# 3 Dimensional data research for property valuation in the context of the LADM Valuation Information Model

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**Abstract**

Property valuation is a process that several land management activities for promoting sustainable development. Access to information on the legal, geometric, physical, locational and environmental characteristics of property units together with the economic indicators are required for an effective property valuation system. Traditional cadastral systems generally provide only two-dimensional (2D) legal and geometric information about property units, however, today's valuation practices would benefit significantly from three-dimensional (3D) information in order better to estimate and explain values of property units. The purpose of this paper is to examine how 3D spatial datasets and spatial analyses have been used in property valuation, and to develop 3D valuation unit profile(s) in line with the examination results for the recently proposed Valuation Information Model that extends the ISO 19152:2012 Land Administration Domain Model (LADM) from the valuation point of view. The study focuses more on 3D locational and environmental characteristics of property units; particularly visibility and especially viewshed analysis in terms of property valuation. By using open topography, building and height datasets of the Netherlands, a number of viewshed analyses are conducted to show how it can be utilized using different 3D data sources. The main contribution of the article is to present how 3D datasets and spatial analyses could be used to support property valuation activities and to investigate to what extent it is possible and meaningful to include derived 3D characteristics of property units in valuation registries.



**Keywords**: Property valuation; ISO 19152 Land Administration Domain Model (LADM); LADM Valuation Information Model; 3D GIS, Viewshed analysis.


## 1. Introduction

Property valuation, the process of estimating the value at a particular moment of time, is an important basis for the decision-making in land management. It is required by public and by the private sector for a number of reasons, such as property taxation, large-scale land acquisitions, spatial planning, land use and development, compensation for expropriated rights, insurance assessment as well as transactions (FAO, 2017). One of the key components of an effective valuation system is access to information on the nature and extent of property units together with the location and physical characteristics (FAO, 2017). Therefore, property valuation systems require the establishment of links between a number of public registries that keep information about property units, such as cadastre, land registry, planning and permitting registries, and building and dwelling registries (Almy, 2014; Cagdas et al., 2016). Such registries, which accommodate regular data maintenance and the updating of property characteristics, ownership details and sales information, are the most fundamental elements underpinning property valuation activities (Thang et al., 2011).

The legal, geometric, physical, locational and environmental characteristics of property units together with the economic, political and social indicators can be taken into consideration during property valuation practices (Wyatt, 1997; Sirmans et al., 2005). Traditional cadastral systems generally provide 2 dimensional (2D) geometrical and legal datasets concerning the legal objects, however, cadastral datasets used for the identification and registration of legal interest in relation to property units may not be sufficient for today's valuation practices, which would benefit significantly from 3 dimensional (3D) datasets and models in order better to understand and explain values of property units (Isikdag et al., 2014; Isikdag et al., 2015). 3D legal (e.g. private and public interests), geometrical (e.g. property boundaries, parcel areas, building floor areas), physical (e.g. building age and quality of structure), locational and environmental (e.g. view, distance to certain points, noise pollution, environmental contamination and slope) characteristics of property units may be derived from 3D data sources. A number of studies grouped these characteristics that influence property value into two categories: internal and external factors (Wyatt, 1996; Tomić et al., 2012; Demetriou, 2018). The former one refers legal, geometrical and physical factors that are directly related to properties, while the latter refers to externalities such as locational, environmental, economic factors, and planning constraint, as well (Wyatt, 1996).

The availability and use of 3D data have substantially increased in the past two decades due to the recent advances in the 3D acquisition, modelling and visualization technologies (Laga et al., 2019; Janečka and Karki, 2016). Thus, a wide range of application domains including property valuation could take advantage of 3D datasets and models through several use cases. In order to derive internal and external characteristics of property units from different 3D data sources (e.g. 3D building, cadastre, and city models), various analyses could be required including 3D Geographical Information System (GIS). The visibility analysis is one of the most employed use cases of 3D GIS to determine the view of property unit (Sirmans et al., 2005; Bourassa et al., 2004). The various forms of visibility analysis (e.g. visibility of landmark, line of sight and viewshed) may be performed to assess the impact of views on property values (Bourassa et al., 2004). These analyses could be carried out using datasets of different level of detail (LoD) and different content. Furthermore, different use cases and applications of 3D data sources may also require certain attributes or datasets of a certain minimum LoD (Biljecki et al., 2015). Therefore, the required capacity for full-fledged utilization of 3D data sources and GIS analyses in property valuation activities should be clearly identified. Moreover, in order to tackle different degrees of availability of 3D datasets and different demands in valuation activities, it may be necessary to determine alternative methodologies for different GIS analyses. Another issue is that some GIS analyses should be performed regularly since periodically conducted valuations (e.g. mass valuation for taxation purposes) need up-to-date characteristics of properties. It is time-consuming and costly to perform these analyses frequently; therefore, an optimal approach should be established to update the derived characteristics of property units. Valuation registries can be supported with the results of analyses at valuation units in order maximally to benefit from the 3D data sources. Recording the analyses' results may provide an opportunity to increase the explanatory power of valuation models, and to save time and effort. On the other hand, some property characteristics, especially the external ones, may change frequently over time. It needs to be determined which characteristics of property units should be registered statically, and which analyzed periodically. Therefore, it is reasonable to state that the information content of valuation registries together with the update and maintenance principles should be reformed by taking into account the latest developments in the 3D domain.

An efficient land administration infrastructure, which aims to enable the management of information concerning the ownership, value and use of land, is expected to link valuation registries with other land information registries and databases (e.g. cadastre, land registry, and building and dwelling registries). Such an integration or link between distributed databases maintained by different organizations can be achieved through spatial data infrastructures (SDIs). One of the main components of the SDI is domain-specific standards that specify the semantics of certain domains (Lemmen et al., 2011). ISO 19152:2012 Land Administration Domain Model (LADM), an international standard for the domain of land administration (ISO, 2012), focuses on legal, geometric and administrative aspects of land administration but considers out of the scope of the value component. Yet a group of researchers has recently developed an information model by means of extending the scope of LADM for specifying the semantics of valuation information maintained by public authorities (Cagdas et al., 2016; Kara et al., 2018; OGC, 2019). The LADM Valuation Information Model has been designed for the recurrently levied immovable property taxation; however, it can be used for other purposes of valuations, as well. It provides a conceptual schema for the data concerning valuation units that are objects of valuation (e.g. cadastral parcel, building and condominium), input and output data used and produced through single or mass appraisal processes, parties involved in the valuation practices, transaction prices and sales statistics (Cagdas et al., 2016). LADM Valuation Information Model provides detailed information on valuation units including their physical characteristics. It links semantics and physical spaces of valuation units with their legal and geometric counterparts defined in the core LADM. However, the current version of the LADM Valuation Information Model does not include detailed information about the externalities of property units.

The main aim of this paper is to determine how 3D spatial data and GIS analyses have been used in property valuation especially for specifying the externalities of property units and to investigate to what extent it is possible to include derived external characteristics in the LADM Valuation Information Model. In other words, this study specifies value affecting 3D characteristics, especially locational and environmental ones, that are generally derived through 3D GIS analyses, and proposes profiles for the LADM Valuation Information Model to record and maintain those characteristics in valuation registries. The study focuses more on a certain use case, visibility analysis. By using open topography, building and height datasets of the Netherlands, a number of viewshed analyses are conducted to show how it can be utilized using different 3D datasets in property valuation activities.

The remainder of this paper is organized as follows: The following section briefly describes the general structure of the LADM Valuation Information Model. Section 3 presents a literature review that shows how property valuation has benefited from 2D and especially 3D data sources and 3D GIS analyses for deriving characteristics of valuation units. This section also examines the data requirements of different GIS analyses and use cases that can be employed in property valuation. The examination concentrates more on 3D visibility and viewshed analysis. Then, methodologies are discussed to perform viewshed analyses using diverse 3D data sources for determining viewsheds of condominium units and the obtained information is used to perform viewshed analyses with open datasets of the Netherlands. Section 4 proposes profiles for the representation of derived 3D environmental and locational characteristics through the LADM Valuation Information Model. The last section presents the concluding remarks and future works.

## 2. The LADM Valuation Information Model

Property valuation systems require information related to property units together with immovable property rights, therefore, it is important to ensure that the units and the rights should have been unambiguously identified. This is supported by the land administration systems including cadastre and land registry. ISO 19152:2012 LADM is a descriptive conceptual model that provides a reference for land administration systems (FAO, 2017, p. 55). It provides a shared ontology, defining a terminology for land administration with three basic packages: Parties, rights (and restrictions/responsibilities) and spatial units with a 2D/3D geometry and topology options. Cadastral representation and registration of 3D spatial units (e.g. parcel, legal space building units) associated with rights and parties are supported in LADM (Van Oosterom and Lemmen, 2015). LADM also provides external classes, which link cadastral information systems with the other land administration related databases, such as valuation, taxation, land use, land cover, building, address, physical utility network, and archive.

The value component of land administration is considered out of scope in the first version of LADM, which actually provides a solid and flexible base for property valuation. A group of researchers has recently developed the Valuation Information Model by extending the *ExtValuation* class of LADM. The model was created by means of maximally reusing the international valuation and geographical standards, data gained from questionnaires replied by the national delegates of FIG Commission 9 and FIG Commission 7, and a comprehensive literature review including country applications (Cagdas et al., 2016; Kara et al., 2018). The LADM Valuation Information Model is in the agenda of LADM v2.0 revision within ISO TC 211 and OGC.

The purpose of the LADM Valuation Information Model is to specify the semantics of valuation registries maintained by public authorities and specify its relations with other land administration registries and databases. Figure 1 represents an overview of the LADM Valuation Information Model. While the classes with white color and LA_ prefix belongs to core LADM, the classes with green color and VM_ prefix represents the Valuation Information Model.

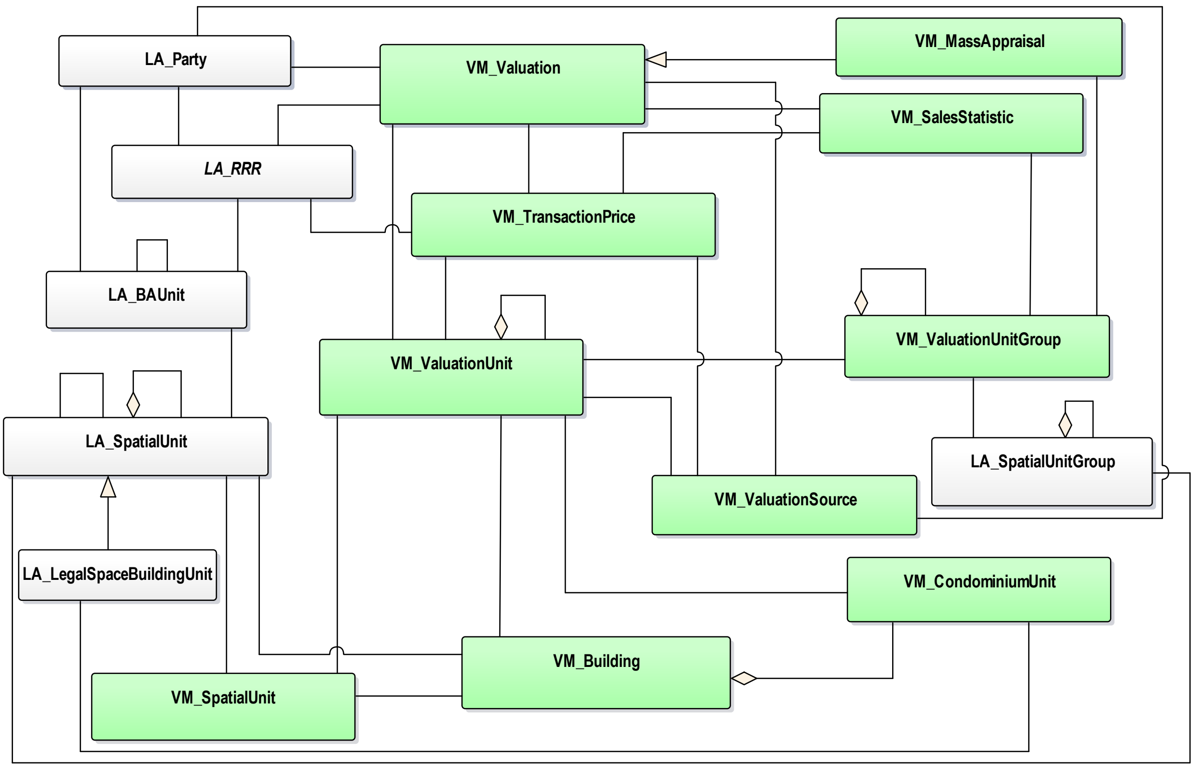



Fig. 1. An overview of the LADM Valuation Information Model and its relations with core LADM

Since the focus of this paper is to investigate how 3D spatial datasets and analyses could be used for deriving external characteristics of property units and recording them in valuation registries, this section only gives information about the spatial part of the LADM Valuation Information Model, namely, objects of valuation. The readers are referred to Cagdas et al. (2016) and Kara et al. (2017, 2018) for more detailed information about the model.

The object of valuation may be (a) only land (e.g. cadastral parcel), (b) only improvements (e.g. buildings), (c) land and improvements together as land property, (d) land and improvements together as condominium property (McCluskey, 1999; Bird and Slack, 2002; Almy, 2014; Cagdas et al., 2016). The designations of core LADM provide a base for the specification of valuation objects; however, they should be supported from a valuation point of view. A cadastral system is generally organized to maintain legal information in relation to immovable properties (i.e. one or more parcels and attached buildings, or condominium units), whereas a valuation registry should be organized in a way that stores information in relation to parcels, buildings, parcels and buildings as a whole, as well as condominium units since these components may individually be the object of valuation. Therefore, the class *VM_ValuationUnit* has been created to represent the basic recording units in valuation registries. It has a characteristic called *valuationUnitType*, which specifies possible types of valuation units (e.g. only parcels, or only buildings, or parcels and buildings together, or condominiums). The *VM_ValuationUnit* also includes neighborhood type characteristic that is used to denote the type of neighborhood where the valuation unit is located (e.g. urban and rural), and the utility services characteristic that represents utility services available to valuation units (e.g. natural gas, electricity and telecommunication). The spatial and physical characteristics of the valuation units are detailed with *VM_SpatialUnit*, *VM_Building*, *VM_CondominiumUnit* classes that have relations with *VM_ValuationUnit* (see Figure 1 and Figure 2).

*VM_SpatialUnit* represents cadastral parcels, as well as sub-parcels in valuation registries (Cagdas et al., 2016). It has a relation with *LA_SpatialUnit* that supports 2D, 3D or mixes representation of spatial units (ISO, 2012). *VM_SpatialUnit* has characteristics for current and future land use. The Hierarchical INSPIRE Land Use Classification System (HILUCS) provides a code list for both existing and planned land use.

LADM is only concerned with the legal space of buildings and building parts (e.g. individually owned apartments, jointly owned building parts), therefore, it does not include any physical characteristics of them. The *VM_Building* specifies the physical characteristics of buildings and building parts that are needed in valuation activities. It provides a set of common characteristics, such as building and condominium use type (e.g. residential, office, retail), floor area and energy performance (see Figure

2). The *VM_Building* may represent buildings that are considered as complementary parts of parcels but may be valued separately from the parcels on which they are located. It may also represent a building containing condominium units (Cagdas et al., 2016). The VM_CondominiumBuilding class is adopted from the LandInfra standard to specify buildings that contain condominium units established according to condominium schemes (OGC, 2016). Accordingly, a condominium building consists of (i) condominium units (e.g. dwellings, shops); (ii) accessory parts assigned for exclusive use (e.g. garages, storage areas); (iii) and joint facilities covering parcel and structural components (e.g. foundations, roofs), accession areas (e.g. entrance halls, spaces), and other remaining areas of buildings (e.g. staircases, heating rooms) (OGC, 2016). The terms and definitions for floor areas are adopted from ISO 9836:2017 Performance Standards in Building (ISO, 2017). The International Property Measurement Standards (IPMSs) can interchangeably be even used instead of ISO 9836:2017. Inspiring from OGC (2016), the LADM Valuation Information Model also includes a *VM_CondominiumUnit* class to record the main physical condominium unit characteristics, such as area, related accessory parts and shares in joint facilities.

In mass valuation practice, the valuation units may be grouped according to zones (e.g. administrative divisions, market zones) that have similar environmental and economic characteristics, or functions of valuation units (e.g. commercial, residential, and agricultural) that have similar characteristics. This issue is addressed by the *VM_ValuationUnitGroup* in the model (Cagdas et al., 2016; Kara et al., 2018).

LADM Valuation Information Model covers detailed information on the physical characteristics of valuation units. For example, since the area and volume of buildings and building parts are required in valuation activities, these measurements are supported in the model by means of 3D representation support of the core LADM and the *VM_Building*. However, the LADM Valuation Information Model does not include the externalities of property units in detail, for instance, the locational and environmental characteristics that may affect values of property units (e.g. view, noise and hazardous areas) were not covered. The 2D and 3D data sources together with GIS analyses can provide great possibilities to derive these characteristics and more for property valuation activities.

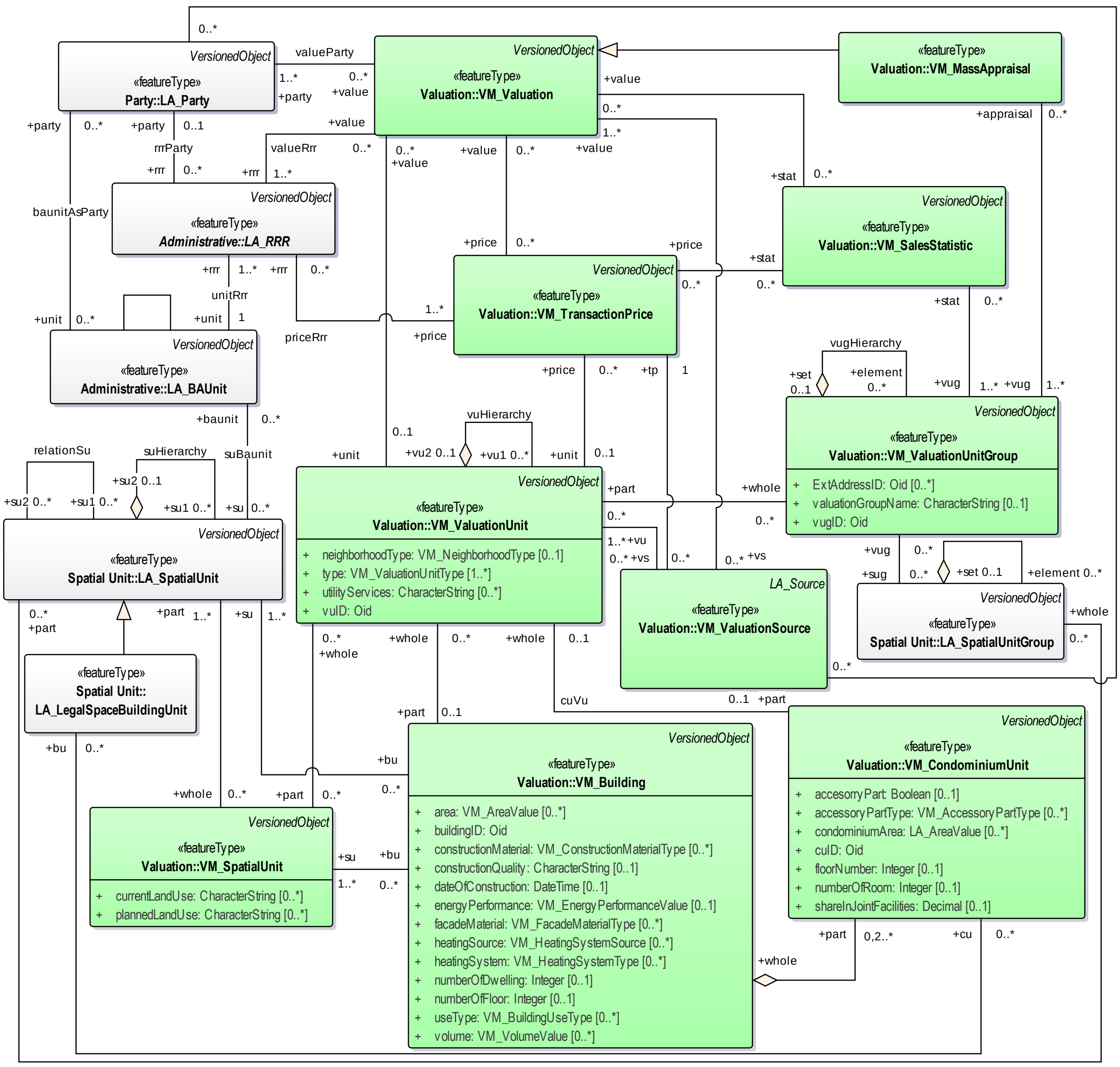



Fig. 2. The spatial part of the LADM Valuation Information Model

## 3. Property characteristics in valuation

A wide variety of property characteristics can be derived from a semantically rich 3D building, 3D city and cadastral models using both GIS analyses. Additionally, diverse datasets including, but not limited to, satellite imagery, laser scanning, cyclorama, and street view images may be used to derive data for property valuation activities.

According to Sirmans et al. (2005), the most frequently utilized internal characteristics in hedonic valuation models are building age, floor area of a condominium unit, lot size, number of room and garage space. A number of use case studies have derived these characteristics using above-mentioned 3D data sources. For example, Biljecki and Sindram (2017) estimated building age using semantically rich, LoD1 3D city model, while Boeters et al. (2015) utilized CityGML LoD2 model enhanced with building interiors to compute net internal floor area. However, these internal characteristics are already recorded in existing property databases or registries. On the other hand, the most frequently used externalities in explaining property prices are the view, distance to a point of interest, level of noise, location and level of crime (Sirmans et al., 2005). Extensive research has been conducted to substitute qualitative valuation methods by quantitative information systems. In the context of property valuation, GIS has made possible the development of databases which can be used to measure better the environmental and locational characteristics of properties (Wyatt, 1996).

The distance or proximity has been used as a variable in almost all valuation models. Table 1 shows some of the distances measured for property valuation. Besides, some other distances have been used in valuation models such as busy road, city center, amenity, school, inundation area and landfill. These distances are usually measured using 2D GIS or web map services, whereas usage of 3D city models and building models including orientation of property units and indoor spaces may provide more natural and realistic distance measurements. On the other hand, types of distance (e.g. Euclidean (beeline) distance, linear distance, walking distance and shortest path for car navigation) measured for valuations should be indicated as it may have an impact on the significance of variable.

Table 1. The distance types measured for property valuation

| Distance To | Reference |
|---|---|
| **Beach** | Bourassa et al. (2004), Jim and Chen (2006), Jim and Chen (2009), Hamilton and Morgan (2010) |
| **River and Lake** | Mahan et al. (2000), Paterson and Boyle (2002), Bourassa et al. (2004), Anderson and West (2006), Wen et al. (2017) |
| **Forest** | Tyrväinen and Miettinen (2000), Paterson and Boyle (2002), Sander et al. (2010) |
| **Park** | Anderson and West (2006), Poudyal et al. (2009), Yuan et al. (2018) |
| **Public transport** | Din et al. (2001), Bowes and Ihlanfeldt (2001), Hess and Almeida (2007), Wen et al. (2017), Yuan et al. (2018) |
| **Central business district** | Din et al. (2001), Boyle and Kiel (2001), Paterson and Boyle (2002), Jim and Chen (2006), Sander and Polasky (2009), Wen et al. (2017), Yuan et al. (2018) |
| **Mountain** | Jim and Chen (2009), Jim and Chen (2010) |
| **Hazardous waste site** | McCluskey and Rausser (2003) |

Estimation of the propagation of noise is another use case that has been used in valuation activities. In noise analysis, 3D data provides an advantage over 2D data due to the refraction of sound level at different elevations (Kubiak and Ławniczak, 2015). There are some studies investigating the relationship between house prices and noise with 2D data. For example, Cohen and Coughlin (2008) investigated airport noise effect on house prices, while Łowicki and Piotrowska (2015) researched noise effect on the undeveloped land value, and Wilhelmsson (2000) searched the impact of traffic noise on values of single-family houses. On the other hand, usage of 3D data for noise analysis is not documented in property valuation but it appears to be likely used in the future (Biljecki et al., 2015).

The estimation of insolation of buildings through sunlight and daylight analyses is a 3D GIS-based use case that has been employed in property valuation. For instance, Helbich et al. (2013) analyzed solar radiation of each real estate with 3D analysis considering high-rise buildings, environment and shadowing effects.

Environmental amenities and risks may also affect property values. The Standard on the Valuation of Properties Affected by Environmental Contamination states that environmental factors are increasingly important in property valuation as the market has become more aware of the potentially detrimental effects of chemical, radiation, noise, and other contaminants on air, water (surface water and groundwater), soil, and overall environment (IAAO, 2016, p. 5). Furthermore, Wyatt (2013) express that there is a positive effect of environmental certification on property values. The literature presents a number of studies that utilize 2D data sources to assess the impact of environmental effects on property values. For instance, Rajapaksa et al. (2017) and McCluskey and Rausser (2003) investigated the impact of flood dynamics and hazardous waste sites on property values, respectively. There are no examples that use 3D data sources.

Concluding, it should be mentioned that slope and aspect analyses using Digital Elevation Model (DEM) and GIS, have also been used in various valuation models (García et al., 2008; Demetrioua, 2016; Demetrioua, 2018) since they have a significant effect on values of property units. This article in the next subsection aims at focusing on the most prevailing use case, namely visibility analysis which utilizes the 3D datasets for deriving externalities related to the view characteristics.

### 3.1 Visibility analysis in property valuation

The view may have a substantial impact on property values. Before 3D GIS technology has emerged, on-site inspection is generally carried out to capture and measure the view of the property. Table 2 presents how the view(s) of properties were evaluated in valuation models without using GIS. Most of the studies have used a single dummy variable (1 if there is a view, otherwise 0) to capture the impact of view(s) to value, while a few have used several dummy variables together with the presence of view(s) such as quality of view and distance to view. Also, there is not a common, standardized measure to define the quality of view in the examined studies. The distance to view was also included as a variable in most of the studies besides the presence of view. GIS distance analysis was performed to measure the distance to view but the type of distance measured was generally not indicated in the studies. The views were usually measured for residential properties, while Fleischer (2012) used the view of hotel rooms as a variable. A field investigation was conducted in most studies to determine view. Jim and Chen (2009) supported on-site inspections with digital map analysis. Some of the studies stated that the view information was taken from a transaction database or a website (Bourassa et al., 2004; Fleischer, 2012; Hui et al., 2012; Schläpfer et al., 2015).

Table 2. Views of property units evaluated with only dummy variable(s) without GIS analysis

| **Type of view** | **Type of property** | **Measure of view** | **Distance to view** | **Field Investigation (other data source)** | **Measures of the quality of a view** | **Reference** |
|---|---|---|---|---|---|---|
| Ocean, Lake, Mountain | Single-family residential | Dummy variables | + | + | Full, Superior partial, Good partial, Poor partial view for the ocean; Lakefront, Non-lakefront | Benson et al. (1998) |
| Forest, Park | Dwelling (terraced house) | Single dummy variable | + | + | - | Tyrväinen and Miettinen (2000) |
| Water, Other | Detached and semi-detached | Dummy variables | + | + | Narrow, Medium, Wide, None | Bourassa et al. (2004) |
| Green | Dwelling units | Single dummy variable | + | + | - | Jim and Chen (2006) |
| Sea, Mountain, Street, Building | Residential estates | Dummy variables | + (seashore, mountain) | + (digital map analysis) | Panoramic, Partially obstructed for sea and mountain | Jim and Chen (2009) |
| Sea, Seaside, City, Garden | Hotel | Single dummy variable | - | - (website) | - | Fleischer (2012) |
| Sea, Garden, Avenue, Street | Condominium | Single dummy variable | - | - (website) | - | Hui et al. (2012) |
| Lake | Residential house | Single dummy variable | + | - (swisstopo) | - | Schläpfer et al. (2015) |

Views are difficult to measure. On-site measurement can be a time-consuming process and it may present a subjective evaluation. GIS visibility analysis, however, provides an alternative to this process with a quantitative approach. The visibility analysis in GIS might still be prone to measurement error; yet the accuracy of the analysis increased with the usage of 3D datasets, improvement in data quality and development in 3D GIS. Many studies have started to use visibility analysis to measure the impact of views on property values using different approaches. It is observed that distance to view and visibility analysis are most used GIS operations to measure and quantify view in the literature. Table 3 shows critical aspects of the studies that used GIS when measuring views, namely the type(s) of view measured, type of property in view analysis, measure of view, information on obstacle model, observer parameters (i.e. observer height and viewing angle of observer), selected maximum radius for visibility, inclusion of distance to view in valuation models besides view variable, and quality assessment of view analysis with other data sources. Below, a brief discussion is presented related to the use of view in property valuation.

Table 3. Critical aspects of views assessed using GIS analysis in valuation models

| Type of view | Type of property | Measure of view | Obstacle | Observer (h=height, ha= horizontal angle, va= vertical angle) | Outer radius | Distance to view | Quality assessment | Reference |
|---|---|---|---|---|---|---|---|---|
| Road, Building and Waterbody | Detached, Terraced | Viewshed | DTM (1 m) (including building heights and slopes)Data sets used | h= (height of a floor (3 m) x (number of stories) + height of observer (2 m)), ha= ±45° | 500 m | + | - | Lake et al. (1998) |
| Road, Railway, Water, Park, Vegetation, Building, Industry | Detached, Semi-detached, Terraced | Viewshed | DEM (1 m) (including building heights, slopes, and vegetation) | h= (height of a floor (3 m) x (number of stories) + height of observer (1.7 m), ha= ±45° | 500 m | + | Comparing with photographs | Lake et al. (2000) |
| Development, Agriculture, Forest, Water | Single-family residential | Viewshed | DEM (3 m) | h= 1.83 m (ground level), ha= 360° | 1000 m | - | - | Paterson and Boyle (2002) |
| Sea | High-rise residential | Viewshed | DEM (including building heights) | h= (height of a floor (3 m) x (number of stories) + height of observer (1.7 m), ha= 180°, va= ±90° | 500 m | - | - | Yu et al. (2007) |
| Lake | Single-family residential | Viewshed | DEM (10 m) | h= 1.83 m (ground level) | - | - | Site visit and databases | Shultz and Schmitz (2008) |
| Ocean | Single-family residential | View angle | Lidar derived DEM (1.52 m) (including heights for built structures and vegetation) | h= (maximum height of a building – 3.05 m), ha= 360° | 1609 m | + | - | Bin et al. (2008) |
| Forest, Grassy area, Water | Single-family residential | Viewshed, Single dummy | DEM (10 m) (including building heights) | h= (top story of a home), ha= 360° | 1000 m | + (Lake, Stream) | - | Sander and Polasky (2009) |
| Agriculture, Tree, Road, Rail, Built, Bush, Water | Detached | Viewshed | DEM (7 m) (including fixed heights for building and tree) | h= 1.8 m (ground level), ha= 360° | Various (70 m to 40 km) | - | Comparing with orthophotographs | Cavailhès et al. (2009) |
| Forest | Single-family residential | Viewshed | DEM (30 m) | ha= 180° | - | - | - | Poudyal et al. (2010) |
| Gulf | Single-family residential | View angle | Lidar derived DEM (1 m) (including heights for building and vegetation) | h= (1.5 or 3 m below the height of a roof), ha= 180° | 1000 m | + (Beach) | - | Hamilton and Morgan (2010) |
| Gulf | Residential | View angle | Lidar derived DEM (including heights forof built structures and vegetation) | h= (highest living level of the home), ha= 180° | - | + (Shoreline) | - | Hindsley et al. (2013) |
| Open, Green, Ocean | Condominium | Viewshed | Lidar derived DTM and DSM (0.5 m) (DSM including heights for building and tree)Data sets used | h= (height of a floor (3 m) × (number of stories) − 1 + (height of human eyes (1.6 m)), ha= 180° | 500 m | + (Green, Ocean) | - | Yamagata et al. (2016) |
| Water, Road, Development, Green, Agriculture | Terraced, Linked, Corner, Semi-detached, Detached | Viewshed | Lidar derived DSM (0.5 m) (including building heights)2D data used or 3D | h= 1.8 m (ground level), ha= 360° | 150 m | - | - | Oud (2017) |
| Sea | Land | Single Dummy | - | - | - | - | - | Demetriou (2016, 2018) |

As indicated in Bourassa et al. (2004), the most studies have examined the impact of a water view (e.g. ocean, lake, or river), while other types of view being the focus of research less often. This trend is still preserved today as a great number of studies employing a variable for the view of water bodies (e.g. sea, lake and ocean), as it can be seen in Table 2 and Table 3. Additionally, other types of view such as a mountain, urban, green spaces, forest, garden, agriculture, development and road have been increasingly utilized in valuation models. The views were generally measured for single-family residential properties in the examined studies, while Demetriou (2016, 2018) performed height analysis in GIS to measure sea view of land parcels.

The studies that computed view with GIS have generally preferred either viewshed or view angle as a measure of view. The most used algorithm to compute viewshed produces a binary detection map of areas that are visible or nonvisible from a point of observation (Fisher 1992; Lagner et al., 2018). The vast majority of the examined studies (Lake et al., 1998, 2000; Paterson and Boyle, 2002; Yu et al., 2007; Shultz and Schmitz, 2008; Cavailhès et al., 2009; Sander and Polasky, 2009; Poudyal et al., 2010; Yamagata et al., 2016; Oud, 2017) selected viewshed to identify view of a property. The angle-based view measurement was chosen by only a few studies. For example, Bin et al. (2008) summed angular widths of all possible fields of ocean view to yield the summed total the view in degrees (0° to 360°) for each property with the line of sight analysis in GIS. The individual property's view angle, ranging from 0° to 180°, was selected to calculate view of the Gulf of Mexico in both Hamilton and Morgan (2010) and Hindsley et al. (2013). It should be noted that different measures of view can be used together, for instance, Sander and Polasky (2009) utilized both viewsheds (calculated for the forest, water and grassy areas), and a dummy variable (the view of downtown) in their valuation model.

The investigation shows that the view angle was preferred to measure a certain type of view, while the viewshed was generally selected to compute which land use(s) could be seen from a property by means of overlaying the viewshed of a property with land use maps. In other words, viewshed of properties and its content in terms of land uses was determined in most of the studies that selected viewshed as a measure of view. On the other hand, a few papers concentrated on measuring a certain type of view with viewshed analysis, for example, sea (Yu et al., 2007) and lake (Shultz and Schmitz, 2008).

The visibility analysis requires obstacle and observer(s) datasets. An obstacle is a raster elevation model (i.e. DEM, Digital Terrain Model (DTM), and Digital Surface Model (DSM)) which can be produced using different datasets in different resolution. All the examined studies included 3D buildings in their obstacle model (see Table 3) except for Paterson and Boyle (2002), and Shultz and Schmitz (2008). They used only topographic (land elevation) data without manmade features as obstacle model. Yu et al. (2007) suppressed the effect of land height on visibility, as the land is relatively flat in their study area, and created an obstacle model considering the heights of buildings. Lake et al. (1998, 2000) combined building heights data and land elevations (triangulated irregular network (TIN) of land heights) to produce an obstacle model. After 2008, Lidar (Light Detection and Ranging) derived obstacle models were created in the vast majority of the examined studies (Bin et al., 2008; Hamilton and Morgan, 2010; Hindsley et al., 2013; Yamagata et al., 2016; Oud 2017). All of the lidar-derived obstacle models included both natural and man-made features on the landscape with their elevations and often derived from first-returns of lidar data. It is worth noting that each storey of a building was assumed 3 m high when creating obstacle model in some studies (Lake et al., 1998, 2000; Yu et al., 2007; Sander and Polasky, 2009; Yamagata et al., 2016). Moreover, when calculating the total height of buildings, Sander and Polasky (2009) added 2 m to the total height of all storey levels to account for roof and basement offsets. On the other hand, Oud (2017) used mean height values of buildings obtained from lidar data to extrude buildings for obstacle model.

Determining observer height and location are crucial for visibility analysis. When determining observer height, three different approaches were followed in the examined studies. Paterson and Boyle (2002), Shultz and Schmitz (2008), Cavailhès et al. (2009) and Oud (2017) calculated the observer height by summing the height of ground point and the height of the observer. The height of floor level of a building was added to the height of observer in Lake et al. (1998, 2000), Yu et al. (2007) and Yamagata et al. (2016). In the last approach, the highest level of the building was utilized when determining observer height. For example, Sander and Polasky (2009) and Hindsley et al. (2013) located observer point at the top level of each home. The observer point was set at an elevation 10 feet below the estimated maximum height of a building by Bin et al. (2008). The observer location was determined according to the roof type of building in Hamilton and Morgan (2010) and was assumed 1.5 or 3 m below the mean height of the roof. Bin et al. (2008) established an observer point at the center point of the building footprint. Last but not least, two observer points were specified for each condominium units in order to mitigate the uncertainty of viewsheds due to the selection of viewpoint by Yamagata et al. (2016).

The maximum view radius was set between 500 m – 1000 m in most of the examined visibility analysis. Cavailhès et al. (2009) performed viewshed analysis with six different radius (0–70 m, 70–140 m, 140–280 m, 280–1200 m, 1.2–6, and 6–40 km) in order to detect which landscapes and features remain significant up to how many meters. They showed that beyond 100 m only a few attributes (e.g. trees and farmland) remain significant, while more than 100–300 m away all attributes have insignificant prices in flat or near flat areas.

Horizontal and vertical angle limits were the other parameters that should be specified in viewshed analysis. The vertical angle (upper and lower limit for viewshed) selected was not stated in most of the examined studies except for Yu et al. (2007) that expressed it between 90° and -90°, while the horizontal angle was generally selected 180° or 360°. It is noted that the horizontal angle proceeds in the clockwise direction and scans the area of the viewshed.

In some of the examined studies, both visibility analysis and distance to view were together utilized in valuation models with different approaches (Lake et al., 1998; 2000; Bin et al., 2008; Sander and Polasky, 2009; Hamilton and Morgan, 2010; Hindsley et al., 2013; Yamagata et al., 2016). For instance, Lake et al. (1998) applied inverse linear distance weighting function to viewshed of each certain view of properties since the impact of view is expected to decrease with distance from the property, while the other studies used two separate variables for distance and visibility. It is noted that a negative relationship was always reported between distance to view and property values (Bourassa et al., 2004; Yu et al., 2007).

A few studies assessed the quality of visibility analysis using different approaches. For example, Lake et al. (2000) compared a selection of viewsheds with photographs taken from the same location and direction and stated that the viewsheds were fairly accurate in the majority of cases. According to their analysis, the most prominent difference originated due to the absence of vegetation information on DEM. Shultz and Schmitz (2008) compared different sources for views of properties and found out that multiple listing service (MLS) classifications underestimated views by 79% and GIS frontage classifications overestimated views by 42%, while GIS viewshed analysis overestimated views by only 0.5%. Lastly, Cavailhès et al. (2009) made a comparison between obstacle model and orthophotographs and stated that the model may underestimate viewshed by exaggerating the amount blocked out by buildings.

Finally, the view of water bodies (e.g. a lake, ocean and sea) were found to have a positive and significant impact on property values in the examined studies (Table 2 and Table 3). Moreover, the results of some studies also indicated that the view of the grassy area (Sander and Polasky, 2009), forest view (Poudyal et al., 2010), and open view (Yamagata et al., 2016) have a positive effect on value. On the other hand, some views negatively affected property values, such as road view (Lake et al., 1998; Oud, 2017), forest view (Paterson and Boyle, 2002), downtown view (Sander and Polasky, 2009), and mountain view (Jim and Chen, 2009).

### 3.2 Viewshed analyses for property valuation with open datasets of the Netherlands

This section investigates how viewshed analysis could be performed by utilizing different data sources and models (approaches) for property valuation activities. Several viewshed analyses were conducted based on obtained experiences from the previous subsection. The purpose of this use case is to present the best approaches to calculate viewsheds of property units using 3D GIS-based visibility analysis and then to record input and output data of the analysis into property valuation registries.

The viewshed analysis is an important method for deriving visibility from any given vantage point (Nutsford et al., 2015). The best practices determined from the literature were utilized in this use case to quantify view of property units can be summarized as follows: The areas of viewsheds for each condominium units were firstly computed using four different obstacle datasets. Subsequently, the viewsheds were overlaid with land use dataset and visibility areas per land-use types were calculated for each individual condominium unit with an automated approach.

The open datasets of the Netherlands, namely datasets from BAG (the Basic Registration Addresses and Buildings), TOP10NL (1:10000 digital topographical base map of the Netherlands), AHN3 (point cloud dataset) and some combination of them were used to design obstacle datasets. BAG provides the footprints of buildings without height characteristics, while TOP10NL provides building footprints and topographic features such as roads, bridges, terrain and water, with height attributes.

The study area is a small part of the Dutch Municipality Alkmaar, where the land is mostly flat. The Viewshed2 tool of ArcGIS Pro 2.0 of Environmental Systems Research Institute, Inc. (ESRI) was used for visibility analysis. This viewshed tool requires point(s) or line as observers and an elevation model (e.g. DEM and DSM) in raster format that represents the obstacles blocking the view. If the observer is selected as a line, an area of viewshed is computed for each points forming the line. The output is a raster file that represents the area of viewshed of the observer(s).

In this use case, the obstacle datasets were constructed with four different approaches, resulted in four obstacles (elevation) models illustrated in Fig. 3.

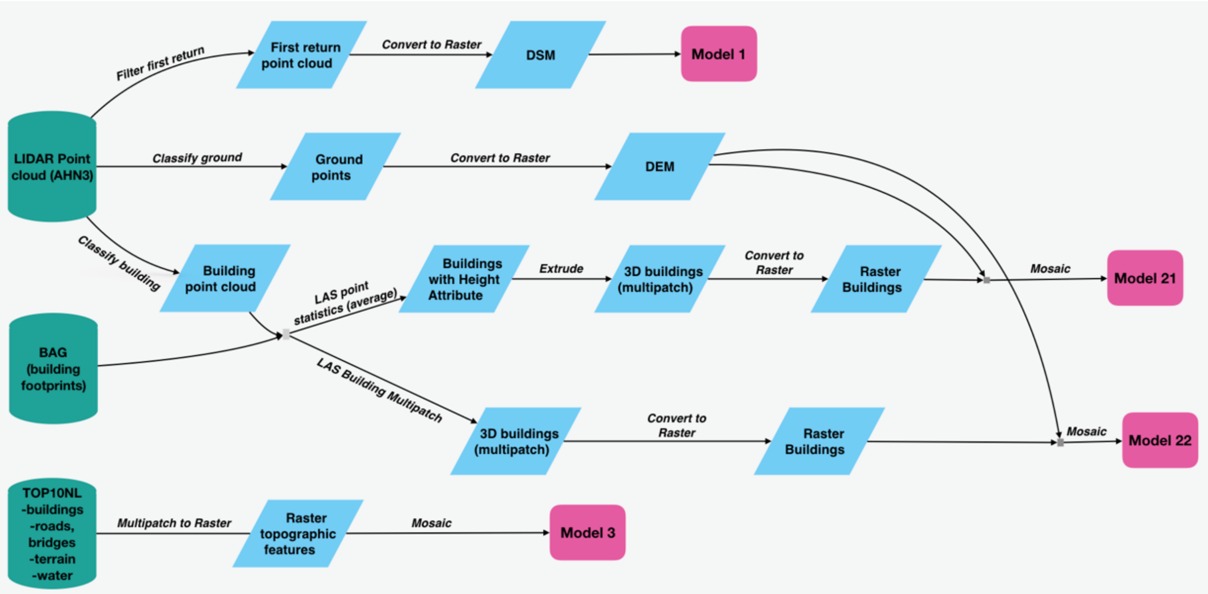
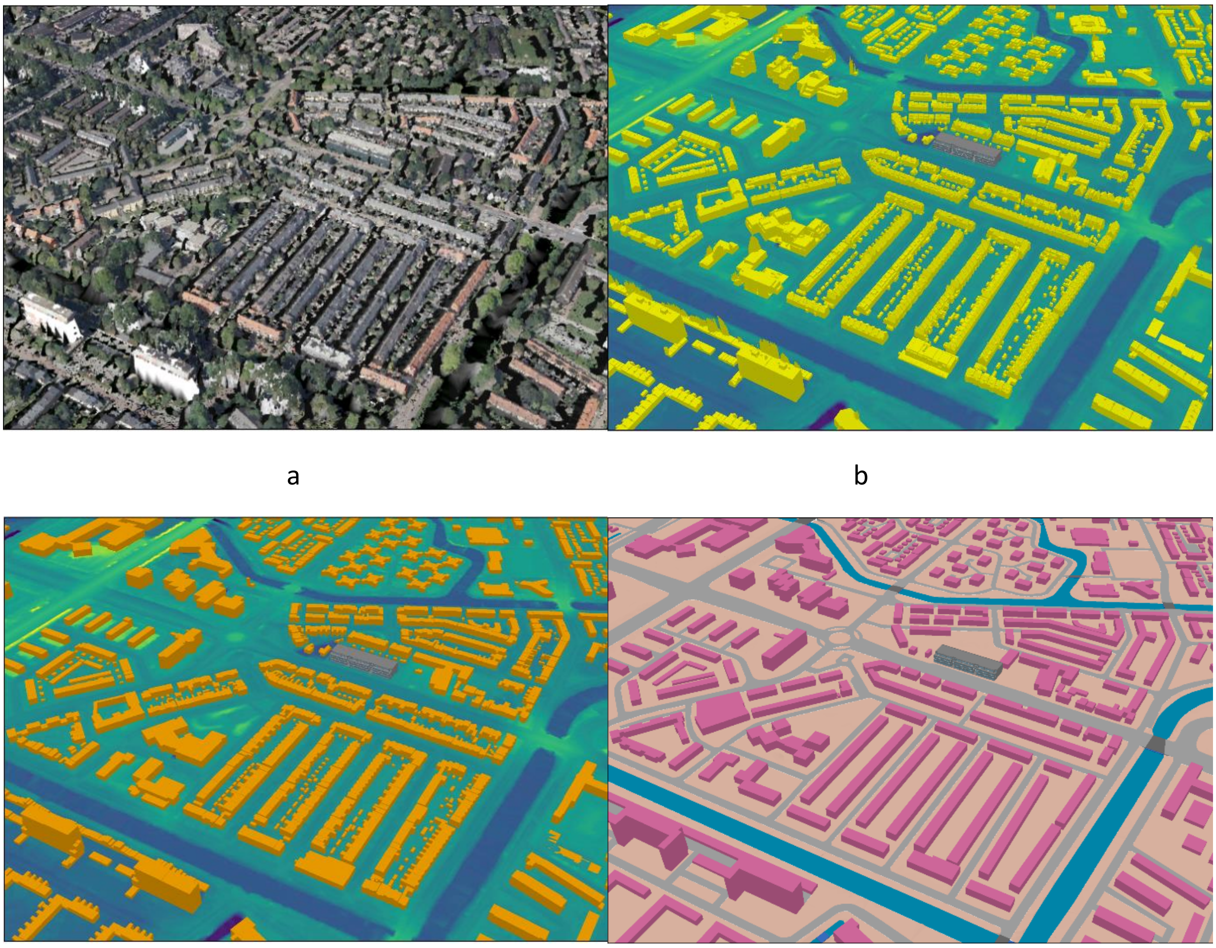



Fig. 3. Workflow for constructing obstacle models using different data sources

Model 1 is a DSM with 25 cm resolution which was produced using AHN3 first return of point cloud data. The ground level points of AHN3 point cloud were classified to produce a 25 cm resolution of DEM for Model 2.1 and Model 2.2. DEM represents the bare ground surface without any objects like plants and buildings. Since vegetation is the main problem to perform more accurate visibility analysis (Lake et al., 2000; Zhang, 2017), 3D buildings dataset combined with DEM was used as obstacle datasets to eliminate the tree canopy covers and to include buildings as impediments for Model 2.1 and Model 2.2. Building footprints (from BAG) and classified point cloud data were used to produce 3D buildings. In Model 2.1, 3D buildings were produced using 'LAS Building Multipatch' tool, and for Model 2.2 building footprints were extruded with mean height values of the classified point cloud using summary statistics tool in ArcGIS Pro. Note that the produced models (both DSM and DEMs) were combined with water surface model in order to create a continuous elevation model. Lastly, TOP10NL dataset was used to construct an obstacle dataset for Model 3. Buildings, water, bridges, 2.5D terrain and roads in the TOP10NL were firstly merged and then converted to raster with 25 cm resolution. The produced obstacle models are illustrated in Fig. 4.



a b

c d

Fig. 4. Obstacle models (a) Model 1: DSM produced with first return points of AHN3 (b) Model 2.1: DTM plus buildings with rooftop geometry (c) Model 2.2: DTM plus buildings extruded with mean height of rooftop point (d) Model 3: TOP10NL dataset

Fig. 5 shows the selected building and the observer condominium units in Alkmaar. The height of observer points was set to 1.7 m above from floor level of each condominium unit, considering the eye level of an average height person. The viewpoints were set the maximum extent of windows of each individual condominium unit taking into consideration the directions of the condominium units. Two observer points were specified for each condominium unit in order to mitigate uncertainty due to the selection of viewpoints similar to the observer's orientation selection made by Yamagata et al. (2016). The viewshed analysis was constrained to a maximum of 180° in terms of horizontal sweep (angle), and by the side of the facade of condominium units. In this use case, the vertical limit of the scan was specified between ±90°, considering the positive angles were above the horizontal plane (0° for each individual condominium unit), negative angles were below the horizontal plane. Note that viewshed was selected as a measure of view for this study. Therefore, total viewsheds were firstly calculated for each condominium unit.


Fig. 5. Observer condominium units

There are two input layers in GIS-based viewshed analysis, namely the observers and the obstacle raster dataset. Input parameters are observer elevation, observer offset (i.e. the height of human eyes) and outer radius in viewshed analysis. The observer elevation indicates the absolute height of the observer points or lines, while the observer offset is a parameter added to the observer points or lines. The outer radius defines the extent of the visible area. The observer elevation was calculated by summing height of the ground, floor height of floor level of the condominium units, and height of human eyes. The outer radius was set to 300 meters since Cavailhès et al. (2009) stated that only a few attributes remain significant up to 150–300 m radius in flat or near flat surfaces for property valuation. If the study area has a rough topography, then the outer radius could be defined between 500 m and 1000 m as extending the visibility analysis to 1 or 2 km would not significantly increase the amount of visible land (Lake et al., 1998; 2000).

The calculated viewsheds for the condominium unit 1 and 3 are illustrated in Fig. 6 and Fig. 7. The areas with red color represent the computed viewsheds of the condominium units.

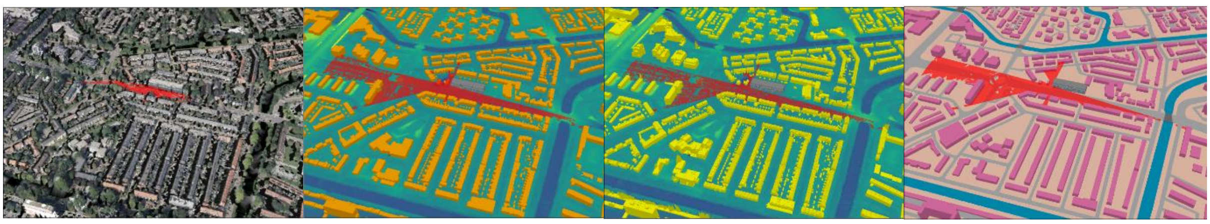


Fig. 6. Visualization of the area of viewshed with four obstacle models for condominium unit 1

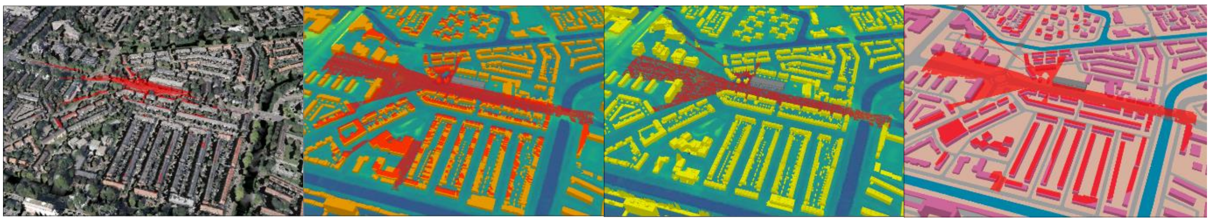


Fig. 7. Visualization of the area of viewshed with four obstacle models for condominium unit 3

The BBG (Land Use Database), which is based on the topographical map of the Netherlands and aerial photos of summer of 2015, was used to compute visibility of land use areas of each condominium unit. The classification of land use data consists of a number of main categories, each of which is subdivided into a number of subcategories. The types of land use were detected as water, recreation, built-up area, industrial zone, highway and railroad in the study area. Land use map of the study area is depicted in Fig. 8. The calculated total viewsheds of each condominium units were overlaid with this land use map to identify which land uses could be seen from each individual condominium units, and to calculate the visible areas of land uses for each condominium unit.

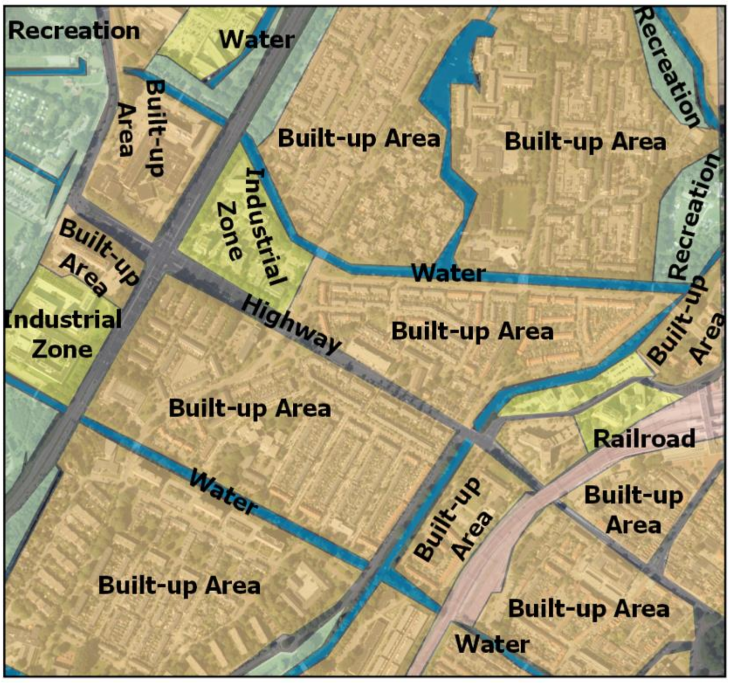



Fig. 8. Current land use in the selected study area

Fig. 9 presents the total visible areas determined through the obstacle models for each condominium unit. The results indicate that there are significant differences between total areas of viewsheds of the same condominium units computed through different obstacles. Since the DSM contains tree canopies and building roofs, the visible areas of the condominium units determined with 'Model 1' are the smallest. It can be considered that the difference between Model 2.1 and Model 2.2 stems from the roof of buildings. Model 2.2 has a greater viewshed since the buildings were represented with the mean height of rooftop points rather than the full geometry of the rooftop as in Model 2.1. Finally, Model 2.2 has smaller viewshed areas compared to Model 3, due to the difference between the mean height of points on roofs and building height attributes in TOP10NL dataset.

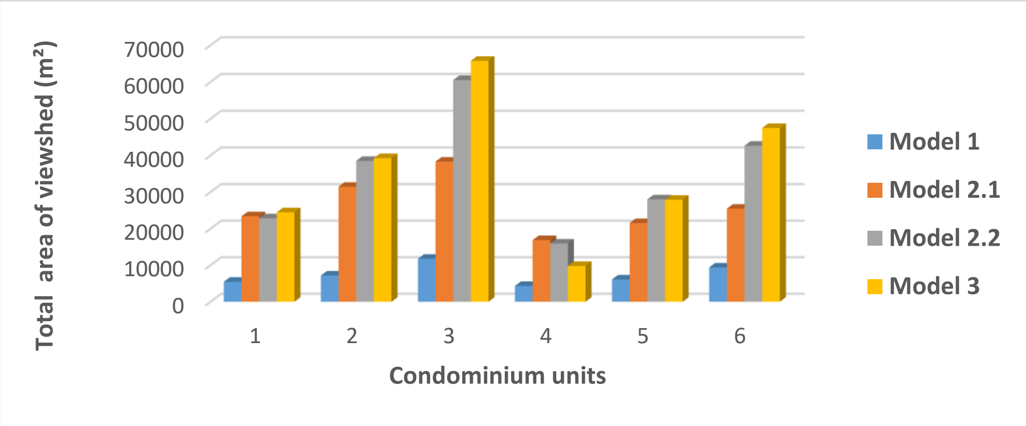



Fig. 9. Total areas of viewshed of the selected condominium units for each obstacle models

As detailed in the previous subsection, many studies firstly calculated total viewsheds, and then compute visibility of land use areas for each property units in order to employ them as a variable in their valuation models (Lake et al., 1998; Paterson and Boyle, 2002; Yu et al., 2007; Yamagata et al., 2016; Oud, 2017). Therefore, in our case, the land use dataset (BBG) and the viewshed polygons were overlaid and the intersection areas were determined, which represent areas of view content of each condominium unit. Table 4 shows the total viewshed areas, and areas of land use types for six condominium units and four obstacle models.

Table 4. The total and land use areas of viewsheds of each condominium units for the obstacle models

| Condominium ID | Obstacle Model | Viewshed Area ($m^2$) | | | | |
|---|---|---|---|---|---|---|
| | | Build-up Area | Water | Highway | Industrial Zone | Total |
| 1 | Model 1 | 2044 *(37.4%)* | 0 *(0%)* | 3426 *(62.6%)* | 0 *(0%)* | 5471 |
| | Model 2.1 | 11750 *(50.3%)* | 69 *(0.3%)* | 10723 *(45.9%)* | 827 *(3.5%)* | 23370 |
| | Model 2.2 | 10533 *(46.1%)* | 69 *(0.3 %)* | 10722 *(47.0%)* | 1506 *(6.6%)* | 22830 |
| | | 12009 | 0 | 10515 | 1931 | 24455 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Model 3** | *(49.1 %)* | *(0 %)* | *(43 %)* | *(7.9 %)* | |
| **2** | **Model 1** | 3159 *(44.0%)* | 1 *(0%)* | 3948 *(55.0%)* | 64 *(0.9%)* | 7172 |
| | **Model 2.1** | 15103 *(48.0%)* | 92 *(0.3%)* | 12781 *(40.6%)* | 3470 *(11.0%)* | 31446 |
| | **Model 2.2** | 22713 *(59.0%)* | 92 *(0.2%)* | 12780 *(33.2%)* | 2913 *(7.6%)* | 38497 |
| | **Model 3** | 21945 *(55.9%)* | 87 *(0.2%)* | 13152 *(33.5%)* | 4073 *(10.4%)* | 39258 |
| **3** | **Model 1** | 6572 *(55.9%)* | 2 *(0%)* | 4740 *(40.3%)* | 441 *(3.8%)* | 11754 |
| | **Model 2.1** | 20506 *(53.5%)* | 108 *(0.3%)* | 13335 *(34.8%)* | 4363 *(11.4%)* | 38312 |
| | **Model 2.2** | 41976 *(69.4%)* | 108 *(0.2%)* | 13333 *(22.0%)* | 5094 *(8.4%)* | 60511 |
| | **Model 3** | 47001 *(71.5%)* | 106 *(0.2%)* | 13831 *(21.0%)* | 4811 *(7.3%)* | 65749 |
| **4** | **Model 1** | 1503 *(34.7%)* | 0 *(0%)* | 2834 *(65.3%)* | 0 *(0%)* | 4337 |
| | **Model 2.1** | 8814 *(52.3%)* | 83 *(0.5%)* | 7961 *(47.2%)* | 0 *(0%)* | 16859 |
| | **Model 2.2** | 7884 *(49.5%)* | 83 *(0.5%)* | 7961 *(50.0%)* | 0 *(0%)* | 15928 |
| | **Model 3** | 5962 *(60.9%)* | 0 *(0%)* | 3830 *(39.1%)* | 0 *(0%)* | 9792 |
| **5** | **Model 1** | 2401 *(39.4%)* | 3 *(0.1%)* | 3678 *(60.4%)* | 10 *(0.2%)* | 6092 |
| | **Model 2.1** | 10325 *(48.0%)* | 102 *(0.5%)* | 11095 *(51.6%)* | 0 *(0%)* | 21523 |
| | **Model 2.2** | 16796 *(60.0%)* | 102 *(0.4%)* | 11095 *(39.6%)* | 0 *(0%)* | 27993 |
| | **Model 3** | 16501 *(59.2%)* | 105 *(0.4%)* | 11280 *(40.5%)* | 0 *(0%)* | 27886 |
| **6** | **Model 1** | 4991 *(53.2%)* | 11 *(0.1%)* | 4314 *(46.0%)* | 62 *(0.7%)* | 9378 |
| | **Model 2.1** | 13280 *(52.2%)* | 115 *(0.5%)* | 12064 *(47.4%)* | 0 *(0%)* | 25459 |
| | **Model 2.2** | 30454 *(71.4%)* | 115 *(0.3%)* | 12064 *(28.3%)* | 0 *(0%)* | 42633 |
| | **Model 3** | 34894 *(73.5%)* | 108 *(0.2%)* | 12453 *(26.2%)* | 0 *(0%)* | 47456 |

As can be seen in Fig. 4 and Table 4, the condominium units on the first floor (1 and 4) has the smallest total area of viewshed and condominiums on the third floor (3 and 6) has the greatest. As the condominiums located on the left side of the building has two facades (see Figure 5), the condominium units numbered as 1, 2 and 3 has a greater area of viewshed compared to condominiums at the right side of the building.

The condominium units have a view of build-up area, water, highway and industrial zone. The view of water bodies is most likely to have a positive impact on property values, but in our case, the total visible area of water body seems insignificant in comparison with the other types of view. The literature review on visibility shows that the views other than water bodies may or may not affect the property values. In other words, the significance of view can differ not only due to the type of view but also due to the study area. On the other hand, the significance of the visible areas cannot be tested without including them as a variable in a regression model. However, since the current study aims to determine which derived locational and environmental characteristics of properties should be recorded and maintained in public valuation registries, and to reveal some approaches to calculate viewsheds of property units for valuation activities, the significance of property characteristics was considered out of scope.

As mentioned above, Model 1 was produced using first return point cloud, therefore it can be considered as a pessimistic obstacle model for viewshed analysis since it may not reflect the true geometry of some objects, especially for vegetation. As Model 2.1 includes 3D buildings with roof geometries and bare earth without vegetation, it can be considered as a more proper model for the viewshed analysis compared to Model 1. Yet, it should be noted that the processing time of the analysis with Model 1 and Model 2.1, is higher than Model 2.2 and Model 3. Additionally, Model 2.2 and Model 3 use single height values for each building and represent roofs as flat surfaces, resulting in less detailed models and lower processing time. Therefore, using these models in viewshed analysis is more practical than using Model 1 and Model 2.1. Total areas of viewshed for Model 2.2 and Model 3 are very close. This may indicate that if Model 3 (topographic raster map) does not include any generalized buildings in the study area, Model 2.2 and Model 3 can be used interchangeably for viewshed analysis in property valuation.

Next section presents a discussion on how input and output datasets of GIS analysis that is used to derive locational and characteristics of property units, especially the view, distance and noise, can be recorded in valuation registries, and on how often they should be updated.

## 4. Discussion

It is essential to identify and collect accurate and timely information on the determinants of value (FAO, 2017). Property related public registries and contracts or declarations submitted by the parties involved in property transactions are the main data sources for property valuation activities. Moreover, on-site inspections have also been conducted to collect data on the characteristics of property units. In the last two decades, 3D digital data sources have been utilized in property valuation. For example, 3D cadastre provides up-to-date information on ownership rights, restrictions, responsibilities (RRR) over properties and their 3D boundaries. Property valuation can also benefit from 3D city models and 3D BIMs to obtain physical characteristics of property units such as building age, quality of structure, floor area of property unit and building volume. Furthermore, annual valuation activities (e.g. mass valuation for taxation purposes) require up-to-date information related to the external characteristics of property units. Since it is time-consuming and costly to collect these characteristics on-site, the above-mentioned 3D data sources together with GIS analyses can be used to derive environmental and locational characteristics. However, performing some of the same GIS analysis repeatedly for the same properties to derive characteristics of property units can cause a loss of time and of labor. Recording them into property valuation registries may solve this problem but there is an indefinite number of environmental and locational characteristics about property units. Therefore, it can be reasonable to record the most used derived characteristics in valuation models into property valuation database or registries. LADM Valuation Information Model can be used to conceptualize this dissertation.

The LADM Valuation Information Model includes 3D legal and physical characteristics of property units required for property valuation; however, it does not include external characteristics that may dramatically change property values. The most used locational and environmental characteristics in valuation models were already determined in Section 3. According to obtained results, it was decided to extend LADM Valuation Information Model to cover these characteristics through 3D valuation unit profiles, as similar to what has been done for the spatial units in Annex E of the ISO 19152:2012 LADM. In this context, two separate 3D profiles were developed for parcel and condominiums.

Fig. 10 depicts the 3D profile for the parcel. The initial value of type was set to parcel in *VM_ValuationUnit*. A new external attribute was added to the same class in order to represent externalities of parcel type of valuation units. As indicated in the literature review section, distance and view information are widely used for the valuation of land. Therefore, characteristics of these externalities were detailed in *VM_ExternalCharacteristic* data type.

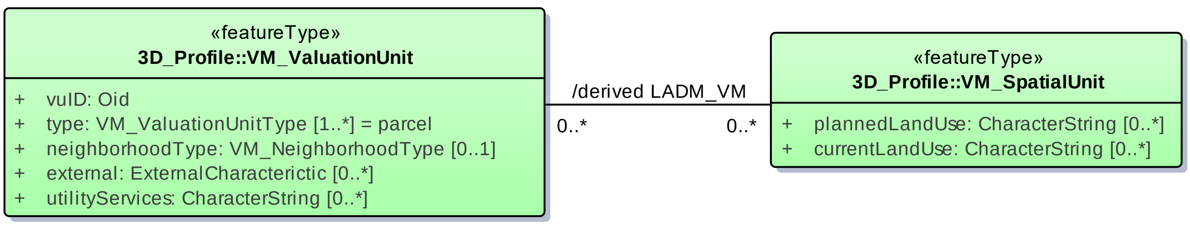



Fig. 10. 3D profile of valuation unit for the parcel

The second profile developed for condominium units (see Fig. 11). The initial value of type was set to a condominium unit in *VM_ValuationUnit*. The distance, view, noise and insolation characteristics of condominium units have generally significant impact on values according to the literature survey presented in the previous section. In order to record these characteristics of the condominium unit, similar to the parcel profile, *VM_ExternalCharacteristic* data type could be used. Note that similar profiles can be developed for other types of valuation units (e.g. only building) to manage derived characteristics.

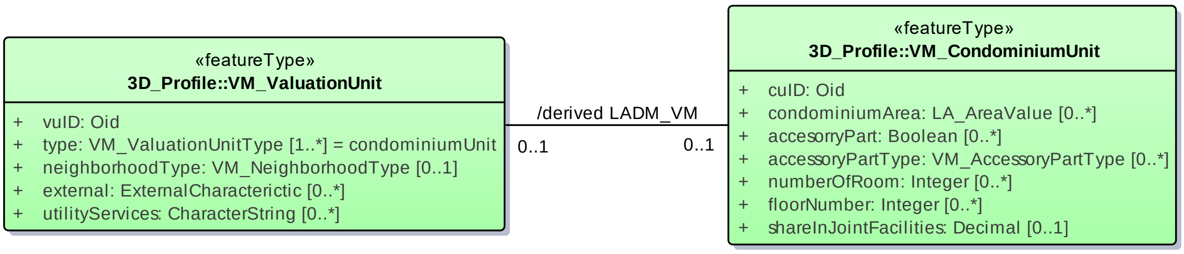



Fig. 11. 3D profile of valuation unit for the condominium unit

The results of both 2D and 3D GIS analysis about the view, distance and noise should be recorded in valuation registries together with the defined input parameters and information on utilized datasets. For this purpose, *VM_ViewCharacteristic*, *VM_DistanceCharacteristic* and *VM_NoiseCharacteristic* data type classes were developed (see Fig. 12). The important aspects of the analyses determined in the previous section were used to design the content of these classes. For example, the *description* characteristic in the *ViewCharacteristic* was included for recording information about the algorithm and utilized datasets (e.g. DTM, DSM, lidar, production method, resolution, data quality, and observer point or line) in the visibility analysis. The *measure* characteristic represents how the visibility of properties is measured (e.g. viewshed, view angle and field inspection). Since there is an indefinite number of view types (e.g. water bodies, green areas, mountain, and so on) and quality types (e.g. restricted view, panoramic view and wide view), a code list was not created for *typeOfView* and *qualityOfView* characteristics. The *landUsePercentageOfView* characteristic represents the visible land-use area percentages of properties. Moreover, a number of characteristics were specified related to observers (i.e. observerOffset, observerElevation, and outerRadius). Note that mandatory characteristics for *ViewCharacteristic* class are only *measure* and *typeOfView*, while the other characteristics are optional.

*DistanceCharacteristic* class has four characteristics to record *typesOfDistance* (e.g. pedestrian way, beeline distance, Euclidean distance, walking distance and shortest path for car navigation), *distance* in meter, *distanceTo* indicating proximity to a certain point from property (e.g. distance to city center, distance to view, so on), and *description* (e.g. utilized datasets and data quality). Note that since an indefinite number of distances may been used in property valuation activities, a code list for *distanceTo* characteristic was not created.

The profile has also a *NoiseCharacteristic* class which includes *typeOfNoise* (e.g. airport and highway), *noiseLevel* in dB, and *description* (e.g. utilized datasets, methodology and data quality) characteristics about noise propagation analysis.

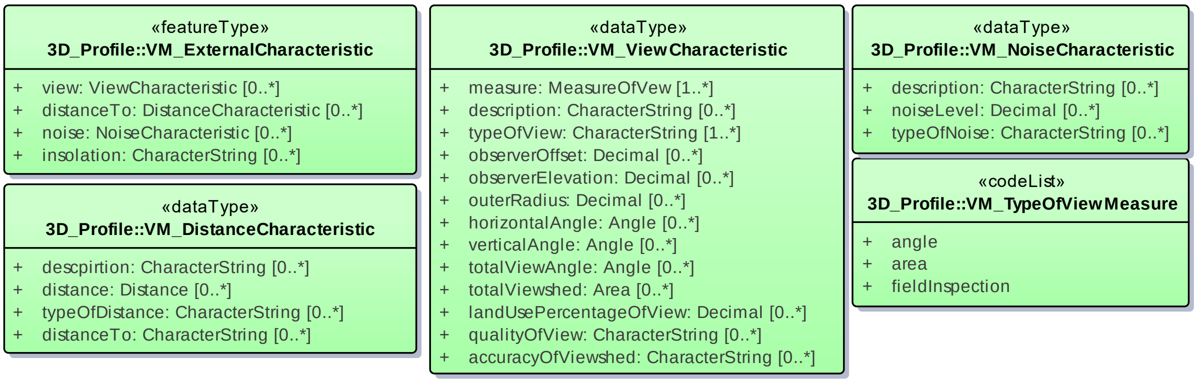



Fig. 12. Data types and code list for 3D profiles of valuation unit

The last profile is developed for the valuation unit groups, see Fig. 13. The reason is that it does not make sense to record some characteristics in valuation unit level such as environmental amenities (e.g. park, tennis court and green spaces), environmental and locational risks (e.g. flood risk, contaminations and crime rates), slope and aspect. These characteristics are meaningful for large areas, such as administrative areas (e.g. districts, municipalities and province) or valuation zones. Therefore, *VM_ValuationUnitGroup* class was detailed with a characteristic named *external* which was further detailed in *VM_ExternalGroupCharacteristics* data type. The mentioned characteristics can be recorded in different spatial distribution by means of *valuationGroupName* characteristic if needed. Note that all the characteristics defined in this class is optional, and according to valuation practices in a jurisdiction, new characteristics can be added to it.

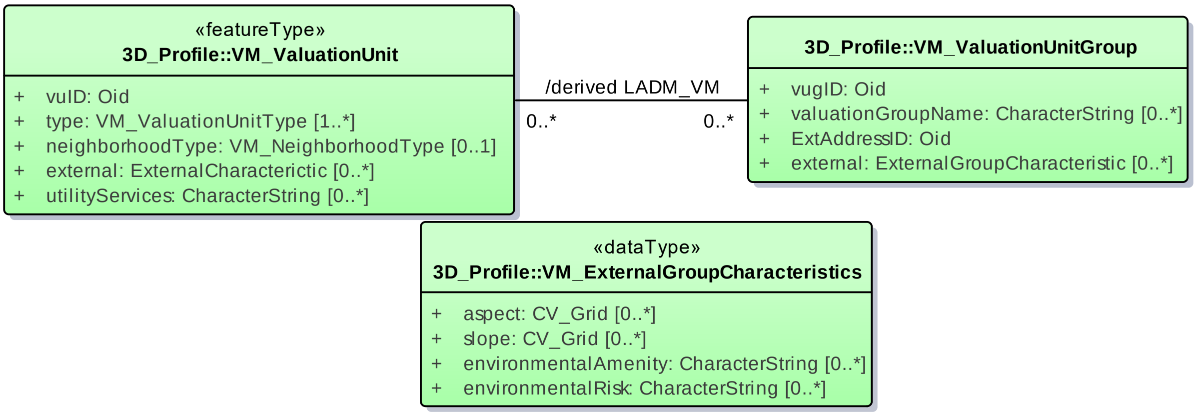



Fig. 13. 3D profile for valuation unit group

Updating and maintenance of above-mentioned derived characteristics are other important issues related to the management of property valuation registries. The internal characteristics of properties are generally more static than the external ones. For instance, the floor area of a property unit or construction date does not change over time, while the view of a property unit can change frequently if a new building is built in the neighborhood. This may indicate that the internalities are registered statically, while the externalities, environmental and locational characteristics of properties, should be periodically performed to record up-to-date information. Therefore, the frequency of analyses should be specified according to valuation regulations and neighborhood characteristics.

A valuation regulation may indicate the update frequency of the analysis, for example, a regular analysis may be demanded for certain types of derived characteristics. It should be noted that the update frequency might be determined according to revaluation periods (e.g. annual, once every two years, and once every four years) in the regulations. Otherwise, the frequency of updates can be specified pursuant to neighborhood characteristics by the responsible organization where properties are located on. For example, the responsible organization for valuation can take a decision to reanalyze the visibility of properties once every three-year period, if there are small changes in the neighborhood that may alter the view such as, demolished building(s), small-scale construction activities, land readjustment or landscape renovation project.

For the update frequency of distance analysis, it is important which types of distance is measured. The Euclidean distance between two points, for example, does not change with time, while the shortest path and walking distance may change if a new road or a new sidewalk are built. Moreover, there may a need to measure some new distances (e.g. new school, new metro station, etc.), if there are new construction activities in the neighborhood. For these reasons, some distances can be recorded to valuation registries statically, while updates and new distance measurements may be required in some certain cases for property valuation activities.

The noise pollution in a neighborhood may vary depending on time, therefore, continuous noise measurements can be required to identify the effect of noise on value. Moreover, the noise pollution may decrease with the changes in buildings (e.g. facade material or quality of building) and/or in the neighborhood (e.g. noise barriers). It may be better to update noise analysis annually since it may change frequently. Finally, it should be indicated that LADM Valuation Information Model enables history management for these analyses as all classes of it inherit from *VersionedObject* class of core LADM, and input and outputs data of the analysis can be recorded with a timestamp.

## 5. Conclusion

In the last two decades, the 3D data datasets and models have been increasingly used to derive characteristics of properties by performing both 2D and 3D GIS analysis. In this study, it is observed that although there are some individual studies benefiting from 3D datasets, models and analyses in to explain and estimate property values; valuation domain is not widely taken advantage of them.

This study focused on the view characteristic which is the most common 3D use case in property valuation and investigated a number of valuation models that utilize view as a variable from many perspectives. Before 3D GIS technology has been in use in valuation domain, many studies evaluated view with on-site inspections. However, such inspections may suffer from subjectivity, especially for determining the quality of a view (e.g. panoramic, wide and restricted). After 3D GIS analysis has made it possible to quantify view (e.g. viewshed) using 3D data sources, it has become an increasingly important tool for property valuation. The studies quantifying view was investigated, and it is found that they used different methodologies with different input parameters (e.g. observer height and outer radius), different assumptions (e.g. storey height of a building) and different obstacle (elevation) model (e.g. DEM, DSM and DTM) in various resolution produced combining various objects (e.g. 3D buildings, other built structures, water bodies, vegetation and trees). The selection of parameters and of datasets utilized in visibility analysis depends on many factors including the purpose of valuation, valuation zone, type of property unit, valuation regulation, and the decision of valuation experts. On the other hand, there is a need for a methodology to perform visibility analysis, especially for periodically conducted valuations (e.g. mass valuation for taxation purposes).

An ad-hoc methodology, which integrates best practices determined from the literature, was applied for visibility analyses using the open datasets of the Netherlands. Four different obstacle models were created to compute total viewshed areas of a condominium unit. Afterwards, the viewshed was overlaid with land use data to calculate visible land use areas for each condominium units. The results of the analysis indicated that large-scale topographical map together with condominium units may be used as an obstacle model for lower processing time of visibility analysis in some cases, for instance in large-scale mass valuation practice. It is noted that a combination of lidar-based DEM and buildings from BAG as obstacle model may provide more accurate visibility results than the other models used in this study.

The derived locational and environmental characteristic of properties should be taken into consideration when developing or improving a property valuation system. Recording them into a database or register may prevent loss of time and of labor by reducing repeated analysis. Therefore, the most used external characteristics in valuation models were determined within the scope of this study. Then, they were used to create different profiles for valuation units and valuation unit groups defined in the LADM Valuation Information Model. The profiles were designed to cover both the input parameters and the results of analysis including view, distance and noise. A property valuation register enhanced with the derived property characteristics may increase the explanatory power of valuation models, and the quality of property valuation practices. Moreover, it may also be used to support fair property taxation and other applications that are related to valuation such as land readjustment and spatial planning. The flexible conceptual schema of LADM can be further used to link valuation registries with other land administration related databases. As future work, an LADM-based approach can be followed for linking valuation registries with registries or databases that keep information spatial planning, building permits and public law restrictions.

## References

Almy, R., 2014. Valuation and Assessment of Immovable Property. OECD Working Papers on Fiscal Federalism, No. 19, OECD Publishing, Paris. https://doi.org/10.1787/5jz5pzvr28hk-en.

Anderson, S. T., & West, S. E., 2006. Open space, residential property values, and spatial context. Regional science and urban economics, 36(6), 773-789.

Benson, E. D., Hansen, J. L., Schwartz, A. L., & Smersh, G. T., 1998. Pricing residential amenities: the value of a view. The Journal of Real Estate Finance and Economics, 16(1), 55-73.

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., & Çöltekin, A., 2015. Applications of 3D city models: State of the art review. ISPRS International Journal of Geo-Information, 4(4), 2842-2889.

Biljecki, F., & Sindram, M., 2017. Estimating building age with 3D GIS. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume IV-4/W5, 2017 12th 3D Geoinfo Conference 2017, 26–27 October 2017, Melbourne, Australia.

Bin, O., Crawford, T. W., Kruse, J. B., & Landry, C. E. (2008). Viewscapes and flood hazard: coastal housing market response to amenities and risk. Land Economics, 84(3), 434–448.

Bird, R. M. and Slack, E., 2002. Land and Property Taxation: A Review. World Bank, Washington, DC.

Boeters, R., Arroyo Ohori, K., Biljecki, F., & Zlatanova, S., 2015. Automatically enhancing CityGML LOD2 models with a corresponding indoor geometry. International Journal of Geographical Information Science, 29(12), 2248-2268.

Bourassa, S. C., Hoesli, M., & Sun, J., 2004. What's in a view? Environment and Planning A, 36(8), 1427-1450.

Boyle, M., & Kiel, K., 2001. A survey of house price hedonic studies of the impact of environmental externalities. Journal of real estate literature, 9(2), 117-144.

Brasington, D. M., & Hite, D., 2005. Demand for environmental quality: a spatial hedonic analysis. Regional science and urban economics, 35(1), 57-82.

Bowes, D. R., & Ihlanfeldt, K. R., 2001. Identifying the impacts of rail transit stations on residential property values. Journal of Urban Economics, 50(1), 1-25.

Cavailhès, J., Brossard, T., Foltête, J. C., Hilal, M., Joly, D., Tourneux, F. P., ... & Wavresky, P. 2009. GIS-based hedonic pricing of landscape. Environmental and resource economics, 44(4), 571-590.

Codosero Rodas, J., Naranjo Gómez, J., Castanho, R., & Cabezas, J., 2018. Land Valuation Sustainable Model of Urban Planning Development: A Case Study in Badajoz, Spain. Sustainability, 10(5), 1450.

Cohen, J. P., & Coughlin, C. C. 2008. Spatial hedonic models of airport noise, proximity, and housing prices. Journal of Regional Science, 48(5), 859-878.

Cagdas, V., Kara, A., Van Oosterom, P., Lemmen, C., Isikdag, Ü., Kathmann, R., & Stubkjær, E. 2016. An initial design of ISO 19152: 2012 LADM based valuation and taxation data model. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, 145-154.

Demetriou, D., 2016. The assessment of land valuation in land consolidation schemes: The need for a new land valuation framework. Land Use Policy, 54, 487-498.

Demetriou, D. 2018. Automating the land valuation process carried out in land consolidation schemes. Land Use Policy, 75, 21-32.

Din, A., Hoesli, M., & Bender, A. 2001. Environmental variables and real estate prices. Urban studies, 38(11), 1989-2000.

Du, X., & Huang, Z., 2018. Spatial and temporal effects of urban wetlands on housing prices: Evidence from Hangzhou, China. Land Use Policy, 73, 290-298.

Fisher, P. F., 1992. First experiments in viewshed uncertainty: simulating fuzzy viewsheds. Photogrammetric Engineering & Remote Sensing 58(3):345-352.

Fleischer, A., 2012. A room with a view—A valuation of the Mediterranean Sea view. Tourism Management, 33(3), 598-602.

Food and Agriculture Organization of the United Nations (FAO). A technical guide on valuing land tenure rights in line with the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security, Governance of Tenure Technical Guide No. 11, Rome, 2017; ISBN 978-92-5-130069-5.

García, N., Gámez, M., & Alfaro, E., 2008. ANN+ GIS: An automated system for property valuation. Neurocomputing, 71(4-6), 733-742.

Hamilton, S. E., & Morgan, A. 2010. Integrating Lidar, GIS and hedonic price modeling to measure amenity values in urban beach residential property markets. Computers, Environment and Urban Systems, 34(2), 133-141.

Helbich, M., Jochem, A., Mücke, W., & Höfle, B. 2013. Boosting the predictive accuracy of urban hedonic house price models through airborne laser scanning. Computers, Environment and Urban Systems, 39, 81-92.

Hess, D. B., & Almeida, T. M., 2007. Impact of proximity to light rail rapid transit on station-area property values in Buffalo, New York. Urban studies, 44(5-6), 1041-1068.

Hindsley, P., Hamilton, S. E., & Morgan, O. A., 2013. Gulf views: toward a better understanding of viewshed scope in hedonic property models. The Journal of Real Estate Finance and Economics, 47(3), 489-505.

Hui, E. C., Zhong, J. W., & Yu, K. H., 2012. The impact of landscape views and storey levels on property prices. Landscape and urban planning, 105(1-2), 86-93.

International Association of Assessing Officers (IAAO), 2016. Standard on the Valuation of Properties Affected by Environmental Contamination. Approved November 2016, Kansas City, Missouri, ISBN 978-0-88329-224-2. Available online at https://www.iaao.org/media/standards/Contamination_2016.pdf (last access: 25.03.2019).

International Organization for Standardization (ISO), 2012. ISO TC/211 - ISO 19152:2012. Geographic information – Land Administration Domain Model (LADM), ed. 1. ISO, Geneva, Switzerland.

International Organization for Standardization (ISO), 2017. ISO 9836:2017 Performance standards in building — Definition and calculation of area and space indicators.

Isikdag, U., Horhammer M., Zlatanova S., Kathmann R., and van Oosterom P., 2014. Semantically Rich 3D Building and Cadastral Models for Valuation. 4th International Workshop on 3D Cadastres, 9-11 November 2014, Dubai, United Arab Emirates.

Isikdag, U., Horhammer M., Zlatanova S., Kathmann R., and van Oosterom P., 2015. Utilizing 3D Building and 3D Cadastre Geometries for Better Valuation of Existing Real Estate. FIG Working Week

2015, From the Wisdom of the Ages to the Challenges of the Modern World, Sofia, Bulgaria, 17-21 May 2015.

Janečka, K., & Karki, S. 3D data management—overview report. In Proceedings of the 5th International FIG 3D Cadastre Workshop. October 2016, Athens, Greece: International Federation of Surveyors (FIG), pp. 215-260.

Jim, C. Y., & Chen, W. Y., 2006. Impacts of urban environmental elements on residential housing prices in Guangzhou (China). Landscape and Urban Planning, 78(4), 422-434.

Jim, C. Y., & Chen, W. Y., 2009. Value of scenic views: Hedonic assessment of private housing in Hong Kong. Landscape and urban planning, 91(4), 226-234.

Jim, C. Y., & Chen, W. Y., 2010. External effects of neighbourhood parks and landscape elements on high-rise residential value. Land Use Policy, 27(2), 662-670.

Kara A., Cagdas V., Isikdag U., van Oosterom P., Lemmen C., Stubkjær E., 2017. Towards an International Data Standard for Immovable Property Valuation. FIG Working Week 2017, Surveying the world of tomorrow - From digitalisation to augmented reality. Helsinki, Finland, May 29–June 2, 2017.

Kara, A., Cagdas, V., Lemmen, C., Isikdag, U., van Oosterom, P., & Stubkjær, E. 2018. Supporting Fiscal Aspect of Land Administration through a LADM-Based Valuation Information Model. In Annual World Bank Conference on Land and Poverty 2018: Proceedings: Land Governance in an Interconnected World.

Kubiak, J., & Ławniczak, R., 2016. The propagation of noise in a built-up area (on the example of a housing estate in Poznań). Journal of Maps, 12(2), 231-236.

Lagner, O., Klouček, T., & Šímová, P., 2018. Impact of input data (in) accuracy on overestimation of visible area in digital viewshed models. PeerJ, 6, e4835.

Lake, I. R., Lovett, A. A., Bateman, I. J., & Langford, I. H., 1998. Modelling environmental influences on property prices in an urban environment. Computers, Environment and Urban Systems, 22(2), 121-136.

Lake I. R., Lovett A. A., Bateman I. J., Day B., 2000. Using GIS and large-scale digital data to implement hedonic pricing studies. International Journal of Geographical Information Science 14(6):521-541.

Li, Y., Chen, Y., Rajabifard, A., Khoshelham, K., & Aleksandrov, M. Estimating Building Age from Google Street View Images Using Deep Learning. In 10th International Conference on Geographic Information

Science (GIScience), 2018. Editors: Stephan Winter, Amy Griffin, and Monika Sester; Article No. 40; pp. 40:1–40:7.

Lemmen, C. H. J., Van Oosterom, P. J. M., Uitermark, H. T., Zevenbergen, J. A., and Cooper, A. K., 2011. Interoperable domain models: The ISO land administration domain model LADM and its external classes. 28th Urban Data Management Symposium, Delft, the Netherlands.

Laga, H., Guo, Y., Tabia, H., Fisher, R., & Bennamoun, M. 2019. 3D Shape Analysis: Fundamentals, Theory, and Applications. 2019 John Wiley & Sons, Inc. https://doi.org/10.1002/9781119405207.

Łowicki, D., & Piotrowska, S., 2015. Monetary valuation of road noise. Residential property prices as an indicator of the acoustic climate quality. Ecological Indicators, 52, 472-479.

Mahan, B. L., Polasky, S., & Adams, R. M., 2000. Valuing urban wetlands: a property price approach. Land economics, 100-113.

McCluskey, W.J., 1999. Comparative Property Tax Systems: An International Comparative Review. Aldershot, UK: Avebury Publishing Limited.

McCluskey, J. J., & Rausser, G. C., 2003. Hazardous waste sites and housing appreciation rates. Journal of Environmental Economics and Management, 45(2), 166-176.

Nutsford, D., Reitsma, F., Pearson, A. L., & Kingham, S., 2015. Personalising the viewshed: Visibility analysis from the human perspective. Applied Geography, 62, 1-7.

Open Geospatial Consortium (OGC), 2016. Land and Infrastructure Conceptual Model Standard (LandInfra). (Version 1.0, Publication Date: 2016-12-20), Editor: Paul Scarponcini, Contributors: HansChristoph Gruler (Survey), Erik Stubkjær (Land), Peter Axelsson, Lars Wikstrom (Rail).

Open Geospatial Consortium (OGC), 2019. OGC White Paper on Land Administration. Editor: Christiaan Lemmen, Peter van Oosterom, Mohsen Kalantari, Eva-Maria Unger and Cornelis de Zeeuw, http://docs.opengeospatial.org/wp/18-008r1/18-008r1.html#_extended_scope_of_conceptual_model.

Oud, D.A.J. GIS based property valuation: Objectifying the value of view. Master Thesis, Faculty of Geosciences These, GIMA, 2017.

Paasch, J. M., van Oosterom, P., Lemmen, C., & Paulsson, J., 2015. Further modelling of LADM's rights, restrictions and responsibilities (RRRs). Land use policy, 49, 680-689.

Paterson, R. W., & Boyle, K. J., 2002. Out of sight, out of mind? Using GIS to incorporate visibility in hedonic property value models. Land economics, 78(3), 417-425.

Poudyal, N. C., Hodges, D. G., & Merrett, C. D., 2009. A hedonic analysis of the demand for and benefits of urban recreation parks. Land Use Policy, 26(4), 975-983.

Poudyal, N. C., Hodges, D. G., Fenderson, J., & Tarkington, W., 2010. Realizing the economic value of a forested landscape in a viewshed. Southern Journal of Applied Forestry, 34(2), 72-78.

Rajapaksa, D., Zhu, M., Lee, B., Hoang, V. N., Wilson, C., & Managi, S., 2017. The impact of flood dynamics on property values. Land Use Policy, 69, 317-325.

Sander, H. A., & Polasky, S., 2009. The value of views and open space: Estimates from a hedonic pricing model for Ramsey County, Minnesota, USA. Land Use Policy, 26(3), 837-845.

Sander, H., Polasky, S., & Haight, R. G., 2010. The value of urban tree cover: A hedonic property price model in Ramsey and Dakota Counties, Minnesota, USA. Ecological Economics, 69(8), 1646-1656.

Schläpfer, F., Waltert, F., Segura, L., & Kienast, F., 2015. Valuation of landscape amenities: A hedonic pricing analysis of housing rents in urban, suburban and periurban Switzerland. Landscape and Urban Planning, 141, 24-40.

Shultz, S., & Schmitz, N., 2008. Viewshed analyses to measure the impact of lake views on urban residential properties. The Appraisal Journal, 76(3), 224.

Sirmans, S., Macpherson, D., & Zietz, E. 2005. The composition of hedonic pricing models. Journal of Real Estate Literature, 13(1), 1-44.

Tang, B., Wong, S., Liu, S. Institutions, property taxation and local government finance in China. Urban Studies 2011, 48 (5), 847–875.

Tomić, H., Roić, M., & Ivić, S. M. 2012. Use of 3D cadastral data for real estate mass valuation in the urban areas. In 3rd International Workshop on 3D Cadastres: Development and Practices.

Tyrväinen, L., & Miettinen, A., 2000. Property prices and urban forest amenities. Journal of environmental economics and management, 39(2), 205-223.

Van Oosterom, P., & Lemmen, C. 2015. The land administration domain model (LADM): motivation, standardisation, application and further development. Land use policy, 49, 527-534.

Wen, H., Xiao, Y., & Zhang, L., 2017. Spatial effect of river landscape on housing price: An empirical study on the Grand Canal in Hangzhou, China. Habitat International, 63, 34-44.

Wilhelmsson, M. 2000. The impact of traffic noise on the values of single-family houses. Journal of environmental planning and management, 43(6), 799-815.

Wyatt, P., 1996. The development of a property information system for valuation using geographical information system (GIS). J. Prop. Res. 13 (4), 317–336.

Wyatt, P., 1997. The development of a GIS-based property information system for real estate valuation. Int. J. Geogr. Inf. Sci. 11 (5), 435–450.

Wyatt, P. 2013. Property valuation. Second Edition, John Wiley & Sons.

Yamagata, Y., Murakami, D., Yoshida, T., Seya, H., & Kuroda, S., 2016. Value of urban views in a bay city: Hedonic analysis with the spatial multilevel additive regression (SMAR) model. Landscape and Urban Planning, 151, 89-102.

Yu, S. M., Han, S. S., & Chai, C. H., 2007. Modeling the value of view in high-rise apartments: a 3D GIS approach. Environment and Planning B: Planning and Design, 34(1), 139-153.

Yuan, F., Wu, J., Wei, Y. D., & Wang, L., 2018. Policy change, amenity, and spatiotemporal dynamics of housing prices in Nanjing, China. Land use policy, 75, 225-236.

Zhang, G., van Oosterom, P., & Verbree, E. 2017. Point Cloud Based Visibility Analysis: first experimental results. In Societal Geo-Innovation: short papers, posters and poster abstracts of the 20th AGILE Conference on Geographic Information Science.