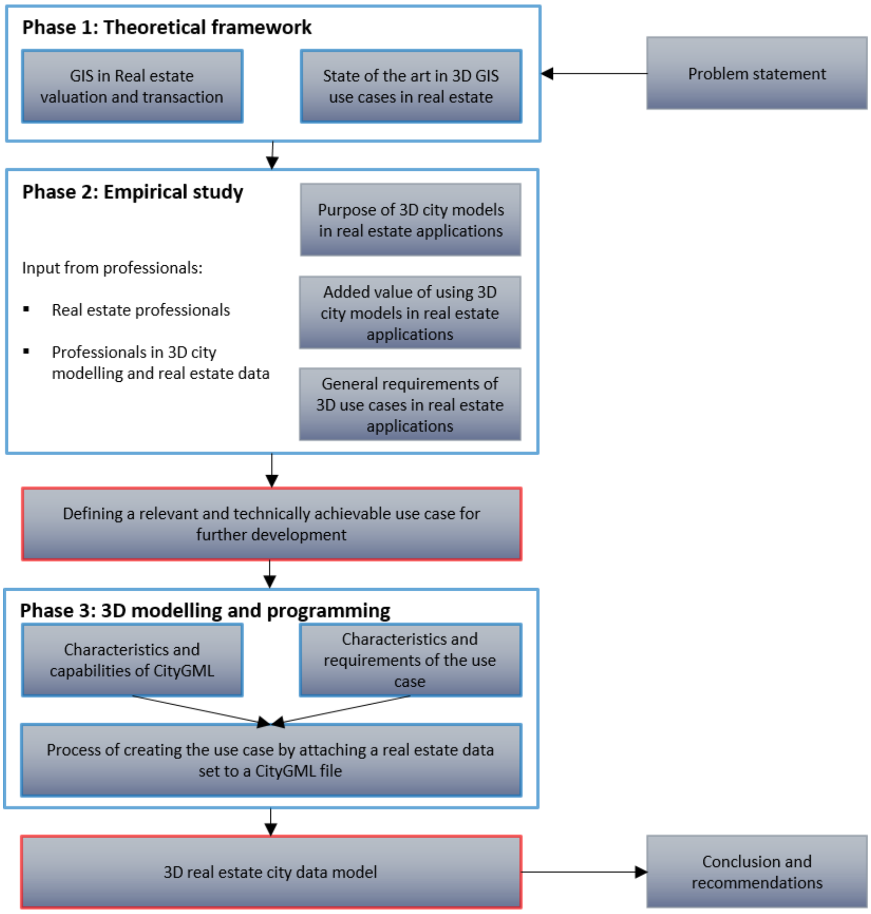

FIGURE 1.2: RESEARCH DESIGN, BLUE: RESEARCH QUESTIONS, RED: RESEARCH GOALS

Although figure 1.2 includes three phases, this research can roughly be split up in to two sections in which both sections aim to achieve the described research goal. The first part of this research is aimed at answering the ''why'' question: why would 3D city models be used in real estate valuation and transaction applications. This question is answered by conducting a literature and empirical study (phase 1 & 2). The second part aims to answer the ''how'' question: how can CityGML be utilized in real estate use cases?. It does so by using the results on of the state of the art in 3D use cases from phase 1, the previous studies on the capabilities of CityGML and by testing certain tools.

1.6.1 Theoretical framework

In the first phase of this research a literature study is performed on the topic of real estate valuation and transactions in relation to GIS, and on the currently studied use cases in which 3D city models are utilized. In this phase the ''why'' question is answered based on previous studies and a framework is constructed that describes why certain use case require 3D city models.

The aim of the first phase is to obtain an overview of the use cases related to real estate that are currently being studied and an overview of use cases that are potentially of interest to be studied in the future. Before describing the use cases a study is performed on the general purpose and added value of 3D with respect to information visualisation and analysis. Phase one ends with an overview of the current and potential use cases of 3D city models in real estate applications and a framework that indicates the purpose and added value of utilizing 3D city models in certain use cases. Based upon the information found in the literature regarding these use cases a research approach is described. This approach could provide the required information from real estate and data professionals on the topic of 3D city models in real estate.

1.6.2 Empirical study

In phase two, input is required from real estate and data professionals regarding the relevancy and the possibilities of 3D city models in different real estate valuation and transaction use cases. The aim of this phase is to obtain feedback on the use cases found in the literature and the framework that is constructed. In this phase the purpose and added value of using 3D city models in real estate use cases should be established based upon opinions from professionals. Besides providing feedback on the context of using 3D city models (the constructed framework) real estate professionals should establish which use cases are relevant in the sector while data professionals should establish which use case are technically achievable.

The research population in this phase consists of real estate advisory firms involved in real estate valuation and transactions and data professionals involved in 3D data modelling. The sixth largest firms in the Netherlands who are also active worldwide, are CBRE, JLL, Savills, DTZ, Colliers and Cushman & Wakefield. Combined they are involved in 70% of the real estate investment volume in the Netherlands in 2014 (Kooijman & Wessels, 2015). The goal is to involve at least three companies from this list. Besides the real estate advisory firms, input is required from at least three professionals that are involved in data analysis and 3D modelling. These include for example the data and (3D) GIS companies: ESRI, Geonovum, Calcasa, Geophy and Vastgoeddata.

The final product of phase two is an overview of which use cases are both relevant and technically achievable. Besides this overview, the general context of using 3D city models based upon purpose and added value the framework is established. This is used to develop one of the use cases in the final phase of this research.

1.6.3 3D modelling and programming

The final phase of this research includes the process of creating a prototype that is able to attach the dataset to CityGML and allows its downstream use e.g. to visualise the required information from that database. For which particularly use case a tool is developed depends on the available datasets, current progress on similar use cases (e.g. March 2016 the Dutch Cadastre started a pilot with 3D registration of apartment rights) and the complexity of the use case.

First, the technical capabilities of CityGML are examined and established in relation to the real estate use cases. Then, different steps are described to create the prototype that fulfils the described use case. The first step is to obtain the required datasets and check the quality. The datasets and specifically the CityGML file are then analysed whether they are suited to be used in the use case or whether they have to be modified. Next the possibilities are examined of using the CityGML file to attach the relevant data from the use case to. In the final step the combined datasets are visualised in a viewer capable of representing the information. During the process multiple tests are performed to determine which method is most appropriate for each step. For further research purpose the possible shortcomings that occur with certain methods are described. The end product is validated by testing the results in a viewer that is capable is visualising information from a 3D city model and the attached data. If the information from the dataset is correctly represented in the 3D model then the end product is valid.

1.7 Report layout

The first chapter is concluded by presenting the general layout of this report (figure 1.3). In the previous sections the background and research design is presented. In the second chapter the real estate valuation and transaction domain is described along with its relation to GIS. This chapter provides a general introduction on why GIS and 3D city models could be used in real estate valuation and transaction applications. The third chapter describes how 3D city models are used in real estate valuation and transaction applications. This chapter starts with an introduction on how the purpose and added value of 3D in the specific use cases can be determined followed by describing the state of the art in use cases. Chapter four describes how the potential use cases are further studied and how additional information providing context to why and how 3D city models could be used is obtained. In chapter five the results of the further research methods proposed in chapter four are analysed to construct an overview of relevant use cases and a description of the use case that is further developed. Chapter six elaborates on the attributes, structure and extension possibilities of 3D data model file format CityGML. This file format is the 3D foundation of the potential use case that is developed. In chapter seven the process of attaching or linking the datasets to the CityGML file and allowing its downstream use and visualisation is described. This report is concluded in chapter eight in which the main research question is answered and recommendations for improvements and additional research are described.

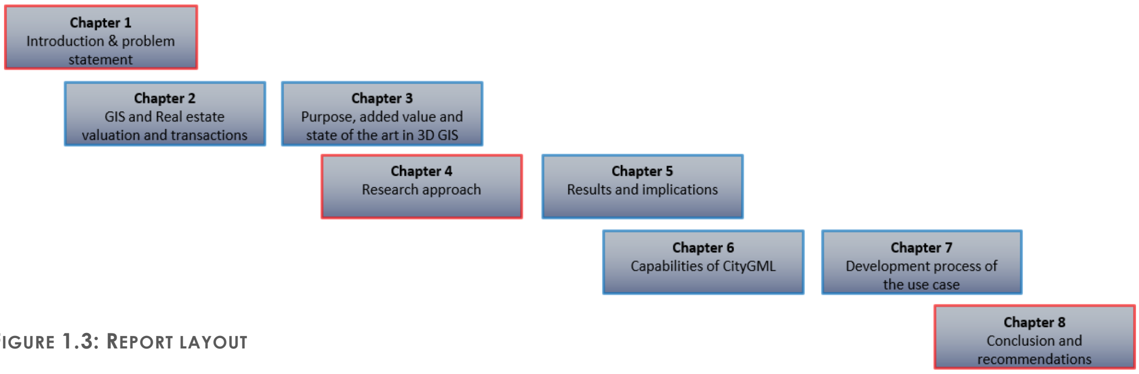

FIGURE 1.3: REPORT LAYOUT

Chapter 2. GIS in Real estate valuation and transaction

This chapter answers the first sub question:

What is the relation between (3D) GIS and real estate valuation and transaction applications?

To answer the first sub question an elaboration is given on real estate valuation and transactions in general in section 2.1. Then in section 2.2 a connection is made between real estate valuation and transactions and GIS. The next section seeks to establish why 3D GIS could be used and which factors are of influence on this shift. In section 2.4 the important aspects in making the shift from 2D towards 3D GIS are explained. This chapter is then concluded with answering the first sub question and thereby providing context to describe how 3D GIS is currently used, in chapter 3.

2.1 Introduction

Within the real estate advisory business primarily two business lines can be distinguished: real estate valuation a real estate transactions. The valuation business line includes the general valuation of real estate property for different purposes. Real estate transactions include the transactions of property ownership or leasing rights. Both applications are described in this section before a general relation to GIS is made in section 2.2. The aim of this research is to define specific use cases within real estate valuation and transactions that could utilize 3D city models. Therefore an elaboration on the general tasks and methods within this applications is given rather than a definition of each topic.

2.1.1 Real estate valuation and GIS

The valuation of real estate can be considered as estimating the best price against a property will be traded (Assimakopoulos, French, Hatzichristos, & Pagourtzi, 2003). The valuation of properties is done by real estate appraisers for different clients and purposes. Clients could for example be municipalities who annually charge property owners with property tax that consists of a percentage of the property value. Other client could be banks whom have outstanding mortgages and require the minimum value of the pledged property. The valuation process consists of six steps (Have, 2007):

1. Determine the assignment;
2. Collect, select and analyse data;
3. Field work, quality checks;
4. Determine valuation method;
5. Final valuation;
6. Report.

With regard to GIS and 3D GIS step 2-3 are most important. In step 2 data is collected on external factors from the neighbourhood, city and the region. Furthermore internal data from the property is gathered regarding the quality of the building, tenants at different floors and ownership. Also data is collected regarding comparable real estate objects in the neighbourhood and possible vacancy rates. After analysing this, mostly spatial information, field work is conducted on sight. With the arising of Google Street View the need for field work has decreased, many aspects can be studied from the view provided by Google. In step 4 the valuation method is selected. A property valuation is done according to one of three methods, sorted ascending to relevancy for this research:

1. The cost approach, this approach takes the sum of the cost of land plus construction costs and is used by developers to find a breakeven point for their property pricing;

2. The income capitalization approach, based upon a calculation of either the gross or net annual rental income times a 'cap-rate'. The cap-rate is depends on the type of property and location and known as the expected rate of return on an investment;
3. The sales comparison approach, based entirely upon location this method searches for comparable properties with the same attributes in the area. Based upon different comparable an average value can be found.

Specifically the sales comparison approach is of interest in this research since it is based upon a property its physical attributes and location for which CityGML data models could be used (Liu, Yu, & Zhang, 2014). The reoccurring factor in all three methods is the factor location. In the first method location is of influence on the price of land. For example the land costs of Amsterdam South-Axis are the highest within the Netherlands. These costs are influenced by different spatial factors such as the proximity to transportation, the allowed building height and the social economic characteristics of the environment. The same factors are of influence on the income capitalization approach. The sales comparison approach is an entirely different method. This method seeks to find sales of comparable real estate objects to obtain a value. Currently the two main variables in finding a comparable sale is time and location. Time means that a comparable sale is not older than three years and location means that a comparable sale is within the proximity of the appraised object. Using GIS or 3D GIS could provide additional variables besides time and location. For example an office floor on the 20^{th} floor in the Amsterdam South-Axis. Currently comparable sales records would be sought on the Amsterdam South-axis. There are however not that many high rise office buildings in the Netherlands and therefore this floor could be compared to a high rise office building in Rotterdam as well if this location has roughly the same environmental conditions.

With the rise of GIS a new method was developed: the spatial analysis method which is considered an advanced valuation method compared to the once mentioned above (Assimakopoulos, French, Hatzichristos, & Pagourtzi, 2003). This method uses spatial statistic methods such as spatial pattern analysis and autocorrelation analysis. This method uses rigorous spatial analysis of property prices based on spatial characteristic to predict the values of real estate of different geographical locations. This method is however quite complex as many algorithms are involved.

2.1.2 Real estate transactions and GIS

The real estate broker is responsible for real estate transactions. These transactions are either leasing or sales transactions. A broker basically transfers the property (leasing) rights from one party to another (Donlon, 2007). The process of a real estate transaction includes a valuation often performed by both parties, this process in relation to GIS is described in the previous section. Within both domains information is provided by either the broker or appraiser based upon data from different sources. The scope of this research is on that data which has a spatial attribute and could therefore be directly connected to a property on a specific location. An example is the ownership and rights registration to different parts of land or a building. The main GIS applications involved in real estate transactions are the property rights that are assigned to a spatial location which in some cases is rather complex. For example the ownership registration of Claude Debussylaan 5 on the Amsterdam South Axis (figure 2.1). The ownership is registered in the Dutch Cadastre which is a GIS. The ownership is however related to objects that are mainly up in the air rather than related to a flat surface. These objects are however in fact one solid volume, only not attached to the ground surface. The result is that on a flat 2D projection these ownership details have to be represented with many numbers (figure 2.2). At the transfer of a real estate object this would imply that a notary has to add and check the ownership title for each small object, represented by a number on a map. While in practice the transaction concerns one solid object. However the 2D registration in the Cadastre does not allow for other ways of property registration.

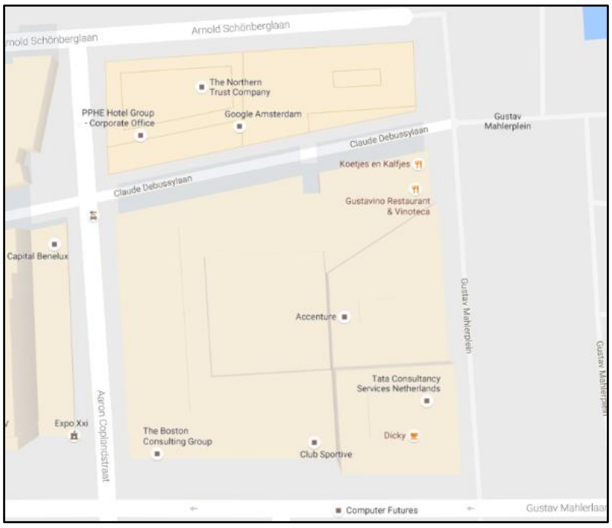

FIGURE 2.1: CLAUDE DEBUSSYLAAN 5 AMSTERDAM SOUTH AXIS, SOURCE: GOOGLE MAPS

FIGURE 2.2: OWNERSHIP REGISTRATION OF CLAUDE DEBUSSYLAAN 5, SOURCE: DUTCH CADASTRE

Another important aspect of real estate transactions is the marketing of properties. A general saying is "A picture may be worth a thousand words but a map tells a storeys" is quite accurate within the real estate transaction domain as both are used in the marketing of properties. In sales brochures or investment memoranda of real estate property visualisation of properties is included as well as maps used to describe property location and environmental characteristics. The combination of both has since recently been used in real estate as well, using 3D visualisations to present new developments of areas (Vastgoedmarkt, 2016).

2.2 The relation between GIS and real estate

Many studies can be found that utilize the capabilities of GIS within real estate valuation and transaction applications. The reason that specifically GIS is used in these applications is mainly driven by the factor location which is an essential factor in both GIS as real estate. Examples can be found in both the literature as well as in practice.

2.2.1 Studies on GIS in real estate applications

Since the early 90's GIS have become of increased use as a system for the analyse of spatial and thematic information of geographic objects (Stoter & Zlatanova, 2003). GIS are extensively used in the analyses of spatial data and are part of different real estate valuation methods. The accuracy of geographic data is of most importance to GIS users while location is the primary factor that influences real value property. A GIS captures and analyses data and visualises the data on map. It allows for real estate advisory firms to comprehend and analyse all data applicable to an object (ESRI Nederland, 2016). Using a map as a product of a GIS speaks to the users and viewers since it exposes the relationship of an object and its surroundings (Donlon, 2007).

Different studies describe the use of GIS in real estate applications (section 1.1.3). These studies acknowledge that location is one of the main variables that is of influence on the value of real estate property. Lomax (2015) has the same conclusion and specifically mentions that the use of GIS adds value in real estate valuations. However Lomax mentions that even though GIS technologies are widely available, the adoption of the full power of GIS, meaning the full and complete integration of GIS and data in a common database, is in the real estate industry rather slow. As a possible explanation Lomax (2015) mentions that the applications used in the real estate industry often operate independently from each other and users have to interact manually as if handling isolated databases. If GIS and real estate data would be fully integrated, one would be able to select and query a specific property on a specific location and have all relevant information presented (Lomax, 2015). GIS are able to visualise data on a map by extracting data from multiple underlying datasets. By extracting this data and visualising relevant information on a map, professionals are able to analyse the data in a more efficient way. According to van Wijk (2006) the traditional purpose of visualisation is to gain insight. Visualising data enables users to gain insight in data and discover information they were not aware of. This helps to define new queries, hypotheses and models. However, van Wijk (2006) mentions that it is hard to measure exactly how much extra insight is achieved through visualisation and therefore it is hard to determine to exact added value of data visualisation. Apart from the exact value of data visualisation the general added value is within the fact that is easier to comprehend, analyse and discover phenomena within data according to GuoDao, RongHua, FuLi, & HuaMin (2013). Indicating the challenging aspects of real estate market data such as the high dimensionality and complex spatial patterns they proposed a web based visual analytics system. This systems allows users to comprehend complex data from real estate markets in China by visualising large and complex datasets on maps and charts.

2.2.2 Practical applications of GIS related to real estate

Dutch government agencies are utilizing the capabilities of GIS as well. They use GIS to share and store property and land related data regarding ownership, functions of property and legislation through different 2D GIS applications:

1. **BAG viewer**[11]: provides information regarding construction year, function and object size;
2. **Cadastre**[12]: provides information of the rights, restrictions and responsibilities (RRR), the interest holder and property valuation for taxes;
3. **Zoning plans**[13]**:** ("Ruimtelijke plannen"): provides zoning plans and formal building legislation.

These applications are often used in real estate valuation and transactions. The BAG for example provides content to link real estate transactions to a location. Each building and unit has a unique identifier. This technique is currently being used at real estate advisory firm Cushman & Wakefield. They are one of the first to provide spatial analysis as additional service (ESRI Nederland, 2016). Cushman & Wakefield being one of the first is in line with earlier findings of Lomax (2015) that GIS has not been fully adopted in the real estate industry thus far. Even though GIS has not been fully adopted in the real estate industry already new developments in the GIS domain emerge. Both scientific researchers as well as professionals see the relevancy of adopting 3D GIS. Dollner, Baumann & Buchholz (2006) already stated that increasing number of applications incorporate virtual 3D city models and specifically mention that real estate portals may want to use this technique to visualise vacancy, construction year and average rents. This potential of 3D is also seen by Cushman & Wakefield. Since not all data is applicable to only an X- and Y-coordinate on earth but a Z-coordinate as well 3-Dimensional GIS could add an extra dimension to this data visualisation according to Boonen[14] (in: ESRI Nederland, 2016). Lomax (2015) states that technological innovations such as 3D GIS provide benefits to multiple stakeholders in the real estate industry. An example are stakeholders such as real estate appraisers. Zhang, Li, Liu, & Liu (2014) studied the capabilities of 3D GIS to count for variables as landscape and sunlight on the value of real estate. While the stakeholders involved in using the BAG, Cadastre and zoningplans applications could benefit from 3D as well.

11 (https://bagviewer.kadaster.nl/lvbag/bag-viewer/index.html)

12 (http://www.kadaster.nl/web/show)

13 (http://www.ruimtelijkeplannen.nl/web-roo/roo/?)

14 Head of research at real estate advisory firm Cushman & Wakefield

According to Stoter (2015) the BAG and zoningplans are applications that could benefit from 3D visualisation.

2.3 The use of 3D GIS in real estate

The previous section describes the importance of location on the value of real estate. To account for this factor GIS have been used in different real estate applications. According to different studies GIS can be used for a more quantitative analysis of spatial, real estate related information (Wyatt, 1997) and to help comprehend and analyse data by visualising real estate data in a GIS environment (GuoDao, RongHua, FuLi, & HuaMin, 2013) & (Lomax, 2015). Section 2.2 also briefly mentions why 3D city models could be used instead of 2D GIS. Since real estate related data is not only applicable to an x and y coordinate but a height coordinate, as well 3D GIS could potentially add an extra dimension. Besides this statement several other arguments support using 3D city models in real estate applications. These arguments are presented in this section.

2.3.1 Developments in 3D availability, capability and demands

There are different developments ongoing that improve the availability of data and 3D city models, increase the capabilities and the increasing demand for using 3D GIS. Within the Netherlands the amount of available 3D data models of different cities is growing (Stoter, 2014). Some of these models, for instance the 3D city models of Rotterdam, are available to be utilized by the public. Models of other cities like Amsterdam have been developed by CyberCity3D[15] but are not yet available to the public. This also applies to the 3D city models created for the cities Eindhoven, Leiden and Breda by LuxCarta[16]. The fact that most available models cost money might be an obstacle for real estate companies to utilize this 3D models. This has been noticed by Almeida, Lu, Ellul & Rodrigues-de-Carvalho (2014) as well. They found that in specifically urban planning processes geo information in not part of the process because of different stakeholders are not willing to invest in 3D data, techniques and applications. According to ESRI (2014) it is important to establish in advance what the costs are of creating or utilizing a 3D city model and the benefits that will likely be achieved. Referring to the initial problem statement (section 1.2) that there are no clear use case to apply 3D city models in real estate valuation and transaction applications, it seems important that these use cases are clearly established in advance. Therefore until then, 3D city models could be more considered as an addition to 2D GIS. Which is in line with findings by Ujang, Azri & Rahman (2015) that even though the availability of 3D city models is increasing, these models are currently seen as a separate add-on within the geospatial infrastructure. However their research states that it is expected that these models become a natural part of the geospatial infrastructure in the future. User demands and developments in data acquisition technologies are the two main factors influencing this trend according to Ujang, Azri & Rahman (2015). Their conclusion regarding the increasing user demand is derived from previous studies indicating that 3D technologies provide a realistic view of the environment allowing users to more easily comprehend real world problems. This argument is supported by Stoter (2015) as well, specifically stating that the world around is in 3D and we therefore should structure our information accordingly. ESRI (2014) mentions an important consideration that has to be made when creating or using a 3D city model. They notice two developments in 3D city models where one model provides a realistic view of the environment (figure 2.3) while the other provide more procedural buildings (figure 2.4). One model allows for perhaps a more realistic understanding of an environment while the other provides a clean visualisation and enables the use of queries and analysis.

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15 www.cybercity3D.com

16 http://www.luxcarta.com

FIGURE 2.3: PICTURESQUE APPROACH PROVIDING A REALISTIC IMAGE OF AN ENVIRONMENT (ESRI, 2014)

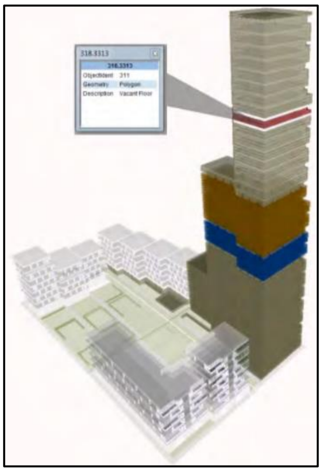


FIGURE 2.4: PROCEDURAL BUILDING PROVIDING A MORE CARTOGRAPHIC IMAGE OF A BUILDING (ESRI, 2014)

There are some users that already noticed the added value of 3D city models and used these models in different applications, of which the real estate related applications are described in section 3.3. An example is from Cagdas (2012) who noticed that when adding additional information to 3D city models by means of an ADE, these models could be used for property valuation purposes. Others have used the capabilities of 3D models to find comparable sales units for valuation purposes (Liu, Yu, & Zhang, 2014). On the other hand Isikdag et al. (2015) conclude that different real estate valuation applications do not benefit from the possibilities 3D city models have to offer. Which is according to their research mainly caused by the lack of awareness of the possibilities these 3D models have to offer.

Even though there are many developments in the field and utilization of 3D city models going on, the full integration of this technique has still to come. The availability, costs and user demands are primarily of influence on the future developments of the utilization of 3D city models in practice.

2.3.2 Use of 3D models in other industries

3D data models have proven its added value in different real estate related sectors other than real estate valuation or transactions. For instance in real estate property management, real estate development and within the architecture, engineering and construction (AEC) industry (Eastman, Liston, Sacks, & Teicholz, 2011). Within the real estate property management and development domain the utilization of 3D building models is in its early stage while the AEC industry has full adopted this 3D building modelling technique known as Building Information Modelling (BIM). The main difference of BIM with 3D city models is that BIM models only contain the model of one single building while CityGML is aimed at representing a city in 3D.

The advantages of using 3D models of buildings over 2D models has been noted by the AEC industry with the implementation of BIM. Instead of sharing data of a building by means of 2D drawings a 3D BIM model is created to store and exchange data of a building. A BIM model is a semantically rich 3D representation of a building that holds extensive amounts of information regarding different attributes of the building. BIM was originally created in order for different experts to be able to design simultaneously within the same building model. They do so by, among other things, exchanging all data in the same file format: the Industry Foundation Class (IFC). This shared file format has increased the interoperability between different fields of expertise within the AEC industry. Gómez-Romero, et al. (2015, p. 202) states that a BIM is “a shared knowledge resource of information about a facility”. Based upon the characteristic of a BIM, El-Mekawy, Paasch, & Paulsson (2014) conclude that a BIM could be utilized for not only visualisation applications but for spatial analyses as well. However the manual work involved in creating a BIM is found to be the main reason why BIM is not widely used for existing buildings. CityGML would therefore be a suitable 3D file format for real estate use cases in which the visualisation or analysis of existing buildings is required. This file format can be seen as the 3D city model equivalent of a BIM to share data. An important feature of a BIM is that its capabilities exceed the design phase and provides added value throughout a building its life-cycle (Gómez-Romero, et al., 2015). Since property valuation is primarily about existing buildings, long past the initial design phase, one could assume that CityGML can add value throughout the life cycle of existing buildings. This assumption is supported by Isikdag Et al. (2015) who state that BIMs contain valuable information for valuation of new properties but the utilization of CityGML provides opportunities in the valuation of existing real estate. In the past few years extensive amounts of research and work has been conducted to improve the exchange format and capability of IFC and the operability with CityGML. However much work and applications of data exchange technologies have tended to focus on the AEC industry alone while the commercial real estate industry lagged behind (Mahdjoubi, Moobela, & Laing, 2013). Therefore the use of 3D city models has not been embedded in the daily activities of real estate professionals like BIMs have in AEC industry.

2.3.3 Increased usefulness of 3D over 2D

Compared to 2D, data models in 3D are useful for visualisation and analytical purposes. Based upon three previous studies Liu, Yu, & Zhang (2014) conclude that 3D GIS could provide real estate professionals with a more professional decision making assistant than 2D GIS. Even though Lomax (2015) state that even 2D GIS has not been fully adopted to its potential, Lomax already refers to 3D GIS as the new important development. Lomax acknowledges the potential usefulness of 3D for real estate professionals but makes an important note. Lomax (2015) state that 3D models are nice to look at but the practical application, usefulness and value is limited for the real estate industry if they remain just simple polygons (white boxes, figure 2.5). This indicates the importance of the LOD of a 3D city model. Up to LOD 2 a city model consist of only polygons forming one solid building. From LOD 3 buildings are containing more information on specific parts, floors and units (Section 1.2.1.2). Visualisation of simple 3D polygons has been found useful however in some applications. Study has found that a simple 3D visualisation appears to improve an urban planners mental image of buildings and its influence on the surroundings (Herbert & Chen, 2015). On the other hand, semantically rich and detailed 3D models are used beneficial within various real estate related domains as well (section 2.3.2). The required semantical richness of a model is different per application and use case.

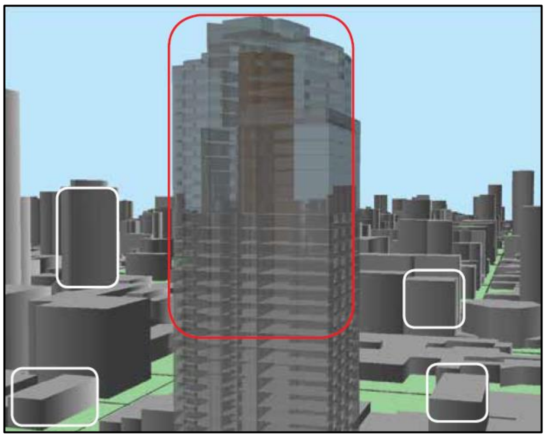


FIGURE 2.5: LIMITED USEFUL 3D OBJECT CIRCLED WHITE, POTENTIAL USEFUL OBJECT CIRCLED RED, LOMAX (2015)

Herbert & Chen (2015) notice the increasing demand of data users for 3D representation but argue the usefulness of 3D compared to 2D in some cases. Little research has been conducted on the perceived usefulness of 3D over 2D. Their research found that in certain applications 2D was preferred over 3D visualisation while in others a combination of 2D and 3D was preferred. It is therefore important to first analyse what the main applications are that actually require 3D instead of 2D visualisations (ESRI, 2014).

2.3.4 Practical application of 3D GIS in real estate application: The cadastre

The Dutch Cadastre is currently the first authority worldwide experimenting with 3D models for ownership registration (Stoter, 2015). The Dutch cadastre made the shift from 2D towards 3D property rights registration in a test use case. In this test use case a rather complex ownership situation was present that requested an alternative registration of property rights than the 2D cadastre provided. In other countries and among others Sweden, 3D information is already provided for but is still begin re-modelled. In Sweden property rights have been registered as 3D property data but in the actual Cadastre the 3D data is solely provided for in plain text (El-Mekawy, Paasch, & Paulsson, 2014). The information is somehow ''lost'' in the process and stored separately from the 2D cadastre. To be able to visualise 3D property data in the Cadastre, research is conducted on the interaction of 3D property data and BIM. Based upon the characteristic of a BIM, El-Mekawy, Paasch, & Paulsson (2014) conclude that a BIM could be utilized for not only visualisation applications but for spatial analyses as well. However the manual work required in creating a BIM, the different stakeholders involved and the need for different datasets are found to be the main reasons why BIM is not widely used for existing buildings according to Isikdag & Zlatanova in El-Mekawy, Paasch, & Paulsson (2014). A first requirement can be derived from this statement: the manual work should be less compared to a BIM. This is the case with automatically generated 3D city models from the BAG and AHN (section 1.4).

2.3.5 Main argument influencing the use of 3D GIS in real estate

To summarise, different developments led to increasing possibilities to utilize 3D city models in different use cases. These developments are supported by the increasing availability of 3D city models to which a side note has to be made that not all models are available for free. Without a clear use case and the (financial) benefits of using a 3D model, these investments will likely not be made. This partly explains why 3D models are up till now still seen as a separate add-on. In the other real estate related industries 3D models have been used with benefits over 2D models. Especially BIM in the AEC industry has proven its added value in among others data exchange. CityGML is seen as an alternative to BIM when 3D models of multiple existing buildings are required. These models could provide decision makers with a better assistant compared to 2D models. However the usefulness per use case depends on the quality of the model and also whether the use case actually requires a 3D model instead of a 2D model. The Dutch cadastre is worldwide the first to use 3D models in the registration of property ownership. The use of 3D models in cadastre ownership registrations has been done in other countries as well. The main conclusion that is drawn from this studies is that using BIM models of buildings for property registration requires too much manual work. This conclusion supports the use of automatically generated 3D models such as CityGML.

2.4 Shift from 2D to 3D GIS

The previous sections in this chapter indicated the relation between real estate applications and GIS. It primarily addressed the common factor of real estate and GIS: the location. It then provided arguments why 3D city models could be used in real estate applications. This sections aims to gain insight in the requirements of the process of making the shift from 2D towards 3D GIS.

2.4.1 Selection of the file format

A consortium founded by the TU Delft (University), Geodan (ICT Company) and Geonovum (Government) acknowledges the need for 3D city models in the Dutch built environment. As a problem for the large scale adoption of 3D technology in the Netherlands they mention that 3D activities are currently fragmented throughout different organisations. The results are many non-coordinated 3D techniques and applications providing too expensive and non-conclusive cases for both government and private companies (Scholten, Stoter, & Velde, 2014). It can derived from this statement that it is wise to adopt one 3D technique and use this for further development. ESRI (2014) stated that a first challenge for businesses is to gain understanding in what type of 3D building models are available along with the advantages and shortcomings of each. In this research CityGML is repeatedly mentioned as 3D format. Multiple arguments support the use of this format:

- Different studies have already discussed the use of CityGML (section 1.1.4)
- 3D CityGML models can be automatically generated (section 1.1.4)
- CityGML is considered to be main 3D extension of GIS (section 1.1.5)
- The publicly available datasets are in the CityGML format (section 1.1.5)
- CityGML capable of holding semantic information of properties (section 1.1.5)
- The file format can be extended in different ways section (1.1.5)
- CityGML is adopted as European standard by the OGC (section 1.1.5)

Other 3D data models described are aimed at the geographic representation of buildings and lacked semantic representation. Therefore the CityGML file format is further used in this research.

2.4.2 Process of moving to the use of 3D GIS

In order to move to 3D GIS it is important to define the primary applications in which 3D data would be required and who the users of this applications are (ESRI, 2014). An example of an application is the utilization of 3D GIS to improve sales comparison approach in real estate valuation by Yu, Liu, Zhang (2014). The application is "sales comparison approach" which is one of three widely adopted valuation methods (section 2.1.1). The users in this application are the appraisers in the real estate industry. A next important step described by ESRI (2014) is to examine the tools and workflow needed to convert 2D GIS data to 3D and what the possible costs and added value could be. Another important question is what the required accuracies of model should be and whether the primary application is just visualisation or spatial analysis as well. The last important factor in developing a 3D application is to consider the future growth plans and maintainability. Bayers et al (2015) describe a somewhat similar approach by stating that first a use case should be made clear. To do so, some important steps have to be considered in the process of making the step towards 3D data (Bayers, et al., 2015):

1. Identify the best practices on added value of 3D over 2D;
2. Identify the requirements of the data content;
3. Improve the awareness of 3D data;
4. Determine the business opportunities that can be realized in 3D applications.

The guidelines provided by ESRI (2014) and Bayers et al (2015) provide multiple steps that should be considered in moving from 2D towards 3D data models. These steps are used in the remainder of this research.

2.5 Conclusion

This chapter aimed to answer the first sub question:

> *What is the relation is between (3D) GIS and real estate valuation and transaction applications?*

The first section describes that in real estate valuation the location is the most important factor on the value of real estate. Different methods to determine the value of property require spatial analyses. The same applies to real estate transactions and specifically in the registration of property rights. However the main purpose of using of GIS in real estate transaction applications is visualisation. The predominant relation between GIS and real estate is that they both place a high value on location. Therefore GIS has been used in many different real estate applications for analysis and visualisation purposes to comprehend spatial phenomena.

3D GIS is the next development within the GIS domain and could be used for real estate applications as well. One argument that supports this is that most real estate information is not only applicable to an x & y coordinate but to a height coordinate as well. An example is the cadastre in which property rights are registered. A recent pilot in the Netherlands was the first worldwide to register property rights in a 3D model in the cadastre. However the costs involved in creating 3D city models and applications are withholding the full adoption of 3D GIS. Up till now 3D GIS has been seen as a separate add-on in the industry. Based upon increased user demand and technical capabilities of 3D city models it is expected that the use of 3D city models will grow. The usefulness of 3D models does however depend on the representation and the quality of the model. In other industries such as the AEC industry 3D models of buildings have already been used with added value in the exchange of data. The 3D BIM models used in this industry do require a lot of manual work and are therefore not cost efficient to be used in 3D city models, even though BIM could potentially be used in spatial analysis. These BIMs could also be used in the cost approach method of real estate valuation. A large scale counter format of BIM is CityGML that is considered to be the main standard in 3D GIS. This file format can be generated automatically from the Dutch BAG dataset and the AHN.

To adopt 3D city models into real estate valuation and transaction applications it is important to define what the applications are and who the users are. Also the requirements of the model have to be considered: what accuracy is required and is the application focussed on visualisation and analysis. Another important factor is to determine the added value of the using 3D instead of 2D. Then a use case can be formed. Based upon the use case the possibilities can be examined regarding the tools and workflow needed to converted 2D GIS data to 3D. This process is also adopted in this research. The next chapter starts with describing the purpose and added value of using 3D and then evaluates different use cases in which 3D city models are utilized.

The most important conclusion of this chapter is that the relation between GIS and real estate applications is defined by the common importance both applications place on the factor location. The second most important conclusion is that GIS is used in real applications to visualisation or analysis complex and vast amounts of data applicable to real estate. The third conclusion is that the use of 3D GIS over 2D is influenced by the increase in user demands and the technical capabilities of 3D GIS.

Chapter 3. State of the art in 3D real estate use cases: purpose and added value

The previous chapter provides an introduction on real estate valuation and transactions and why (3D) GIS is used in this applications. In this chapter an answer is sought to the sub question:

For what purpose and added value is 3D GIS currently used in real estate valuation and transaction applications (state of the art)?

First the purpose and added value of using 3D city models is tried to establish in section 3.1. In the section 3.2 the purpose and added value is combined with the structure of the use cases and a framework is proposed. Then, in section 3.3 the state of the art is described based upon use cases found in the literature. In the next section an overview is presented of the different use cases along with the involved spatial operations and the required quality of the 3D city model. The final section of this chapter concludes by answering the third sub question.

3.1 Defining the purpose and added value of the use cases

In chapter 2 an elaboration is given on why 3D GIS could be used in real estate valuation and transaction applications. According the Geonovum (2011): ''*the potential of 3D beyond nice visualisation is not easy to quantify*''. This is however one of the first steps required in making the shift from 2D towards 3D according to Bayers et al (2015). The first step described in the research is to identify the best practise on added value of 3D over 2D. Before describing the state of the art in 3D use cases it would therefore be wise to identify this best practise on added value. This section aims to quantify the potential by first defining what the purpose of using a 3D city model is. Next this section tries to determine what the potential added value of using 3D city models in real estate valuation and transaction use cases could be.

3.1.1 Purpose of 3D city models

One of the main purposes of 3D city models mentioned in different studies[17] and papers is visualisation. The aim of this visualisation is to gain insight in data which could otherwise not be obtained by using 2D visualisations. Visualisation has many different forms but for the purpose of this research a more technical definition is adopted that is more in line with the computerisation trend mentioned in section 1.1. In this case the definition of Card, Mackinlay and Shneidermann in Fekete Wijk, Stasko & North(2008) is adopted in which they define visualisation as: ''the use of computer-supported, interactive visual representation of data to amplify cognition''. Visualisation in this case should increase the cognitive capabilities of a user to comprehend data by means of a computer supported visualisation. The usefulness however of 3D visualisations over 2D visualisation could be argued (Herbert & Chen, 2015) and as stated in section 2.3.3 should be examined per use case. The other main purpose of using 3D city models is the perform analytical tasks in an automated way[18]. Also the usefulness of 3D city models for analysis could be discussed, especially when buildings in the model remain "empty shells" (Crooks, Hudson-Smith, & Patel, 2011). According the ESRI (2014) the consideration of what the purposes of the 3D map will be: visualisation or spatial analysis should be done in advance. This will help in the development process of the 3D application.

3.1.1.1 Visualisation purpose

The purpose of visualising data is to enable different stakeholders such as researchers, analysts and engineers to obtain insight in data in an efficient and effective way (Van Wijk, 2005). In this

17 Studies: (Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova, 2015) (Fuchs, Hubert, Pouliot, & Wange, 2014) (Herbert & Chen, 2015) Papers: (ESRI, 2014) (Lomax, 2015)

18 (Liu, Yu, & Zhang, 2014) (Tomic, Roic, & Mastelic Ivic, 2012)

aspect and considering that visualisation is "computer supported" the value of visualisation for analysis purposes could be discussed in comparison to the Data Mining technique which is briefly mentioned in section 1.1. The purpose of Data Mining is to search for connections or phenomena in large datasets by means of computer supported programs. However research has shown that even the most advanced automatic analysis methods where not capable of finding some phenomena in data that the human eye could find using visualisations (Keim, et al., 2008). A combination of data mining techniques and visualisation could proof useful however according to Keim et al (2008). This method is also described as visual analytics in which automated analysis techniques are combined with visualisation for understanding, reasoning and decision making.

3.1.1.2 Analysis purpose

Biljecki Et al. (2015) specifically mentions the increasing utilization of 3D city models, not only for visualisation tasks but a vast amount of other tasks as well. Solar potential estimations of roofs, shadows estimations of houses and visibility analysis from houses are some examples. To use 3D city models for analytical purposes these models should contain more than buildings as "empty shells" (Crooks, Hudson-Smith, & Patel, 2011). Socio-economic data should be attached to the building shells. As an example Crooks, Hudson-Smith & Patel (2011) mention that the building shells could be linked to datasets with residential and commercial property information. The purpose of 3D city models in different use cases could basically be divided into either visualisation or analysis. Visual analytics as described by Keim et al (2008) is a combination of these two purposes. It is important to notice that the achievability of a certain purpose strongly depends on the quality of a 3D city model and the data it contains. The more semantics and information a model contains the more advanced analysis can be made.

3.1.2 Added value of 3D city models

Despite of the purpose of visualisation whether it is solely visualisation or analysis as well, there is no consistency in the literature regarding the added value of data visualisation. That 3D GIS adds value over 2D GIS has been acknowledged by researchers from various domains (Almeida, Liu, Ellul, & Manuel Rodrigues-de-Carvalho, 2014). However according to Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) the added value of the ways in which 3D city models are used is often unclear. To overcome this challenge they proposed a hierarchical terminology and developed a theoretical framework to catagorise the different use of 3D city models. In this section first the challenge of defining the added value is addressed. The next section seeks to address the hierarchical terminology of the use cases.

3.1.2.1 Added value in visualisation

Visualisation is considered to have a key role in the successful analysis of geo-spatial information (Keim, et al., 2008). The value of visualisation depends on the point of view the user adopts according to Van Wijk (2005). From a real estate perspective users try to gasp the value and attributes of a real world object at a real location on earth. The traditional aim of visualisation is to gain insight, insight however is hard, if not impossible to measure. A technological approach on the value of visualisation could be adopted which is aimed at assessing the costs and benefits. Visualisation would then be measured in terms of effectiveness and efficiency. In this case the cost and benefits of using a 3D city model could be assessed (Van Wijk, 2005). This technical/economic point of view is supported by Fekete, Wijk, Stasko, & North (2008). They state that visualisation has to be effective and efficient and the added value should be considred from the outside. Thrall in Yu, Lui & Zhang (2015) also mentions that utilizing the full potential of GIS would improve efficiency in the real estate and related industries. This means that an attempt should be made to measure the profit a visualisation resultates in. The profit is defined as the value of the increased knowledge and the cost made to create the visualisation. However the increased knowledge remains hard to quantify and therefore measure. The time however it takes to obtain knowledge, and therefore the effiency could be measured.

3.1.2.2 Added value in analysis

The second purpose of using a 3D model could be analysis, meaning that analysis is performed on the raw data of the model itself, not on the visualised information. In this case the added value is rather simple to define. Height could for example not be derived from a 2D GIS if height is not added as a specific attribute. An example of a use case is the calculation of the effect that a flood will have on homes near a shore line (Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015). If besides automated analysis a form of manual analysis is required by means of visualisation the added value could also be measured in term of efficiency and effectivness. This method is described in section 3.1.1.2 as visual analytics in which visualisation is added for understanding, reasoning and decision making (Keim, et al., 2008).

3.2 Structure of the use cases, their purpose and added value

The previous two section explain how the purposes and added value using 3D city models in real estate could somewhat be defined. Before the purposes and added value could be related to the use cases that are examined in section 3.3, first the structure of the use cases and their relation to real estate applications is described.

Studies described the use of GIS to perform different real estate related spatial operations. These spatial operations can be related to a certain use case, for example finding comparable sales records. This use case is part of the application real estate valuation. Some use cases could also be part of more applications while some spatial operations could be required for in multiple use cases. To structure the use cases Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) created a model that shows the relation between applications, use cases and spatial operations (figure 3.1). This model divides uses cases into different applications (dotted box), and within the use case (solid box) different spatial analysis (blue lines) could be performed.

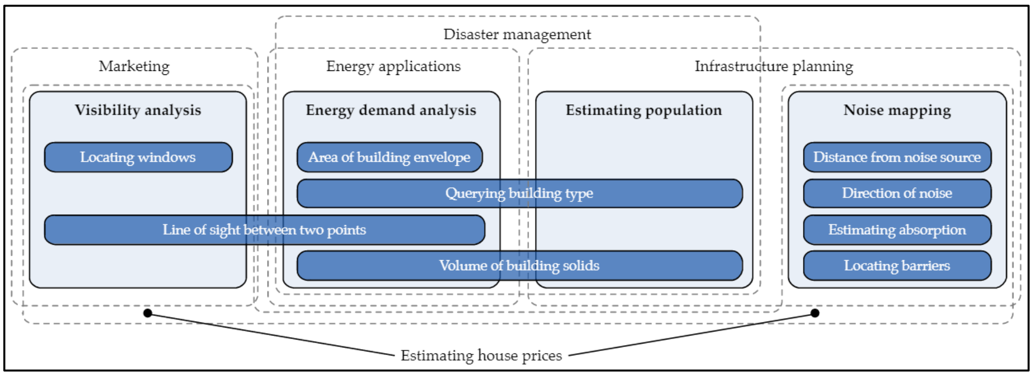


FIGURE 3.1: RELATION BETWEEN APPLICATIONS, USE CASES AND SPATIAL OPERATIONS (BILJECKI, COLTEKIN, LEDOUX, STOTER, & ZLATANOVA, APPLICATIONS OF 3D CITY MODELS: STATE OF THE ART REVIEW, 2015)

In section 3.3 each use case is described and related the real estate application it is part of and the spatial operations it includes. A use case describes the requirements of a system from a user perspective. The use case methodology is used to identify, clarify and organize the requirements of a system and can be defined as a sequence of actions to arrive at or achieve a certain value to the user. The definition of a use case as stated by Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) is adopted. This defintion is specifically applied to GIS and 3D city modelling: "*a use case can be seen as a meaningful set of spatial operations that accomplisch a goal a user wants to achieve with a spatial data set*". In this definition a use case is connected to a specific discipline as for example: real estate valuation. In the case of this research the system would need to visualise certain bits of information from underlying datasets in a 3D representation of a city. The users would in this case be real estate valuation and transaction professionals.

3.2.1 Constructing a framework

In theory every dataset or GIS is possible to integrate with 3D. However this does not mean that the value of the data or analytical possibilities increase. As indicated in the previous sections the added value is hard to quantify. The only quantification that could potentially be used is to assess the added value in terms of efficiency and effectivity.

Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) found that it is indeed hard to catagorise the use and addedd value of 3D use cases. Their research determined that the only research in the added value of 3D over 2D has been done by Herbert and Chen (2015) and that other studies in this category are rare. They found that only suitable aspect in the taxomy of using 3D is the visualisation aspect. Therefore to determine which datasets and therefore use cases, could potentially benefit from 3D city models a distinction is made in two types of use cases (Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova, 2015):

1. Non-(required)visualisation use cases: Use cases in which 3D city models provide solely a digital visualisation of the built environment and do not require visualisation and/or the results of spatial operations.
2. Visualisation based use cases: Use cases that require performing computations and spatial operations that are solely possible with 3D data models and in which visualisation is very important, and the use cases that are possible with 2D/2.5D GIS data but do significantly benefit from 3D data models for the communication of information;

The first distinction beholds use cases in which the visualisation of data in a 3D city model has no added value over 2D visualisation other than a "nice to have'" visualisation. An example is the calculation of the solar potential of roofs by a distributor of solar panels. The outcome of this calculation can be stored in a database without added value in visualisation of the results, the distributer would only like to know which home addresses he could approach. The 3D model in use case is solely used to derive roof shapes and angles from.

Within the second definition of Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) I would argue that two sub types of use cases can be distinguished. The first sub type describes uses case that require performing computations and spatial operations (e.g. analysis with computers) and require visualisation. An example of a use case that requires a 3D model for analysis and does require visualisation as well is the floot calculation use case. In this use case 3D model of an area close to the sea is used to calculate which homes that are subject to the possibility of a flood. The purpose of this use case is to calculate which homes are at risk and provide urban planners with information on how to acount for the risk. In terms of communicating this risk visualisation is required. The second visualisation use case that can be distinguished describes use cases that do significantly benefit in terms of communication of information by visualisation in 3D. An example is the 3D cadastre registration from the Delft train station (SpoorPro, 2016).

Thus three distinctions can be formed:

1. Non required visualisation use cases: these use case have no added value by **visualising** the results;
2. Visualisation use cases (1): these use cases require **visualisation** and are possible with 2D/2.5D but do significantly benefit from 3D visualisations;
3. Visualisation use cases (2): these use cases require **analysis** in terms of spatial operations and computations on the 3D model and **visualisation** is very important.

This separation is comparable to fundamental distinctions made in the use of GIS for spatial analysis. Spatial analysis in GIS includes three types of operations: attribute query (non-spatial),

spatial query, and generating new datasets from an original database (Raju, 2004). The attribute query requires attribute data to be queried endepedently of spatial information. For example query the database for all roofs of houses the are larger than x sqm, no visualisation required. An example of a spatial query is a query that aims to obtain all vacant office floors in area that are more than 20 meters above the ground. 3D visualisation in this use case would significantly benefit over a 2D visualisation. Also Zhang, Li, Liu, & Liu (2014) specifically mention a seperation in the use and added value of 3D GIS in three topics: 1) spatial database management, 2) 3D spatial visualisation and 3) 3D spatial analysis.

Considering that no other studies on the topic of the usefulness of 3D over 2D are available and that it is hard to determine how the added value can be measured the distinction as described above is used. In relation to GIS, the main purpose of GIS which is visualisation and analysis and comparable seperations made in research, this distinction seems most feasible. To construct a bridge between the purpose of using 3D models – the added value and the use cases a framework is proposed (figure 3.2)

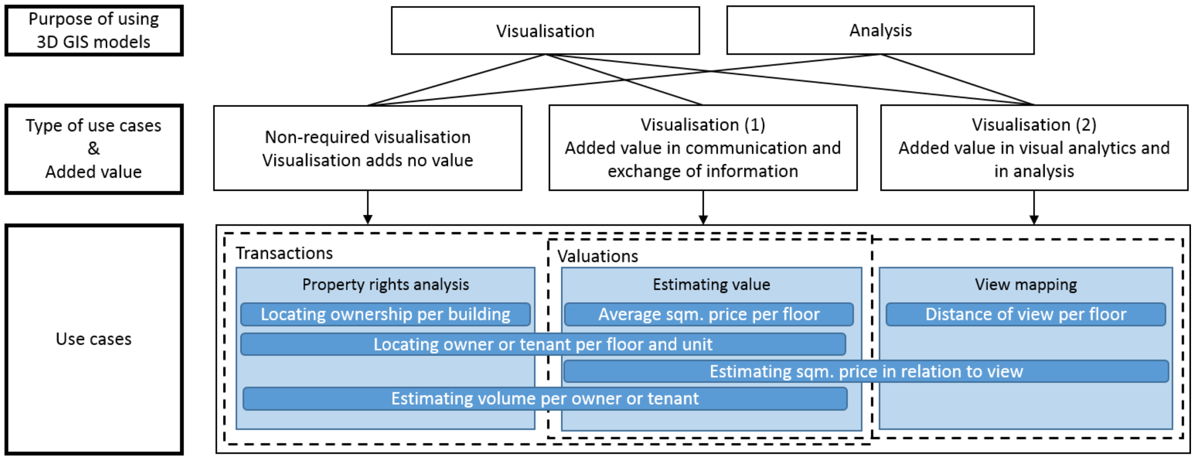


FIGURE 3.2: FRAMEWORK OF PURPOSE AND ADDED VALUE RELATED TO THE GROUPING OF USE CASES FROM BILJECKI, COLTEKIN, LEDOUX, STOTER, & ZLATANOVA (2015)

The framework describes that a 3D model in real estate applications can either be used for the purpose of visualisation or analysis. Both purposes can result in a use case that does not require visualisation per-se to obtain added value. Examples are using 3D models to visualise the amount of energy used per building (e.g. a 2D map would suffice as well) or using 3D models to analyse the solar potential of roofs (e.g. the results in a database would suffice). The only purpose of visualisation (1) use cases could be visualisation considering this types of use case could also use 2D/2.5D models, 3D models in this type of use case only provide better understanding of information. An example of this type of use cases is the "change detection" use case in which 3D models are used to detected where in a city homes have been expanded. The purpose of visualisation (2) use cases is visualisation to perform visual analytics. An example is the flood use case (e.g. perform a visual analysis on the result of a computerised analysis). In the visualisation 1&2 type of use case the added value of using a 3D city model could be assessed in terms of efficiency and effectivity (section 3.2.1).

In the next section the state of the art in the utilization of 3D city models in real estate valuation and transaction applications is described. The use cases in which 3D city models are utilized are described using the framework from figure 3.2. Besides the purpose, added value and structure of the use cases a connection is made to the required quality of the 3D model in terms of the Level of Detail (LOD).

3.3 State of the art: 3D city models in real estate valuation and transactions

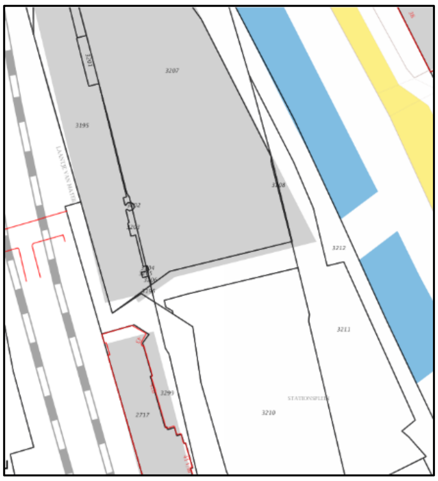
A study on the available literature on the topic of 3D city models utilized in different applications identified multiple real estate related use cases. Six of these use cases were described within the literature or in practise to the extent that they could be used in this research (table 3.1).

TABLE 3.1: USE CASES WITH 3D CITY MODELS IN REAL ESTATE APPLICATIONS

Section	Use case	Application(s)	Source
3.3.1	3D property ownership registration	Real estate transactions	(Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova, 2015) (SpoorPro, 2016) & (Almeida, Liu, Ellul, & Manuel Rodrigues-de-Carvalho, 2014)
3.3.2	3D zoning plans	Real estate valuation	(Berlo & Dijkmans, 2013)
3.3.3	Property valuation and taxation	Real estate valuation	(Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova, 2015) & (Isikdag, Horhammer, Zlatanova, Kathmann, & Oosterom, 2015), (Cagdas, 2012)
3.3.4	Mass valuation of real estate properties	Real estate valuation	(Tomic, Roic, & Mastelic Ivic, 2012)
3.3.5	Identifying comparable sales units	Real estate valuation and transactions	(Liu, Yu, & Zhang, 2014) & (Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova, Applications of 3D city models: State of the art review, 2015)
3.3.6	Vacancy mapping and thematic data in a city	Real estate valuation and transactions	(Dollner, Baumann, & Buchholz, 2006)

3.3.1 3D property ownership registration

Different governments have recently been focussing on the registration of property ownership and rights in 3D. The cadastre which manages and stores different property and land related information does this traditionally on a 2D map connected to an underlying dataset (figure 3.3). The goal of this registration if to facilitate stakeholders with the possibilities to find all property or land related rights and restrictions with regard to the ownership. However buildings have become more and more complex with different ownerships registrations attached to different parts of an object. Therefore some governments are investigating the possibilities to register property rights in 3D instead of 2D (figure 3.4). An example is the Dutch cadastre in cooperation with the municipality of Delft. The property rights of the Delft train station are visualised in a 3D model which is a first worldwide (SpoorPro, 2016). The new train station realised in Delft has three different owners with complex ownership rights throughout the property. The purpose of using a 3D model in this case is to visualise information adding value with a more efficient and effective way of data exchange (type visualisation 1, figure 3.2). Registration of property rights is more efficient this way because it is less time consuming to correctly identify all different property rights. This model adds value in terms of effectiveness because the property rights can now be adequately assigned to spaces and object as small as a pillar or elevator shaft without resulting in complex 2D drawing (figure 2.2). The use case of the 3D cadastre which is a real estate transaction application allows different spatial operations. The main spatial operation is to query the different owners related to one object. The required quality of the 3D model depends on the complexity of the ownership situation.



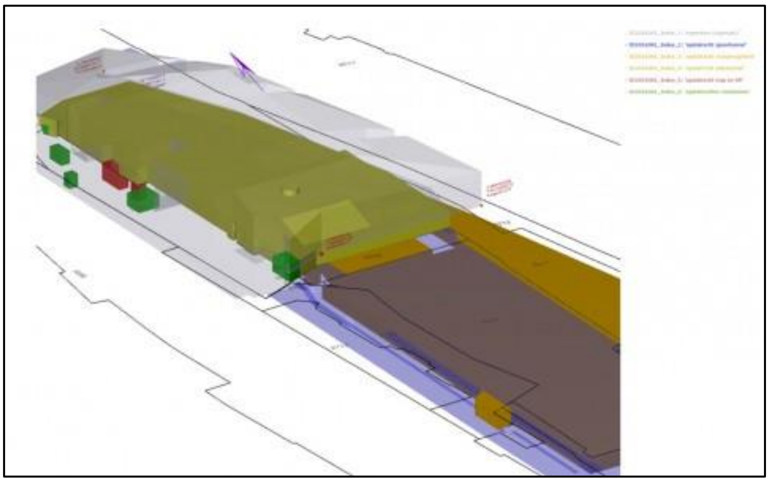


Figure 3.3: 2D registration Delft train station (www.kadaster.nl)

Figure 3.4: 3D registration of Delft train station (SpoorPro, 2016)

3.3.2 3D zoning plans

With the increasing use of 3D models and so called BIM in the AEC industry, Berlo & Dijkmans (2013) proposed a method to digitally approve building permit requests using 3D city models and BIM's. Currently to obtain a building permit, 2D drawings have to be generated from a 3D model to be tested against a 2D zoning plan (figure 3.5). The purpose of using 3D city models for zoning plans is for both analysis and visualisation (figure 3.6). A 3D building model could be uploaded in 3D zoning plan to automatically analyse whether the building is designed according to the basic rules such as building height and volume. With the visualisation possible additional possibilities for the design may occur within the rules set out in the zoning plan. Using 3D zoning plans would add value in terms of data exchange (possibilities of the design and its relation to its surroundings) and analysis (does the building design fit within the legislation). This can be considered a use case of the visualisation 2 type. In GIS terms this use case requires the combination of different datasets (legislation and building models) to analyse clashes or possibilities. The main result would be a more efficient check of new building designs against legislation because drawings do not have to be altered to 2D and manually checked against the 2D zoning plan. The use case 3D zoning plans has different spatial operations of which some are related to the real estate valuation domain. As described in chapter 2, one of the factors of influence on the value of real estate is its legal possibilities and restrictions. Using spatial operations to identify whether a current property is realised according to actual zoning legislation or whether it has potential to be expanded or change in function could be analysed more efficient using 3D visualisation.

Figure 3.5: 2D zoning plan (Berlo & Dijkmans, 2013)

Figure 3.6: 3D zoning plan (Berlo & Dijkmans, 2013)

3.3.3 3D property valuation and taxation

There are different use cases that describe the possibilities of 3D in real estate valuation applications. As section 3 described, there are many different factors of influence on the value of a property. Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) describe a use case in which a 3D city model is used to extract data regarding the floorspace from buildings based upon the Dutch legislation that for example area's where the ceiling is lower than 1,5 meter ar not taken into account for the net area. Visualisation of this data is however not necessary, the information only needs to be extracted from the 3D city model and stored in a database and terefore is a non-visualisation use case. This can be done with city models with only having exterior building data (LOD 1 and 2).

Isikdag et al (2015) stated that 3D city models could be used for the valuation of existing real estate. The research aimed at identifying the information requirements for the three different ways of property valuation and taxation as described in section 3. The research identified multiple operations and therefore needed information requiring 3D city models in property valuation and taxation (Isikdag, Horhammer, Zlatanova, Kathmann, & Oosterom, 2015):

- Deriving volumes and areas to calculate construction costs (cost approach) and determine building net area correctly;
- Deriving walls and windows to calculate for energy labels;
- Estimation of numbers of floors;
- Calculation of the influence of neighbouring homes on the property (sun, level of privacy, visibility);
- Adding environment characteristics by inserting images from Google Earth.

Research by Cagdas focused on the creation of an ADE for CityGML to store the building related legal and administrative data for property taxation. Storing this data in a 3D city model would allow for a more efficient taxation process by municipalities according to Cagdas. The type of use case in this case depends on the variables and operations included, calculating for variables as sun radiation can be considered a visualisation 2 type of use case.

The purpose of the real estate valuation and taxation use cases from Isikdag et al (2015) and Cagdas (2012) is a combination of analysis and visualisation. The use case includes the different operations that calculated required values for property valuation and in some cases uses visualisation from Google Earth for additional valuation capabilities. The LOD required for this use cases is rather high. Walls and windows need to be derived from the model which is only possible in LOD 3+. models These use cases would mainly add value in terms of efficiency, meaning that the operations required could be done quicker than that they could be done manually. However the extracted data could also be stored in underlying databases and visualisation is not essential for each aspect of the use case. Only the operations as the calculation of influence of neighbouring homes and determining the environmental characteristics would benefit from 3D visualisation.

3.3.4 Mass valuation of real estate properties

Section 1.1 of this research described the AVM for mass valuation created by Sprundel (2013). This AVM combines large amounts of data to mass predict the value of owner occupied homes in the Netherlands. Tomic, Roic & Mastelic Ivic (2012) describe how 3D models could be used for the mass valuation of real estate. The research focusses on the visibility polygon of real estate properties as a variable of influence on the value of real estate (figure 3.7). The purpose of the 3D model is to analyse and quantify the visibility polygon for real estate objects in large areas. The added value is mainly in terms of efficiency by performing analysis and visualising the results which makes it a visualisation 2 type of use case. Without the 3D model a broker would have to determine the visibility polygon of a building by going through each floor and making measurements from different positions. With respect to the required LOD, basic analysis could be made by using LOD1-2 models. However in practise visibility can only be accounted for if there is a window or open space in the façade. This would require a model with high interior and exterior quality (LOD4).

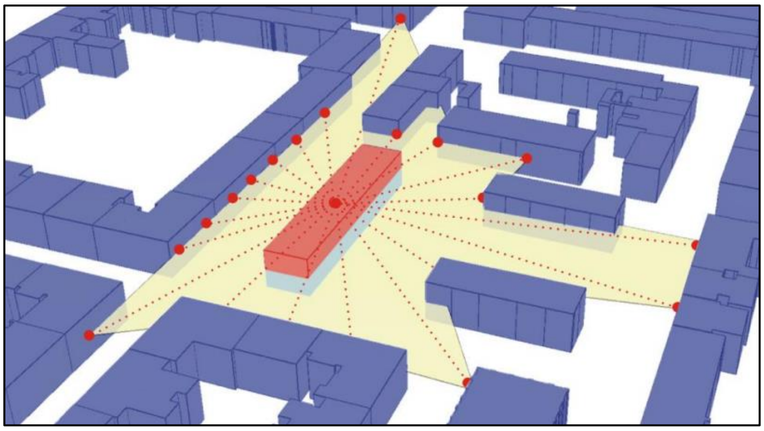


FIGURE 3.7: USING 3D MODELS TO CALCULATE THE VISIBILITY POLYGON (TOMIC, ROIC, & MASTELIC IVIC, 2012)

3.3.5 Identifying comparable sales units

One of three real estate valuation methods described in chapter 2 is the comparable sales approach. This method basically uses sales of comparable real estate object to determine the value of one object. Yu, Liu & Zhang (2014) proposed an improved sales comparison approach based on valuation methods and 3D GIS. Their method is using spatial analysis based upon a 3D city model to find comparable sales units based upon different impact factors on the real estate value. Different impact factors are taken into consideration of which only the 3D measureable factors are within the scope of this research:

- The quality of the view and distances to an ocean, mountain, forest, park etc.;
- The air condition, noise, pollution, power lines etc.

Besides the 3D factors most basic other factors as described in section 2.2 have been taken into consideration as well. The purpose of using a 3D city model to identify comparable sales units is mainly analysis. Different spatial operations are used to calculate for the above mentioned factors. Visualisation is used to present the results on a map and charts (figure 3.8).

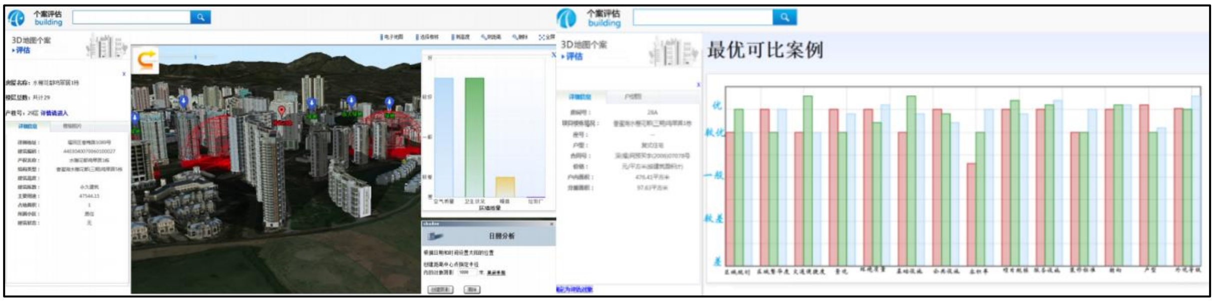


FIGURE 3.8: USING 3D VISUALIZATION ON A MAP AND GRAPHS OF ENVIRONMENTAL DATA (LIU, YU, & ZHANG, 2014)

The added value of this model can be defined in both efficiency and effectiveness. Since the use case requires the combination of datasets and visual analytics this is a visualisation type 2 use case. The model promotes the transparency of the property valuation industry by making comparable sales units easier to identify. While the model also improves the quality of using the sales comparison approach for real estate valuation because it provides for better and more comparable sales units (Liu, Yu, & Zhang, 2014). The required LOD of the city model in this use case has not been defined however, it can be assumed that the higher the LOD the better the found comparable units that were recently transferred are.

3.3.6 Vacancy mapping and other thematic information

In 2006 the added value of 3D city models in conveying spatial related information in a comprehensive way was seen by Dollner, Baumann & Buchholz (2006). Mainly in applications that require analytical and exploratory functionality 3D visualisation could be used. They specifically refer to the different level of abstraction a 3D model could have and state that thematic data require less visual details of buildings since they are not primary interest (figure 3.9). Since their research is from 2006 the actual (potential) use cases they describe have only been described as use case in which they see potential added value with regard to 3D city models. Specifically thematic building data is mentioned as relevant data to visualise in simple 3D city models with less photorealistic appearances. As applications that could be used for information visualisation and data mining they mention building information as: vacancy mapping, ownership and year of construction (Dollner, Baumann, & Buchholz, 2006). This information is used in real estate valuation and transaction applications. The added value of visualising this information on abstract 3D maps is that it provides insight into complex information. The required quality of the 3D model differs per use case. Vacancy and ownership mapping requires the 3D city model to contain different floor levels in a building model while year of construction only requires a simple block or even 2D map. The aim of this visualisation use case is to allow for better understanding and communication of information which makes it a type 1 visualisation use case.

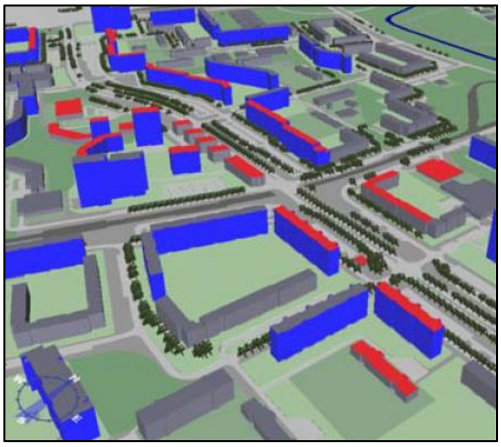


FIGURE 3.9: VISUALIZING THEMATIC INFORMATION (DOLLNER, BAUMANN, & BUCHHOLZ, 2006)

3.4 Use cases for further research

Some of the different spatial operations and analyses that are involved in real estate valuation and transactions applications have been mentioned in the different described use cases. Especially the sales comparison approach (section 2.1) has been extensively embedded in a 3D use case (section 3.3.5). Other supporting spatial operation such as ownership registration, zoning plans and vacancy mapping are also considered in different use cases. However some real estate applications requiring visualisation or analysis that chapter 2 mentions remain relevant to perhaps develop a use case for that utilizes 3D city models. These possible use case are briefly described below and are further studied in this research.

3.4.1 Real estate marketing

An important aspect of real estate transactions is the marketing of the real estate properties for sale. The marketing of properties for sale includes presenting the information of a property and its surroundings in a comprehensive way. Throughout this research 3D city are repeatedly mentioned capable of doing just that. This property marketing use case is part of the real estate transaction application and would enable users the visualise all property related information and additional environmental information, relevant for transaction purposes, in a comprehensive way.

3.4.2 Building cost approach calculation

Besides the capitalisation and sales comparison method a third method is used for real estate valuation. This third method is the building cost approach and calculates the construction costs of a building and adds the costs of land to determine a property its value. To calculate the exact building costs of a property from a 3D city model the model should contain a high amount of semantic building data. The semantical richness of the buildings in the 3D city model should in this case be from the same quality as current BIM models are. Considering that more building permit requests require that an IFC model is uploaded as part of the request, the amount of semantically rich building models could grow. Another approach would be that this use case extracts building volumes and size and determine the type of the building based upon certain characteristics (e.g. multi family, single family) and calculates the approximate value. The purpose of using a 3D model in this use case is mainly analysis and automated information take-off, visualisation is less essential in this use case. The added value of using a 3D city model would be both in terms of efficiency as well as effectiveness. More buildings can be calculated at the same time while using semantically rich building models deliver accurate and complete building information.

3.4.3 Capitalisation and average pricing approach

The previous section mentions the capitalisation method as one of three real estate valuation methods. This method calculates the building value based upon its rental income or rent potential. The rental income of a building, if not a single tenant building, often differs per floor and location of the tenant on a floor. This method often utilizes Excel spreadsheets to calculate the property value. It could however be interesting in terms of data comprehension to visualise the different values of a property throughout a building. If this information is combined with other datasets a user could perhaps discover new relations between rental prices per location and level based upon newly added variables. An example could be that the visibility variable from section 4.3.4 is added. The purpose of this use case is mainly a visualisation 1 type of use case, however if additional datasets are added manual analysis could be performed. The added value of this model is limited to improved data exchange.

3.4.4 BAG Function mapping

In section 1.1 the BAG is described as one of three government applications presenting property data in 2D. The BAG allows user to find different properties with a certain function on a map. Attached to all properties are the different units located in a property for which some basic characteristics are described in text. This basic characteristics are besides the address and BAG ID, the floor space and the function of the unit. The BAG is actually well developed with respect to other countries. However there is room for improvement. When for example one building has 40 units, and therefore potentially 40 different functions, these are represented with dots inside the building parcel (figure 3.10). It is currently nearly impossible for a user to determine the exact location of a unit and its function in the building. Using a 3D city model to visualise this information would allow for a much more efficient and also effective way of comprehending this data.

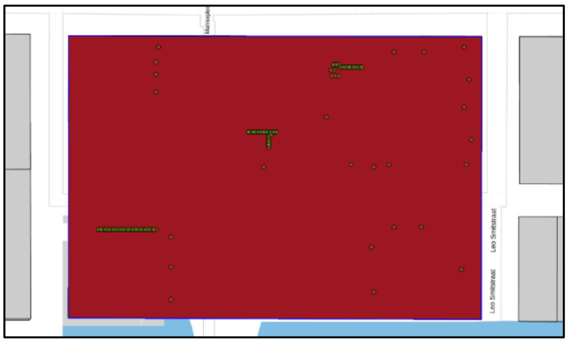


FIGURE 3.10: BAG VIEW OF THE SYMFONIE TOWERS IN AMSTERDAM SOUTH AXIS, SOURCE: HTTP://BAGVIEWER.KADASTER.NL

3.5 Conclusion

This chapter aimed to answer the third sub question:

> *For what purpose and added value is 3D GIS currently used in real estate valuation and transaction applications (state of the art use cases)?*

The added value of using 3D city models is hard to define and therefore measure. First the purpose of using a 3D city model was determined. Different studies indicated that most 3D models as well as GIS are either used for visualisation or for analysis purposes. Based on these two purposes the possible added value was further examined. This indicated that mainly visualisation could somehow be measured when adopting a technical approach (Van Wijk, 2005). The technical approach quantifies added value of visualisation in terms of effectiveness or efficiency. Since only one use case is recently applied in practise the actual effects could not be measured. Therefore an assumption is made, derived from the purpose and use case definition, what the possible added value could be. This assumption is based upon the distinction made in type of use cases by Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015), an addition to their proposal, and the fundamental spatial operation of GIS as described by Raju (2004). The result is a framework that describes that use case utilize 3D models for the purpose of visualisation or analysis. **The type of use case is defined as non-required visualisation, visualisation for information communication and exchange (1) or visualisation for visual analytics (2).** This purpose and type of use case is derived from the actual use case that is described according to the model of Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) stating that a use case is part of an application (e.g. real estate valuation) and includes a set of spatial operation (figure 3.2).

The state of the art in the utilization of 3D city models for real estate valuation and transaction applications showed six use cases. These six use cases where either very specific (e.g. calculation the visibility polygon for real estate valuation) or rather broad (e.g. the visualisation of thematic real estate data). **The added value of using 3D city models in this use cases is mainly to gain insight in in phenomena through visualisation or to perform automated analysis on the model itself (visualisation 1&2 type of use cases).** All six use cases seemed to add value in terms of efficiency since insight in data could be obtained quicker. The 3D cadastre and the sales comparison use case are both most likely to add value in terms of effectiveness as well since the use of 3D models would allow for improved quality of the results.

Based upon the description of real estate valuation and transaction applications in chapter 2, some additional use cases seem relevant to further investigate. These use cases are divided in real estate transaction use cases (example: using 3D city models for marketing purposes) and real estate valuation use cases (example: using 3D city models to visualise price levels throughout a property). One possible use case is related to both real estate valuation and transaction applications and is aimed at visualisation of the Dutch BAG in 3D.

The main conclusion is that 3D city models are used for visualisation type of use cases, including added value in information communication and/or visual analytics. Within the real estate domain multiple studies describe use cases that utilize 3D city models requiring various quality (LODs) of the city models. One use case is so far applied in to practise which is the 3D Cadastre use case aimed at improving the exchange and communication of (complex) property right situations.

Chapter 4. Research approach

This chapter introduces and elaborates on the further approach of this research in which professionals within the real estate, 3D modelling and real estate data domain are questioned regarding the requirements, potential of and relevant use cases for 3D city models. This chapter is structured in to five sections: First, the purpose of further research is discussed in section 4.1, to indicate which information is needed to obtain. In section 4.2 the appropriate research method is selected. In the third section the different subjects are defined. Next the interview population is described along with the characteristics of the selected respondents. In the final section the adopted research approach is evaluated against the research purpose, method and population.

4.1 Purpose of further research

Previous sections of this research have shown the vast availability of studies and information on the two main topics of this research:

1. (chapter 2) Real estate valuation and transactions in relation to GIS;
2. (chapter 3) Added value of 3D GIS and state of the art in real estate use cases.

Chapter two shows the relation between Real estate valuation and transactions and GIS. It also provides different arguments why 3D GIS could be used in these real estate applications. In chapter 3 the purpose and potential added value of using 3D city models in in general is examined. Then the relation between 3D city models and real estate is studied by describing the state of the art in real estate use cases that utilize 3D city models. Most of these use cases are however derived from recent studies, indicating that these use cases are still in the research and development phase. These findings do partly support the problem statement that it is unclear why and what for 3D city models could be applied in practice within real estate valuation and transaction applications (section 1.2). The findings did support why and what for 3D city models could be applied, however not why and what for in practice. The framework constructed indicates that 3D city models can be used for different purposes with subsequently a different potential added value (figure 3.2). The use case could be structured into non required visualisation and visualisation 1&2 type of use cases. Studies indicated that even though the added value of visualisation is hard to measure, a technical assessment can be made in terms of efficiency and effectivity (section 3.1.2).

4.1.1 Research gap

ESRI (2014) & Bayers et al (2015) provided different steps that have to be considered in to make the shift from using 2D to 3D in real estate applications. These steps involved defining the purpose and added value of 3D. The purpose of using a 3D city model in a certain use case should be established in advance. Based upon the capabilities 3D city models and the different spatial operations involved in real estate valuation and transaction applications an overview of current and potential use cases is created in sections 3.3 and 3.4. The potential use cases along with the state of the art in use cases in which 3D city models in real estate applications are utilized, provides input to further research which use cases are relevant for further development or to be created from scratch. The use cases themselves are structured according to a model created by Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) (figure 3.1). This model however only indicates what a use case contains and for which application it is used. The purpose and the added value of using a 3D city model in a particaliar use case is not defined in this model. Therefore, two additional layers are proposed to add to this model that will be used in the remainder of this study (figure 3.2).The purpose of adding these two layers is to enable the selection of a relevant use case based upon the purpose it has and the added value it potentially provides. This model is solely based upon theoretical input and therefore requires empirical testing. To establish the future need of technical developments such as 3D city models the relevancy of certain use cases should be measured, as well as the potential of the use cases. It is however impossible to determine the full potential or all relevant use case of 3D city modelling. For example the inventor of the Global Positioning System (GPS) in 1960's could have never considered this technology nowadays being used in mobile phone devices to catch Pokémon. This example illustrates that the full extend of relevant use cases for 3D city models cannot be completely determined in advance. However using the proposed framework a context of the potential different use cases utilizing 3D city models can explored.

4.1.2 Obtain an indication of the added value

As described in section 3.1, it is hard to measure the actual added value of using 3D city models for visualisation or analysis purposes. This is especially the case when no actual use cases have been applied and the actual costs and benefits cannot be measured. Therefore an approach is adopted that assesses the added value in terms of "efficiency" and "effectiveness". Here, efficiency means that a certain process could be completed in less time. Effectiveness means that the quality of a certain achievement increases. Both are measured by assessing the costs and benefits per use case. Since the use cases described in section 3.3. have not been applied in the real estate industry, the actual costs and benefits cannot be measured in this stage. For the purpose of this research an indication should be tried to obtain on what the possible benefits of using a 3D city model in a certain use case could be in terms of efficiency and effectiveness. The automated valuation model (AVM, section 1.1.1) is an example of a research that resulted in tool that adds value in both efficiency and effectiveness, since valuations can be done faster and with a higher accuracy rate compared to traditional valuations. Zhang, Li, Liu, & Liu (2014) used 3D city models in an AVM and came to the same preliminary conclusion, regarding the added value, that using 3D city models could greatly improve the efficiency and accuracy (effectiveness) of valuations. Using these measurement tools as a preliminary indication of the added value is therefore used.

4.1.3 Aim of further research

In sections 3.3 and 3.4 of this report a number of use cases are described in which 3D city models could potentially be utilized or use cases in which they already are utilized. According to Ujang, Azri & Rahman (2015) there are two main factors of influence on the increasing utilization of 3D city models in practise, these are the user demands and technical developments. The factor "user demands" means that certain tasks cannot be achieved with 2D applications and therefore users require a 3D city model. The factor "technical developments" of 3D city models include the possibilities with, and the quality of 3D city models. Further research should therefore first try to establish the purpose of using 3D city models derived from the user demands, indication the relevancy. Second, it should establish what the technical quality and capabilities of 3D city models are, indication the technical achievability. Besides obtaining information on which use case is relevant and technically achievable to develop, some context on why certain use cases are relevant is required. Bayers et al (2015) described a number of important aspects in making the shift from 2D towards 3D information models. Besides defining a clear use case Bayers et al (2015) named multiple aspects that should be considered (see section 2.4.1 for elaboration):

1. Identify the best practices on added value of 3D over 2D;
2. Identify the requirements of the data content;
3. Improve the awareness of 3D data;
4. Determine the business opportunities that can be realized in 3D applications.

The first aspect is covered in the framework (figure 3.2) that allows to determine the type of use case and potential added value. The second aspect is closely related to the use cases and the added value it aims to achieve. The general requirements regarding the datasets and query possibilities should be identified and differ per use case. Dollner, Baumann, & Buchholz (2006) describe three methods to query a 3D city model: 1) explicit selection of a building, 2) Spatial selection of a group of buildings, 3) Rule based selection. Which method is most suitable depends on the use case. The other two aspects (3&4) are more of a general kind on the topic of 3D city models. These aspects have been mentioned by Lomax (2015) as well. He mentions that most professionals were not aware of the possibilities GIS has to offer and what it could be used for. Since 3D GIS is even one step further it is safe to assume that the awareness on this topic is even lower. In order for 3D city models to be accepted as a new information model these topics should be considered besides identifying the relevant and technical achievable use cases. This is supported by the Technical Acceptance Model (TAM), originally created by Fred Davis in 1985, and developed over time. The TAM examines the role of external variables on the probability of using a system (Collerette, Ingham, & Legris, 2003). The TAM has been used in the empirical studies on the acceptance of information technology. It denotes different variables as being of influence of the perceived usefulness and eventually the intention to use advances in information technology. The TAM considers external variables as: the image of a product, the relevancy to the job, the output quality of the product and the demonstrability. For the purpose of selecting a relevant use case these aspects are perhaps less relevant but they could provide some additional context in how 3D city models could be utilized in real estate applications in general. Information on the business opportunities and the awareness of the possibilities 3D city models offer, could provide valuable information for the development of a use case.

The additional information that is required in the process of this research can be summarized in five main topics. These topics have been examined in different studies (Chapters 2&3) but have not been covered from the user's perspective (e.g. the real estate industry):

1. Identify relevant and technical achievable use cases for 3D city models;
2. Identify what the general requirements are from a user perspective;
3. To support the development of 3D city models identify the general purpose;
4. Determine what the possible added value of 3D visualisations could be;
5. Determine what the possible added value of 3D analysis could be.

4.2 Research method

This section describes which method can be used to obtain the required information. Little examples or cases in practice within real estate valuation and transaction applications utilizing 3D city models, are known and available. The objective of this research is to define new potential use cases for 3D city and select the relevant use cases from existing studies. With the final goal of determining one relevant and technical achievable use case that can be developed. To answer which of the studied or potential use cases are relevant and technically achievable to develop, an addition to the literature study from previous sections is proposed.

4.2.1 Type of research

With little available knowledge on the question that this study seeks to answer, a qualitative research is most suitable according to Baarda & Goede (1995). To find new knowledge using a qualitative research approach, three main methods of data collection can be used:

1. Studying existing information;
2. Making observations;
3. Conducting interviews.

The existing information which is available has already been discussed in the previous sections of this research. Therefore the first method of data collection is not suitable for further research. To obtain further information on which use cases are relevant in practice, the opinion from professionals in the real estate transaction and valuation domain is needed. Interviews are therefore the most suitable method of data collection. Besides opinions from real estate professionals the knowledge of 3D modelling and (real estate) data experts could help to define which use cases are technically achievable. By doing so, two main stakeholders are involved in this research: the users from the real estate industry, the experts on 3D modelling and (real estate) data. Selecting these two stakeholders is in line with the statement of Ujang, Azri & Rahman (2015) that user demands and technical developments are the two factors of main influence on the utilization of 3D city models in practise. The combined knowledge of two of the main stakeholders can also provide context to the use of relevant use cases. The data experts can provide insight in the requirements of the data content while real estate professionals can provide more context for the business opportunities that can be achieved by utilizing 3D city models in relevant use cases. By conducting interviews with both stakeholders the research topics described in section 4.1.4 can be fully covered.

4.2.2 Type of interviews

In this research an individual interview is chosen as most suitable method. This method is chosen since information is required that includes personal opinions, knowledge and experiences. The structure of the interview depends on the amount of knowledge available in advance, which in this research is limited. The full extent of the potential of 3D city models in the real estate industry is unknown as well as what kind of use case they could potentially be utilized in, except for the ones described in section 3.3. What is known however are the possibilities with (3D) GIS, the different spatial operations within real estate valuation and transaction applications and the few use cases in which these are combined. The adopted research approach is exploratory and the exploratory nature of this research can be found in combining the three topics of this research: GIS, 3D city models and Real estate applications. There is little pre-existing knowledge about the combination of these three topics. Therefore a semi structured approach is considered to be most suitable (Baarda & Goede, 1995). To make sure that valuable information is obtained from the interviews the knowledge of the respondents should be aligned with the state of the art in 3D use cases for real estate valuation and transactions. To do so a less structured approach is preferable as well. It is important to align the knowledge per respondent in advance. Real estate professionals are more familiar with real estate valuation and transaction applications and less with 3D city models and vice versa with 3D or data experts. Therefore all respondents are introduced on the topics questioned in the interviews in advance.

The use of semi-structured interviews to obtain knowledge on the capabilities of 3D data models in terms of, among others, data exchange has proven useful in other studies as well. Alshawi, Hore, Redmond, & West (2012) conducted a research on het capabilities of IFC XML[19]. The purpose the research was to harness the capabilities of IFC XML and subsets of XML to design an intergrated platform that would enhance the usability of building information models for multiple disciplines in decision making. A semi-structured interview was conducted among 11 expert respondents with the aim to explore the possibilities how an intregrated process could be applied that would allow faster and cheaper information exhange using cloud and BIM software. The interviews were structured around five main topics which were then catagorised in to six sections with different questions. The 11 experts that were interviewd were either experts on what they do or experts on what they know (Alshawi, Hore, Redmond, & West, 2012). In the research of Redmond & West a similar selection is made on the experts involved in their research. Real estate adivsors are expected to have peformative expertise (e.g. expert on what they do) on real estate valuation and transactions. While the 3D professionals have epsitimic expertise (e.g. expetise as a function of what they know). It can be expected that epistemic expertise provides insight and justification for propositions within the research domain while performative expertise provides insight on how to perform a skill within the rules and virtues of a practise (B.D. Weinsten in Alshawi, Hore, Redmond, & West, 2012). The research by Alshawi, Hore, Redmond, & West (2012) showed that conducting semi-structured interviews based upon a number of topics could be used in an exploratory study on a similar subject. It also supports

19 The main exchange format of 3D BIM

the idea of involving two kind of experts with different types of knowledge in the research. Therefore a likewise type of interviews is adopted in this research.

4.2.3 Interview structure

A semi structured interview with two types of respondents (e.g. experts) is found to be the most suitable method. In the interviews multiple topics are discussed without a prefixed sequence, this sequence could be adjusted per interview according to the respondent's knowledge. The first topic is however fixed. This topic contains the alignment of knowledge on the main subject of this research. The other topics discussed in the interviews are directly related to the use cases or the context of this use cases. Five topics are pre-defined:

- The general purpose and potential of 3D city models in the real estate industry;
- Using 3D city models for the purpose of information visualisation;
- Using 3D city models for the purpose of analysing data;
- Scoring the known and potential 3D use cases on relevancy or technical achievability;
- The general requirements of using 3D city models in real estate use cases.

4.3 Topic definition

Per topic three questions are formulated. This questions serve as guidelines for the interviewer and are by no means exhaustive. If additional information is required the interviewer is able to ask extra questions to obtain in-depth, better or more information from the respondent. Each topic is aimed at obtaining certain pieces of information from the respondents based upon early findings in the literature (chapters 1-3). To obtain the correct information criteria and questions are formulated per topic and related to findings from the literature. When all interviews have taken place the results are analysed and measured according to the pre-defined methods and criteria (Appendix 1.1). The term "measured" should be reconsidered. Interviews are chosen as a qualitative research approach and therefore does basically not allow for quantification of the results. The aim of measuring the results is to find some saturation in the answers given by the respondents therefore an indication on how this is measured is provided. The purpose is however not to quantify the results. Some topics can however be quantified such as the scores on the knowledge alignment and the scores on the relevancy per use case. These scores are however by no means generalizable since the research population is too limited.

It could possibly be difficult for respondents unfamiliar with the capabilities of 3D city models to assess the role and specifically the added value of using a 3D city model. Therefore the respondents are provided with an explanation beforehand. Using 3D city models for analysis and visualisation is defined as an element of problem solving. This operational approach makes that respondents have to consider whether a 3D visualisation would help in manually or automatically extracting the correct information from a 3D city model compared to a 2D data model (van Wijk, 2006).To determine how relevant or how technically achievable the use cases described in the interviews are, a rating scale is used. A five point rating scale is adopted. The risk that a five point scale could lead to respondents using the mid-point of the five point scale as a desirable and neutral answer is acknowledged. However besides given a score on a five point scale the respondents are asked to argument their score. If properly supported a neutral answer could be of equal value as the other scores.

4.4 Interview population

As mentioned by Ujang, Azri, & Rahman (2015) the developments of utilization of 3D city models is supported by two trends: user demands and technical developments. To obtain knowledge on both relevant use cases as well as technically achievable use cases two different types of respondents are needed. The population in this research therefore consists of the respondents who are either in the real estate advisory business or in the technical business. The real estate advisory business core business mainly is the valuation and transactions of real estate. The companies in the technical business are either into 3D modelling, 3D GIS or (real estate) data or a combination of these.

4.4.1 Real estate advisory

Within the Dutch real estate advisory business the top 10 brokers were responsible for an amount of more than 12 billion euro in real estate transaction. The remaining 15 brokers in the top 25 were responsible for little less than 1,5 billion euro (Kooijman & Wessels, 2015). Since the top 10 real estate advisory firms are involved in nearly all of the real estate transactions it is assumed that these companies have most knowledge on the topics of real estate valuation and transactions.

1. CBRE
2. JLL
3. Savills
4. DTZ Zadelhoff
5. Cushman & Wakefield
6. Capital Value
7. Dijk & Ten Cate Vastgoedadviseurs
8. ABC Capital
9. Colliers International
10. Van Gooi Elburg Vastgoedspecialisten

The respondents from the real estate advisory firm are selected based upon their broad knowledge of the sector and research capabilities. In the case of this research specifically the heads of research from different real estate advisory firms are approached to participate in the research. It is expected that when involving employees who are directly and only involved in real estate valuation and/or transactions their knowledge is too limited to provide any context for the relevant use cases.

4.4.2 Experts on data and 3D models.

In the Netherlands an extensive amount of (3D) data experts are present. Especially within the field of 3D geographic data models there are some advanced companies. There is however no clear "top 10" companies involved in 3D modelling, 3D GIS and data that can be formed like it can for the real estate industry. Therefore an overview is created with 10 companies which have been found in previous studies and meetings with experts.

1. Vastgoeddata
2. GeoPhy
3. Calcasa
4. Geodan
5. Geonovum
6. ESRI
7. TU Delft
8. TU Eindhoven
9. Open Geospatial Consortium
10. ConsultingWhere

4.4.3 Respondents selection

In-depth information is required for this empirical part of the study. This type of data collections required many sources and much time. There is no fixed number on how many respondents are needed in this type of research. However a general assumption is that in qualitative research enough respondents are interviewed when the given information starts to repeat itself. This is otherwise known as saturation. Therefore it is not possible to select a fixed number of respondents in advance. The number of respondents have been discussed with the supervisors of this research and has been established at six. Three of the six respondents come from real estate advisory firm while the other three respondents are involved in (3D) geographic data models (table 4.1).

TABLE 4.1: RESPONDENTS OVERVIEW

No.*	Company name	Core business	Respondent	Job description
1	Cushman & Wakefield	Real estate advisory	Michiel Boonen	Head of research the Netherlands, EMEA Capital market investment strategy
2	Colliers International	Real estate advisory	Werner van Sprundel	Head of research Colliers, founder of AVM for owner occupied housing in the Netherlands
3	Savills	Real estate advisory	Jeroen Jansen	Associate Director Research
4	Geonovum	Publishing geo-info and creating geo-info standards	Jantien Stoter	Geo information specialist/ Professor 3D Geo Information
5	ESRI	Geographic product developer	Niels van der Vaart	Product consultant (focus on 3D GIS)
6	Calcasa	Automated real estate valuation	Rogier van der Hijden	Commercial director
7	EurSDR (research group) & ConsultingWhere	Development of Geographic and 3D standards and value	Multiple respondents	Workshop with different stakeholders regarding the economic value of the use cases: 3D valuation and cadastre

* numbers do not correspond with the sequence of the interviews nor with the analysis of the results.

4.5 Conclusion

The main question that this empirical part of the research aims to answer is: which use cases in real estate valuation and transaction applications are both relevant and technically achievable to develop? To support the different possible use cases the respondents are asked question on three topics that consider the purpose, added value and effect of 3D city models in real estate applications. The research continuous to explore the possibilities of 3D city models with in real estate valuation and transaction applications based upon the framework constructed in section 3.2 (figure 3.2). It is assumed that this structure provides a correct distinction of the purpose, added value and type of use case in which 3D GIS can be used. Since it is impossible to study or determine the full extent of the use of 3D city models, as illustrated with the GPS invention example, the remaining part of this research is of an exploratory type. Incorporating respondents from the real estate domain as well as the more technical domain is line with findings that both users and technical developments are of influence on the utilization of 3D city models.

Chapter 5. Interview results and implications

This chapter analyses the results of the interviews that are conducted among three real estate advisory firms, one firm specialised in automated real estate valuation and two companies involved in the research and development of 3D city models and standards (appendix 1.2). Some of the results mentioned in the interview topics were later on mentioned and re-used at the value mapping workshop of the EuroSDR and ConsultingWhere 3D cadastre and valuation group. The results of the workshop and the feedback received is used to provide additional context and support some of the interview results. The results are described in section 5.1 – 5.3. Section 5.1 provides an introduction on the respondents and their knowledge regarding the different topics from the interviews. Section 5.2 analyses the topics that are aimed at defining the purpose of 3D city models in real estate applications. Section 5.3 analyses the relevancy, technical achievability and the requirements of the 3D use cases. In section 5.4 a preliminary use case is described that will be further developed in the final phase of this research. In the last section an answer is given on the fourth sub question:

> *Which use cases utilizing 3D city models are relevant and technically achievable within valuation and transaction applications and what are the requirements?*

The answers given by the respondents are linked to the earlier findings from this research to describe the possible implications of the results.

5.1 Introduction

Six stakeholders from three different types of companies are questioned regarding their knowledge and experiences with 3D city models in real estate valuation and transaction applications. Three real estate advisors are asked why and for what they think 3D city models could be of use and added value. Two 3D data companies are asked to given their opinion on the purpose of 3D city models in real estate applications and indicate what use cases are technically achievable. A third type of company involved in automated real estate valuation is asked what they think 3D city models could be used for. Each company is asked at the start of the interview to give an indication of their knowledge on the four main topics of the interview:

1) Real estate valuation and transaction applications;
2) 3D city models;
3) Developments of 3D city models and data techniques;
4) Use cases in which 3D city models are utilized.

Each respondent provides an indication of their familiarity with the topic to allow the interviewer to ask additional questions or provide additional information.

The results showed that in line with the expectations the four companies involved in real estate valuation and transactions scored the maximum score regarding their familiarity with real estate valuation and transaction applications. Their knowledge regarding 3D city models and developments therein is rather low. The real estate related respondents did however have a general idea of what 3D city models could be used for in real estate applications as they scored this topic above the average score. These results are in line with the expectations and reason that these type of companies are approached: to provide insight in which (new) real estate valuation and transaction use cases 3D city models could be utilized.

On the other hand the two companies involved in the development of 3D city models, modelling techniques and 3D standards showed less familiarity with real estate valuation and transaction applications. They both scored maximum on their knowledge of both 3D city models as well as the developments and data techniques. These companies did also have a general idea of what 3D city models could be used for in real estate valuation and transaction use cases.

This preliminary indication provided by the respondents mainly helped on the topic in which the relevancy and technical achievability of different use cases is discussed. The real estate companies are given more explanation per use case what the 3D city model could do. While the 3D data companies are given more insight in the requirements and spatial operations required for the real estate valuation and transaction. This results in all involved respondents having a corresponding understanding of what a certain use case includes and should do.

5.2 Purpose and added value of 3D city models

In the first part of the interview the respondents are asked what they think the general purpose of 3D city models is or will become in real estate valuation and transaction applications. During the interview the purpose is structured into visualization and analysis purposes and the respondents are asked to indicate how they see the added value of using 3D city models for either visualization or analysis. The effect of this added value on the profession of a real estate broker is considered as well.

5.2.1 General purpose

The respondents mainly mention two important purposes of 3D city models in real estate valuation and transaction applications.

The first main purpose, mentioned by three real estate companies is **using a 3D city model as a database** that includes all relevant information of objects in a city. **The database should at minimum include information regarding floors and units.** This would allow for more transparency of data, more insight and the capability to better benchmark properties according to the respondents. This is an interesting result since 2D GIS is already capable of being used as a spatial database (Culley, 2010) but is however not used to this potential according to Lomax (2015). Different studies did already describe the use of (3D) GIS as a database tool (Zhang, Li, Liu, & Liu, 2014) & (Raju, 2004). Also indications that including floors and units would enhance the usability of 3D models were given (Arroryo Ohori Et al. 2015).

A second purpose of using 3D city models, that was mentioned by all respondents, was **increasing insight in data**. Their expectation is that the use of 3D city models would provide users with better insight in phenomena. **Visualization of data in a 3D model should allow for better comprehension of data** as well as effects of certain properties on their environment. Different studies have concluded that data visualisation with the help of 2D maps are able to increase insight in data (Chapter 1). This second purpose seems feasible and in line with earlier findings regarding the use of GIS for visualisation purposes.

A third interesting purpose is mentioned by one real estate advisor. This respondent stated that 3D city models used as **a database that includes the basic interior of buildings could help in risk calculation**. Specifically the calculation of the risk that a person, a family or a company would move from his or her property, could be calculated from the model. As an example the respondent described a couple of 30 years old living in a 1 bedroom condominium in Amsterdam city centre. The chance of this family having a baby and therefore is required to move is substantial. This example was also used from growing companies that could grow beyond the physical capabilities of their office location. This described use case would require the interior aspects of a building and data regarding inhabitants and would be **used to calculate the risk of moving and therefore a location becoming vacant.** A research by Biljecki, Arroyo Ohori, Ledoux, Peters, & Stoter (2016) recently showed that 3D city models can be used in the esimation of the number of inhabitant of a certain area. Their research showed in most cases added value in using 3D citymodels over 2D datasets. However the 3D models were found not accurate enough compared to current census techniques from the government. This third purpose therefore seems only feasible when the quality of 3D models increases.

Conclusion: The two purposes of 3D city models mentioned by the respondents can relatively easy be combined into one purpose of a 3D city model (Database and insight). The purpose of the 3D city model would be a 3D GIS database to store and gain insight in data by visualisation. This purpose can add value as a visualisation 1 and 2 type of use case according to framework (figure 3.2). However, when solely used as a database this type of use case could also be considered a non-required visualisation use case.

5.2.2 Visualisation

Respondents are asked to give their opinion regarding the use of 3D city models for visualisation purposes compared to 2D visualisations in three questions. The respondents are asked to indicate whether 3D visualisation add value in terms of 1) efficiency or 2) effectiveness and 3) what the impact is on the job description of real estate brokers.

1. **From the six respondents four explicitly state that the use of 3D visualisations of city could provide added value in terms of efficiency** (table 5.1). Two respondents thought that the added value in efficiency is limited compared to the current possibilities provided by 2D maps embedded with other techniques such as Google Street view. With regard to the field work required by real estate agent four out of six thought it could potentially **save time by using 3D city models for visualisation** in advance. Two others explicitly mentioned that if a client requires that a broker or appraiser visits a location it still had to be done. Another respondent that doubts whether 3D visualisation could save time argued that if a 3D is interactive, meaning that one could ''walk through it and click on buildings for information'' it definitely could save time. This is according to Raju (2004) the basic query one could ask, but is not considered as spatial query nor does it require 3D visualisation per-se. This aspect was acknowledged by one other real estate advisor as well mentioning that the added value in term of efficiency would increase over time when 3D city models would become more of a database including more and more real estate information. Based upon these opinions from both real estate advisors and 3D experts it is fair to assume that using **3D visualisation could provide added value in terms of efficiency** according to this respondents.

2. **In terms of effectivity a similar response is seen.** Four respondents state that using 3D city models could add value to effectivity. However when more in-depth questions are asked the extend of potential added value in effectivity decreases* (table 5.1). The one aspect that was mainly mentioned as becoming better was the aspect of **using 3D visualisations for marketing purposes**. Some other aspects that are mentioned are the use of 3D city models to **better check the actual square meters and volumes of a property,** also known as NEN 2580 measurement reports. This has already been done and resulted in accurate measurement results (Arroryo Ohori Et al. 2015). According to one respondent, the communication of information in general would become more effective. Even though four respondents state that 3D visualisations could add value in terms of effectivity, this was limited to marketing and communication aspects.

TABLE 5.1: RESPONDENTS INDICATION OF ADDED VALUE IN USING 3D MODELS FOR VISUALISATION

Respondent / added value in visualisation:	Efficiency	Effectiveness
Respondent 1	Yes	No
Respondent 2	Partly	Partly
Respondent 3	Yes	Yes*
Respondent 4	Yes	Yes*
Respondent 5	Partly	Yes*
Respondent 6	Yes	Yes

3. **With regard to the abstraction level of the visualisation the is no consensus in the answers given by the respondents.** Two respondents prefer a visualisation as close to the reality as possible (photorealistic). Two others prefer a visualisation with some kind of transition between abstract and reality depending on the purpose of the visualisation. While the remaining two respondents prefer an abstract model to allow for better data comprehension. This final argument came from a respondent involved in the mapping industry that state that abstract maps are quicker and allow users to gain more insight in phenomena. This statement is in line with earlier findings of Lomax (2015) and ESRI (2015) in which they state that the abstraction level of a model depends on the purpose of a visualisation but a more abstract model allows for better understanding. The overall tendency is that when commercial activities or marketing is the purpose, a more realistic visualisation is preferred.

Conclusion: From the respondents reactions a general tendency is derived that indicates that 3D visualisation could primarily add value in terms of efficiency. 3D visualisations of cities could save time in field work. The possible added value in terms of effectiveness remains limited to the marketing of real estate and the checking of building volumes.

5.2.3 Analysis

The respondents are asked to give their opinion on the use of 3D city models for analysis purposes within real estate valuation and transaction applications. The same questions as in the visualisation topics are asked.

1. **According to four of six respondents the use of 3D city models for analysis purposes could add value in terms of efficiency** (table 5.2). Since certain analysis can be performed more efficient the respondents expect that it could be of potential influence on the amount of jobs needed. However three real estate advisors argue that it would lead to a change in the job description of a broker in which he would become more of a dealmaker than he already is. In the situation of an appraiser his knowledge in the field of analysis and the data supporting the analysis should increase. One particular interesting answer is obtained from a real estate advisor. **This respondent claims that the amount of brokers and appraisers needed will increase as soon as 3D data models are fully imbedded with data and adopted by users.** The respondents expectation is that when more data becomes available for analyses and the transparency increases, that real estate could become a high-trading product. **This statement is both in contradiction as well as in line with findings of Frey & Osborne (2013).** It contradicts with the statement of Frey & Osborne that the job of real estate brokers will become obsolete. It is however in line with their statement that the job description might shift. Another real estate advisor mentioned the fees of real estate appraisers which is currently under pressure and therefore requires appraisers to work more efficient. The respondent therefore mentions that using 3D city models for analysis purposes could increase the efficiency of valuations. However the respondent also states that automatization in general plays a part in this matter. Concrete examples indicating which aspect would become more efficient are not provided by the respondents.

2. **Four out of six respondents indicate that using 3D city models for analyses could add value in terms of effectivity**. The main reason that they provide is that using a 3D city model for analysis **increases the consistency of the results of an analysis**. This statement is also supported by the EuroSDR working group in which some respondents are developing a use case that uses 3D city models for a more objective valuation of real estate property based upon different variables. A result of this consistency is for example that it is of less importance which broker or appraiser you choose to help you because each one will use the same data and analysis according to one the real estate advisors. **Another form of effectivity is achieved by 3D models because they can perform certain analysis that could not be**

performed in 2D. For example: shadow estimations, noise mapping, view and the amount of time it takes to get from floor 10 to ground level. These examples are given by two real estate advisors and two 3D experts. The same examples are found in the literature, that provided arguments to use 3D models in real estate (section 2.3). The expected added value in effectivity is mainly driven by the increase in consistency and transparency of data and analyses.

TABLE 5.2: RESPONDENTS INDICATION OF ADDED VALUE IN USING 3D MODELS FOR ANALYSIS

Respondent / added value in analysis:	Efficiency	Effectiveness
Respondent 1	Yes	Partly
Respondent 2	Partly	Partly
Respondent 3	Yes	Yes
Respondent 4	No	Yes
Respondent 5	Yes	Yes
Respondent 6	Yes	Yes

3. None of the respondents indicates that the use of 3D city models for analyses could make the job of a real estate broker or appraiser obsolete. **All respondents agree that a shift in a brokers and appraisers work is to be expected however**. This is partly driven by the additional knowledge clients have in advance and partly by the new capabilities that arise from using 3D city models. An example given by one the real estate advisors is that he would be able to analyse in advance with his client which floors of a building could be of interest to rent. The advisor could do this analysis both more efficient and more effective using a 3D city model. When considering the overall technique of using 3D city models for analysis purposes in real estate valuation and transaction the technique is by none of the respondents seen as disruptive for the market. It is rather seen as an advancement in the industry. **Some however mentioned that it could be potentially disruptive if the capabilities of 3D city models increase in the future or if the technique is not adopted by some stakeholders.** In that case 3D models could be disruptive for this none adaptive companies.

Conclusion: Derived from the opinions of the six professionals it is clear that using 3D city models for analysis purpose could increase the efficiency of real estate valuation and transaction applications. Using 3D city models could add value in terms of effectiveness as well and primarily result in more consistency in the results.

5.3 Use case relevancy and achievability

The first part of the interview provides a general idea for what purposes and with what added value 3D city models could be used in general with respect to real estate valuation and transaction applications. The second part of interview dives into pre-defined use cases that are either derived from the literature or based upon real estate valuation and transaction applications and the possibilities with 3D city models. The real estate related companies are asked to score on a scale of 1 to 5 how relevant a certain use case is within their profession. The two companies involved in the development of 3D are asked to score the use case based upon the technical achievability.

5.3.1 Current studied and developed use cases

From the six use cases that are discussed in the interview three scored an average of 4,3/5 (table 5.3). **The cadastre, mass valuation and sales comparison use cases scored above the other use cases.** However one real estate advisor scored both the cadastre and the mass valuation use case a 2/5. **The respondents motivation was that these case are already covered by sophisticated 2D models and dataset and he did not thought that using a 3D city model could add extra potential**. Besides clients as banks and institutional investors as they still prefer the actual valuation methods. In some aspect the respondent might be correct since there are mass valuation models of owner occupied homes that already reach an accuracy of 96% (section 1.1). However this model does not cover the commercial real estate market. From the four real estate advisors participating in the research, two are already very active in using data for different purposes, these respondents only consider 3D city models as an add on that is of value when it can enrich their current methods and calculations.

TABLE 5.3: SCORE AND RESPONSE ON CURRENT USE CASES, NUMBER CORRESPONDS TO SECTION

Section	Use case	Mean Score	Most relevant comments from respondents
3.3.1	3D property ownership registration	**4,3**	Most respondents found this use case very relevant. However one mentions that this use case is only relevant in a limited number of cases as for example Claude Debussylaan in Amsterdam (figure 2.2). One other respondent also mentioned the organisational burden involved in making the shift from a 2D towards a 3D cadastre.
3.3.2	3D zoning plans	**4,1**	This use case would also require great organisational changes to be applied.
3.3.3	Property valuation and taxation	**3,8**	Respondents acknowledge that this use case is already partly covered by existing 2D models and dataset but they do expect that using 3D could count for the additional variables described in the use case.
3.3.4	Mass valuation of real estate properties	**4,3**	Although the general response indicated this relevancy of this use case one respondent stated that clients as banks and institutional investors still prefer the actual valuation methods. The most important note regarding the relevancy of this and the property valuation use case (3.3.3) was that the relevancy depends on the amount of variables that are in the use case.
3.3.5	Identifying comparable sales units	**4,3**	This use case was found relevant especially when additional variables could be used to determine what a comparable sales unit is.
3.3.6	Vacancy mapping and thematic data in a city	**3,9**	In terms of technical achievability this use case is most easy to achieve. This use case was also found relevant, especially from a research perspective, when it enables users to derive information per building floor.

Conclusion: In general the opinion from the four companies involved in real estate valuation and/or transactions is that all 3D use cases are relevant, some more than others. This could be an effect of the fact that hardly any 3D use case with city models have been applied in practise and therefore everything is potentially relevant. The respondents involved in 3D data models both indicate that all the use cases are technically achievable. They state that the challenge is more of an organisational nature. For example the use case of the cadastre and zoning plan would require governments and municipalities to completely change the way they currently work.

5.3.2 Theoretical use cases

The theoretical use cases are all but one less complex than the use cases that are already being studied or developed. Therefore both 3D data professionals indicated that all are technically perfectly achievable. The only side note that is made by both respondents is that the organisational achievability in especially the construction cost pricing use case is complex.

The opinions from the real estate professionals differs per use case (table 5.4). Especially the property marketing use case scored relatively low. However three respondents mention that the relevancy of this use case can increase when more data and information is added in the visualisation. They only argue whether 3D city models are currently capable of that with respect to the information involved and the software capabilities. Two other use cases that are found relevant are the mapping of functions per floor and the average cost prices of buildings per floor. **An argument given was that everything that can show information per floor is relevant because such an application is currently missing.**

TABLE 5.4: SCORE AND RESPONSE ON POTENTIAL USE CASES, NUMBER CORRESPONDS TO SECTION

Section	Use case	Mean Score	Most relevant comments from respondents
3.4.1	Real estate property marketing	**3,5**	A rather strange result is that this use case in which 3D city models could be used for marketing purposes only scored an average of 3,5/5 while the marketing purpose of 3D visualisation were repeatedly mentioned earlier in the interviews.
3.4.2	Building cost approach	**4,9**	The construction cost pricing use case that was mainly argued by the 3D data professionals from an organisational point of view. The real estate professionals find it very relevant to use semantically rich 3D models stored in a city model to calculate the construction costs of a property. Especially to calculate the reconstruction value which is often performed for insurance companies is mentioned as relevant.
3.4.3	Square meter prices	**4,4**	The use cases with regard to average prices and cap rates per floor are found useful in the mostly larger cities as Amsterdam, Rotterdam, Utrecht and The Hague. In smaller cities the situations are often less complex and therefore do not require 3D visualisation.
3.4.3	Capitalization of rent levels	**3,6**	See above.
3.4.4	BAG Function mapping	**4,1**	Regarding the function mapping one real estate professional stated the it is of particular interest for the entire industry to improve the current way functions are mapped (e.g. in the 2D BAG).

Conclusion: The results again show that most use case are found relevant by the respondents from the real estate industry. The most important notes are that the relevancy of some use cases differ per city and that the relevancy of some use cases could increase when software and data capabilities would increase. However according to the 3D data professionals the capabilities with respect to data should not be a problem. Again the fact that most use cases are found relevant could be an effect of 3D city models being a new technique in the real estate domain which could potentially solve some basic issues that some real estate advisors currently encounter.

5.3.3 Use case requirements

Finally the respondents are asked what the general requirements would be of a use case in terms of 1) the most important dataset(s), 2) query possibilities and 3) software to create and utilize the models.

1. **The most important dataset to start with is the BAG according to three real estate professionals.** Particular the quality of the data and completeness is mentioned by one real estate professional. This respondent argues the use of BAG as most important dataset because it is updated frequently and includes all addresses that are all attached to a unique identifier. The importance of unique identifiers has been mentioned repeatedly in previous chapters (1 & 2). One of the 3D data professionals mentions the BAG as well but notes that only few cities have a BAG of a quality level that is good enough to be used to (automatically) create a 3D city model from.

2. With respect to the query capabilities the real estate professional participating in this research, **prefer to first query the model by "clicking" on a building** and deriving the required information. The next query would be from the dataset or spatial selection within the model to find for instance comparable sales in the proximity of the building. Specifically the option to click on a building and obtain information is considered to be relevant for appraisers and brokers. From a research perspective and mass valuation perspective a query via the dataset is more relevant. Technically all types of queries are achievable.

3. **There is no consensus among the respondents with respect to the preferred software packages to utilize and create 3D information models.** Open source is mentioned because it allows for free publishing, it allows for crowdsourcing and everybody could improve the quality. Dedicated software packages such as ArcGIS are mentioned because of their

trusted quality. Another advantage of a dedicated software package mentioned by one real estate advisor is that it would increase the chance of becoming accepted as a tool in the valuation process of buildings.

5.4 Implications for a preliminary use case

Using the input obtained from the four real estate professionals a preliminary use case can be defined that includes the main purposes and noted relevancy from the respondents. Most use cases utilizing 3D city models for one or more purposes are found relevant by the participating real estate professionals. Since there currently are no real estate use cases utilizing 3D city models in practise, let alone 3D city models containing more than simple polygons forming the outer shell, I would propose to start with the basic use case.

The basic use case focusses on the visualisation of real estate information in a 3D city model that includes at least buildings with floors The purpose is to create a 3D database that allows user to gain insight in real estate data in a more efficient way. Two real estate professionals specifically mention the relevancy of attaching and showing leasing transactions and prices per floor in a building:

''It could be nice to show leasing transactions per building floor, that is currently not possible, it could show increasing rent levels as the floors get higher''. – Real estate professional

''As a market analyst and real estate appraiser it would be nice to be able to see which leasing contract are applicable to which floor''. – Real estate professional

Related to this use case are the 3D BAG and vacancy mapping use case since the BAG describes functions per floor and if there is no leasing contract attached to a floor than the floor is possibly vacant. Starting with a use case that includes floors to which information can be attached, altered and visualised would therefore cover the basics of multiple use cases. Following the definition of a use case (section 3.2) the use case should describe the requirements of a system from a user perspective. In the matter of this research it should include a set of spatial operations and query possibilities that allow a user to achieve a goal with a spatial dataset. This use case should allow users the add leasing data to specific floors of a building and allow user to query the model. Considering the requirements that the respondents mention the queries capabilities of the model should include the option for users to retrieve individual information of buildings and floors by clicking on it. Second the users should be able to query the model in a more advanced way, for example: show all leasing contracts linked to floors five and up. The use case should also utilize the BAG dataset since it is continuously updated and considered a reliable source.

5.5 Conclusion

This chapter concludes phase 1 and 2 of this research. An answer is given on the fourth sub question:

> *Which use cases utilizing 3D city models are relevant and technically achievable within valuation and transaction applications and what are the requirements?*

The first conclusion that can be drawn is that in terms of technical achievability all use cases described in this research are achievable according to the 3D modelling professionals. The challenge is not to develop and create the different use cases. The organisation behind the implementation of certain use cases is seen as more of a challenge according to the 3D and data professionals.

The question which use cases are relevant is a bit harder to answer. Therefore an indication was requested from the respondents regarding the general purpose and potential added value of 3D city models. The primary purpose that the respondents mention is using 3D city models as a database and to gain insight in data. A purpose that is in line with earlier findings that describe the use of GIS in real estate applications. The added value that 3D visualisation could propose was mainly seen in terms of efficiency since it allow users to easier comprehend more complex data. If 3D city are used for analytical purposes the added value would be in terms of both efficiency and effectiveness according to the respondents. The effectiveness of 3D city models in analysis is seen in an increase in the consistency of the results of analysis.

Most use cases described in the interviews are found to be relevant by the respondents. However this is possibly the result of 3D city models being an entirely new technique in the industry. Seven of the eleven use cases scored an average of above 4 on relevancy (table 5.5 with a reference to where the use case is described).

TABLE 5.5: OVERVIEW OF MOST RELEVANT USE CASES

Relevant use cases	Mean Score (1-5 scale)	Section
3D property ownership registration	4,3	3.3.1
3D zoning plans	4,1	3.3.2
Mass valuation of real estate properties	4,3	3.3.4
Identifying comparable sales units	4,3	3.3.5
Building cost approach	4,1	3.4.2
Square meter prices	4,9	3.4.3
BAG Function mapping	4,4	3.4.4

Especially the sales comparison approach is relevant considering the limited possibilities currently utilized to determine what comparable sales are (chapter 2). This use case can be related to the use case for mass valuation since current mass valuation tools are also determining value by comparison to other real estate properties (section 1.1). The 3D cadastre use case (Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova, 2015)& (SpoorPro, 2016) is considered relevant as well but an important note is made by one of the real estate advisors that 3D representation of ownership is only relevant in a few complex situations. With respect to the potential use cases three are found to be specifically relevant. Using semantically rich representations of buildings in a 3D city model could help in the valuation of properties based upon their construction costs which is specifically relevant for reconstruction costs for property insurance valuation. The BAG function mapping and Square meter price use cases are found relevant by the real estate professionals since these are specifically related to information visualisation per floor. This can be considered as the basic step to start utilizing 3D city models in real estate valuation and transaction applications.

Therefore the preliminary use case definition describes a use case that starts with information visualisation per floor since this possibility is currently missing (e.g. no floors are defined/visualised in 2D applications). Starting with enhancing the 3D models with floors increases the usability in many applications according to the respondents and research by Arroryo Ohori Et al. (2015). This allows the professionals to create a database that enables them to gain insight in 3D phenomena. This is considered the main purpose using 3D city models according to the real estate professionals. The framework from section 3.2 describes this type of use case as visualisation (1) use case that is aimed at increasing information communication and exchange. The added value is mainly seen in terms of efficiency since data could be structured in a way close to the reality and insight can be gained easier.

The general tendency that can be derived from the real estate professionals participating is that the relevancy of using 3D city models starts with being able to distinguish floors and units in 3D model and being able to attach information to this floors and units (mainly visualisation 1 type of uses cases). Technical achievability is not considered an obstacle as even more complex use cases can and have been developed.

Chapter 6. CityGML a 3D data model

The goal of phase three of this research is to develop the relevant use case described in the previous section. Therefore first an answer is given on the fourth sub question:

What are the capabilities and characteristics of CityGML as a 3D city model?

The answer to this question should provide the technical knowledge to assist in the creation process of the actual use case that is found to be relevant and technical feasible according to the interviewed professionals. The technical demands and capabilities are both of influence on the future use of 3D city models and information technologies in general (Ujang, Azri, & Rahman, 2015)&(Collerette, Ingham, & Legris, 2003). To answer the fourth sub research question the first section provides an introduction on 3D formats and standards and specifically CityGML. Sections 6.2 zooms in on the technical features and the structure of CityGML. Section 3 examines the different extension possibilities for CityGML and explains how these are embedded in the CityGML file structure. In section 6.4. relevant developments in CityGML with regard to this research are described. This chapter concludes with an overview of the relevant capabilities of CityGML for the purpose of this research.

6.1 Introduction

There is an increasing amount of applications utilizing virtual 3D city models (Dollner, Baumann, & Buchholz, 2006) (Groger & Plumer, 2012) and an increase in the amount of the available 3D city models being built by local or national governments (Groger & Plumer, 2012). This sections aim to answer the question which capabilities CityGML has as a 3D data model. Besides CityGML several other standards and formats for the representation of 3D (city) models exist. These 3D standards can be separated into two application domains, the visualisation of 3D buildings and the visualisation of 3D cities. For each of those applications specific standards and formats are provided (Groger & Plumer, 2012).

The IFC format is the most common file format for the visualisation of 3D building models. With regard to cities, that buildings are a part of, which is the scope of this research, multiple standards and formats exists. Most of these formats and standards are mainly efficient for visualisation purposes but lack semantic. Some examples are Collada, X3D, VRML and 3ds Max. These formats define purely geometrical models with lines and polygons to represent shapes and objects. This mean that this models could be used solely for visualisation purpose and could therefore be considered more of a geo-visualisation format (Groger & Plumer, 2012) (Gifford Dsilva, 2009). Groger & Plumer (2012) mention that for most applications not only geometrical and graphical aspects are of importance but the semantics of objects as well. To be able to perform spatial analyses, data mining and queries, semantics and topological aspects need to be added to the model.

CityGML is capable of representing geographic, semantic and visual aspects of a city. This format is aimed at the representation of the semantic properties of 3D city objects and is considered as one of the main 3D standards in the GIS domain (Arroryo Ohori Et al. 2015). The standard was issued by the OGC as an international standard that is aimed at the representation and exchange of semantically rich 3D city objects (Kolbe, 2009). Besides being an international standard, CityGML has been accepted by the software industry and its companies as well and has been part of the interfaces of nearly all important tools provided by these companies (Groger & Plumer, 2012).

Although this research main focus is upon buildings, "city" in CityGML is a term used to indicate that the format not only describes buildings but aspects of vegetation, elevation, water and city furniture as well. However, the building model can be seen as the most important component of CityGML (Groger & Plumer, 2012). CityGML is introduced as a common semantic information model for the representation of 3D urban environments and objects. The file format is designed as an open data model based upon the XML format and as an application schema of the Geography Markup Language 3 (GML3). This means that the CityGML application schema inherits the GML3 schema definition. The first geographic 3D models, developed before 2007, were solely graphical designs and lacked any semantic and topological aspects. Therefore the models sole purpose was visualisation and no queries, analysis or data mining could be performed with this models (Czerwinski, Groger, & Kolbe, 2007). The development of CityGML started in 2002 by members of the Special Interest Group 3D (SIG 3D). The CityGML file format provides different features that can be used in multiple aspects of modelling a 3D city and enriching the model with data. Some of this features that are within the scope of this research are elaborated on in the next sections of this chapter.

6.2 CityGML: structure and features

The most important characteristic of CityGML is the Level of Detail (LOD) of the model. The LOD concept describes the complexity, quality and degree of abstraction from the real world of 3D CityGML model (Biljecki, Ledoux, Stoter, & Vosselman, 2016). The different LODs and their influence on spatial operations is described in section 6.2.1. The information model behind CityGML defines classes and relations of topographic objects in cities including the geometrical, topological and semantics and appearances (Stadler, Nagel, Koning, & Kolbe, 2009). These classes and relations are defined in the core structure of CityGML that is described in section 6.2.2. The most important module, for both this research as within the actual CityGML structure is the *Building module*. The structure of this module is described in section 6.2.3.

6.2.1 Level of detail

The concept of LODs in CityGML does not only indicate the quality of the geometrical aspects of a model. The LOD also conveys the semantic quality and richness of a CityGML file. There are five different LODs ranging from LOD0 to LOD4 (figure 6.1). LOD0 consists of two and a half dimension (2.5D) and contain only a terrain. A map or image can be draped over his terrain model. LOD1 consists of extruded polygons upon a terrain surface. These extruded polygons result in block models with flat roofs. Textures can be mapped onto the block models. LOD2 basically is LOD1 embedded with textures and roof structures. Different surfaces, based upon a certain theme, can be mapped onto the model. This LOD also includes first pieces of vegetation like trees. LOD3 contains architectural details of buildings. This could include structures of the façade and roofs but also balconies and chimneys. In this LOD more detailed pieces of *vegetation* and *furniture* can be mapped ranging from trees to bikes and cars. The highest LOD is level 4. At this LOD the buildings contain an interior structure such as floors, rooms, doors, windows, stairs and furniture. With regard to the use case described in section 5.4 the LOD4 is required in this use case, since one of main requirements is that the model includes floors.

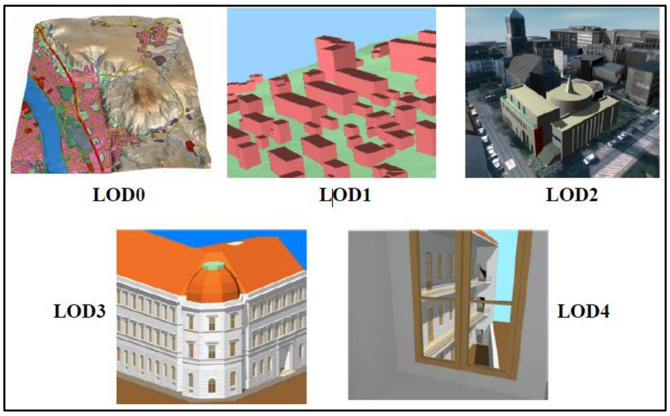


FIGURE 6.1: APPEARANCE OF CITYGML MODEL PER LEVEL OF DETAIL (GROGER, KOLBE, CZERWINSKI, & NAGEL, 2012)

The LOD concept is however by no means exhaustive. Within a LOD the quality could vary strongly which is of influence on the outcome of the performed spatial analysis. The variants of quality within a LOD are referred to as geometric references. The different geometric references of a LOD are the result of the way the CityGML file is created. A city model could be created from measurements conducted from an airplane that creates an altitude map which can be draped over a 2D map resulting in 3D blocks. This is type of modelling with height data is also referred to as LiDAR data. Since a LOD1 model only contains flat roofs it is unclear which height level of for example a pitched roof is used as the top of the building in a model. This is also depended on the amount of points used to measure the height of an object. A LOD1 model of a building could therefore be represented in at least four different geometric references (figure 6.2). Research by Bijecki, Ledoux. Stoter & Vosselman (2016) defined seven different levels at which a building height could be determined. Another variable of influence on the shape of the building block was the way it the block was constructed from the footprint. The building block could be constructed from the footprint at its actual location, it could be derived as a projection of the roof edges of a building or as a third option, a prefixed offset of the roof edges is used. The result is that a LOD1 building could be constructed in 21 (3x7) different ways. The potential influence of this difference, if analysis are performed on the model is apparent. When for example building volumes are analysed in the model they can strongly deviate per geometric reference variant. Since in LOD2 the roof structure is known, the height is measured from a correct level and the roof structure is represented correct. Within the LOD2 model only three variants are possible, depending on how the building is constructed: from the footprint, from the roof edges or with a prefixed offset of the roof edges.

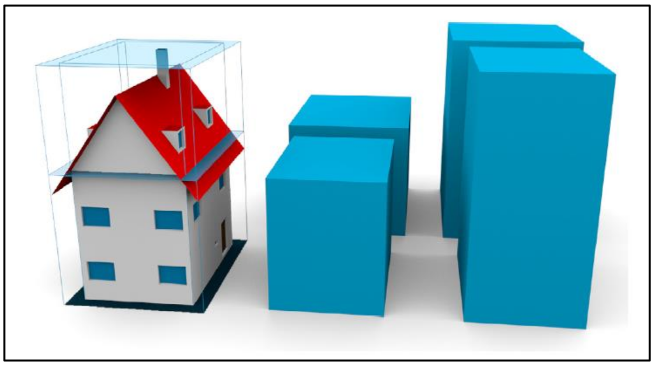


FIGURE 6.2: FOUR VARIANTS OF GEOMETRIC REFERENCE OF AN LOD1 BLOCK MODEL (BILJECKI, LEDOUX, STOTER, & VOSSELMAN, 2016).

It can be concluded that the level of detail and the way the model is constructed is of great influence on the quality and reliability of the analysis that are performed with the model. The amount of variance in analysis decreases per LOD of the model and with an increasing LOD more analytical options become available. An example is the analysis of the building interior at LOD4 which is a bit comparable to an IFC building model. Per use case the required LOD depends on the purpose of the users.

6.2.2 Core structure

The CityGML structure is separated into different modules (figure 6.3). Each module contains a class that describes the most important types of objects that can be found in a city. CityGML Core is the core module and is extended with different modules that inherit the core module. There currently are eleven modules that each cover a specific area of the 3D city model. These modules are: *Appearance, CityFurniture, Generics, Relief, Vegetation, TexturesSurface, Building, CityObjectGroup, LandUse, Transportatio and WaterBody.* Each of the modules are independent from each other but do have a dependency on the CityGML core module (Gifford Dsilva, 2009). Each module imports the CityGML core module. The core module imports two XSD schemas (XML Schema Definition, see section 6.3.4). Within the core module the basic concepts and components of the CityGML file are described.

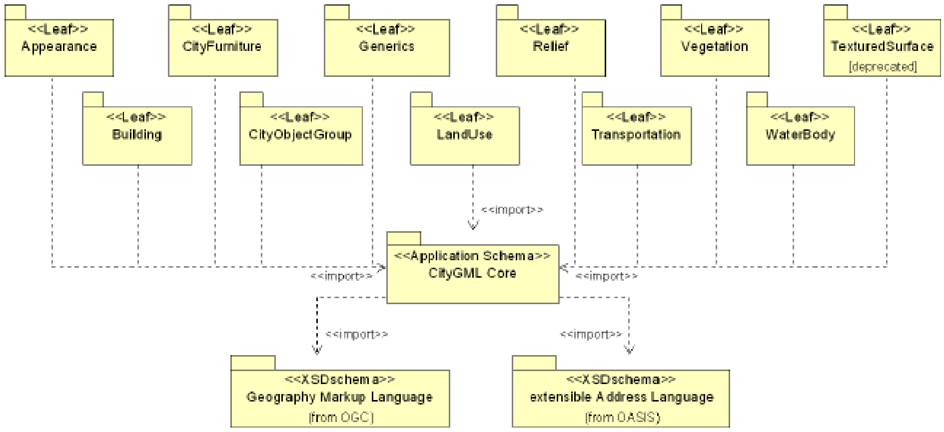


FIGURE 6.3: UML PACKAGE DIAGRAM SHOWING MODULES IN CITYGML AND THEIR DEPENDENCIES (GROGER, KOLBE, CZERWINSKI, & NAGEL, 2012)

Each module contains an arbitrary amount of feature classes. The base class for al features is defined by the core module that describes all common attributes. These common attributes are rather straightforward and describe information such as: creation date, deletion date and external references (see section 6.3.1) (Groger & Plumer, 2012). The features defined in the modules each have attributes and geometrical representations that can be defined in different LOD. An important improvement of CityGML version 1.0 compared to previous versions is that each module now contains its own namespace. All the elements within a module are associated to one namespace. This namespace is a globally unique XML target namespace (Groger, Kolbe, Czerwinski, & Nagel, 2012).

The namespace is defined in the structure by a prefix, for example the prefix of the building module is "bldg". This prefix relates all attributes to the pivotal module. If an element does not contain a prefix then the element is defined within the CityGML core module (e.g. the default namespace in xml) (figure 6.4). The UML diagram of the core module shows the relation to all other elements and modules and their prefix. The diagram shows 12 elements related to modules (blue boxes). This is one more than the eleven described modules at the start of this section. The elements "GenericCityObject" and "GenericAttribute" are however defined within the same module. This can be seen since they are both related to the same prefix "gen". These two classes allow for modelling and exchanging of 3D object that are currently not defined within another module (Groger, Kolbe, Czerwinski, & Nagel, 2012).

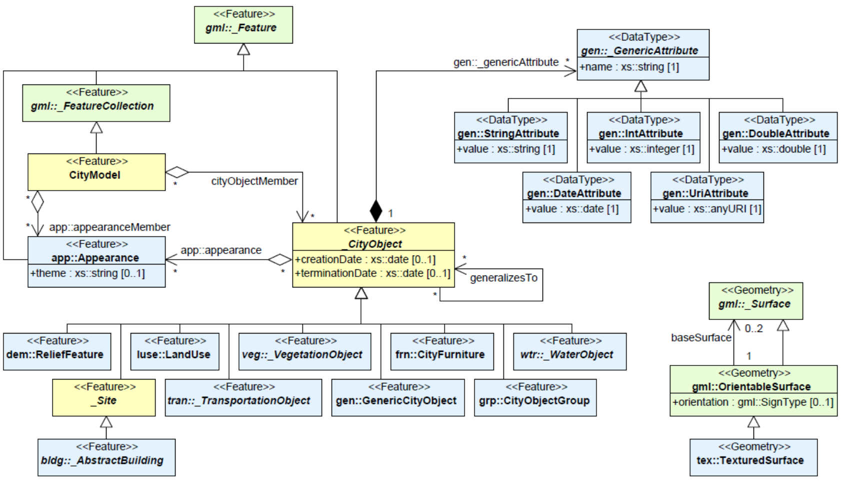


FIGURE 6.4: CITYGML TOP LEVEL CLASS HIERARCHY: A UML DIAGRAM OF THE CORE MODULE (GROGER, KOLBE, CZERWINSKI, & NAGEL, 2012).

The CityGML core module defines the basic concepts and classes of the data model. The other eleven predefined thematic modules cover the most important aspect of different elements of a city. These modules inherent the core module but do all have their own namespace, indicated by a prefix. Each prefix is only associated with one thematic extension module. The next section will zoom in on the building module.

6.2.3 Building module

The building module is considered to be the most important element of the CityGML structure (Gifford Dsilva, 2009), (Groger & Plumer, 2012). The building module allows for the representation of *buildings* and their components. *Buildings* and parts such as *rooms*, *Wallsurfaces* and *Roofsurfaces* inherent all basic attributes from the base class *CityObject*. These attributes are the creation date, deletion date and external references. Other attributes are specifically provided for building such as class, function, usage, year of construction, demolition, measured height, roof type, number and height of stories and an address (Groger & Plumer, 2012). The central class of the building model is *AbstractBuilding* from this class the classes *Building* and *BuildingPart* are derived. These classes are described by attributes inherited from the *AbstractBuilding* class. As can be seen there is an additional link between the class *BuildingPart* and *AbstractBuilding* (figure 6.5). This mean that the class "Building" can inherit object of *BuildingPart*, which seems rather logic (see appendix 2.1 for UML diagram of building module).

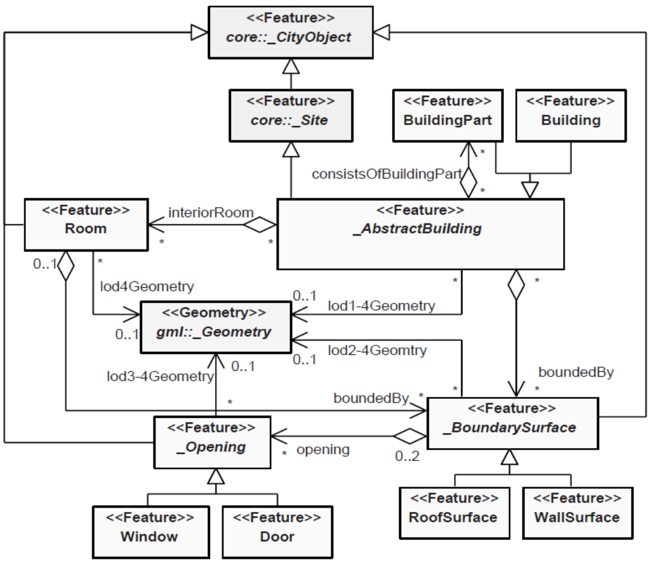


FIGURE 6.5: UML DIAGRAM SHOWING A SIMPLIFIED EXCERPT FROM THE CITYGML BUILDING MODEL (KOLBE, 2009).

6.2.3.1 Influence of LOD on the Building feature

The influence of the different LODs of a city model also has its effect on the structure and attributes of the building module within the CityGML structure. As section 6.2.1 describes the higher the LOD the more attributes a building includes. This can be seen in the UML diagram representation of the building module (figure 6.6). The higher the LOD the more attributes the building module includes. A LOD1 building only consists of a box. A CityGML LOD2 model can contain roof, ground and wall surface as a child-feature of the parent class *BoundarySurface*. Only within the highest LOD the building floor and rooms are included as features "Room" and *FloorSurface*. These two features are most relevant in the case of this research. To attach different forms of floor related information to a CityGML model the model should therefore be of the highest LOD.

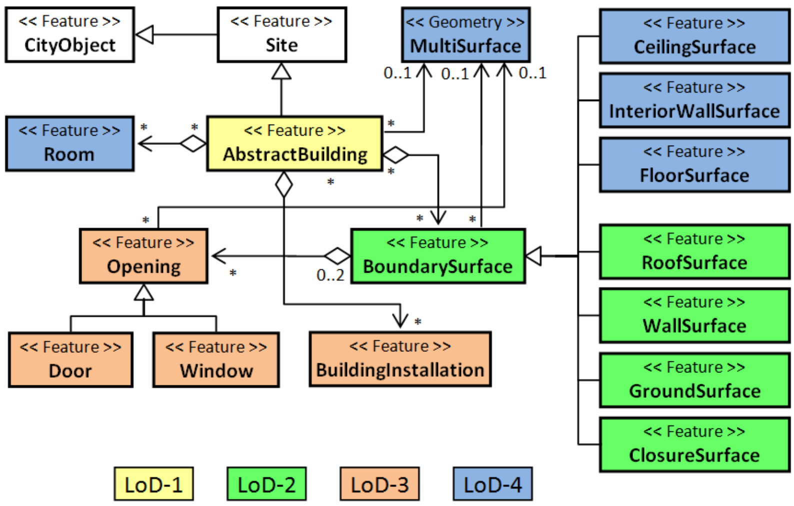


FIGURE 6.6: UML DIAGRAM SHOWING A SIMPLIFIED EXCERPT FROM CITYGML BUILDING MODEL WITH LOD INDICATION PER FEATURE (EL-MEKAWY, OSTMAN, & HIJAZI, A UNIFIED BUILDING MODEL FOR 3D URBAN GIS, 2012)

6.2.3.2 An example of a 3D building model in CityGML

The 3D city model of the Dutch city Rotterdam is publicly available and can be downloaded as an xml document. This XML document can then be uploaded in different viewers or programs to be inspected. To give an example one building from the Rotterdam Liskwartier dataset is selected. In the Rotterdam district "Liskwartier" a building containing, shops, offices and residential units is located. This building is commonly referred to as Eudokiaplein. This building can be located in the XML document with the gml ID: "5EC87D28-38B3-455A-87C0-FEF9387C5DB" and is described as follows (simplified):

```
<cityObjectMember>
<bldg:Building gml:id="{5EC87D28-38B3-455A-87C0-FEF9387C5DB}">
      <gml:name>{5EC87D28-38B3-455A-87C0-FEF9387C5DB}</gml:name>
      <gen:stringAttribute name="voll_tex">
      <gen:value>complete</gen:value>
      </gen:stringAttribute>
<bldg:boundedBy>
      <bldg:RoofSurface gml:id="..">
            <bldg:lod2MultiSurface>
                  <gml:MultiSurface srsName="EPSG:28992" srsDimension="3">
                  <gml:surfaceMember>
                  <gml:Polygon xmlns:gml="http://www.opengis.net/gml"
                  gml:id="c6f4da69-71c2-4c16-acf2-5bd043e708d7">
                        <gml:exterior>
                              <gml:LinearRing gml:id="c2caf665-3b85-4e45-
                        b586-8d6ca00b3901">
                              <gml:posList>93205.94401 ..</gml:posList>
                              </gml:LinearRing>
                        </gml:exterior>
                  </gml:Polygon>
                  </gml:surfaceMember>
                  </gml:MultiSurface>
            </bldg:lod2MultiSurface>
      </bldg:RoofSurface>
</bldg:boundedBy>
```

FIGURE 6.7: EXCERPT OF THE XML DOCUMENT FROM ROTTERDAM 3D DATASET LISKWARTIER

This excerpt does provide readable information. However it is impossible without a visualisation tool to actual see the building this document represents. It does include aspect that are mentioned in the previous sections. First, the document starts with indicating the core module: *CityObjectMember*. Second the prefix “bldg” refers to the namespace of the building module. Third, the LOD of the model (LOD2) is represented in the documentation as well and indicates in this example the surface of the exterior of the building. As figure 6.7 shows, the surface attribute is only include from LOD2 and upwards. This notation does not present a reader with an understandable image of the building known as Eudokiaplein. However when uploaded in to a data viewer that is capable of reading an xml file the model becomes clear (figure 6.8).

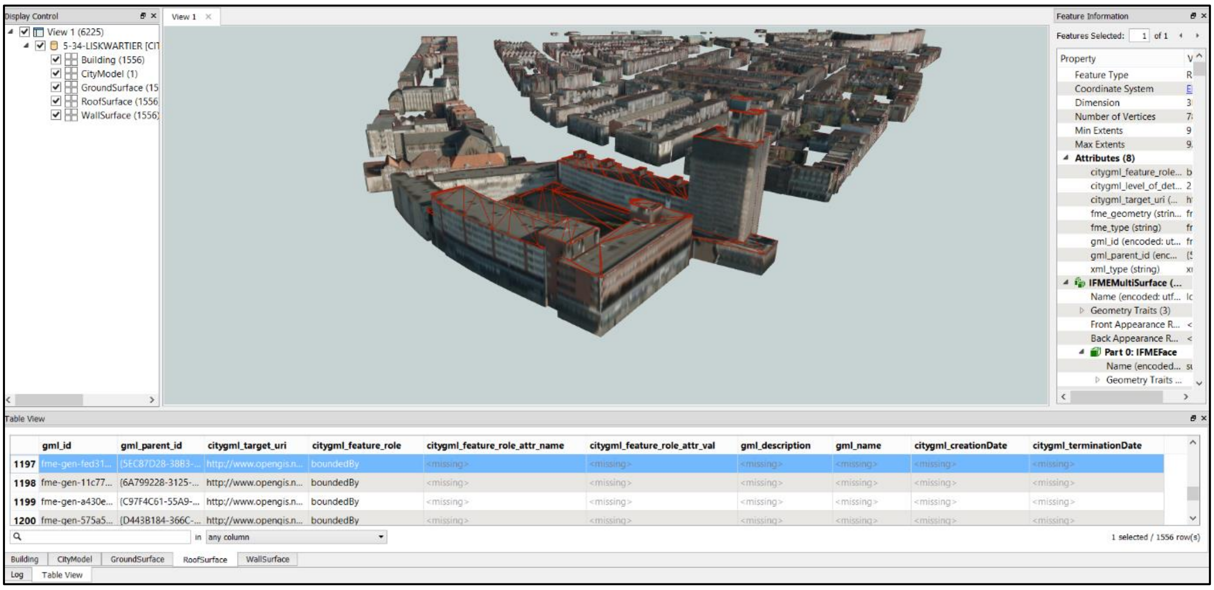


FIGURE 6.8: FME DATA INSPECTOR SHOWING BUILDING "EUDOKIAPLEIN" FROM ROTTERDAM 3D DATASET LISKWARTIER

6.3 CityGML: extensions

Besides the attributes and classes from the eleven thematic extension modules and the core module the CityGML base model is extendible. CityGML has purposely been designed as a universal topographic base model. It does however allow for extension of this base model by means of a generic attribute or application domain extension (ADE). A third more simplistic option, that is not considered an extension is an external reference. External reference is however quite essential and is therefore described in this section.

6.3.1 External reference

One extension capability of CityGML has been previously mentioned and is part of the core module of CityGML. This means that this capability is inherited in each one of the eleven thematic modules as well. This capability of CityGML is called the external reference. The external reference cannot really be considered to be an extension of the CityGML model but it does allow users to refer to the same object in an external dataset by means of a unique resource identifier (URI). An example is the reference from an *AbstractBuilding* to the same building within the BAG dataset. This reference is an attribute from the core building module that is inherited in the *AbstractBuilding* and contains a URI to the exact same building in the BAG dataset. This capability of CityGML is quite essential since many objects in the model can be related to the same object in other datasets. It is essential since different types of objects are updated regularly and sometimes require additional information that is not embedded in the CityGML model. The concept of external references allows for any *CityObject* an arbitrary number of links (e.g. URI’s) to corresponding objects in external information systems (Groger, Kolbe, Czerwinski, & Nagel, 2012).

6.3.2 Generic attribute

The generic attribute is one of two methods provided by CityGML to extend the CityGML model. The other method, application domain extension is described in the next section. The first methods include the usage of generic city object and generic attributes. Both are included in the core structure of CityGML and defined within the module *generics* (figure 6.3 & 6.4). Any CityObject can have an arbitrary number of generic attributes included (Kolbe, 2009). The use of generic attributes is rather ad hoc and can be done during runtime and does not require an application schema. This however means that the generic part of the dataset cannot be validated against the CityGML application schema. Besides this shortcoming, the usage of a generic attribute has two other disadvantages. First, generic attributes can only include one of five types of data: integer, string, double, data and a URI. Second, since no application schema is required naming conflict of generic objects and attributes can occur (Gifford Dsilva, 2009).

6.3.3 Application domain extension (ADE)

An application domain extension allows for the addition of properties to existing CityGML classes. The ADE defines systematic extensions for the CityGML data model. It therefore requires, in contrast to a generic attribute, that an application schema definition is created with its own namespace (Kolbe, 2009). This application schema does explicitly have to import the XML schema definition of the extended CityGML modules. An ADE allows to add new properties to existing CityGML classes. It can be used to define new object types by for example adding new attributes to a building such as the attribute "inhabitants". Since the ADE requires an application schema definition the extension is formally specified and could therefore be further developed and standardised by interested communities (Gifford Dsilva, 2009) & (Groger, Kolbe, Czerwinski, & Nagel, 2012). It also allows great flexibility since one ADE can be inherited into different CityGML modules. Another advantage of ADE is that more than one can be used in the same data model (Gifford Dsilva, 2009). For example: the *building module* could be extended with multiple ADEs that include information on inhabitants, floors, energy usage etc. as long as each application schema inherits the schema definition of the ADEs.

6.3.4 CityGML file format and structure explained

The topics that are described above cover a lot of different terms and standards that are all related to CityGML. In order to understand how the structure is defined in terms of programming terminology an explanation is given. As described in section 6.1 CityGML is an extension GML which is XML based. The ADEs described in the previous section are an extension of CityGML (figure 6.9).

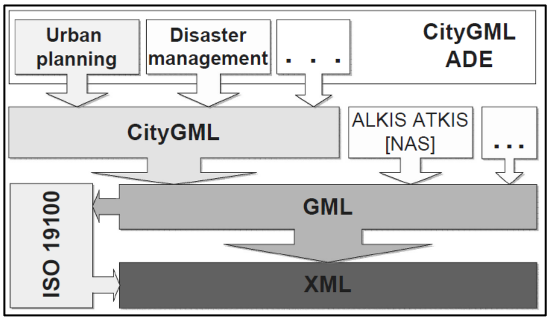


FIGURE 6.9: SCHEMATIC REPRESENTATION OF CITYGML INHERITING GML AND XML SCHEMA DEFINITION WHILE ADE INHERIT THE CITYGML SCHEMA DEFINITION (KOLBE, 2009).

First it has to be understood that the example given in section 6.2.3.2 includes an excerpt of the XML application schema that defines the content of 3D model and a visualisation of the content by a tool that is capable of reading CityGML file formats. The definition of the content, meaning what the content could be (numbers, letters, date's, addresses, coordinates) is described by the schema definition in xsd documents. These xsd documents are also XML based. As section 6.2.2 describes, the CityGML structure is divided into a core module with eleven sub modules. Each module is separated from the others and defined in a separate schema definition. A correct CityGML document therefore has first to be validated against the core module, and the sub modules that are included in the file. Secondly, since CityGML is based upon GML it has to be validated against this schema definition as well. And thirdly if applicable, a CityGML file could include additional information that is defined in an ADE to which the file has to be validated against as well. This is shown at the top of a CityGML file were it is importing the schema's to which it has to be validated against (figure 6.10). In this example the lines that define the namespace of subsequently the CityGML base schema, the GML schema and the building schema are shown.

```
<?xml version="1.0" encoding="UTF-8"?>

<CityModel xmlns="http://www.opengis.net/citygml/1.0"
xmlns:core="http://www.opengis.net/citygml/base/1.0"
xmlns:tex="http://www.opengis.net/citygml/textures/1.0"
xmlns:gml="http://www.opengis.net/gml"
xmlns:bldg="http://www.opengis.net/citygml/building/1.0"
xmlns:app="http://www.opengis.net/citygml/appearance/1.0"
xmlns:dem="http://www.opengis.net/citygml/relief/1.0"
xmlns:tran="http://www.opengis.net/citygml/transportation/1.0"
xmlns:gen="http://www.opengis.net/citygml/generics/1.0"
xmlns:frn="http://www.opengis.net/citygml/cityfurniture/1.0"
xmlns:wtr="http://www.opengis.net/citygml/waterbody/1.0"
xmlns:luse="http://www.opengis.net/citygml/landuse/1.0"
xmlns:veg="http://www.opengis.net/citygml/vegetation/1.0"
xmlns:xAL="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0">
```

FIGURE 6.10: EXCERPT OF TOP OF THE CITYGML DOCUMENT OF ROTTERDAM LISKWARTIER, SHOWING THE DIFFERENT SCHEMA'S THAT THE UNDERLYING DOCUMENT IS VALIDATED AGAINST. MARKED YELLOW: RELEVANT SCHEMAS FOR FURTHER EXPLANATION

The schema definitions referred to in the CityGML file are stored separately at the location defined in the URI (http://www.opengis.net/citygml/...). The excerpt of the Rotterdam CityGML model refers to the CityGML version 1.0, currently version 2.0 is available which is used in the remainder of the explanation.

As stated in section 6.3.3 each schema definition does explicitly have to import the XML schema definition of the extended CityGML modules. This means for a start that the schema definition of the core module of CityGML has to import the schema definition of GML (figure 6.11).

```
<?xml version="1.0" encoding="UTF-8"?>

<xs:scheman xmlns="http://www.opengis.net/citygml/2.0"
xmlns:xAL="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0"
      xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:gml="http://www.opengis.net/gml"
      targetNamespace="http://www.opengis.net/citygml/2.0"
elementFormDefault="qualified" attributeFormDefault="unqualified">
      <xs:import namespace="http://www.opengis.net/gml"
schemaLocation="../3.1.1/base/gml.xsd"/>
      <xs:import namespace="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0"
schemaLocation="../xAL/xAL.xsd"/>
```

FIGURE 6.11: EXCERPT OF THE TOP OF THE SCHEMA DEFINITION OF THE BASE MODULE OF CITYGML, SHOWING THAT IT IMPORTS GML. (WWW. CITYGML.ORG)

The building module is based upon the core module and GML it therefore has to import both application schemas (figure 6.12).

```
<?xml version="1.0" encoding="UTF-8"?>

<xs:scheman xmlns="http://www.opengis.net/citygml/building/2.0"
xmlns:core="http://www.opengis.net/citygml/2.0"
	xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:gml="http://www.opengis.net/gml"
	targetNamespace="http://www.opengis.net/citygml/building/2.0"
elementFormDefault="qualified" attributeFormDefault="unqualified">
	<xs:import namespace="http://www.opengis.net/gml"
schemaLocation="../3.1.1/base/gml.xsd"/>
	<xs:import namespace="http://www.opengis.net/citygml/2.0"
```

FIGURE 6.12: EXCERPT OF THE TOP OF THE SCHEMA DEFINITION OF BUILDING MODULE OF CITYGML, SHOWING THAT IT IMPORTS THE CORE MODULE AND GML. (WWW.CITYGML.ORG)

If for example an ADE is created it has to import the modules it is applicable to as well. As section 2.3.3 describes, an ADE can be applicable to multiple modules. An example is the Noise ADE that defines the structure of noise information from the objects within the modules: *Transportation, Buildings and Furniture.* Besides these modules the ADE is also an extension of the *core module* and *GML*. This means that the ADE schema definition has to import five other schema definitions (figure 6.13).

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:scheman xmlns="http://www.citygml.org/ade/noise_de/2.0"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
	xmlns:frn="http://www.opengis.net/citygml/cityfurniture/2.0"
xmlns:tran="http://www.opengis.net/citygml/transportation/2.0"
	xmlns:bldg="http://www.opengis.net/citygml/building/2.0"
xmlns:core="http://www.opengis.net/citygml/2.0"
	xmlns:gml="http://www.opengis.net/gml"
targetNamespace="http://www.citygml.org/ade/noise_de/2.0"
elementFormDefault="qualified"
	attributeFormDefault="unqualified">
	<xsd:import namespace="http://www.opengis.net/gml"
schemaLocation="../../3.1.1/base/gml.xsd"/>
	<xsd:import namespace="http://www.opengis.net/citygml/2.0"
schemaLocation="../../CityGML/cityGMLBase.xsd"/>
	<xsd:import
namespace="http://www.opengis.net/citygml/transportation/2.0"
schemaLocation="../../CityGML/transportation.xsd"/>
	<xsd:import namespace="http://www.opengis.net/citygml/building/2.0"
schemaLocation="../../CityGML/building.xsd"/>
	<xsd:import
namespace="http://www.opengis.net/citygml/cityfurniture/2.0"
schemaLocation="../../CityGML/cityFurniture.xsd"/>
```

FIGURE 6.13: EXCERPT OF THE TOP OF THE NOISE ADE SCHEMA DEFINITION, SHOWING THAT IT IMPORTS FIVE OTHER SCHEMA DEFINITIONS. (WWW.CITYGML.ORG)

If information about noise was described in the CityGML file of Rotterdam according to the Noise ADE then the CityGML file should have named the schema definition of the ADE in top of the description from figure 6.10 as well.

The structure of CityGML is rather straightforward. The examples showed that basically every topic that is included in a CityGML file is defined in a separate schema definition. For all existing topic (e.g. modules) schema definitions are provided for by the OGC while new ones can be defined by means of an ADE. The most important aspect when extending the CityGML with an ADE is to include or import all related schema definitions.

6.4 CityGML: developments

The field of 3D city modelling has developed extensively in recent years. Many of these developments have focused on the improvement of overall standards and the extension of CityGML by means of ADE. ADE for noise mapping, facility management, indoor navigation and 3D cadastre are some examples (Groger & Plumer, 2012). However one development is found to be of particular interest in the matter of this research. Section 2.3.3 describes that 3D models in the real estate industry were less useful when only consisting of one block and that 3D information was often applicable to a certain floor or unit within a building. Section 6.2.3.1 shows that floors are not part of the 3D city model until LOD4. The models that are currently publicly available such as the Rotterdam 3D city model are LOD2 models meaning that floors are not included in the building model. Recent research by Arroyo Ohori Et al. (2015) aimed to contribute to the possibilities of automatically enhancing LOD2 CityGML models with indoor geometry (figure 6.14). The research concluded that many different applications do require city models with indoor geomtries but do not require very high level of details as defined by in LOD4. The usability of LOD2 models with storeys added to the model with a comparable LOD as the exterior of LOD2 models increases significantly (Arroryo Ohori Et al. 2015).

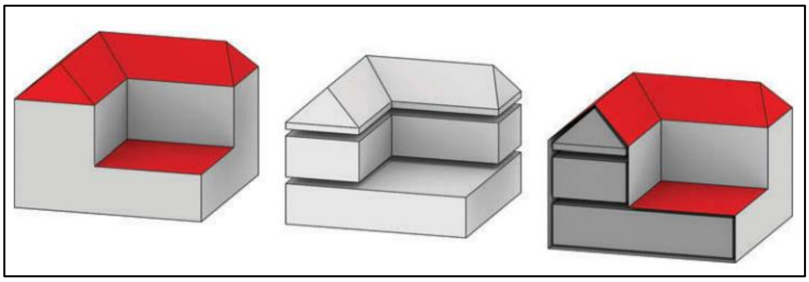


FIGURE 6.14: LOD2+ MODEL ON THE RIGHT WITH THE CORRESPONDING LOD2 EXTERIOR MODEL ON THE LEFT AND THE CORRESPONDING INDOOR MODEL IN THE MIDDLE (ARRORYO OHORI ET AL. 2015)

Indoor information can however not be stored in a LOD2 citymodel. Therefore LOD2+ is proposed. LOD2+ is defined as an extension of LOD2. This means that the authors of the research have chosen to extend the current CityGML 2.0 schema with an additional feature (figure 6.15).

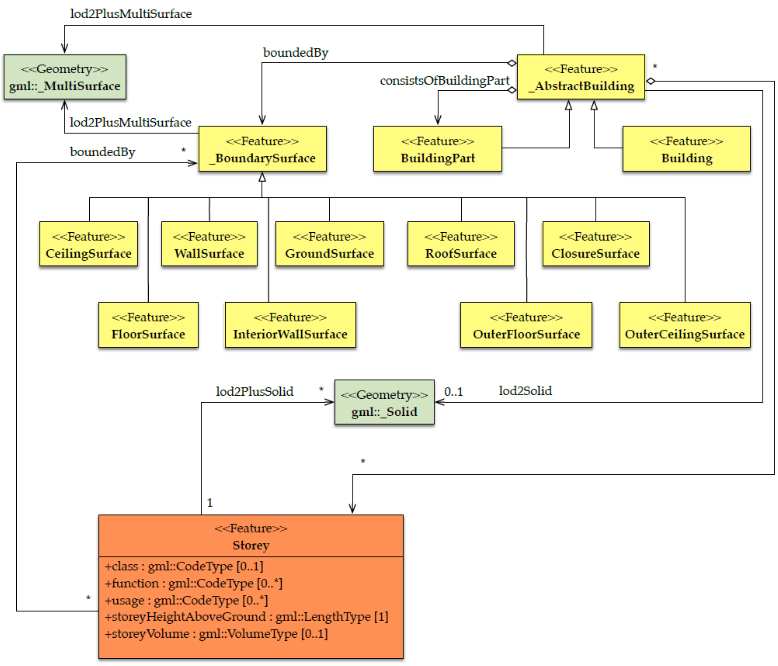


FIGURE 6.15: UML DIAGRAM SHOWING A SIMPLIFIED VERSION OF THE CITY GML BUILDING MODULE WITH THE LOD2+ EXTENSION (ORANGE) (ARRORYO OHORI ET AL. 2015)

With respect to this research, in which the addition of floors to attach real estate information to is of importance, the automatically enhancement of LOD2 models to LOD2+ is of high importance. The research describes four steps to create to LOD2+ model (Arroryo Ohori Et al, 2015):

1. Repairing the building geometries in the LOD2 model using City Doctor;
2. Converting CityGML into Nef polyhedral;
3. Perform geometric operations to obtain a volumetric representation of LOD2+;
4. Classify the surfaces.

The research used the Rotterdam 3D dataset as a case study. A part of this dataset is used to enhance the buildings with floors and as a next step use this model to obtain the square meters per building floor. The results are compared to the actual measurements of the floors defined in NEN2580[20] reports and were found to be 77% accurate within the tolerance boundaries. The research concludes that the creation of LOD2+ models do not come with significantly increased acquisition costs and that it allows for CityGML to become a more of a general purpose product that can be used in different application areas.

6.5 Conclusion

The fourth sub questions aims to answer what the characteristics and capabilities of CityGML are. These characteristics and capabilities can then be utilized in the development process of a relevant real estate use case utilizing the 3D city model. In this chapter the technical definition is described and explained. Derived from this technical definition are the most important characteristics and the capabilities of CityGML.

The main characteristic of CityGML is that it is an extension of the GML3 schema definition and that it is an xml based format. The structure of CityGML is divided into a Core module with eleven sub modules that each define a different aspect of a city. The core module defines the basic attributes of all other modules while each module defines additional module specific attributes. Each module has to import the CityGML *Core module*. The *building module* is considered the most importance module of the structure for both this research as well as in general. The different attributes that the *building module* can describe depend on the LOD. The LOD is the most important characteristic of CityGML. The LOD determines the semantical richness of the city model in five different levels from LOD0 to LOD4. The LOD has is influence on the different modules and for instance the building module does not include indoor geometries up to LOD4. **This means that building floors are not defined in CityGML files of until LOD4. With respect to this research the importance of building models including floors is repeatedly mentioned.**

With regard to the capabilities of CityGML the possibilities of extending the CityGML core structure with additional data is examined. Three options are discussed of which an ADE seems to be most convenient way of extending a CityGML file in a proper way. An ADE is defined in a separated schema definition and is specifically inherited by the application schema. Since the ADE is defined in a separated schema definition it allows for further specification, development and re-use by the CityGML community. The use of generic attributes is less favoured since it is more of an ad hoc solution than a constructive solution. **Therefore using an ADE is adopted in further development of a real estate use case that utilizes a 3D city model.**

Since the importance of floors in a 3D model for the real estate industry is repeatedly mentioned the developments that allow for the creation of floors without requiring a LOD4 model are of particular interest. **Research by Arroryo Ohori Et al, (2015) indicated that it is possible to automatically enhance a LOD2 city model with floors.** The research also showed that the floors created were of a good accuracy when compared to actual NEN2580 measurements reports of those floors. It is safe to assume that any use case that this research aims to develop requires a building model to have floors. Therefore the use of this and possibly other techniques should be considered when creating the use case.

20 NEN2580 is a Dutch norm that provides standards and measurement definitions for the surface of terrain and property

Chapter 7. Use case development

The result of chapter 5 is a preliminary use case description based upon input from real estate professionals. To create this use case the characteristics and capabilities of CityGML are studied in chapter 6. This chapter starts with defining the actual use case along with its technical features, datasets and requirements and thereby answering the fifth sub question in section 7.1:

> *What are the requirements of the use case and what datasets are required to create this use case?*

The process of developing the use case is described in section 7.2. By trial and error an answer is given on the sixth and final sub question:

> *How could CityGML be used to attach the dataset to and allow its downstream use e.g. to visualise the required information from that dataset?*

In section 7.3 the final model is evaluated and its potential and shortcoming in practice elaborated on. This chapter concludes with answering both sub questions in section 7.4.

Development process introduction

In section 2.4 of this research different steps and tools are described that are required to make the shift from 2D towards 3D according to ESRI (2014) and Bayers et al (2015). The first step is identifying the added value of using 3D over 2D in the particular use case. This is done in the interviews with the professionals from the real estate companies. Next an important factor is the selection of the users of the use case. This is done in section 7.1. Then the data requirements can be selected which is done in section 7.1.2. Next the tools and workflows to convert 2D into 3D should be selected, this is done in section 7.2. The eventual business opportunities that can be realized are described in section 7.3.

7.1 Use case definition

Section 1.2 described the general definition of a use case that is adopted in this research (Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova, 2015):"a use case can be seen as a meaningful set of spatial operations that accomplisch a goal a user wants to achieve with a spatial data set". This section defines the spatial operations, the users and the spatial dataset. The opinions from real estate profesionals indicated the relevancy of using 3D city models to visualise information that could not be visualised in 2D. They would like to see the use of a 3D city model as a database to which informaition could be connected to specific parts of a building. The added value was mainly seen in gained insight and more efficient information analysis.

Use cases are particulary used in the development of software applications and can be defined in a use case diagram according to he Unified Modelling Language (UML) standard. However since the use case is not that complex or detailed a use case description instead of a diagram will suffice. Since the use case itself involves hardly any development risks a very detailed description is not required either (Fowler & Scott, 2000).

7.1.1 Use case description

First the actors (or users) involved in the use case are established. The purpose of this research is to determine a relevant use case for real estate applications. The main actor is therefore the real estate professional. A second actor is the data professional that provides and maintain both real estate data and the 3D dataset.

As derived from the interview with real estate experts the main purpose of the 3D use case is to store and visualise leasing data per building floor and allowing professionals to query the different building floors. The primary use case demands are therefore to enable users to extract information per building floor. The second demand regards the data attached to the building and floors which in this case is data regarding ownership and lessees. In terms of the framework proposed by Biljecki, Coltekin, Ledoux, Stoter, & Zlatanova (2015) this use case is considered a real estate transaction application and use case is named: ownership and leasing rights.

The real estate professional should be able to:

1. Query the dataset via the model itself and via the underlying dataset;
    a. Query by clicking on an object
    b. Query via the (leasing) dataset on different variables
2. Derive square meter prices per floor;
3. Derive leasing terms per floor;
4. Visualise results from the query;
5. Add or adjust data from the leasing dataset;
6. Identify tenants per building floor.

The data professional should be able to:

1. Provide updates of the 3D dataset;
2. Add new ADEs to increase the capabilities of the model as a database;
3. Attach new datasets to the 3D dataset.

To perform the different operation two spatial datasets are required. First a 3D model of the preferred area is required. Second a dataset is required that includes all or most leasing and ownership conditions of the tenants and owner of the buildings within this area. Both might have to be converted and adjusted to be suited for the use case. The process of creating this use case is descripted in the next sections.

7.1.2 Use case requirements

The use case has different requirements regarding the 3D city model, query capabilities and the dataset. The requirements are derived from the CityGML capabilities and interview results:

- The use case requires data to be attached to certain parts of a building. Therefore a 3D city model is required that is capable of holding and visualising semantic information. 3D city models aimed at solely the graphic representation of building are therefore not suited (Chapter 6, capabilities of CityGML);
- The 3D city model should contain at least floors within a building. The current models that are available represent buildings as one object composed of ground, wall and roof surfaces (Chapter 5, interview results);
- The 3D City model should be able to hold information on ownership and leasing rights (Chapter 5, interview results);
- The use case should be able to be extended with additional information and datasets to use the 3D city model as a database. The development process should therefore use an approach that is repeatable and allows for extensions (Chapter 6, capabilities of CityGML);
- The users should be able to query the 3D city model via the model itself and via the dataset (Chapter 5, interview results).

7.2 Development process

As described in the previous section the use case includes the visualisation of leasing and ownership information per floor and per building. The actors involved in the use case should be able to query the model for information and add new or edit current leasing information. To create this model different products are required:

1. 3D city model of an area;
2. A tool to create floors within a 3D city model from the CityGML standard;
3. An ADE that defines leasing and ownership information per building and floor;
4. Dataset that contains leasing information from different floors.

The development process of this products is described in sections 7.2.1 to 7.2.4. Each product requires a set of operations in order the acquire or develop the product required in the next step. Therefore after each step the product is evaluated and checked whether it is qualified to be used in the next step.

In the first step, described in section 7.2.1, the process of obtaining, analysing, and possibly converting a 3D model of a city to CityGML is, described. This step is completed when a 3D model in CityGML of sufficient quality is acquired. The aim of the second step is to generate building storeys in the 3D model in a way that these storeys are viewable in a CityGML viewer and that the code is valid according to the CityGML schema definition. When a valid model with storeys is obtained then an ADE can be created that describes the information that the newly generated storeys can include. The process of creating an ADE is described in section 7.2.3. The ADE is validated against the core and related modules of CityGML. In the final step a dataset that includes ownership and leasing information of buildings is altered and attached to the 3D model via the ADE. A flowchart is created that describes the process and identifies the validation moments in the development process (figure 7.1).

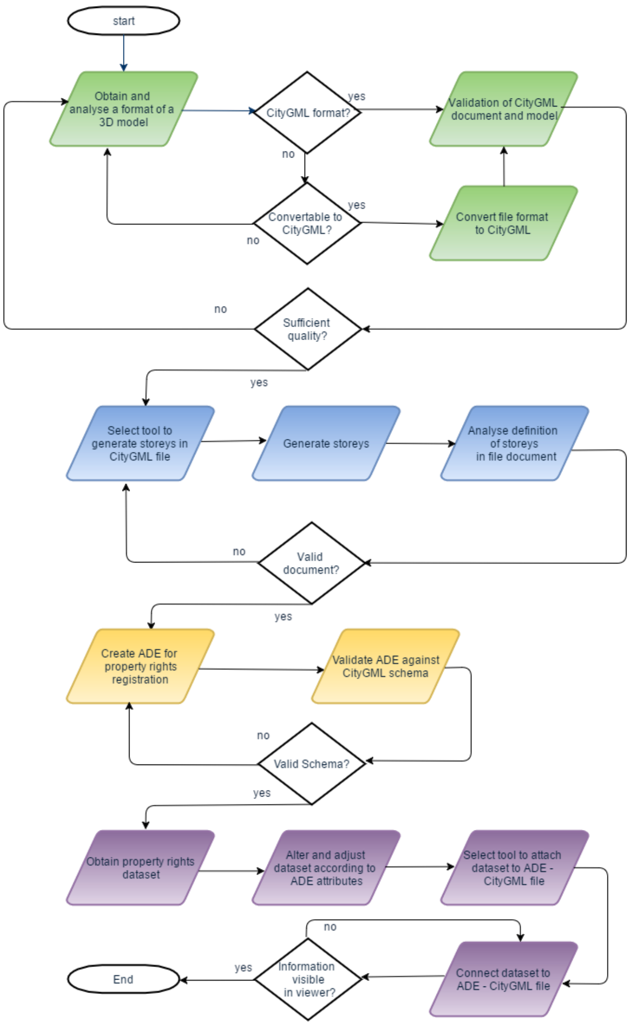


FIGURE 7.1: PROCESS OF DEVELOPING A PROTOTYPE OF THE USE CASE

7.2.1 Obtaining a 3D city model

This section describes the process of obtaining a 3D city model and validates it quality to be used in use case development. The first wish is to obtain a 3D city model of an area that is known to most respondents in this research and of which data is available regarding ownership and tenants. Therefore the Amsterdam South-Axis is selected which is also considered the central business district of the Netherlands (figure 7.2). From the this area two 3D datasets are available. However both are not available to the public and have to be bought or used with special permission. One dataset provides the Amsterdam South Axis in 3D in the Collada format. This data format is however aimed at the geographical visualisation of buildings and lacks semantic representations. The second 3D dataset that could be obtained from the Amsterdam South-Axis is from the municipality of Amsterdam. They created a 3D model of the entire Amsterdam South region. There are however some limitations regarding this model. First the file size is rather large (50 mb) and requires a lot of computer capacity to run. Second the model is provided for a Microstation file format (.dgn). To be able to work with the model it first has to be altered to reduce the size in terms of MB's and the reduce the area to solely the business district (figure 7.3). Since Microstation is related to Autocad the model can easily be converted to a CAD file (.dwg). The model has detailed building surfaces especially of the building in the top right corner (figure 7.3).

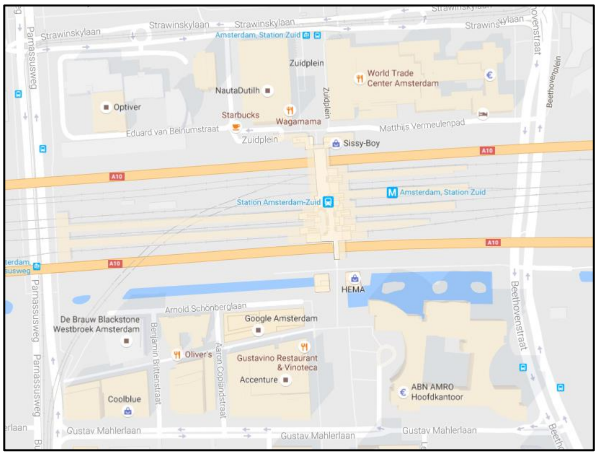


FIGURE 7.2: AMSTERDAM SOUTH AXIS, SOURCE: GOOGLE MAPS

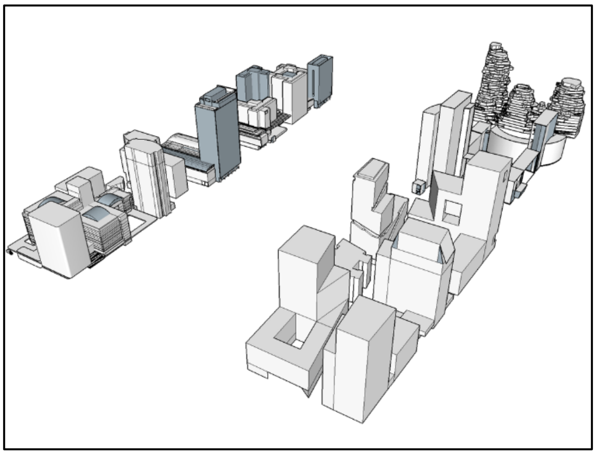


FIGURE 7.3: EXCERPT OF 3D MODEL AMSTERDAM SOUTH-AXIS SOURCE: MUNICIPALITY OF AMSTERDAM

The 3D CAD model can be converted to the CityGML file format using a FME workbench workflow. In this workflow the different layers from the CAD file are converted to CityGML feature types such as *WallSurface*, *GroundSurface* and *RoofSurface*. There is however one problem, the buildings in the CAD file are modelled in one layer: buildings. Therefore no connection can be made between different parts of a building in the CAD file (e.g. roof, wall and ground) and the feature types from CityGML. The result is that after the conversion a valid CityGML file format is obtained however only describes polygons with coordinates and no semantics (figure 7.4).

```
<?xml version="1.0" encoding="UTF-8"?>
<core:CityModel xmlns:smil20="http://www.w3.org/2001/SMIL20/"
xmlns:grp="http://www.opengis.net/citygml/cityobjectgroup/1.0"
<gml:boundedBy>
      <gml:Envelope srsDimension="3">
            <gml:lowerCorner>119112.200833431 483312.781 -0.5
            </gml:lowerCorner>
            <gml:upperCorner>120284.34072995 486387.108042888
      105.500000112369</gml:upperCorner>
      </gml:Envelope>
</gml:boundedBy>
<core:cityObjectMember>
<gen:GenericCityObject>
<gen:lod4Geometry>
<gml:Polygon srsDimension="3">
<gml:exterior>
<gml:LinearRing>
<gml:posList>119112.200833431 483312.781 0 119112.200895212
483312.820284469 0 119112.200833431 483312.781 0</gml:posList>
</gml:LinearRing>
```

FIGURE 7.4: EXCERPT OF GML FILE OF AMSTERDAM SOUTH AXIS AFTER CONVERSION FROM CAD USING FME WORKBENCH

CityGML was explicitly selected because of its capabilities to describe the semantics of objects and therefore the model of Amsterdam South-Axis is not used.

7.2.1.1 3D model of Rotterdam

From the city of Rotterdam a 3D model is available in CityGML with LOD2. The model is publicly available and can be downloaded from the municipality website[21]. From Rotterdam an area is selected known as ''Kop van Zuid'' (figure 7.5). In this area multiple office building are located from which information is available regarding ownership and leasing. The 3D model of this area is available with exterior appearance but can also be viewed and used without the exterior appearance (figure 7.6)

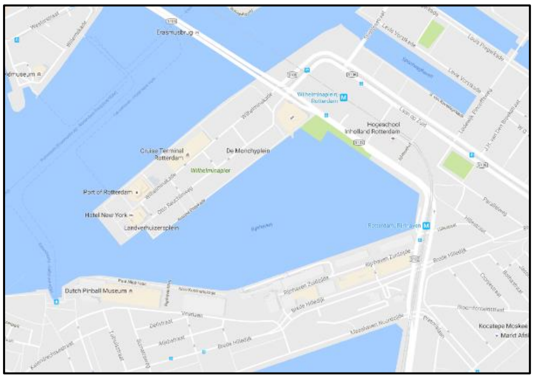


FIGURE 7.5: ROTTERDAM KOP VAN ZUID, SOURCE: GOOGLE MAPS

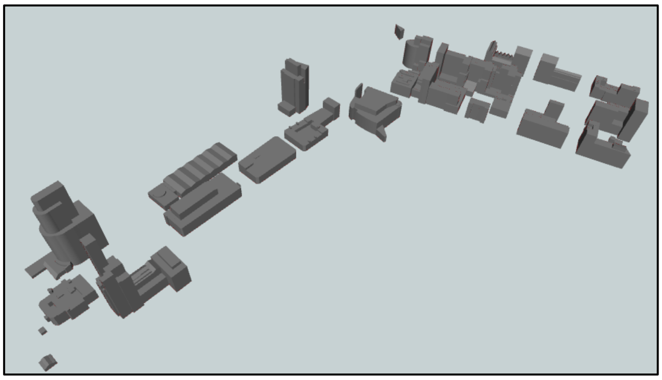


FIGURE 7.6: KOP VAN ZUID 3D, SOURCE: ROTTERDAM MUNICIPALITY

The CityGML file contains the semantic description that the converted example of Amsterdam South-Axis lacked. Besides using the Rotterdam city model has some other advantages as well. First all buildings are georeferenced which means that if the 3D model is uploaded in an ArcGIS viewer that the building are placed on the correct place on earth on a map. Second all buildings are of LOD2 and are properly defined in an xml document as buildings with a unique *gml id* and contain the *featuretype* of CityGML from the *building class*. Since the building is in LOD2 the roof shapes are properly defined, therefore no "additional" storeys can be constructed in the model because of wrong measurements (see section 6.2.1). One of the shortcomings of the model is that not all polygons are properly connected. This shortcoming is seen in more 3D datasets of Rotterdam (Arroryo Ohori Et al, 2015). It means that not all buildings

21 http://www.rotterdam.nl/links_rotterdam_3d

consist of closed surfaces. Despite of this shortcoming the 3D model of Rotterdam is of sufficient quality to be used in the further development of the prototype use case.

7.2.2 Creating floors

The next step is to select and use a tool that is capable of creating floors in the CityGML file. Different tools are available that allow for the creation of floors in 3D models with each a different result.

7.2.2.1 Split floors in ESRI CityEngine or ArcGIS pro

ESRI released in early 2016 a tool to create floors in 3D models using a set of tools in ArGIS pro or CityEngine. The Geoprocessing tool allows users to select a building and set the floor heights per floor number and then generate the floors (Taylor, 2016). In order to use this tool either ArcGIS pro or CityEngine software packages is required. Both tools are developed by and can be purchased from ESRI. To use the "Split floor" tool the CityGML file first has to be converted into a file format that is recognised by ESRI software: 3DCIM. ESRI provided a workflow to import and export CityGML and 3DCIM files using ArcCatalog. The workflow aggregates LOD2 features as *Ground-*, *Wall-* and *Roofsurface* into a "Buildingshell" (figure 7.7). When the CityGML file is converted into a 3DCIM file it can be opened in ArcGIS pro and CityEngine. The Split floor tool creates floors in the building that are visible and can be selected. For the purpose of this research the buildings with floor then need to be exported back into the CityGML format. This is however a problem since the floors are nog recognised as CityGML feature types and the building shell is now one shell instead of ground, wall and roof surface types. This method is perhaps useful when the further development of this prototype would take place in an ESRI environment. ESRI does provide the capabilities to attach data from different dataset to geographical locations and objects. However since this research is aimed at using CityGML this method is not used.

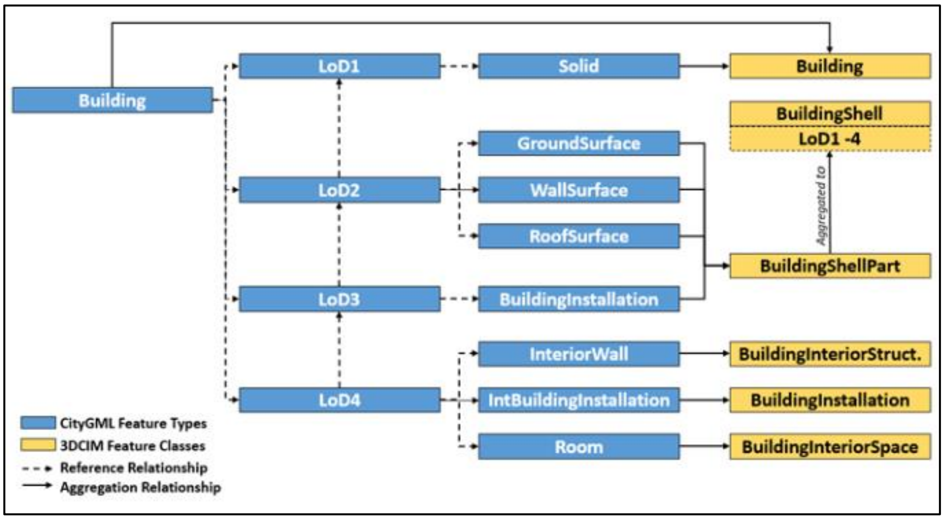


FIGURE 7.7: IMPORT BUILDING FROM CITYGML TO 3DCIM USING ARCCATALOG 3DCIM CITYGML TOOLBOX, SOURCE: HTTP://DESKTOP.ARCGIS.COM/EN/3D/3D-CITIES/3D-CITY-BASE-LAYERS/IMPORT-AND-EXPORT-WITH-CITYGML-TOOLS.HTM

7.2.2.2 CityObjectGroup

The CityGML standard provides a way to group objects into, among others, storeys. This technique is also known as *CityObjectGroup* (Groger, Kolbe, Czerwinski, & Nagel, 2012). Storeys are represented as an aggregation of all the building features at a certain height. This would require that wall surfaces that usually consists of one polygon of the entire facade are fragmented into polygons per storey. This method is based upon different steps that have to be performed manually or by a written script. First all semantic object that belong to a specific storey are grouped. The attributes of the created *CityObjectGroup* are then set. The Class attribute is assigned with the value "building separation", the function has the value "lodXStorey" in which de LOD can be everything between 1 and 4. As a last step the storey can be given a name using the *gml:name* property (Groger, Kolbe, Czerwinski, & Nagel, 2012). This method can be used, however it requires a lot manual work to split the building *wallsurfaces*. Another argument to not use this technique is that it is expected that storeys will become a part of the next CityGML standard (Arroryo Ohori Et al, 2015). When updating the prototype in the future it will not be consistent with the standard.

7.2.2.3 Enhancing CityGML LOD2 model with interior geometry

In section 6.4 some developments in CityGML data modelling techniques are described among which the LOD2+ technique. Research by Arroryo Ohori Et al. (2015) aimed to develop LOD2 CityGML models with simple indoor geometries. This LOD was labelled LOD2+ and included indoor geometries of storeys in a building. To be able to define storeys in the CityGML 2.0 schema they proposed an extension of the schema rather than using an ADE or *CityObjectGroup*. Their believe is that the extension of the schema will eventually become part of CityGML standard in the next version that will be released. Their argument against using *CityObjectGroup* is that it will exclude the joint storage of a LOD2+ and LOD4 model. Using an ADE is however becoming increasingly used for different applications. The technique to generate building storeys and extending the CityGML schema does however required multiple steps to be taken. This method is validated by using in the use case "computing and validating the net internal area". This use case used the generated CityGML model with floors to extract the net internal area from buildings and floors and compare the result with the net internal area registered in the BAG dataset. The result showed that extracted net internal area of 77% of the buildings are within the allowed tolerance. Their possible explanation for the 23% not satisfying result is that some municipalities adopted and registered another definition of net internal area before the official NEN2580 standard was defined (Arroryo Ohori Et al, 2015). This method of generating floors within a LOD2 CityGML model seems to provide a satisfactory result. Even more important is that the idea to add storeys as a new feature to the building module is expected to become a part of CityGML standard in the future. Therefore this method is favoured to be used in this research.

7.2.2.4 Creating floors using the selected method

The method described by Arroryo Ohori Et al (2015) extends the CityGML document in two ways. First storeys are automatically generated by running a sequence of scripts. Second, three generic attributes are added to the document that describe the *floor area*, *BAG use area* and the *Net height area*. The first extension is of most interest to this research. The basic scripts that are used to generate storeys in a building are publicly available in the Github from the TU Delft[22]. The authors have written five scripts to automatically generate storeys. These scripts import different other scripts of which the most important is the CGAL library. The scripts perform a sequence of healing functions on the CityGML file to obtain valid volumes, then a conversion to Nef Polyhedra since this format allows to perform geometric operations on. Next storeys are created based upon a set of geometric operations and data describing the number of storeys per building. In the final step the obtained surfaces are classified according to the CityGML standards. It takes approxamitly 16 seconds per building, depending on computer capacity, to perform the described steps. The result is a building in which storeys are geometrically

22 https://github.com/tudelft3d/lod2plus

represented and defined in the XML document as featuretype of buildings (bldg:storey, appendix 3.1) (figure 7.9).

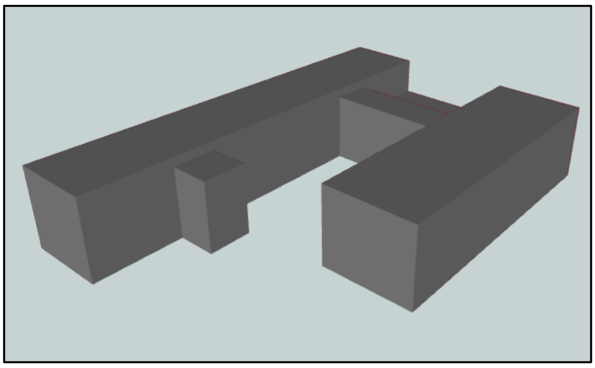


FIGURE 7.8: MODEL OF ROTTERDAM HOOGVLIET ZUID FROM INITIAL MODEL, SOURCE: MUNICIPALITY OF ROTTERDAM

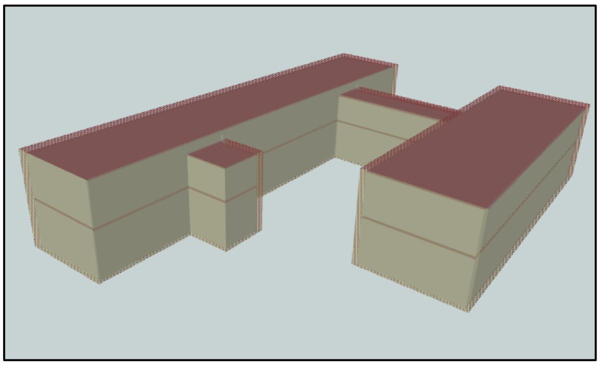


FIGURE 7.9: MODEL OF ROTTERDAM HOOGVLIET ZUID WITH FLOORS, GENERATED ACCORDING TO THE METHOD OF ARRORYO OHORI, BILJECKI, BOETERS, & ZLATANOVA (2015)

Unfortunately a transformation from the 3D city model ''Kop van Zuid'' has not been achieved. To enable the different scripts to run and import the correct additional scripts, mainly from the CGAL library extensive knowledge within the programming domain is required. This is however outside the scope of this research and capabilities of the author, also given the timeframe of this study. Therefore an output file from the tool is requested from the authors to further use in the prototype development. The authors provided two output files that can be used for further research (appendix 3.1).

The obtained XML document is validated against the CityGML standard using Netbeans[23]. Two main validation errors appear when checking the document:

1. "Storey" is defined in the xml document as a class of the building module;
2. The entire structure of the output is not in line with the CityGML standard.

The first error states that "storey" is not recognised as a valid attribute of *building*. The authors defined *storey* as a class within the building module and provided the according namespace (bldg.). However, *storey* is not defined in the building module schema nor in an ADE that extends this schema. To be able to attach information to a feature such as *storey,* and properly validate the document, it has to be defined in an xml schema. This has to be considered in the next step when the ADE is created. The second validation error occurs multiple times. The error repeatedly states that according to the schemas of the CityGML standard another attribute is expected in the sequence of the document. This indicates that even though the authors created a geometrical correct model of stories, the document structure is not in accordance with the CityGML standard.

To obtain a valid CityGML document the output received needs to be altered. First the document is re-structured to the correct sequence described in the CityGML standard. Since the document contains over 4.000 lines with information, a Python[24] script is written to re-structure the document and provide a new valid output (appendix 3.2). The script restructures the sequences of the elements in the document. To be able to validate the document against the CityGML standard also *storey* has to be defined. This is done according to the CityGML guidelines for extensions of the standard by creating an ADE (section 7.2.3.1). First an ADE is proposed that is capable of including the property rights information, which is required for in the use case.

23 https://netbeans.org/

24 https://www.python.org/

7.2.3 Creating an ADE

In section 6.3 the different possibilities to extend the CityGML information model with additional attributes are described and an ADE is mentioned to have certain advantages over generic attributes. In similar use cases like the one described in section 7.1 an extension of the CityGML schema was requested as well. Both Cagdas (2012) and Gifford Dsilva (2009) created an ADE to extend the CityGML schema with attributes related to ownership of buildings. The purpose of the ADE is to define in an xml schema defintion which information a building and a storey can hold and the structure of that information. The first step into modelling the ADE is to define its structure and relation to related modules and classes from the CityGML standard in a UML schema. Both Cagdas (2012) and Gifford Dsilva (2009) started with creating a UML Diagram of the proposed ADE (appendix 2.2 & 2.3). A UML diagram is even used to automatically generate an ADE schema (Stoter, Brink, & Zlatanova, 2012). The automatic generation is however outside the scope of this research but the use of a UML diagram does provide a structured idea of the ADE and its connections.

The proposed ADE in this research aims to define the property rights information regarding ownership of a building and leasing information per floor as described in the use case (section 7.1). The ownership information is related to the building and holds information as: owner name, transaction date, transaction price and whether the property is on leasehold or not. The leasing information holds information on: the tenant name, leased size, rental price, contract start, contract end, sqm price, lease options and comments on the lease. The ownershiprights can be mapped as a direct attribute of the class *AbstractBuilding*. These are application specific attributes of *Abstractbuilding* and are named: *GenericApplicationPropertyOfAbstractBuilding*.

As section 7.2.2.4 describes unfortunately the feature type storeys has not been defined (yet) in the building schema nor in an ADE schema. Ideally the storey feature type is defined as a class in the building module as proposed by Arroryo Ohori Et al. (2015). As part of the building module, storeys is described within the original building schema so that the ADE proposed in this research can be mapped in to the structure as an extension of both the *storey* and *abstractbuilding* feature types (figure 7.10).

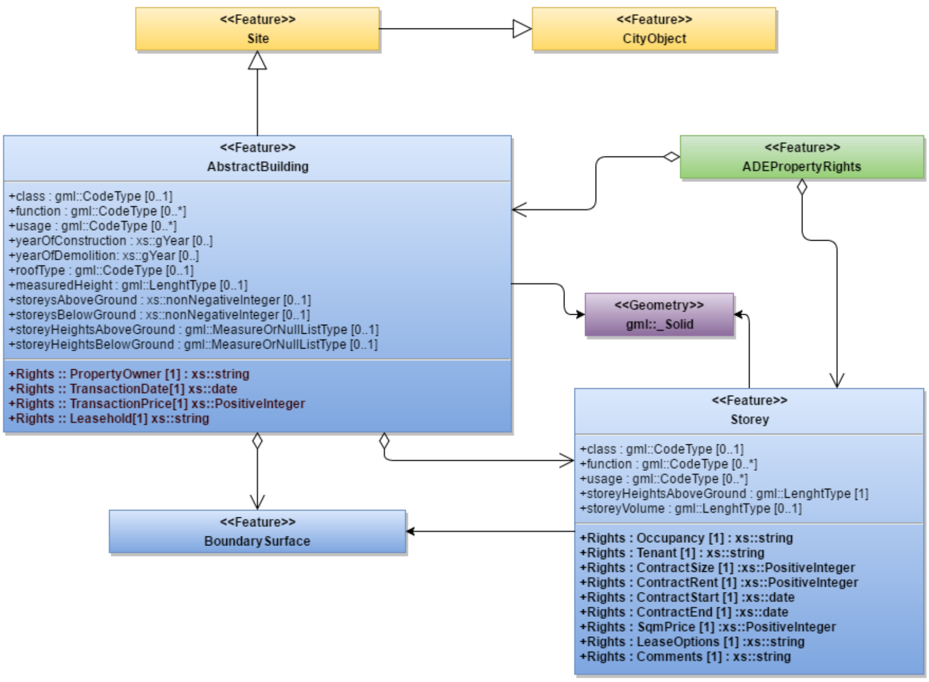


FIGURE 7.10: UML DIAGRAM OF PROPOSED ADE FOR PROPERTY RIGHTS PER BUILDING AND STOREY, BLUE: BUILDING FEATURES + PROPOSED STOREY FEATURE (AS CLASS OF ABSTRASCTBUILDING), GREEN: PROPOSED ADE FOR PROPERTY RIGHTS. OWN CREATION BASED UPON: (ARRORYO OHOR ET AL. 2015) & (GROGER, KOLBE, CZERWINSKI, & NAGEL, 2012).

Based upon the UML diagram an ADE schema is written. This schema is written according to the example in section 6.3 and imports the schema definitions of the core module, the building module, and GML. This ADE assumes that storeys is already part of the building schema. Therefore it uses the namespace of the building schema (bldg). Additional attributes for both building and storey are mapped as a generic element of building (appendix 3.3): *bldg*:*_GenericApplicationPropertyOfAbstractBuilding* or a generic element of storey: *bldg*:*_GenericApplicationPropertyOfStorey*. Since the ADE assumes storey is already defined in the building schema it does not require the import of an additional schema that defines storeys. This schema can be used in the future when *storey* becomes part of the building module in the CityGML Standard. This is however not the case yet, and this schema will not work unless *storey* is somehow defined in a CityGML schema definition.

7.2.3.1 Creating an alternative ADE

The previous section described the ideal situation that *storeys* is already defined within the building module of CityGML or within an existing ADE. Since the storey class created by Arroryo Et al (2015) is not defined in an ADE nor in the building schema, first a schema has to be created for this class. This research does support the idea of including storeys in the next version fo the CityGML standard and hopes that results of this research might be of importance to support this inclusion.

There are multiple options that could provisionally solve the issue described in the section above. Two of these options options are described below.

Option 1: Storeys as inheritance class of AbstractBuilding

The storey class is quite similair to the building class since it describes a part of the *building*. In terms of geometry these classes are very similair. To support the idea of including storeys in the CityGML standard this research proproses to add the *storey* class as an inheritance of *AbstractBuilding*. Currently the class *Building* and *BuildingPart* are the child classes of *AbstractBuilding*. Since this research does not want to alter the original (Abstract)Building schema the storey class is defined as an inheritance class that has the same definitions as *Abstractbuilding*. Since storeys is mapped as a subclass of *AbstractBuilding* it inheritice all the attributes and relations of *Abstractbuilding* (Groger, Kolbe, Czerwinski, & Nagel, 2012). Therefore the direct relation between storeys and the proposed ADE Property rights is no longer required since the *PropertyRights* is already related to the *AbstractBuilding* class. In the future when building models become even more detailed (LOD4) and rooms are part of the model, the storey *Propertyrights* could be assigned to this class as well. This option however, requires that the initial building schema has to be altered. In the building schema Storey has to be defined similair to *BuildingPart* and *Building*. This options however means that other users would have to adopt the building schema from this research to validate the model. This is not in line with the open distributed standard from the OGC. This option is therefore not favoured.

Option 2: Storeys as separate class mapped as an ADE for building

In the second option the consideration of the authors from the "storey research" is adopted that storeys should be a separate class in the building module. Also the guidelines of the OGC are considered that the CityGML standard should only be extended using one of the prescribed options (section 6.3) This means that storeys is defined in a separate ADE. Therefore two ADEs should be created. The first ADE defines *storey* and the second defines the *PropertyRights* as generic extensions of the classes *AbstractBuilding* and *ADEStorey*. If the model includes rooms then the *PropertyRights* ADE could also be extended by defining more generic extensions. For now this research focusses on defining *Storey* in an ADE and defining the property rights attributes of *AbstractBuilding* and *ADEStorey* in a separate ADE (figure 7.11).

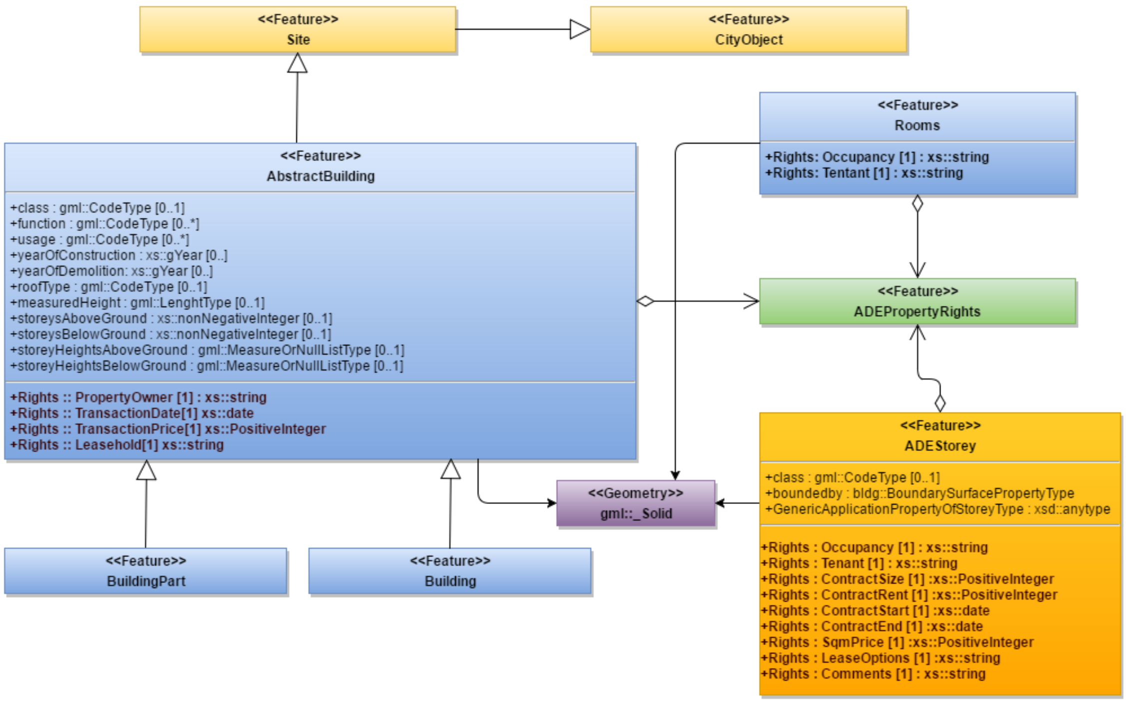


FIGURE 7.11: SIMPLIFIED UML DIAGRAM OF ALTERNATIVE PROPOSAL FOR BUILDING MODULE WITH ADESTOREY AND ADEPROPERTYRIGHTS, OWN CREATION BASED UPON: (ARRORYO OHORI ET AL, 2015) & (GROGER, KOLBE, CZERWINSKI, & NAGEL, 2012)

Creating ADEStorey and ADEPropertyRights

To be able to validate the output from Arroryo Ohori Et al (2015) first the document is restructured using a Python script. This output cannot be validated either untill the class *storey* is defined in an ADE (appendix 3.4). The Storey ADE describes *storey* as a generic element of a building: *bldg:_GenericApplicationPropertyOfAbstractBuilding*. The class *storey* includes three elements: *class, boundedBy* and *GenericApplicationPropertyOfStoreyType*. The *boundedBy* element is of the same type as the *boundedBy* element of building: "bldg:BoundarySurfacePropertyType". This means that a *storey* can have the same type of surfaces as a *building*. Adding *GenericApplication* element allows to add additional attributes to a *storey* in a similar manner as additional attributes can be added to a *building* (section 7.2.3). Therefore an ADE is created that uses this feature and add attributes to both *storey* and *building* (appendix 3.5). The difference of this ADE with the previously created ADE is that in this ADE, besides the *building* schema, also the newly created *storey* schema has to be imported. Since *storey* is defined in a separate schema it has its own namespace "storey". To both classes different property rights attributes are added (table 7.1).

TABLE 7.1 ATTRIBUTES ADDED TO *BUILDING* AND *STOREY* IN THE PROPERTYRIGHTSADE

Bldg:_ *GenericApplicationPropertyOfAbstractBuilding*	storey:_ *GenericApplicationPropertyOfStoreyType*
PropertyOwner	Occupancy
TransactionDate	Tenant
TransactionPrice	ContractSize
Leasehold	ContractRent
	ContractStart
	ContractEnd
	SqmPrice
	LeaseOptions
	Comment

7.2.4 Attaching data to the City model

As a final step the information regarding the attributes (table 7.1) can now be added to CityGML document of the building that is obtained. The building model consists of 3 floors, each floor has its own unique ID. The ID derived from the building ID which is derived from the BAG. The BAG ID of the building used in this example is "0599100000756252" which can be found in Rotterdam Kroelinge 10/12 (figure 7.12 & 7.13).

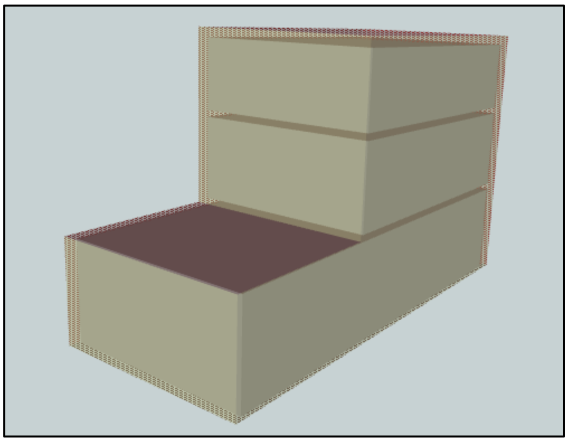


FIGURE 7.12: VALIDATED BUILDING MODEL WITH STOREYS, AFTER RESTRUCTURING AND ADDED ADES SOURCE: OWN ADJUSTMENTS & ARRORYO OHORI ET AL. (2015)

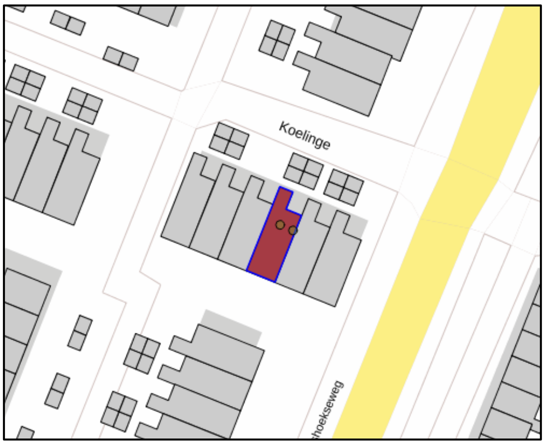


FIGURE 7.13: LOCATION DERIVED FROM BAG VIEWER ID: 0599100000756252 SOURCE: WWW.BAGVIEWER.KADASTER.NL

The IDs of the storeys are represented by the BAG ID plus the floor number (example: F01). A fictional dataset is used to attach to the model, since of this particular building no data is available (table 7.2).

TABLE 7.2: FICTIONAL DATASET INCLUDING INFORMATION OF THE BUILDING AND STOREY PROPERTY RIGHTS

gml:id	BAG0599100000756252F00	BAG0599100000756252F01	BAG0599100000756252F02	BAG0599100000756252
Occupancy	Yes	Yes	No	
Tenant	Timco Toppen	TUE		
ContractSize	300	200		
ContractRent	10000	6000		
ContractStart	20-8-2016	20-8-2016		
ContractEnd	20-8-2020	20-8-2020		
SqmPrice	33	30		
LeaseOptions	1*5	n*5		
Comment	New lease agreement	Moved from Eindhoven		
PropertyOwner				Rich guy
TransactionDate				8-10-2012
TransactionPrice				200000
Leasehold				no

There are different options to link the data from a dataset to CityGML. One option is to manually describe all attributes in the CityGML document, which can be done relatively easy when dealing with only one building with few storeys. However when the amount of buildings in the CityGML file and the amount of data that should be attached to this buildings and storeys increases an automated method is preferred. A tool that is capable of linking data from different dataset to each other is FME Workbench[25]. Using FME Workbench a property rights dataset in Excel is inserted along with the CityGML document and the created ADEs (figure 7.14). To be able to connect the Excel dataset with the CityGML file, both files are required to have corresponding IDs. In this case the BAG ID is represented in both the Excel dataset as well as CityGML document. A workflow can be created that links and writes the corresponding attributes of both datasets. It is important that both ADEs are uploaded in FME. Without this ADEs the element *storey* and the property rights attributes are not recognised.

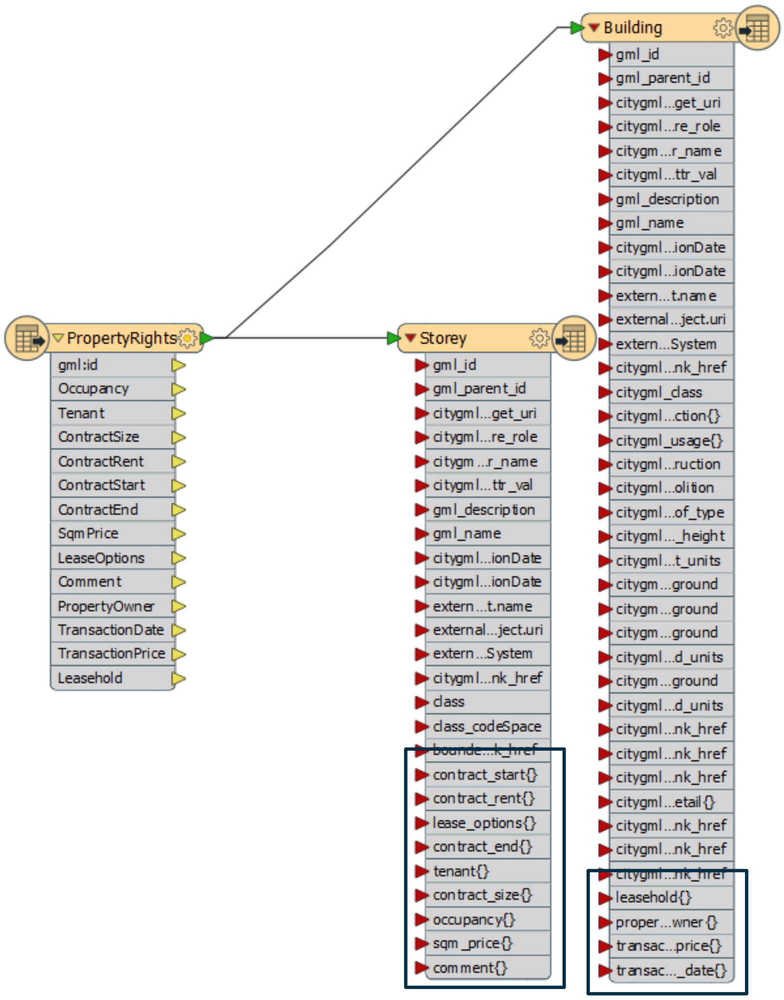


FIGURE 7.14: EXCERPT FROM FME WORKBENCH THAT INCLUDES PROPERTY RIGHTS DATASET (EXCEL) AND STOREY AND BUILDING ATTRIBUTES (CITYGML)

7.3 Result

The result of performing all steps (figure 7.1) from obtaining a CityGML file to connecting relevant data to this file is a 3D CityGML model capable of including and visualising property information.

A repository is created that includes the CityGML standard schema documentation. In the top folder three main documents are added:

1. RightsADE.xsd
2. StoreyADE.xsd
3. FixCityGML.py

25 www.safe.com

In this repository users can add the output of the tool from Arroryo Ohori Et al. (2015) and name it "OutputLOD2plus.xml". Then the Python file (FixCityGML.py) can be opened and executed. The result is a restructured CityGML document named: "OutputRestructure.xml". Users then only need to add the local schema locations to the root element of this output file to be able to add property rights to the buildings and storeys present in the CityGML file (figure 7.15). If this repository is used then the local schema locations as presented in the example can be used.

```
<CityModel xmlns="http://www.opengis.net/citygml/1.0"
            xmlns:app="http://www.opengis.net/citygml/appearance/1.0"
            xmlns:bldg="http://www.opengis.net/citygml/building/1.0"
            xmlns:gen="http://www.opengis.net/citygml/generics/1.0"
            xmlns:gml="http://www.opengis.net/gml"
            xmlns:storey="http://isbe.tue.nl/citygml/storey/1.0"
            xmlns:rights="http://isbe.tue.nl/citygml/rights/1.0"
            xmlns:xAL="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0"
            xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
            xsi:schemaLocation="http://www.opengis.net/citygml/1.0
            CityGML/CityGML/cityGMLbase.xsd
            http://www.opengis.net/citygml/building/1.0
            CityGML/CityGML/building.xsd
            http://www.opengis.net/citygml/generics/1.0
            CityGML/CityGML/generics.xsd
            http://www.opengis.net/citygml/appearance/1.0
            CityGML/CityGML/appearance.xsd
            http://isbe.tue.nl/citygml/storey/1.0 StoreyADE.xsd
            http://isbe.tue.nl/citygml/rights/1.0 RightsADE.xsd">
```

FIGURE 7.15: EXCERPT OF THE ROOT FROM THE VALID CITYGML MODEL IMPORTING BOTH ADES

7.3.1 Visualisation of the results

When the documentation from the repository is correctly used and the property rights information is added either manually or using FME workbench the data can be visualised in a viewer. Two viewers are selected to test the results: FME Datainspector and LandXplorer CityGML viewer[26]. These tools are selected because the first visualises all GML documentation and does not require a well formed CityGML document per-se. The second tool only visualises an xml document when it is structured according to the CityGML standard.

FME Datainspector reads and imports the valid building with additional ADEs correctly (figure 7.16). The building can be selected and a table overview from *storey* derived. The table overview allows users to select a *storey* and view the property rights information in the attribute table on the right. Even though the model and information is visualised correct there are some downsides to using this viewer:

1. *Storey* cannot be selected in the model, only in the table;
2. No queries can be made.

LandXplorer CityGML viewer does also recognise and reads the created CityGML file properly (figure 7.17). It allows users to look in to the building and see the different storeys. Like FME Datainspector users are only able to select features from the attribute tree. This viewer has limitations as well:

1. *Storey* cannot be selected in the model, only in the table;
2. The table does not show attributes that are defined in an ADE of an ADE (e.g. storey rights (PropertyrightsADE) are attributes of *storey* from the StoreyADE);
3. No queries can be made.

26 http://download.autodesk.com/us/landxplorer/docs/ldx_citygml_viewer/html/index.html?view.htm

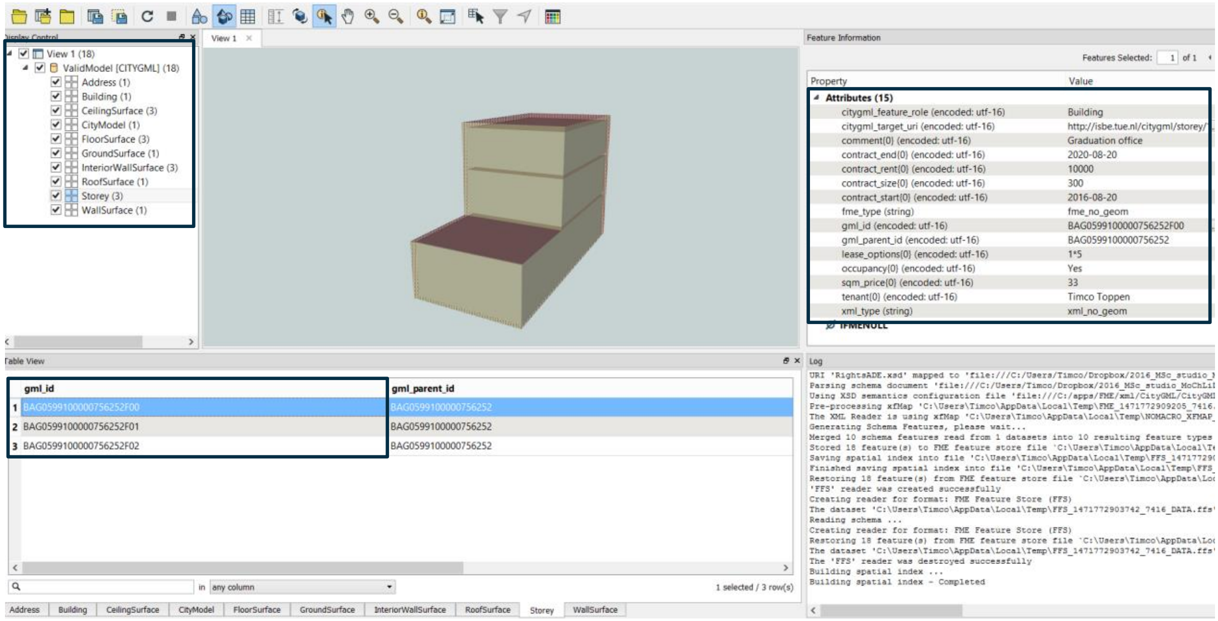


FIGURE 7.16: VISUALISATION OF BUILDING MODEL WITH STOREYS IN FME DATA INSPECTOR SHOWING: STOREYS, GML_ID AND ATTRIBUTES FROM PROPERTYRIGHTSADE

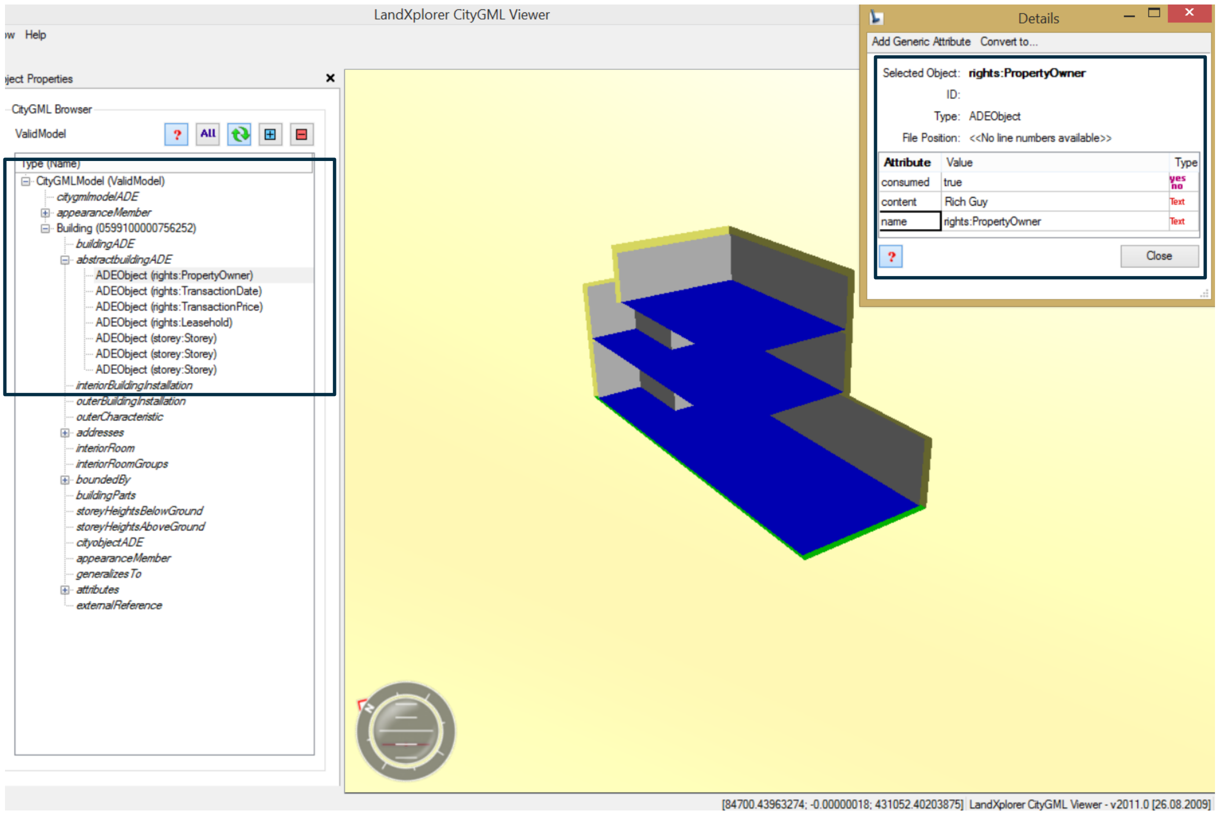


FIGURE 7.17: VISUALISATION OF BUILDING MODEL WITH STOREYS IN FME DATA INSPECTOR SHOWING: STOREYS, GML_ID AND ATTRIBUTES FROM PROPERTYRIGHTSADE

7.3.2 Proposed improvements

In section 7.1.2 five requirements of the use case are described. Based upon these requirements some improvements are proposed to meet all the given requirements, if not met already, in the future (table 7.3). From the five requirements three are met. The prototype developed includes a semantical rich 3D building model, the model contains storeys and the prototype is able of holding property rights information. The requirement that the used method should allow for future extension of the database is only partly met. This is because the adopted method strongly depends on the output of the tool from Arroryo Ohori Et al. (2015). In the timeframe of this research it is not achieved to get this tool running. The output of the tool also requires automatic restructuring which has been tested on the output of one building, however not yet on the output of multiple buildings. The prototype lacked most query capabilities since the only options in both viewers was to query the model via the table. The option to query the model via the database has not been tested since the prototype only concerns one building.

TABLE 7.3: USE CASE REQUIREMENTS CHECK

Requirement	Achieved?	Comment
Use a 3D model with semantic quality	Yes	CityGML is selected as 3D model because it is capable of holding semantic information of properties (section 7.2.1).
The 3D model should contain at least floors within a building	Yes	Using the output from the CityGML based tool from Arroryo Ohori Et al. (2015) showed that a CityGML LOD2 file can be enhanced with building storeys. However the output document is not a valid CityGML file and therefore has to be restructured for which a Python script is written (section 7.2.2.4).
The 3D model should be able to contain property rights information	Yes	Two ADE are created that define storeys and define the property rights attributes with regard to storeys and buildings (section 7.2.3).
A method should be adopted that allows for future extensions	Partly	By adopting the ADE extension method from the CityGML standard it is possible to further extend and improve this ADEs. The inclusion of storeys to enhance the usability of CityGML is argued as well. Till storeys are defined in the CityGML standard the tool to generate storeys is required. Since this tool is complex to run and the output requires restructuring afterwards this requirement is only partly met. Also when larger datasets are used an automated workflow in a FME like tool should be created to link the property rights dataset to the corresponding elements in the CityGML file.
The 3D model should be queried via the model and database	No	Visualising the result in two viewers showed that the model could not be fully queried by clicking on the different floors in de visualisation itself. The model could only be queried via the table structure. Since no large dataset has been used no test have been performed on querying the model via the database. Therefore this requirement is not achieved.

Two requirements of the prototype should be improved:

1. To be able to extend the database in the future the tool to enhance building models in CityGML with storeys should be used. However a binary version of this tool should be available to increase the ease at which this tool can be used. Another option is that *storeys* become part of the CityGML standard (see section 8.2 recommendations). This would however still require existing datasets to be altered. When larger datasets are used a tool is required that maps data from a property rights dataset to the corresponding buildings and storeys in the CityGML file.
2. Especially when larger datasets are used the query capabilities should be examined and improved. An option could be to transform the CityGML file to a file format that can be imported by GIS software package. These packages allow for more advanced query possibilities.

7.4 Conclusion

This chapter aimed to answer the fifth and sixth sub question:

> *What are the requirements of the use case and what datasets are required to create this use case?*

And:

> *How could CityGML be used to attach the dataset to and allow its downstream use e.g. to visualise the required information from that dataset?*

To create the use case two main datasets are required:

1. A 3D building model with storeys;
2. A dataset containing the property rights of the building in the 3D model.

Five requirements of the use case are formulated based upon input from the interviews and the capabilities of CityGML (table 7.3). Three requirements are met in the prototype that is developed in this chapter. The created prototype includes a semantical 3D city model that includes storeys that is capable of holding information on the property rights of both a building and a storey. However the tool to enhance a CityGML building model with storeys is not properly executed within this research. This limits the possibilities at his point to re-use and extend the development method described. Since the enhancement of storeys is a crucial requirement of the use case the tool to enhance the model with storeys has to be included. The fifth requirement that stated that the use case should include query capabilities via the dataset and the visualised model is not met at all. The current viewer did not allow to query the model other than via the attributes table.

To use CityGML to attach a dataset to and allow its downstream use five steps have to be taken:

1. The 3D model should be enhanced with indoor geometries (storeys). Therefore the method of Arroryo Ohori Et al. (2015) is adopted. Their tool did however not run properly and the output received was nog longer in line with the CityGML standard;
2. The output from the model has to be restructured using a Python script that re-structures the output in accordance to the CityGML standard;
3. Since the output of the enhanced CityGML file with storeys includes elements (storey) that are not defined within the CityGML standard, an ADE must be created that defines these elements in accordance to the CityGML standard;
4. To include property rights in the CityGML file an ADE must be created that defines which property rights a *building* and a *storey* can hold;
5. The property rights data can then be attached to the CityGML document manually or by using a workflow from a tool such as FME Workbench.

The results of this steps are combined in a repository folder that allows future users to restructure the output obtained from the tool, that enhances CityGML files with storeys, by running the Python script. Then only the schema locations of the created ADEs have to be defined in the root element of the document in order to be able to include property rights information.

Chapter 8. Conclusion, recommendations and reflection

The general purpose of this research is to gain insight in why and how a relatively new development (within the real estate domain) as 3D city models can be applied. This purpose is divided into two goals, each aimed at providing insight in a specific part of the development of a real estate use case that utilizes a 3D city model:

1. **Provide insight in the purpose and added value of using 3D city models compared to 2D models and determine in which use cases it is relevant to utilize these 3D city models.**

The first goal aims to answer the "why" question. Why 3D city models are and can be used in real estate valuations and transaction applications is described in chapters 2 till 5. The answer to this why-question is based upon findings in the literature and input from professionals.

2. **Determine the technical capabilities of CityGML in relation to real estate use cases and describe the required process of creating a prototype that allows CityGML to be used in a relevant use case.**

The second research goal aims to answer the "how" question. How 3D city models could be used in a specific use case is described in chapter 6 and 7. The answer to this how-question is based upon findings in the literature and by creating and testing different XML schemas and documents. The extent to which the goals have been achieved is the subject of this chapter. Therefore in section 8.1 an answer is given on the main research question. In section 8.2 recommendations are given with regard to research design and the practical development of the use case. In the final section a reflection upon this research and the result is provided.

8.1 Conclusion

The main research question was split into 6 sub-questions, three related to goal 1 and three to goal 2. These sub-questions will be answered successively before the main question will be answered.

1.What is the relation between (3D) GIS and real estate valuation and transaction applications?

The relation between real estate and (3D) GIS is built upon the shared factor "location" on which both place a high value. The most important factor on the value of real estate is location. Both real estate transactions and valuations require the storage and analysis of spatial data. The main purpose of GIS is to visualise and analyse data to comprehend spatial phenomena. Since not all data is applicable to solely an x and y coordinate, 3D GIS is used. An example in the real estate transaction domain is the registration of property rights in a 3D cadastre. Currently 3D GIS is seen as a separate add-on, but due to increase in user demands and technical developments the use is expected to grow.

2.For what purpose and added value is 3D GIS currently used in real estate valuation and transaction applications (state of the art use cases)?

In general 3D GIS can be used for two purposes: visualisation and analysis. The added value of using 3D GIS for this purposes depends on the type of use case. There are 3 types of use cases: 1) non-required visualisation, 2) visualisation for communication and 3) visualisation for visual analytics (figure 3.2). In the first type there is no added value of using a 3D city model, the use is considered as "nice to have". Since there are no use cases applied yet, the added value in the other type of use case is measured in terms of efficiency and effectiveness. Six real estate use cases are found in the literature that describe the use of 3D city models. All six use cases are of type 2 or 3 and do mainly add value in terms of efficiency.

3.Which use cases utilizing 3D city models are relevant and technically achievable within valuation and transaction applications and what are the requirements?

According to real estate professionals 3D city models can be used for the purpose of data storage and to gain insight in real estate data. Using 3D models for visualisation and analysis would provide primarily added value in terms of efficiency. Of the eleven use cases discussed seven are found particularly interesting:

1. 3D property ownership registration;
2. 3D zoning plans;
3. Mass valuation of real estate properties based upon different variables;
4. Identifying comparable sales units on variables other than location and time;
5. Building cost approach based upon semantically rich 3D models;
6. Square meter prices per building floor;
7. BAG Function mapping in 3D.

According to the experts in the field of 3D modelling all use cases are technically achievable to create. The basic requirement of a use case is that the 3D model includes building floors to which data can be added and queried.

Research goal 1: Defining a relevant and achievable use case.

Since all use cases are technically achievable but none have been applied, this research proposes to start with the basic request: A use case that enables to attach information to building floors in a 3D city model.

4.What are capabilities and characteristics of CityGML as a 3D city model?

The main characteristic of CityGML is that the quality and the richness of the model is defined in the Level of Detail (LOD). Building floors are not defined in the model until LOD4. However a tool is created that enhances LOD2 model with indoor geometries (storeys). The CityGML standard can be extended using one of two options: generic attributes or creating an Application Domain Extension. The last method is favoured since it allows for re-use and further developments by others within the CityGML community.

5.What are the requirements of the use case and what datasets are required to create this use case?

The use case requires two datasets: a CityGML model and a dataset with information on the property rights. The use case requires that the 3D city model includes storeys in a building, that property rights information can be attached to the building and storeys, the method to create the use case should allow for developments and extension and the 3D model should allow for different queries.

6.How could CityGML be used to attach the dataset to and allow its downstream use e.g. to visualise the required information from that dataset?

CityGML can be utilized for the described use case when certain steps are taken. First the model is enhanced with storeys using a tool from researchers of Delft University. Then the output of this tool is re-structured using a Python script. Then two ADEs are created that 1) define storeys as an element of a building 2) define which property rights information a building and storey can hold. The final step is to attach the property rights dataset to the CityGML file manually of using a FME workflow.

Research goal 2: Utilizing CityGML in a real estate use case

The result is stored in a repository to which users can add output of the tool from the Delft University of Technology and then run the Python script to re-structure the output. In the root element of the output file users can define the local schema locations and add either manually or by using a FME like tool property rights information to the 3D CityGML file.

The answers given on the sub questions provide the answer to the main research question:

Why and to what purpose could 3D city models in CityGML instead of 2D models be utilized in real estate valuation and transaction applications and how could the requirements of a relevant 3D real estate use case be technically achieved?

The literature on GIS and real estate showed that GIS is used in real estate applications for the purpose of data visualisation and analysis. 3D GIS has the same capabilities as 2D GIS with certain added value. Some use cases require data visualisation in 3D since the data is applicable not only to an x, y coordinate but to a height coordinate as well. To gain insight in, and analyse this data, 3D GIS can be used. According to the real estate professionals, using 3D city models could provide added value in terms of primarily efficiency. These professionals stated that using 3D city models to visualise and store data per building storey is a use case that is currently missing. 3D City models can be used for the same purposes as 2D GIS is used in real estate valuation and transaction applications, with the purposes of visualising and analysing data. However with 3D, an extra dimension is added that was currently missing. This is seen in different 3D use cases that have been studied. These use cases utilize 3D city models to visualise data for better understanding of data or for analytical purposes. This answers the question to what purpose and "why" 3D city models can be used.

CityGML is studied to answer "how" 3D city models can be used in a relevant real estate valuation and transaction use case. Most of the relevant use cases require that a building at least is separated into storeys. Different studies did already indicate that a building as one solid box (e.g. multiple polygons) is not that useful for real estate applications. CityGML models do however not include indoor geometry and therefore storeys until LOD4. To be able to technically create a relevant use case five requirements have to be met (figure 8.1). To meet this requirements a process is completed. 1) obtain a CityGML file, 2) enhance it with storeys, 3) to repair the output create a Python script (appendix 3.2), 4) create an ADE that defines the storeys and an ADE that defines the database information: property rights (appendix 3.3 & 3.4), 5) attach the information from a dataset to the CityGML manually or with a created tool. This steps enable users to technically create a relevant use case with CityGML as a 3D format.

FIGURE 8.1: REQUIREMENTS OF A USE CASE AND THE PROCESS TO ALLOW CITYGML TO BE USED

8.2 Recommendations

Based upon findings in this research recommendations can be made of both a practical and scientific kind. The practical recommendations consider the development of the prototype and the CityGML standard. The scientific recommendations consider shortcomings of this research and recommendations for further research.

8.2.1 Practical recommendations

Five recommendations are made with regard to the practical development of use case utilizing 3D city models in real estate applications.

1. Increase the scale of the City model in which storeys are created in line with the Python script written in this research;
2. Create a workflow that automatically links data from a dataset to a CityGML file;
3. Include *storey* in the CityGML standard as LOD2;
4. Improve the property rights ADE to multiple tenants at one floor in different rooms;
5. Apply some of the studied use cases that were found relevant in practice.

1. This research showed how to develop a prototype for a use case. This prototype contained one building with three storeys. This prototype used a building with storeys generated by a tool from Arroryo Ohori Et al. (2015). Within this research it turned out to be not achievable to get this tool properly working and therefore an output file was requested from the original authors. Based upon their ouput file a Python script is written that restructures the output. This Python script proves to be able to re-structure a file with one building into a valid CityGML file. It is expected that this script will also work for a CityGML file containing multiple building, this however should be tested. It can therefore be recommended that the tool created by Arroryo Ohori Et al. (2015) is used on a larger scale for different LOD2 datasets in association with the Python script written in this research.
2. When a CityGML file with multiple buildings that includes storeys is obtained, a workflow should be created in a FME like tool, that automatically can add property rights data or other data to the corresponding buildings and storeys in the CityGML file. For few buildings with only few storeys the data can be added manually. When however a larger dataset is obtained it is recommended that an automated converter is created.
3. In line with findings of Arroryo Ohori Et al. (2015) this research does support the idea of storeys becoming part of the CityGML standard at a LOD2 level. Inlcuding storeys does greatly enhance the different possibilities with the CityGML file in real estate related use cases.
4. The use of ADEs to add attributes to elements from the CityGML standard is found to be a sufficient method which can be used for differt real estate related use cases. The ADE that is created for property rights is currently limited to one tenant per *storey*. It is however a possibillty that a *storey* contains multiple tenants. The current ADE does not allow for multiple tentants on a *storey*. The ADE can relativly easy be improved so it can include multiple tenants. However this research recommends the use of *room* featuretype to be associated with the property rights ADE.
5. This research showed that different use cases are found to be relevant according to real estate professionals, some have already been developed and tested for research purposes. It is recommended that for example uses cases as the 3D BAG and using 3D city models for property valuation are being developed to be applied in practice. When applied the general awareness of the possibillities with 3D city models could increase. As a result different new potential use cases may arise.

8.2.2 Scientific recommendations

The scientific recommendations consider a review of the research design adopted in this research and recommendations for further research. Two recommendations concern shortcomings of this research and the other is aimed at further research:

1. Focus of this research;
2. Research design and interviews;
3. Study the added value of 3D city models in a quantitative manner.

1. This research focussed on answering two questions regarding 3D city models: 1) why should these 3D city models be used in real estate applications and 2) how can the use case technically achieved? Given the limited timeframe of this research, at a certain point a start had to be made with answering the second question while the first was not entirely clear yet. Besides the first part could have been studied more extensively (see second recommendation). Both questions deserve a full research to discover the potential of the use of 3D city models in real estate applications.
2. The research design of this research included four real estate professionals to give their opinion on the purpose, added value and the relevant use case of 3D city models in real estate applications. The foundation of this purpose and added value was derived from the literature on the use of GIS, its purpose and the relation the real estate applications. These findings in the literature are assumed correct and partly supported by the real estate professionals. However the knowledge of real estate professionals regarding the 3D topic is at this moment too limited to fully support the findings from the literature and provide a good indication of (all) the relevant use cases. I would recommend future research on this topic instead of individual interviews, including a group interview. This group interview should be done in a workshop setting that allows all participants to gain the same understanding of the purpose of 3D city models and next to identify the possibilities and potential added value. The interactive workshop organised by EuroSDR in cooperation with Consulting Where involving different stakeholders showed is a good example. When stakeholders from different companies are involved the knowledge can be better aligned and ideas regarding purposes and added value directly discussed. It is my personal opinion that in this way faster, more and more conclusive results regarding the potential use of 3D city models can be found.
3. The final recommendation regards the quantification of the added value of using 3D city models in measurable terms such as time and money. In this research different use cases are described. None of these has however been applied and could therefore be truly measured in terms of added value. The indication of the added value in this research was therefore limited to terms as “efficiency” and “effectiveness”. As described by Collerette, Ingham, & Legris (2003) one of the factors that influence the use of a new technology is the measurable profit. Recently the Dutch cadastre included its first 3D property right registration (SpoorPro, 2016). When more property rights are registred in the cadastre a comparison can be made between the usefulness of the 3D registration over the 2D registration. Research on the usefulness and added value is currently limited to research by Herbert & Chen (2015). I would recommend to study the time (efficiency) that it takes to correctly (effectiveness) derive all property rights related to an object from a 2D map compared to a 3D model.

8.3 Reflection

This reflection is written from the authors personal point of view and reflects on both research process and development of a prototype of the use case.

In this research I have tried to provide an answer on why and how 3D city models could be used in real estate valuation and transaction applications. Up till now 3D city models have not been used these applications to my knowledge and findings. This research therefore is of a very exploratory nature which continuously requested that I continuously made an educated decision between quantity and quality. I found that the why and how questions are two questions that deserve a research by themselves. Since the use of 3D city models in the real estate industry is entirely new the full potential is unknown and could be studied extensively. Also the capabilities and possibilities of CityGML with regard to relevant and potential use cases is enormous. I chose to provide an answer on both questions since it is my belief that without some sort of indication why 3D city models can be used, it is not relevant to study how it can be done, let alone create a prototype. However I do doubt this decision now. During this research I have found that the use of 3D city models is such a new development within this industry that it is very hard for real estate professionals to provide an indication of what they truly find relevant or even indicate the potential added value. In line with the recommendations I do think that is wise to first come up with an example use case in which real estate professionals can get an idea of the potential. A good example is the BAG. It is my personal belief that when accurate, trusted and publicly available datasets such as the BAG becomes available in 3D, the further utilization will increase. Other new developments have shown a similar trend that it was first required to be implemented in one application and that it slowly began to be utilized in others (e.g. GPS, Google Maps). So perhaps the "how" question deserves the most attention for now and once multiple stakeholders are more familiar with the possibilities the focus can shift to the potential use cases.

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Appendix 1. Empirical research

1.1 Topic description

	Topic	Description	Criteria	Measured by
x	General introductio n	Company description Job description Length of employment Knowledge on 3D city models Knowledge on real estate valuation and transactions		
x	Knowledge alignment	The first section serves as an introduction on the topic and aims to identify the level of familiarisation of the respondents with the main topics of the interview by asking them to score their own familiarity per topic.	Lomax (2015) mentioned that most professionals were not aware of the possibilities GIS has to offer and what it could be used for. Since 3D GIS is even one step further it is safe to assume that the awareness on this topic is even lower. Therefore the awareness on the topic of 3D city models and use cases is checked in advance.	Scale 1 to 5, in which 1 is not familiar and 5 is very familiar.
1.	Use cases	The most important goal of the interviews is to determine which (kind of) use cases are relevant according to real estate professionals and/or which are technically achievable according to data experts and 3D city model experts. The relevancy is one factor of influence on the acceptance of a certain information technology (Collerette, Ingham, & Legris, 2003). Both the user demands and technical capabilities are of influence on the utilization of 3D city models (Ujang, Azri, & Rahman, 2015).	Each use case is explained to the respondent and he or she is asked how relevant or technically achievable he or she finds this use case to apply in practice. To identify the type of use case the framework from section 3.2. is used.	The relevancy of each use case is scored on a scale from 1 – 5. On this scale 5 is considered highly relevant/technical achievable and 1 is considered not relevant or technically achievable. The data experts are questioned to score the use cases in terms of technical achievability.
2.	Use case requiremen ts	According to Dollner, Baumann, & Buchholz (2006) there are three ways of queriying a 3D city models. Respondents are asked which of these three they prefer (1). The respondents are asked to indicate whether the current datasets available are adequete or if new and improved data is needed (2). Finaly the respondents are asked in what kind of environment they would like to utilize and alternate 3D city models and data (3).	1. The respondents need to name one or more preferred query techniques. 2. The respondents need to give an indication whether the current datasets are adequate or which improvements are required. 3. The respondents can chose one of two options: the 3D city model is utilized through a prefixed system application such as ArcGIS or an open source approach is preferred.	Question 1 & 3 are measured by the amount of saturation in the given answers. If the same answer is given 5-6 times it is considered reliable, 3-4 times is less reliable, 1-2 not reliable. Question 3 is hard to measure since this strongly depends on the data each individual is currently familiar with.
3.	The role of 3D city models for visualisation purposes	Visualising data in a GIS environment help comprehend and analyse data (GuoDao, RongHua, FuLi, & HuaMin, 2013). Three subject are covered considering the role of 3D city models: efficiency (1), effectivity (2) and level of detail of the visualisation (3)as this seems to differ per use case according to ESRI (2014). The aim is to further	1. Respondents are asked whether 3D visualisations make the job of real estate agents easier and certain task become faster to perform? 2. Respondents are asked if 3D city models increase the quality of the delivered products? 3. The respondents are asked what Level of detail would be favoured for	Questions 1 & 2 are measured by the amount of saturation in the given answers. The answers to these questions are either: it becomes more efficient/effective or it does not. If the same answer is given 5-6 times it is considered reliable, 3-4 times is less reliable, 1-2 not reliable. Question 3 has only two answer possibilities

		asses the framework constructed in section 3.2 and determine the potential added value.	visualisation purposes: abstract or picturesque?	and is counted according to the same score related to the saturation in the given answers.
4.	The role of 3D city models for analysis purposes	The potential of 3D city models in real estate applications focusses on use cases of which analysis is the purpose. According to Wyatt (1997) GIS could be used for a more quantitative analysis of spatial real estate data. This topic sees to identify whether 3D city models add value in terms of efficiency (1) or effectivity (2) of the analysis. Next the possible consequences on the amount or job description of brokers is questioned by assessing the impact of this new technique. The aim is to further asses the framework constructed in section 3.2 and determine the potential added value.	1. Respondents are asked whether 3D analysis make the job of real estate agents easier and certain task become faster to perform? 2. Respondents are asked if 3D city models increase the quality of the delivered products? 3. The respondents are asked to assess the influence on the job of a broke and whether the 3D technique is disruptive or an advancement in the industry.	Questions 1 & 2 are measured by the amount of saturation in the given answers. The answers to these questions are either: it becomes more efficient/effective or it does not. If the same answer is given 5-6 times it is considered reliable, 3-4 times is less reliable, 1-2 not reliable. The first part of question 3 is an open question that supports the final part of this question that has only two answer possibilities and is counted according to the same score related to the saturation in the given answers.
5.	The general purpose of 3D city models	This topic aims to answer the question what the general purpose would be of 3D city models in the real estate valuation and transaction industry. The aim of this topic is rather wide and should provide context on how professionals consider the use of 3D city models in the real estate domain.	The respondents are asked to name the main purpose of 3D city models within the industry and perhaps name some other less important purposes. These purposes could be others than visualisation and analysis or could be related to one of those.	The different purposes mentioned by the respondents are measured by the amount of saturation given in the answers. If the same answer is given 5-6 times it is considered very important, 3-4 is less important, 1-2 not important.

1.2 Interviews

Interviews

1. Personal introduction, research background and general goals;
2. General introduction on 3D city models as information models for real estate valuation and transaction applications;
3. Purpose of this research: identify relevant use-case in which 3D city models could be utilized;
4. Results of interviews and further research aim.
5. The score 1- 5 is used to indicate the familiarisation with a certain topic and the relevancy or technical achievability of a 3D use case. 1 is considered not familiar with the topic, use case is not relevant or the use case is not technically achievable. While 5 indicates the opposite.

First part consists of general questions on 3D topic and familiarisation

1. How familiar are you with real estate valuation and transaction applications?

   1 2 3 4 5

2. How familiar are you with 3D city models?

   1 2 3 4 5

3. How familiar are you with the developments in 3D data modelling techniques?

   1 2 3 4 5

4. How familiar are you with different use cases in which 3D city models are utilized?

   1 2 3 4 5

Discussion on 5 topics

1. **Could you describe what and why the purpose would be of using 3D city models in real estate valuation and transaction applications?**
   1.1 What would the main purpose be of utilizing 3D city models in the real estate industry?
   1.2 What other purposes could you think of and which one do you consider most important?

2. **Which role (visualisation) would 3D city models play in the real estate industry when compared to the current role of 2D applications?**
   2.1 If so, how do visualisations of 3D city models add value in terms of efficiency?
      a) Would it save time in manual analysis and why? (e.g.: field work, site visits)

   2.2 If so, how do visualisations of 3D city models add value in terms of effectivity?
      a) Could it for instance add value of in marketing, if so why?

   2.3 In terms of visualisation what level of detail would be favoured and why?
      a) Describe different level of abstraction.

3. **The potential (analysis) of 3D city models in real estate applications, will it be an important part of the brokers day to day activities or will it replace it?**

   3.1 If so, how do analysis in 3D city models add value in terms of efficiency?
      a) How does this influence the amount of jobs needed to perform real estate valuations or transactions?

b) How does this influence the job skills of a broker needed to perform real estate valuations or transactions?

3.2 If so, how do analysis in 3D city models add value in terms of effectivity?

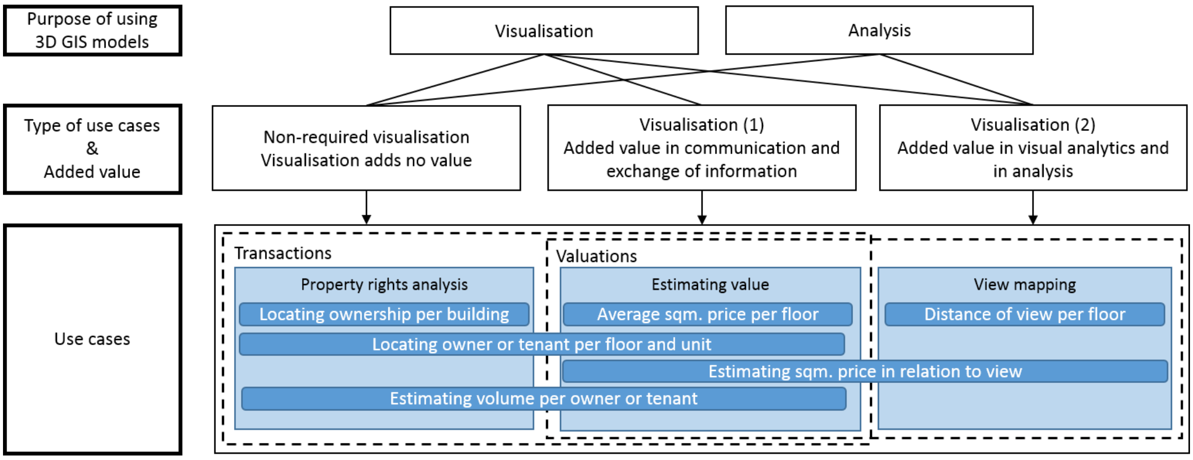
a) What would improve in particular?

b) How does it suit the need of the client?

3.3 If a 3D application like Google Maps is in 2D would become publicly available would it make the work of the broker obsolete, why or why not?

a) Would you the consider the rise of 3D city models as disruptive or an advancement (next step) in the industry and why?

4. What would the use case be in which 3D City models could be utilized and what spatial operations would be relevant?



Existing use cases: application – use case – spatial operation

- 3D cadastre: Real estate rights – 3D cadastre – ownerships registration

  1 2 3 4 5

- 3D zoning plans: Building legislation – 3D zoning plans – building legislation & change detection

  1 2 3 4 5

- 3D property valuation: real estate valuation – property tax – view & solar radiation

  1 2 3 4 5

- Mass valuation: real estate valuation – property valuation – visibility polygon & others?

  1 2 3 4 5

- Sales comparison: real estate valuation – sales comparison approach – view, noise, pollution, solar radiation & shadow estimates

  1 2 3 4 5

- Vacancy mapping: real estate transactions – vacancy mapping – office lease terms, vacant units

  1 2 3 4 5

Potential use cases:

- Function mapping: real estate valuation & transactions – function mapping – functions in urban area, vacancy per function

  1 2 3 4 5

- Construction cost pricing: real estate valuation – cost approach – quantity take-off

  1 2 3 4 5

- Average prices: real estate valuation & transactions – sqm prices – price levels per building floor

  1 2 3 4 5

- Capitalization approach: real estate valuation – cap rap – cap rate per building floor

  1 2 3 4 5

- Property visualisation: real estate transaction – property marketing – visualising a property in its environment

  1 2 3 4 5

5. **What would the requirements be of 3D city models in real estate valuation and transaction use cases?**

   5.1 Considering the use cases above, to what extend are these use cases covered by existing datasets?

   a) Which datasets would you consider to be the most important?

   5.2 How would you prefer to query the 3D city model? Via the database, the map or a spatial query?

   5.3 Would you prefer using designated software package or more of an open source approach and why?

Appendix 2. UML Diagrams

2.1 Building module

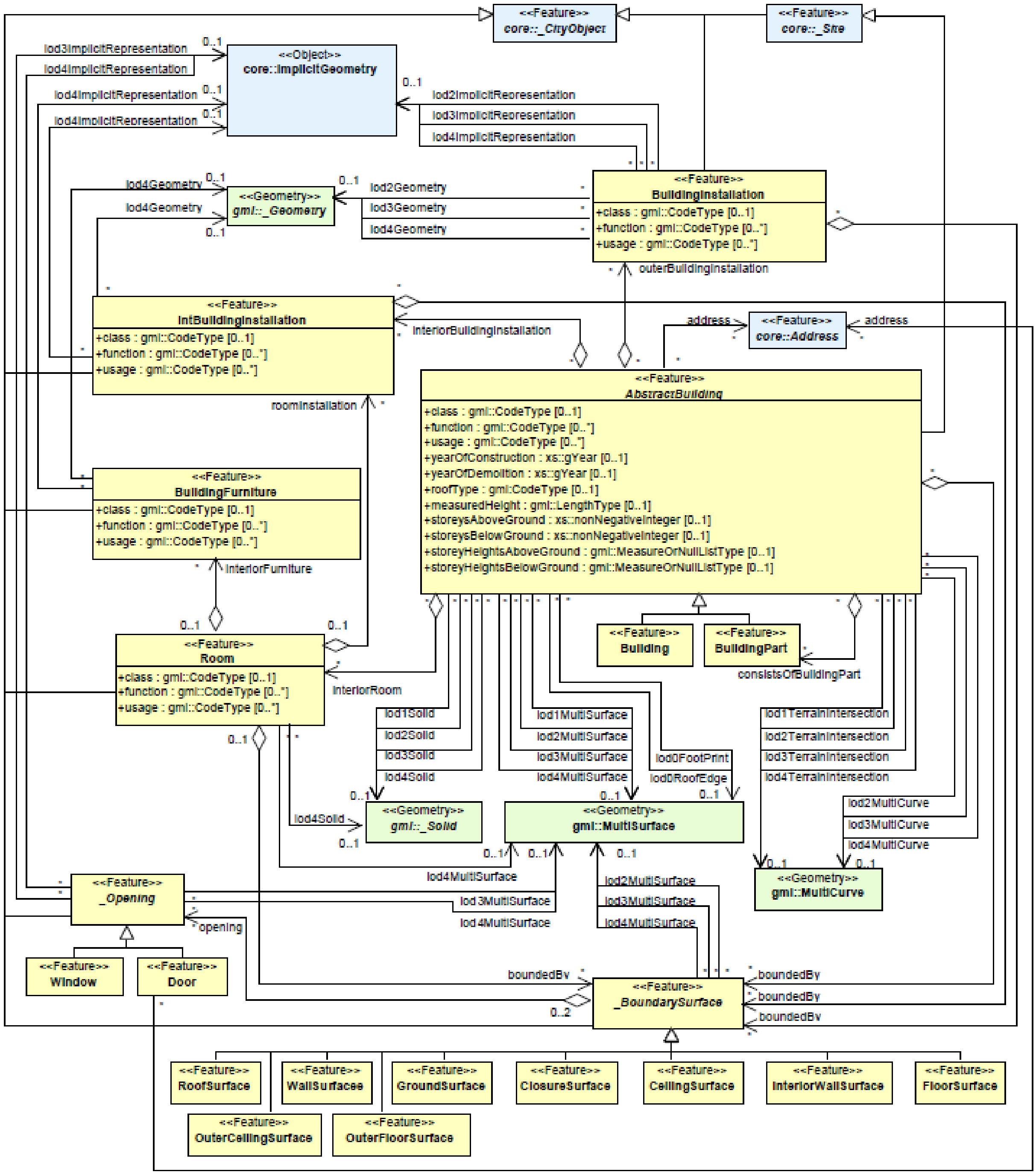


FIGURE A2.1: UML DIAGRAM OF THE BUILDING MODEL IN CITYGML, SOURCE: (GROGER & PLUMER, 2012)

2.2 ADE by Cagdas

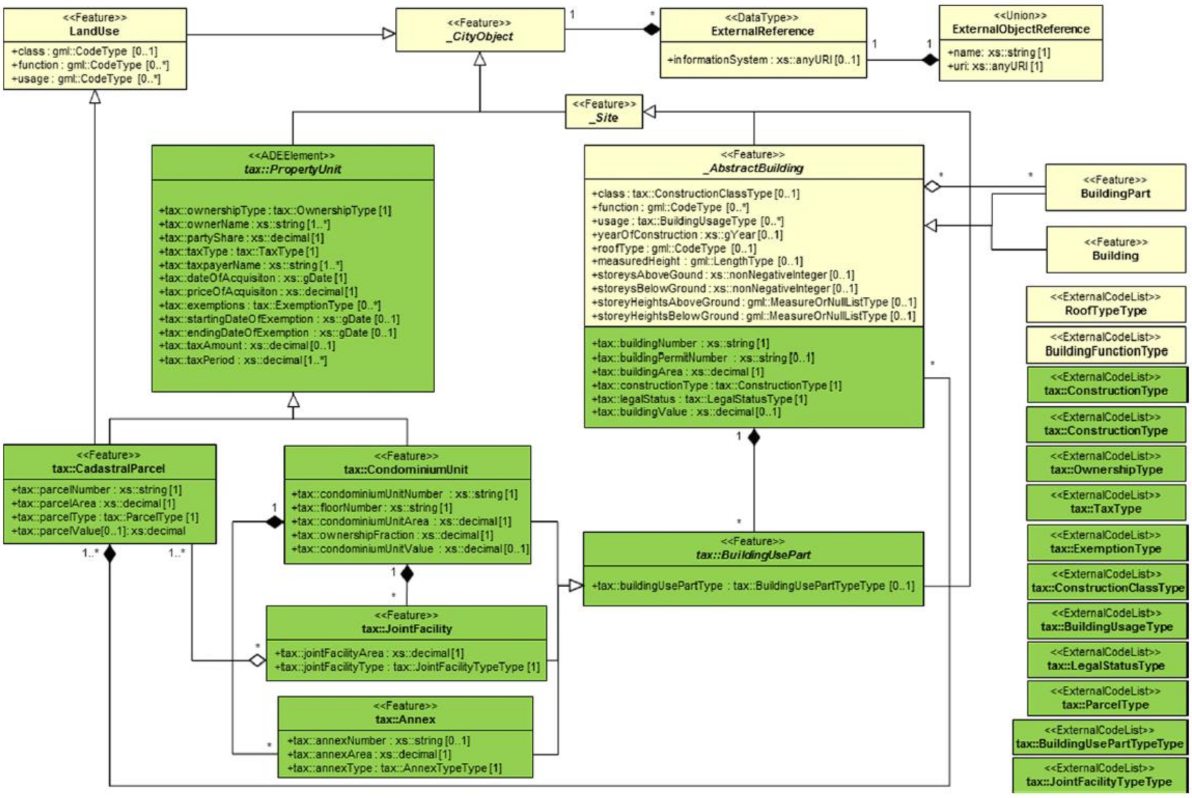


FIGURE A2.2: UML DIAGRAM OF THE PROPOSED ADE FOR IMMOVABLE PROPERTY TAXATION, SOURCE: (CAGDAS, 2012)

2.3 ADE by Gifford Dsilva

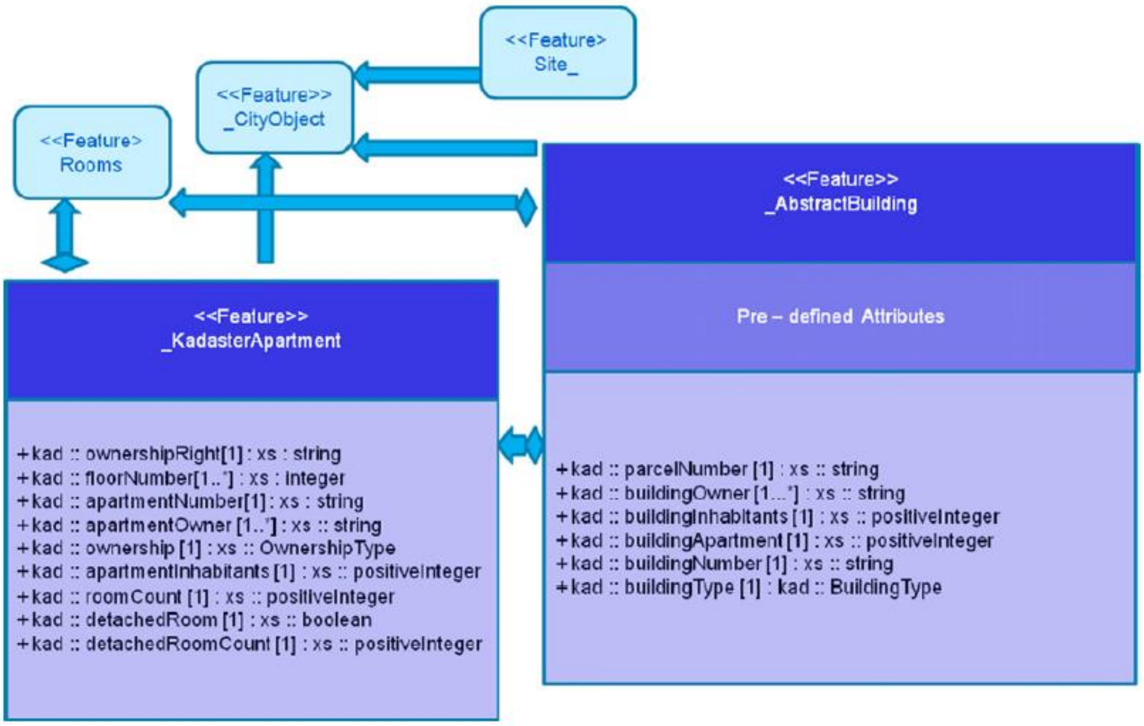


FIGURE A2.3: UML DIAGRAM OF THE PROPOSED ADE FOR CADASTRAL INFORMATION, SOURCE: (GIFFORD DSILVA, 2009)

Appendix 3. XML – XSD documents and Python script

3.1 XML document of building with storeys output

```
<?xml version="1.0" encoding="UTF-8"?>

<CityModel xmlns="http://www.opengis.net/citygml/1.0"
               xmlns:core="http://www.opengis.net/citygml/base/1.0"
               xmlns:tex="http://www.opengis.net/citygml/textures/1.0"
               xmlns:gml="http://www.opengis.net/gml"
               xmlns:bldg="http://www.opengis.net/citygml/building/1.0"
               xmlns:app="http://www.opengis.net/citygml/appearance/1.0"
               xmlns:dem="http://www.opengis.net/citygml/relief/1.0"
               xmlns:tran="http://www.opengis.net/citygml/transportation/1.0"
               xmlns:gen="http://www.opengis.net/citygml/generics/1.0"
               xmlns:frn="http://www.opengis.net/citygml/cityfurniture/1.0"
               xmlns:wtr="http://www.opengis.net/citygml/waterbody/1.0"
               xmlns:luse="http://www.opengis.net/citygml/landuse/1.0"
               xmlns:veg="http://www.opengis.net/citygml/vegetation/1.0"
               xmlns:xAL="urn:oasis:names:tc:ciq:xsdschema:xAL:2.0">
        <gml:boundedBy>
               <gml:Envelope srsName="EPSG:28992" srsDimension="3">
                      <gml:lowerCorner>83043.35 429126.61 0.0</gml:lowerCorner>
                      <gml:upperCorner>85928.45 431510.85 98.08390791</gml:upperCorner>
               </gml:Envelope>
        </gml:boundedBy>
        <cityObjectMember>
               <bldg:Building gml:id="BAG0599100000756252">
                      <gml:name>0599100000756252</gml:name>
                      <gen:doubleAttribute name="floorArea"
xmlns:gen="http://www.opengis.net/citygml/generics/1.0">
                             <gen:value>190</gen:value>
                      </gen:doubleAttribute>
                      <gen:doubleAttribute name="BAG use Area"
xmlns:gen="http://www.opengis.net/citygml/generics/1.0">
                             <gen:value>175</gen:value>
                      </gen:doubleAttribute>
                      <gen:doubleAttribute name="Net height area"
xmlns:gen="http://www.opengis.net/citygml/generics/1.0">
                             <gen:value>0</gen:value>
                      </gen:doubleAttribute>
                      <gml:MultiSolid>
                             <gml:solidMember>
                                    <bldg:lod2Solid>
                                           <gml:Solid>
                                                  <gml:exterior>

......

                             <gml:solidMember>
                                    <bldg:Storey>
                                           <bldg:lod2Solid>
                                                  <gml:Solid>
                                                         <gml:exterior>
                                                                <gml:CompositeSurface
srsName="EPSG:28992" srsDimension="3">
                                                                       <bldg:boundedBy>

        <bldg:CeilingSurface
               <gml:surfaceMember>
                      <gml:Polygon xmlns:gml="http://www.opengis.net/gml"
gml:id="BAG0599100000756252_CeilingSurface_4_1">
                                           <gml:exterior>
                                                  <gml:LinearRing>
                                                         <gml:posList>84699.0271
431036.5486 2.9600 84704.2341 431034.4640 2.9600 84704.4569 431034.5603 2.9600 84699.0271
431036.5486 2.9600</gml:posList>
                                                  </gml:LinearRing>
                                                         </gml:exterior>
                                                         </gml:Polygon>
                                           </gml:surfaceMember>
```

FIGURE A3.1: XML DOCUMENT EXCERPT FROM BUILDING WITH AUTOMATICALLY ENHANCED STOREYS BASED UPON RESEARCH BY ARRORYO OHORI, BILJECKI, BOETERS, & ZLATANOVA (2015)

3.2 Python script to remodel output

```
import xml.dom.minidom as minidom
import xml.etree.ElementTree as ET

def register_namespaces(filename):
    ns = {}
    dom = minidom.parse(filename)
    n = dom.documentElement.attributes
    for i in range(n.length):
        a = n.item(i)
        if a.prefix == "xmlns":
            ns[a.localName] = a.value
            ET.register_namespace(a.localName, a.value)
        elif a.name == "xmlns":
            ET.register_namespace('', a.value)
            ns['default'] = a.value

    return ns

def indexOf(parent, child):
    for i in range(len(parent)):
        if parent[i] == child:
            return i
    return -1

def fixBoundedBy(parent, boundedBy):
    parent.remove(boundedBy)

    surface = \
        boundedBy.find("bldg:GroundSurface", ns) or \
        boundedBy.find("bldg:RoofSurface", ns) or \
        boundedBy.find("bldg:CeilingSurface", ns) or \
        boundedBy.find("bldg:FloorSurface", ns) or \
        boundedBy.find("bldg:InteriorWallSurface", ns) or \
        boundedBy.find("bldg:CeilingSurface", ns) or \
        boundedBy.find("bldg:WallSurface", ns)

    if surface is None: return None

    lod2MultiSurface = ET.SubElement(surface, 'bldg:lod2MultiSurface')
    multiSurface = ET.SubElement(lod2MultiSurface, 'gml:MultiSurface',
parent.attrib)

    for surfaceMember in surface.findall("gml:surfaceMember", ns):
        surface.remove(surfaceMember)
        multiSurface.append(surfaceMember)

    return boundedBy

def fixBuilding(building, solidMember):
    compositSurface = solidMember.find('.//gml:CompositeSurface', ns)
    for boundedBy in compositSurface.findall('bldg:boundedBy', ns):
        fixBoundedBy(compositSurface, boundedBy)
        building.insert(indexOf(building, multiSolid), boundedBy)

def fixStorey(building, solidMember):
    storey = solidMember[0]
    storey.tag = "{http://isbe.tue.nl/citygml/storey/1.0}Storey"
    compositSurface = solidMember.find('.//gml:CompositeSurface', ns)
```

```
        for boundedBy in compositSurface.findall('bldg:boundedBy', ns):
            fixBoundedBy(compositSurface, boundedBy)
            storey.append(boundedBy)
            boundedBy.tag = "{http://isbe.tue.nl/citygml/storey/1.0}boundedBy"

        storey.remove(storey[0])
        solidMember.remove(storey)
        building.append(storey)

inputfile = "OutputLOD2plus.xml"
outputfile = "OutputRestructure.xml"

ns = register_namespaces(inputfile)

ET.register_namespace('storey', 'http://isbe.tue.nl/citygml/storey/1.0')
ns['storey'] = "http://isbe.tue.nl/citygml/storey/1.0"

ET.register_namespace('rights', 'http://isbe.tue.nl/citygml/rights/1.0')
ns['rights'] = "http://isbe.tue.nl/citygml/rights/1.0"

ET.register_namespace('gen', 'http://www.opengis.net/citygml/generics/1.0')
ns['gen'] = "http://www.opengis.net/citygml/generics/1.0"

tree = ET.parse(inputfile)
root = tree.getroot()

for building in tree.findall('.//bldg:Building', ns):
    multiSolid = building.find('gml:MultiSolid', ns)

    for solidMember in multiSolid.findall('gml:solidMember', ns):
        if solidMember[0].tag ==
"{http://www.opengis.net/citygml/building/1.0}lod2Solid":
            fixBuilding(building, solidMember)
            multiSolid.remove(solidMember)
        elif solidMember[0].tag ==
"{http://www.opengis.net/citygml/building/1.0}Storey":
            fixStorey(building, solidMember)
            multiSolid.remove(solidMember)

    building.remove(multiSolid)

for material in tree.findall('.//app:X3DMaterial', ns):
    trans = material[0]
    material.remove(trans)
    material.insert(1, trans)

for texture in building.findall('.//app:appearanceMember', ns):
    building.remove(texture)
    root.insert(2, texture)

tree.write(outputfile)

print("Done")
```

Figure A3.2: Python script that imports the output of the tool from Arroryo Ohori, Biljecki, Boeters, & Zlatanova (2015) and re-structures this output into a valid CityGML document.

3.3 Provisional ADE for property rights

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:scheman xmlns="http://isbe.tue.nl/citygml/rights/1.0"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
    xmlns:bldg="http://www.opengis.net/citygml/building/1.0"
xmlns:core="http://www.opengis.net/citygml/1.0"
    xmlns:gml="http://www.opengis.net/gml"
targetNamespace="http://isbe.tue.nl/citygml/rights/1.0"
elementFormDefault="qualified"
    attributeFormDefault="unqualified">
    <xsd:import namespace="http://www.opengis.net/gml" schemaLocation="./gml.xsd"/>
    <xsd:import namespace="http://www.opengis.net/citygml/1.0"
schemaLocation="./cityGMLBase.xsd"/>
    <xsd:import namespace="http://www.opengis.net/citygml/building/1.0"
schemaLocation="./building.xsd"/>
    <!-- ============================================================ -->
    <!-- ====================== RightsBuildingSegment  ================ -->
    <!-- ============================================================ -->
    <!-- ========== Application specific attributes for AbstractBuilding  === -->
    <!-- ============================================================ -->
    <xsd:element name="PropertyOwner" type="xsd:string"
        substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <xsd:element name="TransactionDate" type="xsd:date"
        substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <xsd:element name="TransactionPrice" type="xsd:positiveInteger"
        substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <xsd:element name="Leasehold" type="xsd:string"
        substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <!-- ============================================================ -->
    <!-- ======== Application specific attributes for ADEStorey  ============ -->
    <!-- ============================================================ -->
    <xsd:element name="Occupancy" type="xsd:string"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="Tenant" type="xsd:string"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="ContractSize" type="xsd:positiveInteger"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="ContractRent" type="xsd:positiveInteger"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="ContractStart" type="xsd:date"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="ContractEnd" type="xsd:date"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="SqmPrice" type="xsd:positiveInteger"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="LeaseOptions" type="xsd:string"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="Comment" type="xsd:string"
        substitutionGroup="bldg:_GenericApplicationPropertyOfStoreyType"/>

</xsd:schema>
```

FIGURE A3.3: XSD SCHEMA OF PROPOSED PROPERTY RIGHTS ADE IF STOREY BECOMES PART OF THE CITYGML STANDARD AS FEATURE OF ABSTRACTBUILDING

3.4 Proposed ADE for Storey

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:scheman xmlns="http://isbe.tue.nl/citygml/storey/1.0"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
            xmlns:bldg="http://www.opengis.net/citygml/building/1.0"
            xmlns:gml="http://www.opengis.net/gml"
            xmlns:core="http://www.opengis.net/citygml/1.0"
            targetNamespace="http://isbe.tue.nl/citygml/storey/1.0"
elementFormDefault="qualified"
            attributeFormDefault="qualified">
    <xsd:import namespace="http://www.opengis.net/citygml/building/1.0"
schemaLocation="./building.xsd"/>
    <xsd:import namespace="http://www.opengis.net/gml"
schemaLocation="CityGML/3.1.1/base/gml.xsd"/>
    <xsd:import namespace="http://www.opengis.net/citygml/1.0"
schemaLocation="CityGML/CityGML/cityGMLBase.xsd"/>
    <!-- ============================================================================ -->
    <xsd:complexType name="StoreyPropertyType">
        <xsd:sequence minOccurs="0">
            <xsd:element ref="Storey"/>
        </xsd:sequence>
        <xsd:attributeGroup ref="gml:AssociationAttributeGroup"/>
    </xsd:complexType>
    <xsd:complexType name="StoreyType">
        <xsd:complexContent>
            <xsd:extension base="core:AbstractCityObjectType">
                <xsd:sequence>
                    <xsd:element name="class" type="gml:CodeType" minOccurs="0"/>
                    <xsd:element name="boundedBy" type="bldg:BoundarySurfacePropertyType"
minOccurs="0" maxOccurs="unbounded"/>
                    <xsd:element ref="_GenericApplicationPropertyOfStoreyType" minOccurs="0"
maxOccurs="unbounded"/>
                </xsd:sequence>
            </xsd:extension>
        </xsd:complexContent>
    </xsd:complexType>
    <!-- ============================================================================ -->
    <xsd:element name="Storey" type="StoreyType"
                 substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <xsd:element name="_GenericApplicationPropertyOfStoreyType" type="xsd:anyType"
abstract="true"/>
</xsd:schema>
```

FIGURE A3.4: XSD SCHEMA OF PROPOSED STOREY ADE

3.5 Proposed ADE for Property rights

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xsd:scheman xmlns="http://isbe.tue.nl/citygml/rights/1.0"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
    xmlns:bldg="http://www.opengis.net/citygml/building/1.0"
xmlns:core="http://www.opengis.net/citygml/1.0"
    xmlns:gml="http://www.opengis.net/gml"
xmlns:storey="http://isbe.tue.nl/citygml/storey/1.0"
targetNamespace="http://isbe.tue.nl/citygml/rights/1.0"
elementFormDefault="qualified"
    attributeFormDefault="unqualified">
    <xsd:import namespace="http://www.opengis.net/gml" schemaLocation="./gml.xsd"/>
    <xsd:import namespace="http://www.opengis.net/citygml/1.0"
schemaLocation="./cityGMLBase.xsd"/>
    <xsd:import namespace="http://www.opengis.net/citygml/building/1.0"
schemaLocation="./building.xsd"/>
    <xsd:import namespace="http://isbe.tue.nl/citygml/storey/1.0"
schemaLocation="./StoreyADE.xsd"/>
    <!-- ================================================================== -->
    <!-- ========================= RightsBuildingSegment  =================== -->
    <!-- ================================================================== -->
    <!-- ========== Application specific attributes for AbstractBuilding  === -->
    <!-- ================================================================== -->
    <xsd:element name="PropertyOwner" type="xsd:string"
        substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <xsd:element name="TransactionDate" type="xsd:date"
        substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <xsd:element name="TransactionPrice" type="xsd:positiveInteger"
        substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <xsd:element name="Leasehold" type="xsd:string"
        substitutionGroup="bldg:_GenericApplicationPropertyOfAbstractBuilding"/>
    <!-- ================================================================== -->
    <!-- ======== Application specific attributes for ADEStorey  ============ -->
    <!-- ================================================================== -->
    <xsd:element name="Occupancy" type="xsd:string"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="Tenant" type="xsd:string"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="ContractSize" type="xsd:positiveInteger"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="ContractRent" type="xsd:positiveInteger"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="ContractStart" type="xsd:date"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="ContractEnd" type="xsd:date"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="SqmPrice" type="xsd:positiveInteger"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="LeaseOptions" type="xsd:string"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>
    <xsd:element name="Comment" type="xsd:string"
        substitutionGroup="storey:_GenericApplicationPropertyOfStoreyType"/>

</xsd:schema>
```

FIGURE A3.5: XSD SCHEMA OF PROPOSED PROPERTY RIGHTS ADE