3D Variables Requirements for Property Valuation Modeling Based on the Integration of BIM and CIM

Siham El Yamani [1,2,*], **Rafika Hajji** [1], **Gilles-Antoine Nys** [2], **Mohamed Ettarid** [1] **and Roland Billen** [2]

1 College of Geomatic Sciences and Surveying Engineering, IAV Hassan II Rabat, Rabat 6202, Morocco; r.hajji@iav.ac.ma (R.H.); m.ettarid@iav.ac.ma (M.E.)
2 Geomatics Unit, Department of Geography, ULiège—Place du 20 Août, 4000 Liège, Belgium; ganys@uliege.be (G.-A.N.); rbillen@uliege.be (R.B.)
* Correspondence: selyamani@doct.uliege.be; Tel.: +21-261-585-9876 or +32-485-066-095

Abstract: The growing rate of urbanization and vertical urban development has aroused the significance of geo-related variables for property units disposed vertically within the same building. Among these, 3D indoor physical and outdoor environmental variables are impacting the property value for each building unit. However, in the literature, the identified 3D variables, by using hedonic pricing models (HPM) for property valuation, are mainly restricted to 3D visualization. Their use in 3D simulation for an accurate evaluation of the property value is still limited. Furthermore, their value is often defined for a specific valuation purpose (e.g., taxation). This paper aims to investigate 3D variables with a significant impact on property value, to combine them with 3D technical requirements and to be integrated in a future valuation model. Moreover, their 3D spatial and non-spatial elements are analyzed to identify which variables can be provided from 3D city models and building scale elements. To accomplish this, the potential of 3D building information modeling (BIM) and city information modeling (CIM) in property valuation is examined. From indoors; BIM/IFC (Industry Foundation Classes) models are the main data sources for structural and living quality variables. While from outdoors, environmental variables and the surrounding building's information are provided from 3D city models (CityGML).

Keywords: 3D variables; valuation modeling; city information models (CIM); building information models (BIM)

1. Introduction

Residential properties contribute predominantly to the market economy. In the last decades, construction policies and the increase of land prices have led to the development of high-rise building's tendencies. This influence consequently impacts the value of the property's variables such as indoor illumination, view quality, air pollution, noise level, etc.

Property valuation should be performed in a 3D space since real estate value is the association of indoor elements related to the property as 3D objects (e.g., volume, height) and 3D elements from the property's outdoor environment (e.g., view, shadowing, pollution) [1]. Hence, property value is the process of estimating the amount of which the property will be exchanged in the market [2]. Moreover, property valuation refers to the identification and quantification of the factors impacting its value [3]. Consequently, an accurate estimation of these 3D variables helps decision makers (government, real estate stakeholders such as valuers, developers, and buyers) to improve their property value estimation. Such a need puts forward the necessity to investigate the relevant impact of 3D variables on property value.

In this context, studies have examined 3D variables to estimate the residential property value, using hedonic pricing models (HPM) [4–6]. The results of such a computation method show explicitly 3D variables which are correlated to the property price. These

variables have a significant impact on property value such as the impact of increasing air pollution on each property storey value. The significant factors are integrated to hedonic model computations based on the qualification of their value. However, these pricing models give little consideration to the third dimension of these variables.

Integrating 3D modeling techniques are promising to real estate valuation [7–9]. It allows geospatial analysis to be performed taking the vertical dimension in better consideration by performing variables simulations which are a 3D-related. While 3D spatial modeling and analysis are relevant in the context of real estate valuation, their use is still limited and their integration to valuation models is mostly restricted to individual visualization in the context of local submarkets.

The recent 'Valuation Information Model' as the extended version of LADM: Land Administration Domain Model (ISO 19152:2012) is developed for international immovable property taxation to serve valuation practices in administration authorities based on 3D modeling of properties [8,10].

Existing data models, such as CityGML and IFC for buildings and 3D urban features in general, provide geometric and semantic potentialities allowing modeling and simulating 3D variables in terms of indoor and outdoor components. In the context of city modeling, CityGML is an open standardized model for CIM (city information modeling), which supports storage and exchange of 3D features in the urban built environment [11]. CityGML proposes a rich geometric and semantic model about buildings according to several LODs (level of details) and particularly allows modeling of their interiors (rooms, furniture, spaces, etc.) and handling of the spatial relations with other city objects (i.e., relation between building and infrastructure). IFC, developed for BIM (Building Information Modeling) within the architecture, engineering, and construction (AEC) domain, provides detailed and rich physical information of a building in terms of their spatial elements and functional properties.

The integration of (BIM/IFC) and (CIM/CityGML) in the context of property valuation has been investigated by several authors [12,13]. Some research has also been done about the BIM workflow to automatically assess the property value. While others, introduce 3D GIS techniques to automate the process of real estate valuation. Yu and Liu (2014) are among the first authors to experiment the integration of GIS and BIM for real estate valuation [14]. However, the work that has been done in terms of introducing the BIM and city modeling to property valuation modeling is introductory. There are still other 3D geospatial techniques to be investigated especially for identifying 3D variables which define the property value. This has motivated us to conduct research in this field by proposing a valuation model based on the integration of BIM and CIM in order to accurately estimate the property values.

Other 3D modern approaches for 3D visualization, including the immersive virtual environments, can be introduced to 3D property value. The virtual reality (VR)-based 3D environment could provide a realistic visualization for detailed information related to the property characteristics (property height, etc.) [15].

Besides, VR combined with BIM may be applied to property valuation in the context of users' intuitive experience, such as a potential property buyer or real estate appraisal, that would have a subjective opinion about the quality of a specific indoors attribute for the valuation purposes [16]. However, such a promising technique is out of the scope of our manuscript. We focus on modeling 3D variables elements for a standardized valuation model.

This paper analyzes and presents 3D variables which have a significant impact on the value of residential property units as a first step for defining the structure of a new and more encompassing valuation model. We define their 3D technical requirements and examine the potential of BIM and CIM in providing 3D variables elements (indoors and outdoors).

The paper is organized as follows: Section 2 presents a literature review about 3D variables that has been investigated and proved to have a relevant impact on residential

value. Section 3 the first part: analyzes the relevant 3D variables for property valuation and identifies those relevant for our model. The second part propose the classification for the analyzed 3D variables requirements. Section 4 proposes to classify the selected variables and their potential data sources with regards to their potential data source: (BIM/IFC) and (CIM/CityGML). Finally, Section 5 gives some concluding remarks and provides an insight for future work on developing an encompassing 3D property valuation model as a proof of concept.

2. Related Works

3D variables have a substantial impact on property valuation. Recent studies have been conducted to assess their impact on property value [8,13,17,18]. These variables can be classified into indoor variables (physical, inherent to the property unit) and outdoor variables (locational, environmental) [19]. The physical variables refer to indoor spatial elements defining the geometric extent of the building and its content. The locational variables define the property's location to neighborhood relevant amenities such as the proximity to public transportation and facilities (education, health, etc.). While the environmental variables refer to the property's outdoor environmental conditions impacting its value such as noise (airport, traffic, etc.), air pollution, sunlight conditions, and view. Scholars stated that residential property value is strongly correlated with 3D physical characteristics [20–22]. Indeed, property size, shape, floor level, and building height have an important impact on property value. The authors of [23] demonstrate that property value tends to rise with the building height and justify this by the fact that taller building means better building construction quality. On the other hand, [24] prove that residential property prices vary differently with building height and floor level due to the impact of the surrounding vertical urban developments and different amounts of light for each floor level. In addition, other studies argued that building construction materials cost have a significant impact on property value: a building with better materials properties increases the cost of building maintenance and reduces the cost of the running energy [25].

Another factor related to indoor variables is energy performance of residential buildings which was proved to be significant for property valuation. Kim and Berber [26] pointed out that high energy consumption raises the apartment value by 13%. Li and Chen [6] emphasized that property units naturally illuminated, warm, quiet, and easy ventilated reduce the energy consumption and running costs. Recent studies examined the significant impact of energy performance on the occupant living quality. The results are not based on 3D simulation but on a simple interview with building residents in different property storey levels. The study finding shows that property units with less natural daylight, less ventilated, and noisy are less purchased than the other properties within the same building [27]. Another energy related variable is the building solar potential. Helbich et Jochem [28] proved the positive impact of solar radiation on residential property value as long as better solar potential reduces the energy consumption. They also stated that properties with high roof solar potential dispose of high property value. Figure 1 is inspired from the Helbich study and shows the different sunlight value for each property unit. Furthermore, indoor living quality differs significantly between buildings apartments. For instance, [25] argued that floors with high daylight illumination increases the property value from 5% to 6%.

Other significant type of variables impacting the value of residential properties are outdoor environmental variables. This value is strongly impacted by the surrounding built environment and the proximity to environmental features. Scholars show that traffic noise and air pollution have a negative impact on property value which varies with their building height, the sound refraction, and the pollution dissemination due to elevation impact [29]. Figure 2 represents the noise level components to determine its value: reflected noise, noise directly from traffic source, and the propagated noise into indoors space (this figure is inspired by [26]). Additionally, the proximity to the road network and industries negatively impacts the apartment price [30].
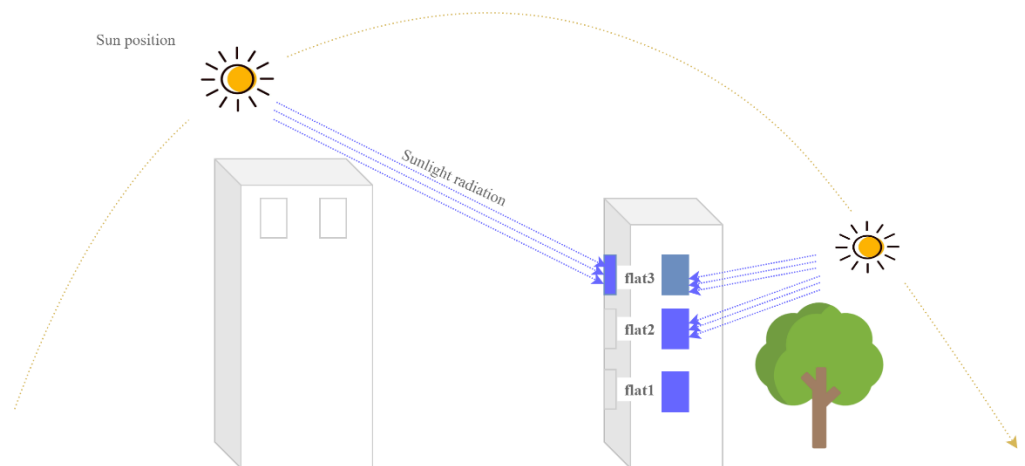
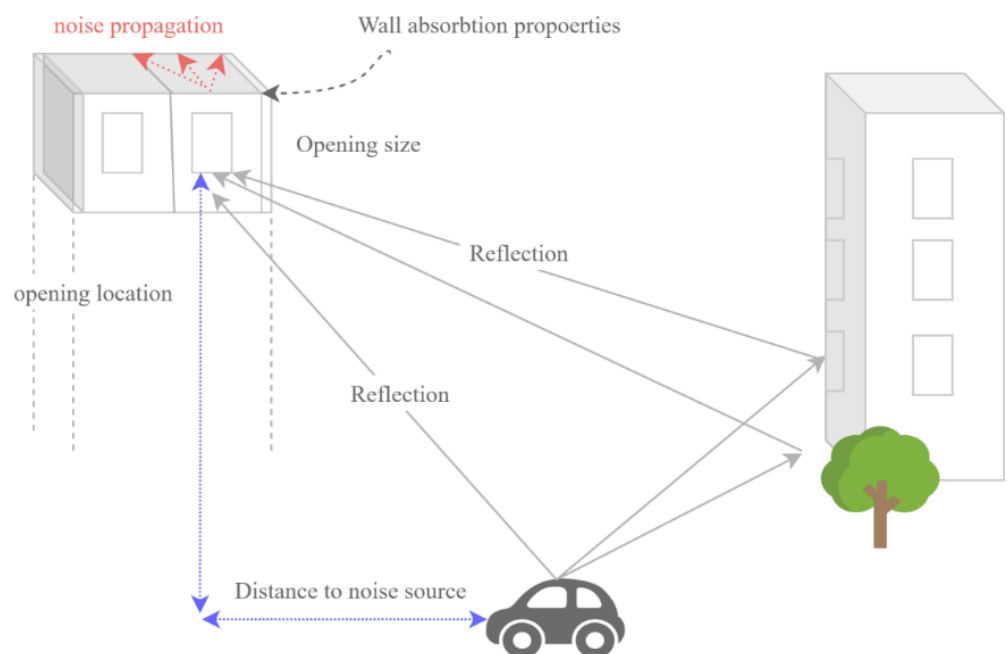**Figure 1.** 3D sunlight exposure for the flat's level.

Figure 2. Illustration of noise level effect on outdoor and indoor spaces.

Moreover, authors assumed that flats with open view perceived from a high-rise building have a high property value. Fleming et al., [31] determined that flats located in high floor levels are more in demand rather than the lower ones. It is explained by their better exposition to natural sunlight. Helbich et al., [28] used specific sunlight computation to eliminate the impact of the surrounding obstacles such as shadowing and building elevation on sunlight occlusion. Table A1 (in the Appendix A) summarizes all the sunlight definitions significant to 3D property valuation based on literature review analysis. Wen et al., [29] proved that the impact of traffic noise, air quality, and sunlight exposure vary from floor to floor within the same building due to the impact of the building surrounding the built environment.

Current research introduced 3D geospatial analyses to define some variables. For example, [17] generated 3D outdoor buildings based on extruding existing 2D building footprints. They concluded that procedural models can quantify sunlight factors. Ref. [21] state that building information models can be used to extract property volume for a better real estate valuation. The recent 'Valuation Information Model' as the extended version of LADM (ISO 19152:2012) is developed for immovable property taxation to serve valuation

practices in administration authorities. It provides also information related to physical property units' characteristics, locational and some environmental characteristics (i.e., view quality). The physical variables are mainly derived from the 3D cadastral model while 3D locational and environmental variables are derived from 3D spatial datasets. Kara et al., [10] conducted a study case to focus on assessing the view quality based on 3D data sources. They used basically: open topography, building and height datasets of the Netherlands. The results show a number of viewshed analyses to show how it can be utilized using different 3D data sources.

Previously, the identified 3D variables remain very limited to specific contexts (e.g., taxation) and their 3D component is not integrated accurately, especially since most of the relevant 3D variables are identified through their correlation into the 3D regression analysis [32]. Their value is not accurately determined based on 3D geospatial analysis; the variables are mainly qualified by 3D visualization which are not akin with a more realistic simulation result. Therefore, existing 3D spatial analysis techniques and 3D data sources are not extensively explored or documented in the context of real estate valuation despite their high relevance and impact in this field. Their integration to valuation models is mostly restricted to 3D visualization. In the next section, we focus on identifying 3D significant variables to be adopted in our future valuation model by specifying their required 3D elements for variables assessment.

3. 3D Relevant Variables for Property Valuation

In this section, we focus on identifying significant variables and required information to build a new 3D property valuation model for residential property units. Attention is given to identify these variables associated to individual property units for future residential building projects. We first propose to classify the selected variables in terms of indoor and outdoor variables, then we analyze their spatial/not spatial elements.

3.1. Indoor/Outdoor Variables

(a) Indoor variables: refer to specific 3D characteristics of indoor property units in terms of structural and physical elements (property geometry, size, cost, etc.), as well as to indoor living quality: variables simulated and assessed based on the indoor 3D space of the property (spatial daylight autonomy, sound level etc.).

(b) Outdoor variables: refer to the 3D environmental variables assessed at the property level. These variables include noise level, air quality, view quality, and sunlight exposure, as well as the proximity to relevant amenities such as distance to industries, to road, and to view types, and buildings elevation since they are needed for assessing the view quality, noise level, and air quality.

Among 50 variables reviewed in the literature, we selected 25 variables which are significant to our approach. Most of them are identified through literature review, some of them are proposed due to their potential impact on the valuation process. Figure 3 above shows variables impacting the value at the property unit scale.

From indoors, we consider 3D variables related to indoor living quality, namely spatial daylight autonomy, sound level, air flow, and level of temperature. Other existing variables from the literature such as daylight autonomy, heating, ventilation, and air-conditioning comfort, etc., are not retained in our valuation model. It is explained by the fact that they are either insignificant in term of the non-spatial extent of their definition or have a minor impact in the case of estimating the value-based individual building properties:

● Indoor daylight: the spatial daylight autonomy is considered as the relevant one. It is defined as the indoor spatial distribution of sufficient natural light for each property unit floor, which measures the percentage of the property unit floor area that receives enough ambient natural light. This variable is assessed based on illuminance level distributed spatially in each floor area. The existing definition-based energy performance considers the value for SDA (spatial daylight autonomy) for each building floor level. We applied the same concept for each property unit floor [16].

- Indoor Quietness: the sound level is considered as the relevant variable since it refers to the amount of indoor noise level diffused from the adjacent property units to the different indoor parts (e.g., room). This variable is determined based on information related to the property unit 3D geometry, information about construction materials-based isolation, and thickness. We excluded the energy acoustic comfort, since the degree of indoor sound is largely sufficient for assessing the impact of indoor noise on property value [25,26].
- Indoor ventilation: it is represented by two parameters: (1) "air flow" and (2) "indoor air quality". "Air flow" consists of the amount of natural ventilated air to the different property unit's parts based on the opening's dimensions and materials properties and information about the surrounding wind data. "Indoor air quality" estimates the air conditions of the ventilated space to get good performance [25,26]. We excluded the energy HVAC (heating ventilation and conditioning) comfort since we are not concerned by the ventilated system value (the same for acoustic comfort).
- Indoor temperature: is defined by the temperature level which refers to the natural heating level conditions of every property unit part based on close surrounding temperature data which is relevant to determine to which extent every room and indoor unit is heated without using any heating system (the reason why the thermal comfort is not relevant). That is why information-based property unit's construction materials and openings size are important to determine temperature levels [25,26].
- Energy Efficiency: this variable is relevant for new construction since the efficiency of energy systems changes for each property unit within the same building. It is more significant at the operations phase. However, simulations at the design/conception phase can already assess the energy efficiency and show differences between the building units [27].
- Solar Potential: defined as the impact the solar radiation potential of the roof or external building envelop on the building property value which is a constant value in the case of our model since it is related to the same building.

From outdoors, we mainly choose the relevant 3D variables by analyzing the suitable definition which may provide an accurate value with a significant impact on property unit values. We limited our definition of outdoor variables to some specific features including the noise level-based road segment, air pollution from industries and traffic, view quality, and sunlight exposure. Other variables such as "airport noise" and "dust pollution" are not adopted in our model. Indeed, these parameters are rarely present in every valuation context and are limited to a specific area. The proximity to the surrounding environment is considered irrelevant until it is unchanging for the same building. However, some proximity elements are required to determine outdoor variables such as the view and air quality. We summarize the definition of the selected outdoor variables as follow, classified in environmental and "proximity" variables:

- Noise level defines the outdoor noise disturbance level assessed at property unit level that is perceived from surrounding roads (traffic noise) and the reflected noise on the 3D surrounding environment [28].
- Air quality defines air pollution level assessed at the property unit. We differentiate two relevant pollutants sources: the first one is directly imminent from the nearest industries and roads while the second is propagated due to obstructing building and surrounding vegetation elements [23].
- View quality defines the quality of the view perceived from every property unit's openings based on two relevant indicators: proximity to view (building, vegetation) and the quality of the view (visibility analysis result). The second indicator considers an obstacle model derived from the surrounding city elements to perceive which views are obstructed by these elements and which views are open. This definition is partially based on a recent study about assessing 3D view characteristics to be introduced to the LADM-Valuation Information Model [5].

- Sunlight exposure defines the sunlight assessed at the property outdoor surface, which includes already the reflected and obstructed light from neighboring obstacles (building, shadowing, vegetation, etc.) [29]. Sunlight has different definitions. For example, it can be defined as the amount of sunlight hours during the day or as a cumulative sun radiation mainly related to the outdoor walls and roof solar potential which we consider not relevant to our model [20]. Table A1, in the Appendix sections, presents an example of the technical specification's table, which is analyzed for each variable based on previous studies relevant to 3D valuation.

Consequently, we come up with a generic structure of 3D variables which can be grouped mainly from 25 detailed sub variables into 16 categories of the generic ones. Figure 4 below presents the proposed structure.
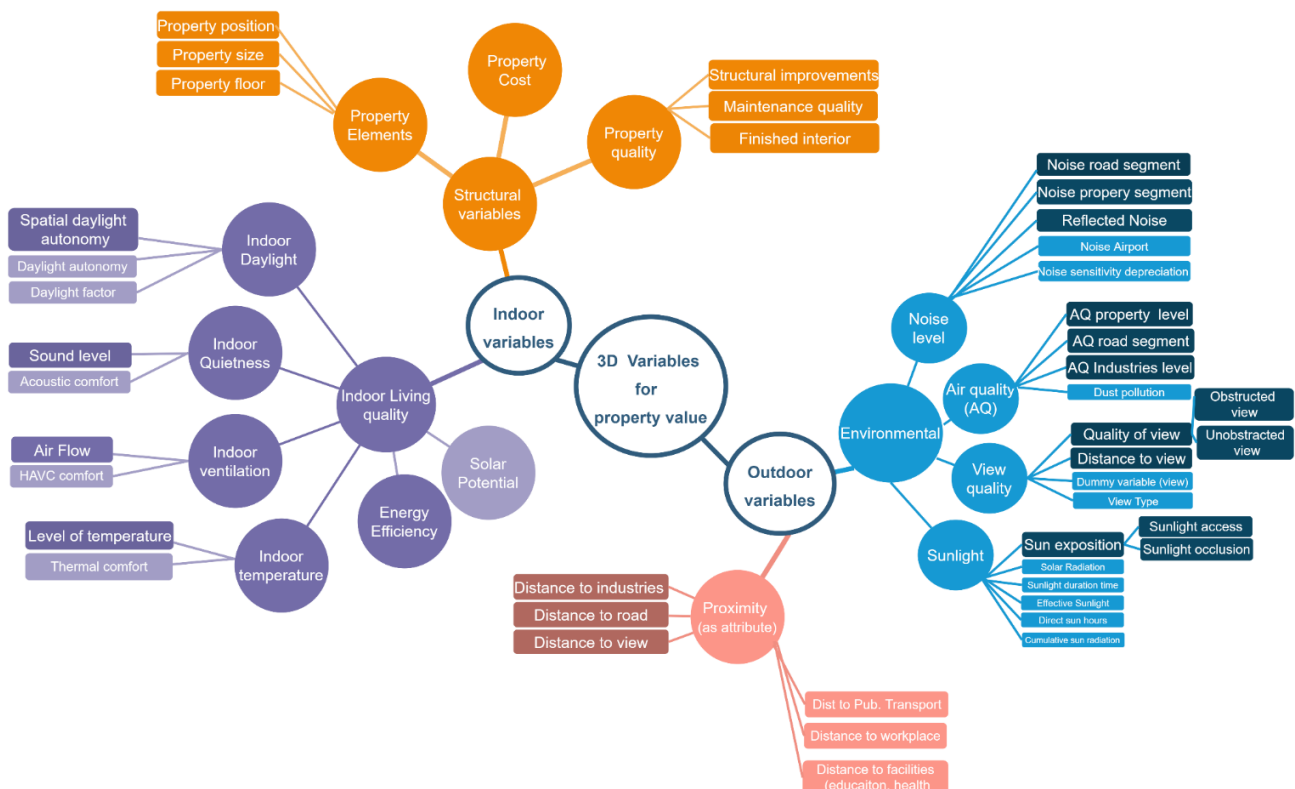

Figure 3. 3D selected variables for property units' value. (Dark color represents the relevant 3D variables to our valuation; the light color corresponds to the non-included 3D variables into our model).
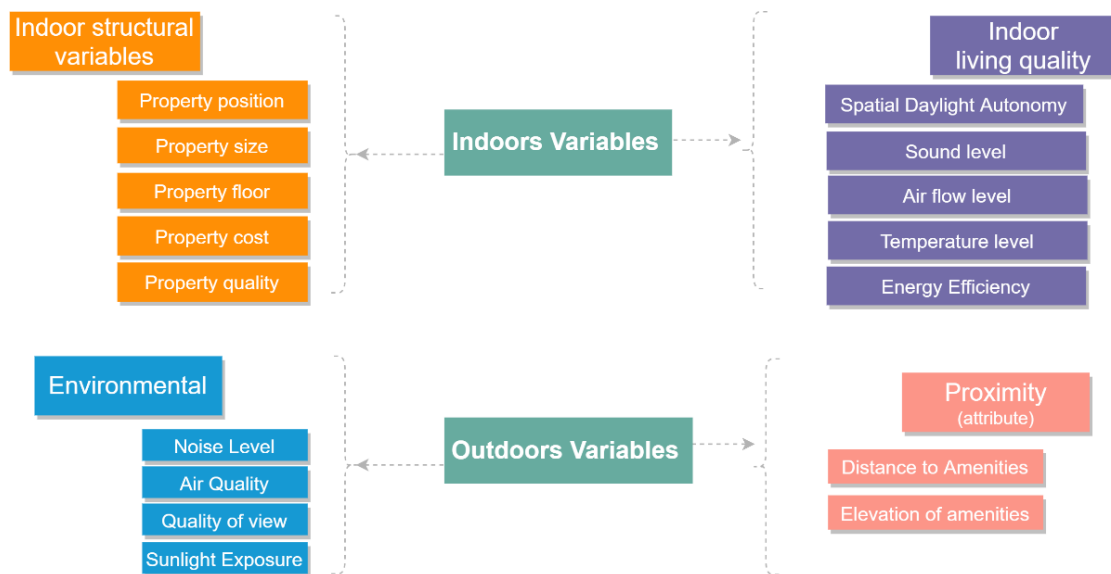
Figure 4. The 3D selected variables for property valuation model from indoors and outdoors 3D space.

3.2. Variables Classification: Spatial/Non-Spatial Elements

A property valuation model requires information about physical characteristics related to property units, information about construction materials and surrounding urban features. Therefore, it is important to ensure that the elements required for each indoor and outdoor 3D variable are clearly identified. These elements can be primarily classified into 3D spatial and 3D non-spatial elements:

- 3D variables-based spatial elements: defined either by directly 3D property elements (e.g., property height, volume) or indirectly where the spatial extent of these elements is needed to determine the quality or the quantity of these 3D variables. They can be either 2D or 3D elements related to the small building constructive element (construction quantities), to the building scale including building parts (room volume, wall surface, virtual spaces, etc.) and to building exterior envelope elements necessary for locating noise sources, elevation of noise barriers, absorption attenuation factor in vertical noise propagation, etc.).
- 3D variables-based non-spatial elements: defined without using 3D/2D spatial extent of variables. They concern information (attributes) related to spatial elements (e.g., material properties of 3D building part, thermal characteristics, costs, etc.), (noise level, etc.) atmospheric conditions in a specific 3D location (pollutant concentration at a specific floor level), etc.

Some of these elements are still not yet applied or documented for property valuation application in the 3D spatial extent, even though their relevant impact was examined in the literature [3,30]. For example, the noise level is one of the relevant outdoor variables in property valuation models since it impacts negatively the property unit at different floor levels [22]. However, since the noise level is propagated in 3D spaces from the source to the specific property 3D location, the restricted use of 2D spatial elements cannot provide the noise refraction at different elevations and the 3D urban obstacles impacting the noise source for a specific direction. The Figure 5 below illustrates the use of 3D spatial and non-spatial elements for 3D noise estimation.
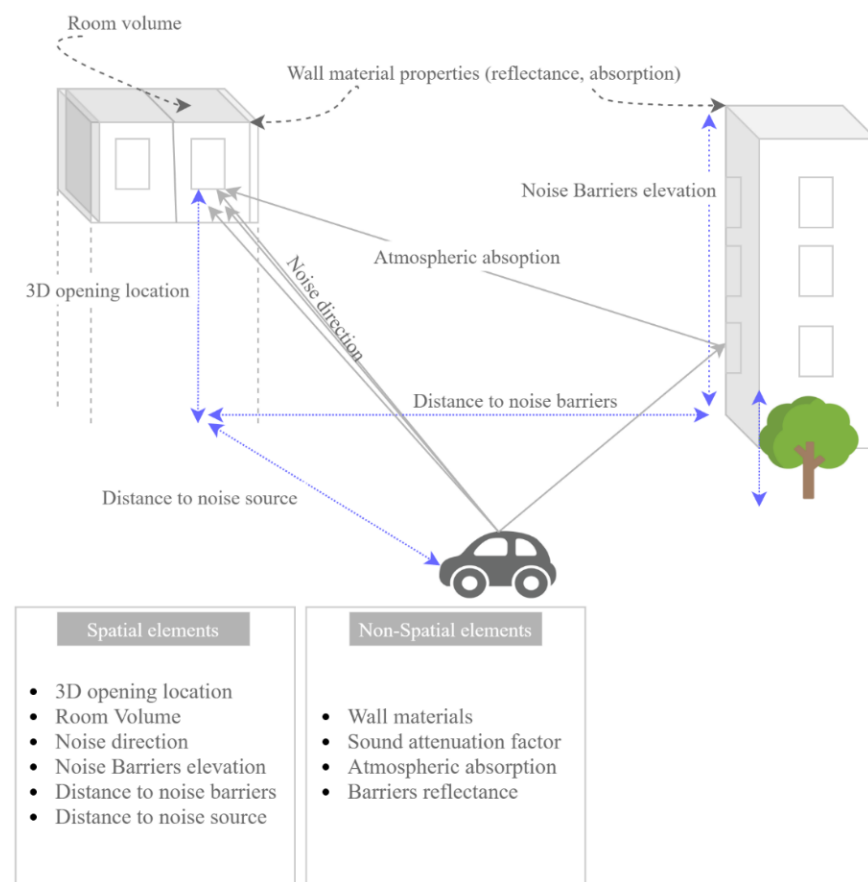
Figure 5. Illustration of noise level classified to spatial and non-spatial elements.

Moreover, the 3D parameters, required to assess environmental variables value, are associated to the building and city level. From the 3D building scale, information about the property height is significant since the environmental variables have different values for each property unit. This is due to the different disposition of the surrounding 3D urban elements and their impact in terms of occlusion and obstruction. Besides, 3D building elements contain also 3D property units' parts where each variable is significantly simulated, such as room for noise level and openings for the rest of variables (view, sunlight, air quality). For example, the observers may assess different views quality from each opening position. Additionally, the noise level is diffused mainly through each property room based on the isolation quality of room materials.

To predict the variables, it is mandatory to compute the value for each flat with accurate 3D information related to physical entities (room, openings, etc.). At the city scale, 3D surrounding urban features are required to assess accurately environmental variables among which: elevation of the surrounding area, proximity to the existing road and industrial zones for noise and air quality variables; height of the neighboring built environment which restrict the direct diffusion of environmental variables to the property unit and weather conditions in the surrounding area. Consequently, the required elements for assessing 3D relevant variables from indoors and outdoors need to be represented and simulated accurately.

Table 1 summarizes the specific elements involving spatial and non-spatial elements applicable to 3D selected variables for the valuation model. It puts them in parallel with the buildings elements to which they are related (sunlight exposition to windows, etc.). A detailed definition of these elements requirements is presented below.

Table 1. 3D variables elements defined by spatial and non-spatial elements.

Requirements Elements	Spatial Elements	Non-Spatial Elements
Construction materials	• Materials quantities (thickness, width, height)	• Materials properties (optical, thermal): - Absorption properties - Conductivity, transmittance, reflectance - Specific Heat, solar heat gains - Glazing properties • Cost element
Openings	• Openings dimensions • Openings 3D location: - *3D external opening* - *3D internal opening*	• Openings materials
Building parts	• Building unit: (size/3D location) • Thermal zone: (volume, area) • Room: (volume, height) • Floor (area) • Internal wall: (dimensions/location)	• Building unit variables Value: - ILQ variables value - Outdoor variables value • Materials properties (room, wall, floor) • Installation quality • Cost estimation
Building envelops	• External wall: (dimensions/location)	• External Wall material properties
Surrounding amenities	• Location of amenities (distance to road, distance to vegetation etc.) • Elevation of amenities	• Type of amenities (barriers, source of variable) • Amenities properties (reflective, absorptive)
Atmospheric conditions	• Sun position • Wind direction • Noise direction • Absorption attenuation coefficient (db./km)	• Pollutant concentration • Degree of humidity • Solar radiation • Sky conditions

- Construction materials: defined by two main elements: materials properties (non-spatial) and quantities of specific building elements (e.g., wall, openings) related to the property unit or building part elements (spatial element). These construction materials can be also relevant in the case of any changes impacting the interior's constructive elements (e.g., new interior wall, new materials type (wood)) or in the context of renovations operations.

  Materials properties such as absorption coefficient of the wall materials, thermal transmittance or the openings double glazing are among of the relevant properties impacting the value of specific property valuation 3D variables. For detailed definition of the identified properties, check the appendix Table A1 for more details related to material properties definitions.

- Openings: defined by two relevant elements: the first one refers to 3D openings location and size (spatial element) while the second one is related to openings properties (non-spatial). The location of external openings is one of the relevant elements defining view quality, the indoor diffused daylight. Since the view quality and the amount of solar radiation is changing from each property unit openings. Considering the verticality of urban features, the view can be obstructed by a building from one opening and opened from the other within the same property unit.
- Building parts: define the building elements such as room, wall, roof. Determined by their spatial extent (room volume, thermal zone etc.) and non-spatial extent (e.g., cost estimation). The indoor living quality variables are one of the main variables-based building parts. Since the simulation of these variables requires a 3D indoor space, boundaries and specific thermal properties impact their assessment.

- Building envelope: defines which property unit's building elements is required from the external envelope to determine a variables value. e.g., the spatial extent of the external wall exposed to sunlight. This element is determined by two quantities: the external wall surface and location (spatial element) and its materials properties (non-spatial element).
- Surrounding amenities: define the relevant urban features in the close surrounding which are relevant elements to assess outdoor variables. They are based on two categories: spatial elements including distance and elevation of amenities while the non-spatial ones refer to the amenities type: source (e.g., road) or barriers (e.g., buildings).
- Atmospheric conditions: define the atmospheric properties impacting the propagation of noise, air flow, or solar radiation in 3D space.

Once the valuation model elements are identified, we propose in the Table 2 below to present a cross analysis to assign for each indoor and outdoor variables the corresponding elements. The table proposes to structure variables in terms of spatial granularity from the small constructive element to the building scale and large neighborhood level (e.g., surrounding amenities) [30]. We propose to address 3D variables requirements based on this approach as we need specific information at different dimensions and scales. It is mandatory to determine 3D variables specifications for our property valuation model and their potential inputs later.

Table 2. Classification of 3D variables requirements for property valuation modeling (*italic*: spatial elements; **bold**: non-spatial elements).

Var. Type	Requirements Elements Variables	Construction Materials	Openings	Building Part	Building Envelops	Building Surrounding Amenities	Atmospheric Conditions
Indoor Structural variables	Property position			*Building unit height*			
	Property size			*Building unit 3D Volume/area*			
	Property floor			*Floor area*			
	Property cost	**Materials cost** *Materials quantities*		**Cost estimation**			
	Property quality	**Materials cost** *Materials quantities*	**Openings properties**	**Installation quality** **Installation type**			
Indoor Living Quality (ILQ)	Spatial daylight autonomy (SDA)	**Solar absorptance** **Transmittance** **Conductivity**	*Internal and external opening 3D localization* **Openings materials**	Room (**materials**/*size*) Walls (**materials**/*size*) **Building unit: SDA Value**	**External** **Wall material properties**		*Solar position* **Solar intensity** **Sky luminance** *and distribution* *Sunlight direction*
	Sound Level	**Absorbing + scattering properties**	*Internal opening 3D localization*	Room (**materials**/*size*) Walls (**materials**/*size*) *Thermal Space* **Sound level Value**			
	Air flow	**Absorbing + scattering properties**	*Internal opening 3D localization*	Room (**materials**/*size*) Walls (**materials**/*size*) *Thermal Space* **Air flow Value**			
	Level of temperature	**Materials properties**	*Openings 3D location* and **properties**	*Thermal Space* **Temperature Value**	**External** **Wall material properties**		**Temperature degree**
Outdoor environmental	Noise level	**Absorption + reflectance properties**	*External openings 3D location*	*Room Volume* **Noise level Value**	**External** **Wall absorption and scattering properties**	*Distance to Amenities (road)* *Elevation of Amenities (building, vegetation)*	**Absorption conditions** *Noise direction*
	Air Quality		*External openings 3D location* and **properties**	*Room Volume* **Air Quality Value**	**External** **Wall absorption and scattering properties**	*Distance to Amenities (road, industries)* *Elevation of Amenities (building, vegetation)*	**Absorption conditions** **Pollutants concentration** **Degree of fogginess**
	View quality		*External openings 3D location*	**View Quality Value** **View type**		*Distance to Amenities* *Elevation of Amenities (building, vegetation)*	
	Sunlight exposure	**Solar conductivity, transmittance, reflectance**	*External openings 3D location* **Openings materials**	**Sunlight exposure value**	**External** **Wall material properties**	*Distance to Amenities* *Elevation of Amenities (building, vegetation, building shadowing)*	*Solar position* **Solar intensity** **Sky luminance** *and distribution* *Sunlight direction*

4. CIM and BIM Capabilities for 3D Property Valuation

The aforementioned 3D variables requirements are classified in terms of their granularity scale (from building parts to surrounding environment), on the nature of their indoor and outdoor elements and their classifications (spatial and non-spatial elements), as summarized back to Tables 1 and 2, presented in Section 3. These two scales of analysis require defining potential tools and standards to model the indoor and outdoor variables of the property value. To tackle this issue, we propose to study the potential of BIM/IFC and CIM/CityGML in modeling and simulating 3D variables defining the residential property value.

This section examines which indoor variables can be derived from BIM/IFC and the ones to be derived from CityGML models (outdoor variables). Since these two models have shown many capabilities to determine these 3D variables requirements in different contexts (energy efficiency, daylight, air pollution, etc.). Therefore, they need to be explored for modeling all the relevant 3D predefined variables for our future valuation model. However, each 3D variables category is modeled based either on a specific BIM/IFC element either on CIM/CityGML objects (from both core schema or extensions).

4.1. BIM/IFC

Building information modeling (BIM) has proven to be one of the major innovations in the building industry. By offering a rich 3D model with geometric, topologic, and functional characteristics of the building at the conceptual design phase, BIM is structured according to the specifications of the IFC standard. It provides 3D semantically rich data of building models and each building parts. It also provides capabilities to extract any detailed information related to the building indoors. BIM allows spatial analysis and simulations such as the extraction of 3D building elements (window, wall, slab, etc.) and construction materials.

Researchers has been interested lately in exploiting BIM/IFC capabilities to extract physical entities in the context of 3D cadastral models and 3D urban planning restrictions [33] such as the volume of the property legal space [34,35] and for cost estimation [13]. However, the 3D building models capabilities are not yet largely explored for modeling all the indoors variables to be integrated for property valuation. Since BIM mapping elements and automated data integration are still at its embryonic stage.

4.2. CIM/CityGML

OGC CityGML is an open data model that represents the 3D urban built environment and allows storing and exchanging semantics information over different applications [11]. It does not only describe buildings but also other city objects such as vegetation, land use, waterbodies, etc. These city elements are mostly required to derive information related to outdoor variables.

This standard offers also extensibility capabilities to be improved with other outdoor references, that can enrich the standard for a specific discipline called application domain extension (ADE) [36] and provide detailed information that can be applied to property valuation field. Some of them have been already explored such as the view quality and sunlight accessibility.

4.3. 3D Variables Classification

The recent version of CityGML 3.0 offers powerful changes, improvements, extensions, new concepts such as the improved modeling of construction and the enhanced merging capabilities with IFC which is of great interest to integrate the two standards for our valuation model. To accomplish this, we propose to classify 3D variables based on elements provided from either BIM/IFC or CIM/CityGML. Therefore, we come up with the mapping schema in Figure 6 below.
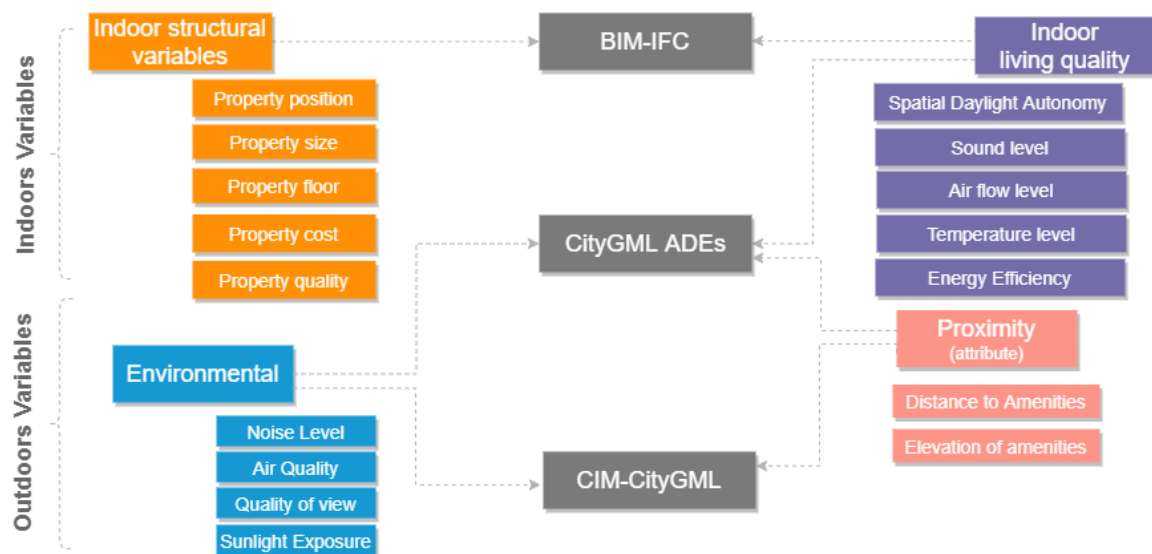
Figure 6. Classification of 3D variables based on their potential 3D data sources: For indoors variables: Indoor structural variables are driven BIM/Industry Foundation Classes (IFC) elements while Indoor living quality are provided from both BIM and CityGML elements. Outdoor variables and the proximity to the surrounding amenities are basically derived from CityGML elements and its extended versions.

Regarding our defined 3D variables requirements, we come up (in the subsections below) with a deep analysis of the potential of BIM/IFC and CIM/CityGML potential to provide in modeling and simulating the selected variables elements for our model. It should be mentioned that the BIM model used, in this section, for showing the elements used to model 3D indoors variables elements is based on a future residential project [37].

4.3.1. Indoor Variables Based BIM/IFC

In the scope of our valuation model, indoor variables can benefit from the capabilities of BIM/IFC to derive 3D spatial and non-spatial elements required for individual residential property. In this part, we describe elements that can be provided from BIM to assess the indoor structural variables:

- BIM/IFC models maintain rich semantic information about the architectural and physical space of building and building parts which allow to extract specific building elements (walls, openings, etc.) for a specific property unit [38]. This allows the extraction of structural variables spatial elements related to property position at a specific opening position, to define its storey level. Information related to indoor 3D physical space make it possible to provide property elements size (volume, room area etc.). Figure 7 shows an example of the architectural elements of a residential building model based on IFC standard. These IFC elements can be used to model the property opening's location, size and property area etc.

- Moreover, BIM provides information about the structural materials of building elements and their thermal properties. Combining this information with the building elements cost, the property cost estimation can be extracted. This process can be modeled based on IFC classes for quantity take-off "building elements" and information related to elementary fabrication cost ''cost item''. However, this process is mainly relevant for new or future residential properties where information related to cost fabrication is introduced accurately. Table 3 summarize a concrete example of cost estimation based on structural BIM models elements.

- However, the process to estimate cost variable for each property unit is not an automated process. That is why the extraction-based IFC classes need to be explored.

Table 3. Cost estimation-based BIM of constructive elements for residential building property.

Building Elements	Constructive Element Cost €	Total €
Walls	23,428	
Pillars	36,036	
Foundations	76,045	1,715,882
Stairs	3000	
Roof	33,079	
Doors	30,460	
Windows	19,800	
Wood furniture	11,040	94,527
Electronical equipment's	33,227	
Sanitary installations	15,060	
Fixed appliance	1736	16,796
	Total	28,291,100 €

4.3.2. Indoor Living Quality Variables-Based BIM/IFC and CIM/CityGML

BIM/IFC models' capabilities about 3D physical space include also virtual space of the building unit's thermal zones. This information associated with structural materials can be used for building parts energy analysis purposes. Figures 7 and 8 represent the virtual space provided by the building model based on IFC standard. Since indoor living quality variables derive basically from some of the energy variables factors, we can extract these variables simulations results for a specific property unit.

However, information related to the surrounding environments (example: weather data, surrounding building, etc.) is required to simulate accurately indoor variables. That is why we need to combine information related to indoor building elements with outdoors 3D geospatial data. For example, Figure 9a,b, shows the use of BIM to simulate the sun position (a) in order to simulate the spatial daylight autonomy variables.

The existing CityGML ADE, mainly "ADE Energy", may provide the needed outdoors elements to simulate indoor living quality variables.
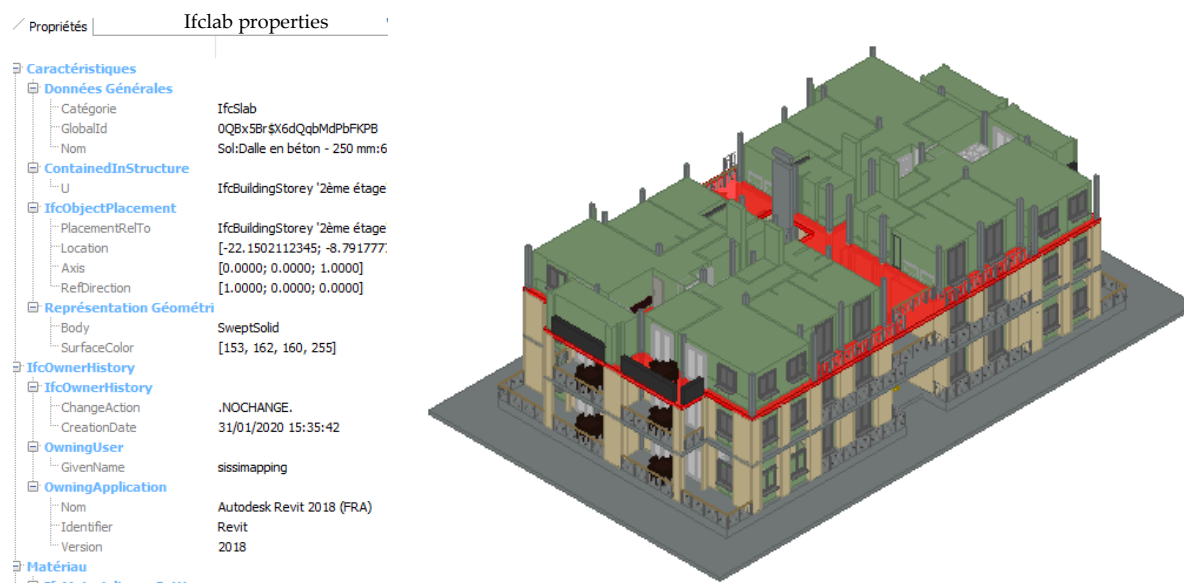
(**a**)

Figure 7. *Cont*.
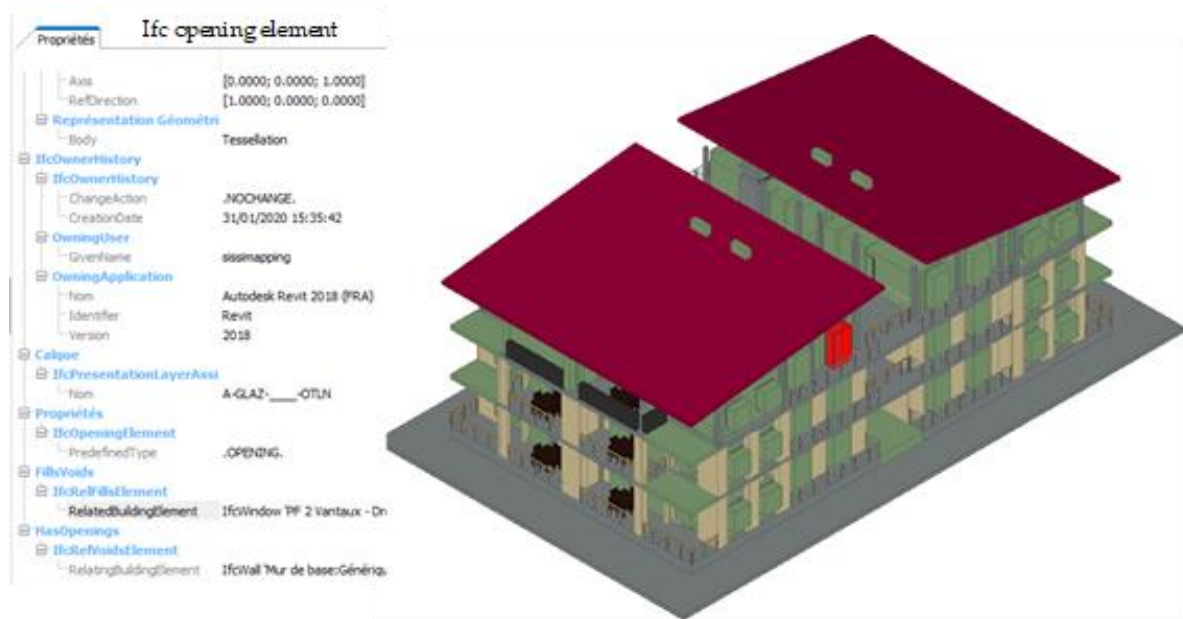
(**b**)

Figure 7. Examples of architectural elements for a residential property BIM based on IFC standard that can be used to model 3D indoors variables elements (i.e., (**a**) IfcSlab for property floor, area, etc.) and (**b**) IfcSpace (room volume etc.).
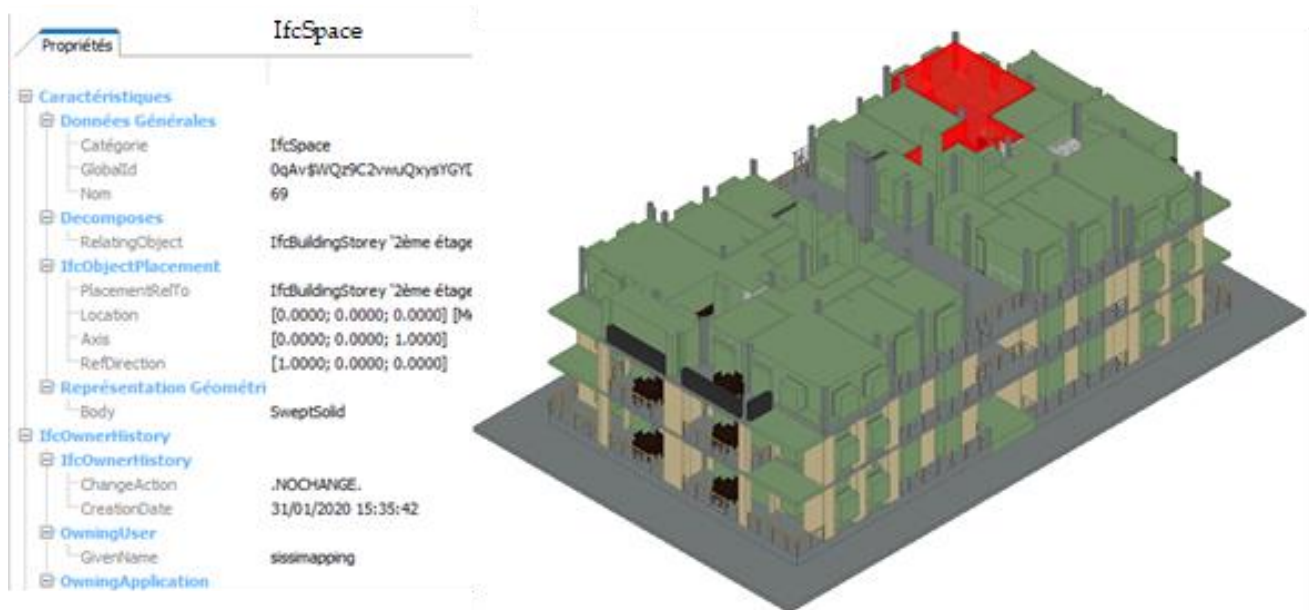

Figure 8. BIM capabilities to generate property indoors spaces based on IFC standard that can be used for modeling property unit indoors 3D size and volume.
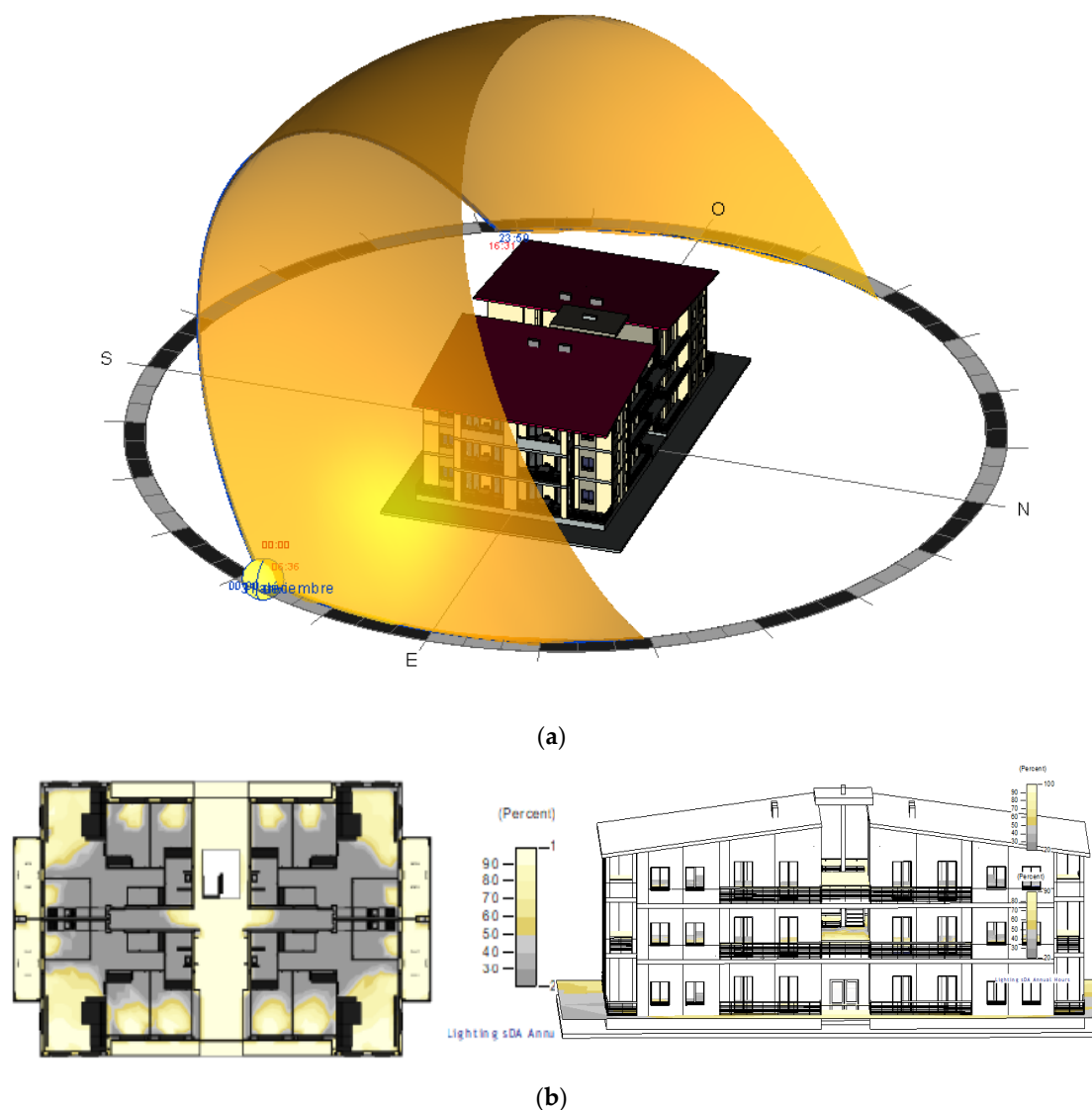
(**a**)

(**b**)

Figure 9. (**a**) Sun position and path during different annual seasons/direction and the speed of the wind, (**b**) BIM-based Spatial Daylight Autonomy (SDA) simulation for each property level that can be used to model the indoors daylight elements.

4.3.3. Outdoor Variables Based CIM/CityGML

CityGML dispose of different modules related to *CityObject* elements such as vegetation, transportation, land use that can be relevant to our 3D city data requirement-based outdoor variables. These modules are recently extended and described in the new CityGML version 3.0. Besides, outdoor variables can be derived from existing CityGML ADEs advances in terms of modeling environmental parameters in 3D outdoor urban applications [39]. These ADEs can offer elements related to 3D variables for valuation modeling regarding the outdoor environmental variables such as the "Noise ADE" for modeling urban noise levels [39], "Air Quality ADE" for [40,41] and 3D solar rights for modeling the sunlight exposure based on the neighboring conditions of shadowing and building obstruction [42]. This information based on existing ADE will provide a basis for standardized information related to our valuation model.

5. Conclusions

This paper identifies the significant 3D variables and the required information to build a new encompassing 3D property valuation model for residential property units. We

also highlighted the potential of BIM and CIM in this respect and proposed an analysis of how BIM and CIM will contribute to modeling and simulating the defined 3D variables elements respectively from indoors and outdoors which will be adopted in our future valuation model. For this purpose, a classification is proposed to identify the spatial and non-spatial elements required for the determination of each 3D variables elements.

Several 3D variables were identified through a deep literature review and the relevant ones to our valuation model were defined. Technical requirements were analyzed and classified based on the building and city scale required elements to our model.

BIM models were found to be more suitable to the valuation of indoor variables due to their semantic and geometric capabilities at the building elements scale. They provide information related to 3D indoor variables at the building scale such as the property elements, orientation, property cost, and property quality. It provides these 3D variables requirements for future residential property construction during its entire life cycle which is of a great interest to valuation purposes since property estimation requires accurate and up-to-date information related to the property unit variables.

CIM/CityGML models were found to be more suitable in the case of modeling the 3D outdoor variables. Note that some internals' variables requirements are also useful in the case of spaces related to indoor living quality simulation. In addition, CityGML models can provide better alternatives to enrich data models that may be applied to property valuation applications. Thanks to its domain extensions, it includes both indoor and outdoor variables modeling in the context of property valuation.

However, complementary work is needed to integrate the selected 3D variables to our future 3D property valuation model for residential property units. Since CityGML extended models (ADEs) [36] provide relevant information for indoor and outdoor variables that may enable to provide a standardized 3D variables data requirement. Few valuation models were developed recently to standardize the international valuation practices where one or two variables were modeled such as the view [10] others studied the computation of 3D variables withing a hedonic model and studied four variables (shadows, thermal comfort, air quality, noise, ventilation) based on residents interviews [9]. Further work needs to be done to integrate all the relevant 3D variables towards an international valuation model.

Finally, it should be noted that this paper proposes a conceptual definition of the pertinent 3D variables for property valuation and their corresponding elements' requirements and analysis the capabilities of (IFC/CityGML) in modeling and simulating the associated information. The upcoming work will focus on developing a 3D property valuation model that includes the proposed 3D variables requirements which can be projected on a case study for test and evaluation purposes.

Author Contributions: Conceptualization, S.E.Y., R.H. and R.B.; methodology, S.E.Y., R.H. and R.B.; validation, R.H., R.B.; writing—original draft preparation, S.E.Y., R.H. and R.B.; writing—review and editing, S.E.Y., R.H., R.B., M.E., G.-A.N.; visualization, S.E.Y.; supervision, R.H., R.B. and M.E. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors are well informed about the objectives of this current research, and they have provided consent and declared that they have no competing interest.

Appendix A

Appendix A.1. Example of Technical Specifications Review for the 3D Variables

- **Variable name**: Sunlight
- **Variable type:** Environmental Variable (Outdoor)
- **Relevant references:** (Helbich et al., 2013); (Zhang et al., 2014); (Yu, 2014); (LIU, 2016); (Ricker, 2019); (Li et al., 2019); (Zhang, 2019); (Amoruso et al., 2019); (Fleming et al., 2018).
- **Definitions**:

- *Solar Radiation:* solar radiation is defined as the sum of direct and diffuse solar radiation. Diffuse means that the radiation was already reflected before reaching the surface, while direct radiation reaches the surface of interest directly without being scattered by the atmosphere or reflected by any other objects (Helbich et al., 2013).
- *Sun exposition:* Determine the sun exposure for each house unit; Classify every house units depending to the longest/lowest sun exposure in order to define the sunshine indexes.
- *Sunlight duration time* (quantitative method of computing sunlight): The number of cumulative or continuous hours of sunlight received by the building (site) during the period of effective sunlight.
- *Period of effective sunlight:* The period of effective sunlight based on the solar elevation angle and azimuth, the intensity of solar radiation, and the indoor sunlight condition on the reference day, which is represented by true solar time.
- *Standards of buildings sunlight:* The minimum number of sunlight hours received by the building (site) during the period of effective sunlight. This quantity depends on the climate region, the scale of the city, and the function of the building (site).
- *Direct sunlight hours:* the average daily hours of direct sunlight received during the year by each house.
- *Sunlight quality:* calculated whether a building could receive direct sunlight at the specific orientation during different times of a day. The orientation was determined based on the questionnaire on buyers' preferences.
- *Sunlight duration professional analysis:* using software for simulation (BIM sunlight analysis module) simulate the sun movement in a particular day and result in a grid with sunlight hours on the surface of buildings.

Table A1. Sunlight technical specifications-based literature.

Variable Definition	Data Attributes	Measurement Building Unit	Technical Analysis	Standards Classification	Authors
Solar Radiation (kwh/m^2/year)	- Sun position (incidence angle) - Clear sky factor - shadowing effect - floor height - App Area - Orientation	Apartment Openings (3D)	Solar radiation analysis	—	[28]
Indoor Sun Exposition	- House orientation; - Lightning time; - Sunshine duration; - House unit number - DEM: terrain elevation - floor number - floor height - window location - Surrounding - Building	Openings (Windows) Apartment (2.5)	Viewshed analysis based sightline	Qualification classes (moderate, best, good) Depends on the sunlight value quantity	[17]
Direct sunlight hours (h)	- View index '75' (how much of a view of at least 75° each house) - Elevation (DEM) - Sunshine (winter, summer months) - House location (calculate direct sunlight hours)	Apartment (2.5D)	Viewshed analysis		[31]
Sunlight quality	Based on Fleming sunlight definition but determined by qualitative survey	Apartment (2.5D)	People's Preference(contingence)		[16]

Table A1. *Cont.*

Variable Definition	Data Attributes	Measurement Building Unit	Technical Analysis	Standards Classification	Authors
Sunlight duration Time (h)	- House orientation; - Bottom edge of window - Weather - Building - Obstructed buildings		sun-path diagram methods and shadow diagram methods	>2 h (sunlight duration standard) 8–16 h (period for effective sunlight)	[42]
Sunlight duration (every hour)	- Openings (Windows) - Buildings blocks - Sun duration - Surrounding building - View of vegetation - View of water	Room based sunshine quantification	- Viewshed analysis - Sun volume analysis (every 1 h the volume is generated)	- No less than 2 h per a day blocked - app = 1 unblocked - app = 2 (sunshine duration from short to long	[24]
Average sunlight radiation levels (year)	- Windows (solar blind systems) - Construction Material definition: - Emittance - Conductivity - Thickness - Orientation - Solar reflectance	Building units (based rooms)	- Sunlight h/year - Solar radiation analysis	—	[43]

Appendix A.2. Variables Material Properties

Table A2. Definition of the relevant materials properties based on their variables value impact.

Materials Properties	Description	References
Absorption	Define building materials capacity of absorbing sound and noise level while the noise is propagated through a building or a barrier, the resulting value is noise attenuation in the case of high absorption factor.	[26]
Reflectance	Some types of materials dispose of high reflectance for solar radiation, sound, and noise level such as glass.	[43,44]
Transmittance	The fraction of solar radiation diffused through a specific type of materials related to its opacity or transparence (called also solar heat gain coefficient)	[45]
Conductivity Specific heat	The thermal conductivity of the material (W/mK) Specific heat capacity of the material (J/kgK)	[44]
Glazing properties	Openings (windows, doors) with double/triple glazing properties decrease the amount of diffused noise and air from outdoor to indoor or within indoors different units.	[46]

References

1. El Yamani, S.; Ettarid, M.; Hajji, R. Building Information Modeling Potential for an Enhanced Real Estate Valuation Approach Based on the Hedonic Method. In *Building Information Modelling (BIM) in Design Construction and Operations III*; WIT Press: Southampton, UK, 2019; Volume 1, pp. 305–316. [CrossRef]
2. RICS International Valuation Standards. *Int. Valuat. Stand.* **2020**. [CrossRef]
3. Wyatt, P.J. The development of a GIS-based property information system for real estate valuation. *Int. J. Geogr. Inf. Sci.* **1997**, *11*, 435–450. [CrossRef]
4. Hussain, T.; Abbas, J.; Wei, Z.; Nurunnabi, M. The effect of sustainable urban planning and slum disamenity on the value of neighboring residential property: Application of the hedonic pricing model in rent price appraisal. *Sustainability* **2019**, *11*, 1144. [CrossRef]

5. Higgins, C.D. A 4D spatio-temporal approach to modelling land value uplift from rapid transit in high density and topographically-rich cities. *Landsc. Urban Plan.* **2019**, *185*, 68–82. [CrossRef]

6. Li, X.; Chen, W.Y.; Cho, F.H.T. 3-D spatial hedonic modelling: Environmental impacts of polluted urban river in a high-rise apartment market. *Landsc. Urban Plan.* **2020**, *203*, 103883. [CrossRef]

7. Toppen, T. The Use of 3D City Models in Real Estate Valuation and Transactions. Master's Thesis, Eindhoven University of Technology, Eindhoven, The Netherlands, 2016.

8. Kara, A.; Oosterom, P.V.A.N. 3D Data for Better Property Value Estimation in the context of LADM Valuation Information Model 3D Data for Better Property Value Estimation in the context of LADM Valuation Information Model. In Proceedings of the 6th International FIG Workshop on 3D Cadastres, Delft, The Netherlands, 2–4 October 2018; pp. 549–570.

9. Ying, Y.; Koeva, M.; Kuffer, M.; Asiama, K.O.; Li, X.; Zevenbergen, J. Making the Third Dimension (3D) Explicit in Hedonic Price Modelling: A Case Study of Xi'an, China. *Land* **2021**, *10*, 24. [CrossRef]

10. Kara, A.; van Oosterom, P.; Çağdaş, V.; Işıkdağ, Ü.; Lemmen, C. 3 Dimensional data research for property valuation in the context of the LADM Valuation Information Model. *Land Use Policy* **2020**, *98*, 104179. [CrossRef]

11. Gröger, G.; Plümer, L. CityGML—Interoperable semantic 3D city models. *ISPRS J. Photogramm. Remote Sens.* **2012**, *71*, 12–33. [CrossRef]

12. Yu, H.; Liu, Y.; Zhang, C. China, Integrating Geographic Information System and Building Information Model for Real Estate Valuation. 2016. Available online: https://www.oicrf.org/-/integrating-geographic-information-system-and-building-information-model-for-real-estate-valuation (accessed on 2 March 2021).

13. Arcuri, N.; De Ruggiero, M.; Salvo, F.; Zinno, R. Automated Valuation Methods through the Cost Approach in a BIM and GIS Integration Framework for Smart City Appraisals. *Sustainability* **2020**, *12*, 7546. [CrossRef]

14. Yu, H.; Liu, Y.; Zhang, C. Using 3D Geographic Information System to Improve Sales Comparison Approach for Real Estate Valuation. Available online: https://www.oicrf.org/-/using-3d-geographic-information-system-to-improve-sales-comparison-approach-for-real-estate-valuation (accessed on 2 March 2021).

15. Edler, D.; Keil, J.; Wiedenlübbert, T.; Sossna, M.; Kühne, O.; Dickmann, F. Immersive VR Experience of Redeveloped Post-industrial Sites: The Example of "Zeche Holland" in Bochum-Wattenscheid. *KN J. Cartogr. Geogr. Inf.* **2019**, *69*, 267–284. [CrossRef]

16. Ricker, B.A. Assessment of 2D and 3D Methods for Property Valuation Using Remote Sensing Data At the Neighbourhood Scale in Xi'an, China. Master's Thesis, University of Twente, Enschede, The Netherlands, 2019.

17. Zhang, H.; Li, Y.; Liu, B.; Liu, C. The application of GIS 3D modeling and analysis technology in real estate mass appraisal—Taking landscape and sunlight factors as the example. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2014**, *40*, 363–367. [CrossRef]

18. Juan, H. A 3D Gis-Based Valuation System for Assessing the Scenic View in Residential Property Valuations. Ph.D. Thesis, The Hong Kong Polytechnic University, Hong Kong, China, 2019.

19. Sirmans, S.; Macpherson, D.; Zietz, E. The Composition of Hedonic Pricing Models. *J. Real Estate Lit.* **2005**, *13*, 1–44.

20. Yu, S.M.; Han, S.S.; Chai, C.H. Modeling the value of view in high-rise apartments: A 3D GIS approach. *Environ. Plan. B Plan. Des.* **2007**, *34*, 139–153. [CrossRef]

21. Isikdag, U.; Horhammer, M.; Zlatanova, S.; Kathmann, R.; Van Oosterom, P. Utilizing 3D Building and 3D Cadastre Geometries for Better Valuation of Existing Real Estate. In Proceedings of the FIG Working Week 2015, Sofia, Bulgaria, 17–21 May 2015; pp. 1–18.

22. Wyatt, P. The development of a property information system for valuation using a geographical information system (GIS). *J. Prop. Res.* **2010**, *9916*. [CrossRef]

23. Zhang, J. Developing a Comprehensive Framework for Property Valuation Using 3D and Remote Sensing Techniques in China. Master's Thesis, University of Twente, Enschede, The Netherlands, 2019.

24. Turan, I.; Chegut, A.; Fink, D.; Reinhart, C. The value of daylight in office spaces. *Build. Environ.* **2020**, *168*, 106503. [CrossRef]

25. Kim, M.K.; Barber, C.; Srebric, J. Traffic noise level predictions for buildings with windows opened for natural ventilation in urban environments. *Sci. Technol. Built Environ.* **2017**, *23*, 726–735. [CrossRef]

26. Šujanová, P.; Rychtáriková, M.; Mayor, T.S.; Hyder, A. A healthy, energy-efficient and comfortable indoor environment, a review. *Energies* **2019**, *12*, 1414. [CrossRef]

27. Helbich, M.; Jochem, A.; Mücke, W.; Höfle, B. Boosting the predictive accuracy of urban hedonic house price models through airborne laser scanning. *Comput. Environ. Urban Syst.* **2013**, *39*, 81–92. [CrossRef]

28. Wen, H.; Gui, Z.; Zhang, L.; Hui, E.C.M. An empirical study of the impact of vehicular traffic and floor level on property price. *Habitat Int.* **2020**, *97*, 102132. [CrossRef]

29. Szczepańska, A.; Senetra, A.; Wasilewicz-Pszczółkowska, M. The influence of traffic noise on apartment prices on the example of a European Urban Agglomeration. *Sustainability* **2020**, *12*, 801. [CrossRef]

30. Fleming, D.; Grimes, A.; Lebreton, L.; Maré, D.; Nunns, P. Valuing sunshine. *Reg. Sci. Urban Econ.* **2018**. [CrossRef]

31. Xu, Z.; Zhuo, Y.; Li, G.; Liao, R.; Wu, C. Towards a Valuation and Taxation Information Model for Chinese Rural Collective Construction Land. *Sustainability* **2019**, *11*, 6610. [CrossRef]

32. Kitsakis, D.; Kalantari, M.; Rajabifard, A.; Atazadeh, B.; Dimopoulou, E. Exploring the 3rd dimension within public law restrictions: A case study of Victoria, Australia. *Land Use Policy* **2019**, *85*, 195–206. [CrossRef]

33. Atazadeh, B.; Kalantari, M.; Rajabifard, A.; Ho, S.; Ngo, T. Building Information Modelling for High-rise Land Administration. *Trans. GIS* **2017**, *21*, 91–113. [CrossRef]

34. Atazadeh, B.; Rajabifard, A.; Zhang, Y.; Barzegar, M. Querying 3D Cadastral Information from BIM Models. *ISPRS Int. J. Geo-Inf.* **2019**, *8*, 329. [CrossRef]

35. Biljecki, F.; Kumar, K.; Nagel, C. CityGML Application Domain Extension (ADE): Overview of developments. *Open Geospat. Data Softw. Stand.* **2018**, *3*, 1–17. [CrossRef]

36. Kutzner, T.; Chaturvedi, K.; Kolbe, T.H. CityGML 3.0: New Functions Open Up New Applications. *PFG J. Photogramm. Remote Sens. Geoinf. Sci.* **2020**, *88*, 43–61. [CrossRef]

37. Plebankiewicz, E.; Zima, K.; Skibniewski, M. Construction cost and time planning using BIM-based applications. In Proceedings of the Creative Construction Conference, Krakow, Poland, 21–24 June 2015; pp. 537–545.

38. Kumar, K.; Ledoux, H.; Commandeur, T.J.F.F.; Stoter, J.E. Modelling Urban Noise in Citygml Ade: Case of the Netherlands. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *4*, 73–81. [CrossRef]

39. Arco, E.; Boccardo, P.; Gandino, F.; Lingua, A.; Noardo, F.; Rebaudengo, M. An Integrated Approach For Pollution Monitoring: Smart Acquirement and Smart Information. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2016**, *4*, 67–74. [CrossRef]

40. Casazza, M.; Lega, M.; Jannelli, E.; Minutillo, M.; Jaffe, D.; Severino, V.; Ulgiati, S. 3D monitoring and modelling of air quality for sustainable urban port planning: Review and perspectives. *J. Clean. Prod.* **2019**, *231*, 1342–1352. [CrossRef]

41. Li, L.; Lei, Y.; Tang, L.; Yan, F.; Luo, F.; Zhu, H.; Atazadeh, B.; Rajabifard, A.; Zhang, Y.; Barzegar, M. A 3D spatial data model of the solar rights associated with individual residential properties. *Comput. Environ. Urban Syst.* **2019**, *74*, 88–99. [CrossRef]

42. Amoruso, F.M.; Dietrich, U.; Schuetze, T. Integrated BIM-Parametric Workflow-Based Analysis of Daylight Improvement for Sustainable Renovation of an Exemplary Apartment in Seoul, Korea. *Sustainability* **2019**, *11*, 2699. [CrossRef]

43. Rosser, J.F.; Long, G.; Zakhary, S.; Boyd, D.S.; Mao, Y.; Robinson, D. Modelling urban housing stocks for building energy simulation using CityGML energyade. *ISPRS Int. J. Geo Inf.* **2019**, *8*, 163. [CrossRef]

44. OGC; 3D GIS. CityGML Energy Application Domain Extension. 2016. Available online: https://www.citygmlwiki.org/index.php/CityGML_Energy_ADE (accessed on 2 March 2021).

45. Warren-Myers, G.; Kain, C.; Davidson, K. The wandering energy stars: The challenges of valuing energy efficiency in Australian housing. *Energy Res. Soc. Sci.* **2020**, *67*, 101505. [CrossRef]

46. Benloukilia, S.; Darkaoui, W.; Hajji, R.; El Yamani, S. L'apport du BIM Dans L'évaluation Immobilière: Cas d'un Bien Résidentiel. Master Thesis, IAV Hassan II Institute, Rabat, Morocco, 2019. Available online: http://ametop.ma/wp-content/uploads/2020/02/BENLOUKILIA-Siham-DARKAOUI-Wafae.pdf (accessed on 2 March 2021).