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Towards Extending CityGML for Property Valuation: Property Valuation ADE

Siham El Yamani[1,2,3], Rafika Hajji[2], Roland Billen[3], Ken Arroyo Ohori[1], Jasper van der Vaart[1], Amir Hakim[1], Jantien Stoter[1]

[1] 3D Geoinformation, Urban Data Science, Delft University of Technology, The Netherlands
(S.E.ElYamani, K.Ohori, J.A.J.vanderVaart, S.Hakim, J.E.Stoter)@tudelft.nl
[2] College of Geomatic Sciences and Surveying Engineering, IAV Hassan II Rabat, 6202 Rabat, Morocco - r.hajji@iav.ac.ma
[3] Geospatial Data Science and City Information Modeling (GeoScITY), UR Spheres, University of Liège, 4000 Liège, Belgium - rbillen@uliege.be

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Abstract

This paper introduces Property Valuation Application Domain Extension (ADE) within CityGML 3.0, aiming to integrate relevant indoor and outdoor 3D variables (cost estimation, view quality, etc.) for accurate property valuation. Current models lack the necessary features for this specific application. Leveraging IFC data for indoor elements, this ADE extends CityGML, addressing the existing gap. This paper identifies and categorizes data requirements, leading to the conceptualization and development of the model. By enriching CityGML 3.0 with IFC data, the approach introduces new features like the "Property Unit" to ensure adaptability across diverse valuation scenarios. Despite encountering data integrability challenges, we here commit to refining the model and overcoming these obstacles. A preliminary implementation using CityJSON demonstrates successful integration and paves the way for future implementation. These include developing an API platform and establishing an official repository to facilitate practical usability and scalability. This research significantly contributes to advancing property valuation processes by providing accurate valuations for stakeholders and promoting the use of 3D urban data in domain-specific extensions.

1. Introduction

Given the rapid urbanization and population growth, residential properties tend to be more densified and vertically developed. That has led to more complex urban areas which require more than before efficient and sustainable city management. 3D urban models and City Digital Twins (CDTs) are increasingly developed to deal with the new requirements of the city such as sustainability, efficiency, and well-being (Lehtola et al., 2022; Schrotter & Hürzeler, 2020). Real estate valuation, recognized as a main issue in city management, should benefit from the advancements in 3D building/city modeling to allow precise and reliable valuation of properties. Indeed, the presence of high-rising residential buildings and the complexity of the surrounding urban environments add significant challenges for real estate stakeholders (investors, taxation administration, valuer, etc.) to assess the property value accurately (Figure 1).

The property value is defined as the association of indoor elements related to the property as 3D objects (e.g., volume, height) and 3D simulations from the property's outdoor environment (e.g., view, noise, pollution). Therefore, considering both indoor and outdoor variables in an urban context, characterized by high-rising residential buildings and complex surrounding urban environments, requires efficient methods for modeling and simulating the property value.

Recent works have identified relevant 3D variables (indoors, and outdoors) for property valuation (Biljecki et al., 2015; El Yamani et al., 2021; Kara et al., 2020; Jafary, 2022). El Yamani et al., (2021) have proposed a classification of 3D variables in terms of spatial granularity, covering several scales: from building elements of a building part (e.g., construction materials, openings,) to the large neighborhood level (e.g., building envelope, surrounding amenities, atmospheric conditions). Thus, a property value simulation should be performed at the building scale (indoor variables), at the neighborhood or the city scale (outdoor variables), or by considering the two scales when it comes to interactive variables implying the interaction between indoor and outdoor variables. Therefore, to accurately define the value of the property, it is necessary to have access to spatial and non-spatial elements required to determine the 3D variables' value and to identify where and how to obtain them.

3D property valuation has witnessed lately significant advancements with the introduction of CityGML, a generic data model designed to represent 3D city data. However, while CityGML offers valuable modules and tools for 3D spatial-semantic modeling of urban and landscape features, these are not extensive enough to cover all urban use cases such as property valuation. To address this limitation and cater to the specific requirements of property valuation applications, there is a need for a specialized Application Domain Extension (ADE) that seamlessly integrates both indoor and outdoor variables related to property valuation.

The Industry Foundation Classes (IFC) and CityGML are among the most advanced data models for indoor (building elements) and outdoor (building's environment), respectively. While IFC and CityGML offer distinct geometry, topology, and semantics, their integration poses significant challenges due to discrepancies in geometric and semantic coherence during the conversion process, as observed in prior studies (Arroyo Ohori et al., 2018; Biljecki & Tauscher, 2019; Floros et al., 2018; Zadeh et al., 2019).

The last version of CityGML 3.0 is a comprehensive data model that is independent of applications. However, various applications require specific data that is not covered by the CityGML Conceptual Model. To address this challenge, CityGML offers two approaches: one involves utilizing generic objects and attributes to store specialized information, while the other relies on the Application Domain Extension (ADE) mechanism (Biljecki et al., 2021a; Forouzandeh et al., 2024; Ohori et al., 2018; Van den Brink et al., 2013). The first approach presents certain challenges, such as difficulties in maintaining the consistency of extended entities or attributes using standard tools, as they can only be defined textually, resulting in complex data interoperability (Shen et al., 2020). In contrast, the second approach leverages ADEs to systematically and structurally incorporate application-specific data within CityGML.

One of the widely used approaches to designing an ADE is developing independent data models that are shaped for individual use cases, each featuring unique data packages, classes, and attributes (Kolbe et al., 2021). Consequently, overlaps may occur, given that multiple use cases may require the same subset of information. Most ADEs developed nowadays belong to this category since they are applied to a specific use case. The Energy ADE is one of the examples developed using this approach(Chatzinikolaou et al., 2020). However, no ADEs were developed to integrate 3D variables (indoor, and outdoor) for the property valuation application.

From the perspective of property valuation, prior approaches have primarily centered on fulfilling 3D cadastral taxation criteria by adopting LADM (Land Administration Domain Model) as the standard model (Kara et al., 2020). To this end, Çağdaş (2012) developed an extension for taxation valuation, known as "ADE Taxation," using CityGML. Other authors have focused on extracting variable requirements from IFC in the indoor context, such as valuation units for apartment legal boundaries based on Ifcspace (Jafary, 2022; Li et al., 2016; Mete et al., 2022), indoor daylight obtained from BIM simulations (Celik Simsek & Uzun, 2021), or specific outdoor requirements like view quality by determining viewshed requirements based on GIS analysis (distance to view, etc.) (El Yamani et al.,2023; Kara et al., 2020).

Therefore, the research presented in this article aims to propose an ADE within CityGML 3.0, named the Property Valuation ADE, to incorporate the 3D variables that are essential for property valuation purposes. The data requirements have been identified and categorized by the findings presented in Section 2. The ADE is developed and constructed at a conceptual level, an implementation by the emerging CityJSON format is illustrated in section 3 to assess data integrability (El Yamani et al., 2023; Noardo, 2022, 2021) and to showcase its challenges.

Moreover, we present an in-depth exploration of the integration of IFC into CityGML ADEs, a critical aspect of 3D property valuation. While previous studies have explored IFC enrichments to CityGML ADEs, they have been tailored to other use case scenarios and did not sufficiently address the relevant requirements of property valuation. Our approach seeks to propose a new ADE that combines different urban aspects, specifically designed to serve property valuation needs while harnessing the potential of IFC datasets for indoor variables.
This article contributes significantly to the advancement of property valuation processes by leveraging the interest of 3D urban data and domain-specific extensions. Our research seeks to make valuable contributions to the research in property valuation and provide an accurate valuation for all the stakeholders (contractors, valuers, users, etc.) (Figure 1).

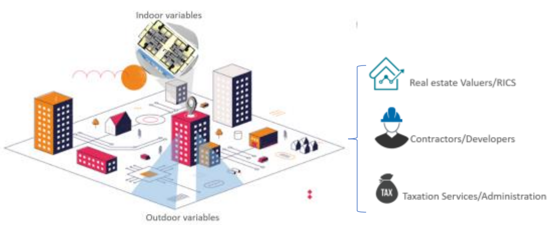

Figure 1. Potential users of ADE-Valuation.

2. Background and Related Works

2.1 ADEs for CityGML Urban applications

CityGML allows for extensibility through the Application Domain Extension (ADE) mechanism, which allows extensions for specific use cases. This mechanism allows for augmenting and expanding the CityGML data model to supply specific use cases (Energy, taxation, etc.) and capture additional information beyond its native capabilities (Biljecki et al., 2018).

ADEs enable three main types of extensions: (1) expanding attributes, (2) creating new features, and (3) introducing non-standard geometries to existing classes/features. For example: the Noise ADE allows modeling noise barriers as lines (Kumar et al., 2017)

Numerous ADEs have been developed to enhance CityGML's functionality for distinct urban purposes. For example, the ADE for immovable property taxation, as proposed by (Çağdaş, 2012), extended CityGML to facilitate precise and efficient taxation of immovable properties within urban areas. Similarly, the Air Quality ADE, by incorporating specific data requirements crucial for air quality assessment, has improved the capacity for in-depth analysis and data-driven decision-making to combat air pollution (Höhle et al., 2012). Additionally, urban planning and architecture have benefited from the 3D Solar Rights Model for Sunlight Exposure, which assists in evaluating sunlight exposure on buildings, leading to optimized energy efficiency and enhanced quality of life (Beetz et al., 2012).

Moreover, noise pollution assessment and management in urban environments have been greatly facilitated by the Noise ADE developed by Kumar and colleagues (2017), which includes noise-related data and simulations. Furthermore, the Energy ADE, as described by Agugiaro et al. (2018), has provided a framework to incorporate energy-related data, enabling comprehensive energy modeling and analysis in urban settings. This, in turn, contributes significantly to sustainable urban development and efficient energy management, the "thermal zone" (Agugiaro et al., 2018).

However, despite the successful implementation of these ADEs in addressing specific urban challenges, they often face significant challenges in terms of their integration with IFC. This integration is crucial for our model, which requires the seamless inclusion of comprehensive property valuation variables. Existing ADEs typically focus on their specific urban applications and may not inherently provide a comprehensive scenario for effective integration with IFC datasets. Consequently, our research must address the complexity of merging these ADEs with IFC datasets to create a more cohesive and comprehensive framework for property valuation.

2.2 Integration of IFC in CityGML ADEs

Extensive research has explored the integration of IFC into CityGML ADEs. Several studies aimed to bridge the gap between IFC and CityGML, with a specific focus on semantic data transfer, utility networks, and enrichments for various urban scenarios.

In one notable study(Berlo and Laat) (2011) proposed extending CityGML with semantic IFC data, enabling the seamless exchange of building information between these two standards. Similarly, (El-Mekawy et al., 2012) introduced a Unified

Building Model (UBM), aimed at bridging IFC and CityGML. Their research primarily sought to determine how much information from an IFC model could be transformed into a CityGML model, particularly concerning semantic information.

(Tatjana Kutzner and Kolbe, 2018) directed their efforts towards supporting utility networks in CityGML, which led to the development of the Utility Network ADE. In their research, they explored the extraction of relevant features from Building Information Models (BIM) to achieve this objective.

Another relevant study by (Biljecki et al., 2021a) focused on the IFC-ADE, aiming to preserve valuable information from IFC data not natively supported in CityGML. This allowed for the retention of specific details for use cases such as energy analysis, urban planning, and livability. However, the IFC-ADE did not cater to property valuation use cases and their specific data requirements.

While these developments in integrating IFC with CityGML ADEs have been valuable, they often cater to specific use case scenarios (e.g., energy, noise) and may not address the requirements of property valuation (IFC-ADE). Although these specific-use-case ADEs inspired our work, we needed datasets covering both indoor and outdoor variables related to noise, sunlight, and air quality. Existing ADE mechanisms did not provide a means to connect multiple ADEs. Therefore, our approach was to propose and develop a new ADE that consolidates various urban requirements into a unified model designed explicitly for property valuation. Additionally, we outline scenarios for enhancing the CityGML Property Valuation ADE in general with semantic datasets from IFC.

3. Methodology and Approach

3.1 ADE Design

There are various ways to design an ADE based on the specific use case application. Among them, three approaches have been identified and derived from Biljecki's work in 2021 (Figure 2):
"

Approach 1: *Involves developing independent ADE data models for each use case. Therefore, each of the developed ADEs will have their data model structure with customized and new data packages, classes, and attributes. Thus, they will inevitably have an overlap since multiple use cases may require the same subset of information. Most ADEs nowadays belong to this category as they are developed to suit a particular use case and domain, e.g., EnergyADE [58] and Cultural Heritage ADE.*

Approach 2: *A single ADE data model accommodating the data requirements for all use cases into a single structure. There are ADEs catering to multiple use cases, such as Dynamizer ADE [60], and they are largely used in the domain of national geographic information standards.*

Approach 3: *An ADE data model with a shared core structure to which there are attached additional ADEs, i.e., new data packages or classes that are representative for each of the use cases (e.g., new data package with new classes/attribution for use case "A", new data package with new classes/attribution for use case "B" and so on). This approach is in a way related to the cross-domain building models discussion by Knoth et al., and it is akin to developing ADEs and extending existing ADEs."*

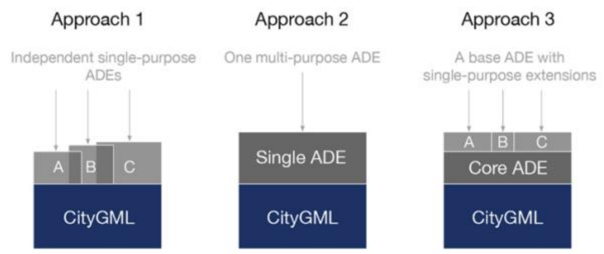

Figure 2. Different Approaches to Design an ADE for a specific or multiple use case application derived from (Biljecki et al., 2021b).

In our work, we have opted for the first approach due to its practicality and flexibility in our property valuation model. Indeed, in our use case, each 3D variable requires a specific data model and an adapted IFC data scenario for integration. To ensure precision and specificity for each variable, we assign them to individual packages with distinct requirements.
Although each variable package operates independently, they are interconnected to form the complete ADE-Valuation model.

Furthermore, each variable package requires a unique data model, as the data enrichment scenarios differ based on specific use cases and transformations required to store the data into CityGML extension models.

Regarding the IFC data enrichment scenarios, we can consider three approaches as follows:

(i) Features entirely required to enrich our CityGML ADE: For instance, classes such as *IfcBuilding*, *IfcBuildingStorey*, and *IfcSpace* are entirely enriching the CityGML requirements classes *Building, BuildingFloor,* and *Room*, respectively.

(ii) Features entirely required to enrich a new ADE feature: In this case, *IfcSpace* and zones are transformed and processed to enrich the new feature "property unit" within our ADE-Valuation model.

(iii) Attributes required from IFC to enrich the existing CityGML ADE or introduce a new attribute within it: As an example, the *indoorDaylight* attribute is an indoor variable that will be transformed into a new attribute within the CityGML *Room* class.

3.2 ADE's Requirements

In this subsection, we present the requirements of the ADE-Valuation model concerning indoor and outdoor variables. Figure 3 shows the classification of these requirements.

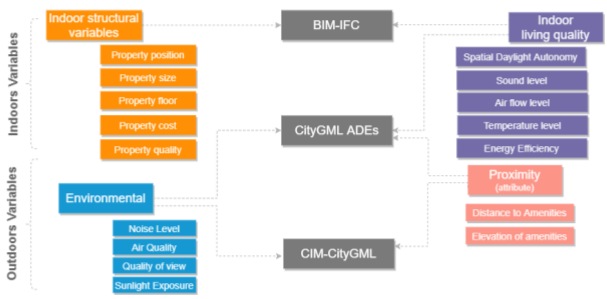

Figure 3. ADE's requirements classification

Indoor Requirements-based BIM/IFC:

In the context of our valuation model, indoor variables can greatly benefit from the capabilities of BIM and IFC to derive 3D spatial and non-spatial elements essential for individual residential properties. Figure 3 illustrates the architectural elements of a residential building model based on the IFC standard, showcasing the potential elements that can be utilized in our assessment process.

With rich semantic information about architectural and physical spaces, BIM/IFC models allow for the extraction of specific building elements (e.g., walls, openings) related to a particular property unit. This enables us to assess structural variables, such as property unit position at specific openings and storey levels. Additionally, information related to the indoor 3D physical space allows for the determination of property element sizes, including volume and room area, contributing to assessing property value. Furthermore, by combining BIM data on structural materials and their thermal properties with the cost information, we can estimate property costs. However, automating the process of estimating cost variables for each property unit is not straightforward, and further exploration of IFC classes for extraction is required.

Indoor Requirements based-CityGML ADEs and IFC:

CityGML ADEs, specifically the "Energy ADE," play a pivotal role in meeting the indoor requirements of our valuation model. The 3D spatial capabilities of BIM/IFC models seamlessly extend to encompass the virtual space associated with the thermal zones within building units. This new concept of space in CityGML 3.0 is notably flexible and can be effectively matched with the "IfcSpace" class, especially when considering thermal zoning. These thermal zone data, in conjunction with information regarding structural materials, prove invaluable for conducting energy analyses. The virtual spatial representation offered by the building model empowers us to derive simulation outcomes for indoor living quality variables based on specific energy-related factors.
To ensure the precision of simulations related to indoor variables, it becomes imperative to combine information about indoor building elements with 3D geospatial data from the external environment, including weather data and the surrounding building structures. By integrating pertinent elements from established CityGML ADEs, notably the "ADE Energy," we gain access to the required outdoor components for more efficient simulation of indoor living quality variables.

Outdoor Requirements based-ADEs/CityGML:

CityGML offers various modules related to CityObject elements, including vegetation, transportation, and land use, which are crucial for addressing the outdoor variables in our 3D city data-based valuation. The latest version, CityGML 3.0, introduces extensions that further describe these modules. Additionally, existing CityGML ADEs, like the "Noise ADE" for modeling urban noise levels, the "Air Quality ADE" for air quality assessment, and the 3D solar rights model for sunlight exposure based on neighboring conditions, can provide valuable elements related to outdoor environmental variables. These existing ADEs serve as a foundation for standardizing information in our valuation model, ensuring a comprehensive and accurate assessment of outdoor variables.

By leveraging BIM/IFC capabilities, CityGML ADEs, and existing ADEs for indoor and outdoor variables, our ADE-Valuation model can effectively integrate and analyze the 3D variables requirements necessary as an input to the 3D property valuation model.

4. Property Valuation ADE

4.1 ADE Core

For the creation of the ADE-Valuation model, we enhance features from the CityGML 3.0 Building and Construction modules by proposing a core module for the proposed ADE and packages for each independent model related to variables (indoors; and outdoors). Although version 3.0 of the standard has not yet been formally adopted, we rely on recently available proposals and the conceptual model available on GitHub. This decision is made because the new version of the standard offers notable advantages over the previously adopted version 2.0 from 2012. These advantages include improved consideration for indoor features (new concepts of objects and spaces(Billen et al., 2016, 2008) such as the introduction of storeys, multiple levels of detail, and interoperability with IFC). Additionally, considering the rapid progress and ongoing discussions, it is likely that CityGML 3.0 will be adopted very shortly. By aligning with the upcoming version, the ADE-Valuation model can leverage the enhanced features and ensure compatibility with the latest standards for seamless integration into the CityGML framework.

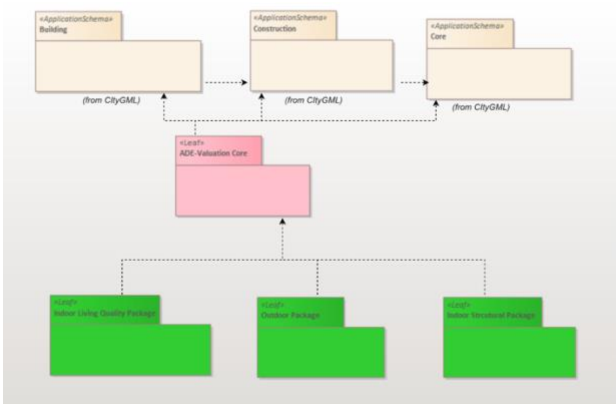

Figure 4. The color-coded modular structure of the ADE valuation UML diagram is embedded into the CityGML core. (Beige: existing CityGML schema required; Rose proposed ADE valuation generic core; green leaves are the variables independent packages for indoor and outdoor requirements).

Figure 4 describes each package of the ADE:

4.1.1 ADE-Valuation Core: This core module extends the existing building and building part classes within CityGML. It introduces a novel feature known as the "Property Unit," a generic class closely associated with the concept of valuation unit spaces. These spaces serve as the abstract class for modeling and simulating all variables, essentially serving as the primary assessment unit for every variable package. The integration of data into the "Property Unit" from indoor sources is allowed via the IFC, utilizing the enrichment options discussed in the preceding subsection. This feature seamlessly extends the CityGML "Building: BuildingUnit" class and establishes connections with "openings," which are vital for handling outdoor variables. Additionally, it is linked to "Building: BuildingRoom" where simulations for indoor living quality packages take place (refer to Figure 5 for schema).

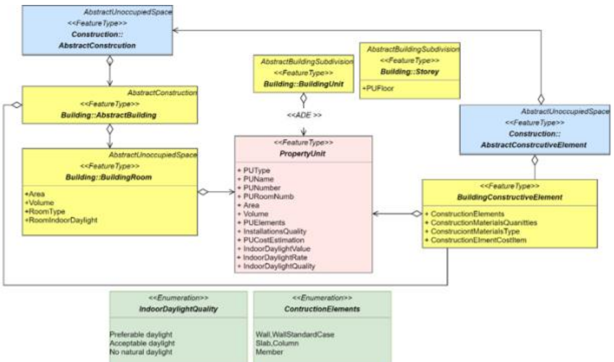

Figure 5. Schema model of the ADE-Valuation core model (blue: ..., yellow; Rose : new ADE feature, green ; code lists)

4.1.2 Indoor Structural Package: contains the indoor physical variables related to the building property units (such as property unit cost, materials, area, position, property unit installation, etc.) which extend the CityGML core classes "building", "buildingunit", "buildingconstructiveelements" and stored as "PropertyUnit" attributes: +Area, +Volume, +PUElements (property unit rooms and units), +InstallationQuality, +PUCostEstimation (See Figure 5).

The integration of indoor structural variables is achieved through the IFC enrichment scenarios. These data are available at the level of different IFC features: "IfcBuilding", "IfcBuildingStorey", "IfcSlab", "IfcColum", "IfcWall", "IfcRoof".

Through the enrichment process, we translate and merge relevant data from: "IfcSlab", "IfcColum", "IfcWall", and "IfcRoof" to "Buildingconstructiveelements" and the parent/child hierarchy to "PropertyUnit" as a child of buildingunit.

4.1.3 Indoor Living Quality contains the indoor living quality variables which are stored directly as attributes of the Room class within CityGML. These variables include factors such as indoor daylight, air quality, acoustic comfort, and other parameters that contribute to the overall quality of living within a property unit.

The integration of indoor living quality variables is achieved through the IFC enrichment scenario. The data for these variables is initially available at the level of the IFC space, which contains information about the indoor environment and its various characteristics.

Through the enrichment process, we transform and map the relevant data from the IFC space to the corresponding Room class in CityGML. This transformation ensures that the indoor living quality variables are accurately stored within the CityGML representation of the building model, specifically within the Room class.

The hierarchical relationship between the Room class and the "Property Unit" class is crucial in the Indoor Living Quality Package. Each Room is associated with a specific "Property Unit," and this hierarchical relationship allows us to systematically organize and link the indoor living quality variables to the broader context of the property valuation.

By storing the indoor living quality variables as attributes of the Room class, we make these variables readily accessible within the CityGML framework. This direct integration facilitates seamless data management and retrieval during the property valuation process, making it easier to analyze and assess the indoor living conditions within a property.

4.1.4 Outdoor Variables Package: The Outdoor Package in the ADE-Valuation model primarily consists of environmental variables related to the outdoor surroundings of a property.

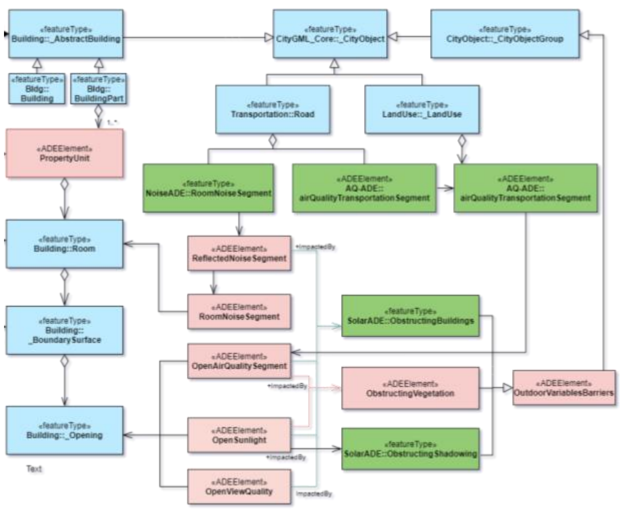

Figure 6. The Conceptual Model of Outdoor Variables Package
These variables play a crucial role in property valuation and are directly sourced from various environmental data sources. The main components of the Outdoor Package are as follows (figure 4.6):

Environmental Variables: This element includes variables such as noise, air quality, view quality, and sunlight exposure. Each of these variables is associated with a specific source that contributes to its value. For example, the noise variable may have sources such as roads, railways, or other transportation features, while the air quality may be influenced by transportation emissions. The view quality variable could be related to surrounding buildings, vegetation, or other landscape features, and the sunlight exposure variable may be influenced by the presence of nearby buildings or other obstacles.

Outdoor Variables Barriers: This element represents obstacles or barriers that impact certain outdoor variables. For instance, for sunlight exposure and view quality variables, buildings and vegetation may act as barriers affecting the amount of sunlight or the quality of the view. The Outdoor

Variables Barriers feature allows for the consideration of these obstacles in the assessment of outdoor variables.

Assessment Classes: The assessment of outdoor variables is carried out using specific classes within the ADE-Valuation model. For sunlight exposure, air quality, and view quality, the "Openings" class is utilized. The Openings class represents openings in buildings or structures that allow the assessment of outdoor variables within indoor spaces. By analyzing the openings in relation to the surrounding environment, the model can estimate variables such as sunlight exposure, air quality, and view quality.

Noise Assessment Class: For the noise variable, the "Room" and “Openings” classes is employed for assessment. The Room class represents indoor spaces, and in the case of noise assessment, it allows for the evaluation of noise levels within these spaces coming from outdoors through openings.

To support the integration of outdoor variables into the CityGML framework, the Outdoor Package relies on ADE classes that extend the CityGML CityObjects. These ADE classes include transportation segment features and road segment features, which enable the modeling of transportation-related sources of outdoor variables, such as noise and air pollution.

In summary, the Outdoor Package in the ADE-Valuation model incorporates environmental variables sourced from outdoor surroundings, such as noise, air quality, view quality, and sunlight exposure. It utilizes assessment classes like Openings and Room to evaluate these variables based on the presence of barriers or obstacles. The package also leverages ADE classes extending CityGML CityObjects to model specific sources of outdoor variables related to transportation and road features, ensuring a comprehensive assessment of outdoor factors for property valuation (Figure 7).

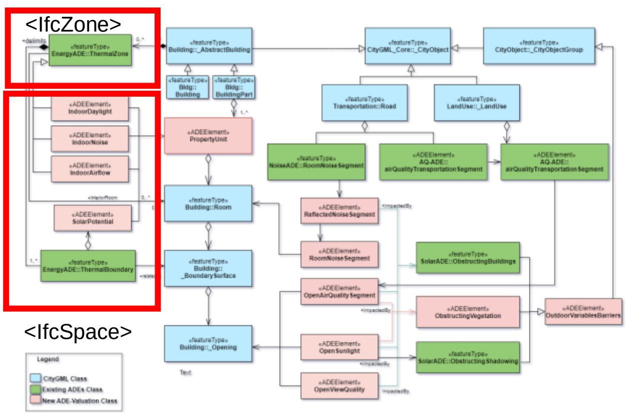

Figure 7. Detailed classes of ADE Valuation model

4.2 ADE-Data Integrability Challenges

In this section, we delve into the challenges of data integrability within our Valuation ADE model, considering its applicability to CityGML 3.0. Then we illustrate the implementation with the emerging CityJSON standard that demonstrates the applicability of our 3D generic property valuation model.

Firstly, there is complexity arising from the development of an ADE specifically from the structure and interdependencies inherent in the CityGML 3.0 standard (Kutzner et al., 2020). To ensure seamless alignment with the CityGML 3.0 framework, our ADE-Valuation necessitates a profound understanding of the standard's technical intricacies. Furthermore, the nuances of GML encoding further amplify the complexity within our model (CityGML, 2021; GML, 2021).

A notable challenge we face is due to limited software support compatibility. The availability of comprehensive software tools and platforms capable of fully accommodating CityGML ADEs, particularly within the context of CityGML 3.0, remains relatively scarce (CityGML, 2021). This limitation can pose substantial hurdles during the development and integration phases of the ADE-Valuation, potentially leading to compatibility and interoperability issues when attempting to incorporate our model into existing software workflows (Zalantova et al, 2021).

When assessing the integration challenges specific to our Valuation ADE, these challenges can be categorized into concerns regarding interoperability, flexibility, and implementation, as defined within our ADE-Valuation specifications.

For instance, obtaining data sets related to indoor factors like daylight and costs for integration into the ADE involves extracting enriched subset information from IFC. This extraction process is not straightforward due to the lack of interoperability between IFC and CityGML standards and data models. Additionally, automating the extraction of necessary data from IFC entities into CityGML features, especially for elements like Cost stored at the smallest building entity level (IfcSlab, IfcWall, etc.), requires further processing to model cost information at the property unit level and there is no standardized way to compute it. This lack of flexibility underscores the necessity for modeling guidelines to be established early on in building modeling, allowing for a more flexible approach, and enhancing data integrability complexity for the model data requirements.

Considering these limitations and challenges, the exploration of alternative encodings like CityJSON could be a promising direction for future work. CityJSON, a JSON-based encoding designed for storing 3D city models or digital twins, aims to provide a compact and developer-friendly format (Ledoux et al., 2019).CityJSON offers a streamlined and lightweight representation of CityGML-like data, potentially streamlining the implementation process and addressing software support and interoperability issues unique to our Valuation ADE.

Furthermore, the integration of our Valuation ADE with IFC data presents challenges, particularly in the domain of data extraction. While certain research endeavors have explored automated data extraction from IFC files, these automated *processes primarily rely on geometry and may lack critical semantic information. For instance, tools like* "IfcEnvelopeExtractor," which we tested, highlight the need to tailor the extraction process for each specific package and use case scenario within our Valuation ADE(Vaart, 2022).

The CityJSON format facilitates easy visualization, manipulation, and editing of files and is specifically designed to support programmers, enabling the rapid development of tools and APIs. Multiple open-source options are available (CityJSON, 2021). Similarly, CityJSON defines Extensions, which are JSON files that document how the core data model of CityJSON may be extended (CityJSON, 2021). CityJSON supports extensions to the core data model of CityGML for specific applications and use cases (like the concept of ADE for CityGML). These Extensions are defined as simple JSON files and support the addition of new feature types and attributes for features and datasets, an aspect that aligns with our property valuation ADE exploration (CityJSON, 2021).

To evaluate the feasibility of our Valuation ADE, we implemented a preliminary illustration using the emerging CityJSON format. The implementation involves two phases:

1) Property valuation integrability based on CityJSON
2) Testing the data integrability for indoor daylight data.

For the first stage, specifications are provided from the ADE valuation model (core and packages) and mapped to CityJSON classes. Figure 8 illustrates three key structures: "extraproperties" (e.g., quality of daylight), "extraattributes" (e.g., indoor daylight), and "extrafeatures" (e.g., property unit) (CityJSON, 2021).

```
{
  "type": "CityJSONExtension",
  "name": "Pvaluation",
  "url": "https://www.cityjson.org/tutorials/files/pvaluation.ext.json",
  "version": "1.0.0",
  "versionCityJSON": "1.1",
  "description": "Extension for assessing 3D variables for property valuation",

  "definitions": {
    "3D variables measure": {
      "type": "object",
      "properties": {
        "value": { "type": "number" },
        "uom": { "type": "string" }
      },
      "required": [ "value", "uom", " ],
      "additionalProperties": false
    },

    "BuildingRoom": {
      "type": "object",
      "properties": {
        "usage" : {"type": "string" },
                "Area": { "type": "integer" },
        "Volume": { "type": "integer" },
        "RoomHeight": { "$ref": "#/definitions/measure" }
      },
      "additionalProperties": false
    }
  },

  "extraRootProperties": {},

  "extraAttributes": {
    "BuildingRoom": {
      "+IndoorDaylight_Value": { "type": "string" },
      "+IndoorDaylight_Quality": { "enum": [ "Preferable Daylight", "Acceptable Daylight", "No
Natural Daylight"  ]},
      "+IndoorAirFlow_Value": {  },
      "+IndoorAirFlow_Quality": { "enum": [ "need to ventilate", "Acceptable aeration", "Better
ventilation"  ]},
      "+IndoorNoise_Value": { "$ref": "#/definitions/measure" },
      "+IndoorNoise_Quality": { "enum": [ "Noisy", "Acceptable Noise", "less noisy"  ]},
      "+OutdoorSunlight_Value": { "$ref": "#/definitions/measure" },
      "+OutdoorSunlight_Quality": { "$ref": "#/definitions/measure" },
      "+OutdoorNoise_Value": { "type": "integer" },
      "+OutdoorNoise_Quality": { "type": "integer" },
      "+OutdoorAir_Quality": {
        "type": "array",
        "items": { "type": "integer" } },
          "+ViewType": { "$ref": "#/definitions/measure" },
      "+ViewRate": { "$ref": "#/definitions/measure" },
      "+ViewQuality": { "type": "integer" },
    },
```

Figure 8. Property valuation main script based CityJSON.

The second phase involves the assessment of data integration for Indoor Daylight. During this stage, a data pre-processing step was performed before incorporating the data into a CityJSON data file. For this evaluation, we utilized IFC data from a residential building and converted it into CityGML 3.0.

For data transformation, we employed two conversion processes, namely IFC to CityJSON and CityGML to CityJSON.

IFC to CityJSON: We used a tool-based C++ called "IfcEnvelopeExtractor" (Vaart, 2022) for this transformation step, which holds significant importance (refer to Figure 9). This stage was selected for demonstration purposes to automate the conversion of IFC files into CityJSON format. However, it is worth noting that this process primarily focuses on converting the building envelope and regrettably results in the loss of semantic information related to elements such as cost, dimensions, and more. To address these limitations, we proceeded to the next step, which involved a more extensive conversion process. The outcomes of this conversion were subsequently validated (please refer to Figure 10).

Figure 9. IFC2CityJSON automatic transformation results (from left to right: input file, output LOD 2.2 and LOD3.2.

Figure 10. Results validation IFC2CItyjson through cjval.

CityGML2CityJSON: We use the Python tool "CityGML-tools" and employ the "to-CityJSON" command within its command interface for automated conversion of CityGML files (refer to Figure 11).

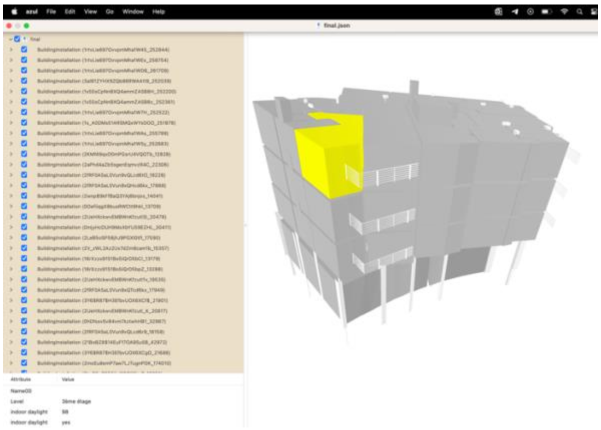

Figure 11. From CityGML to CityJSON results

The second phase involves merging the output files from both the IFC2CityJSON and CityGML2CityJSON processes using the "cjio" tool. This consolidation results in a single output file that contains the indoor daylight data, facilitating the creation of the extension data file that aligns with the extension requirements.

The final step includes the implementation of the indoor daylight extension, which is constructed based on the CityJSON output generated during the processing phase. This extension, incorporating indoor daylight and daylight quality as new attributes, is enriched with semantic and geometric data. The results are visualized using Ninja visualization software, as shown in Figure 12. Subsequently, the data and schema model codes undergo validation on an online platform for syntax and schema compliance. The results are edited to ensure validity.

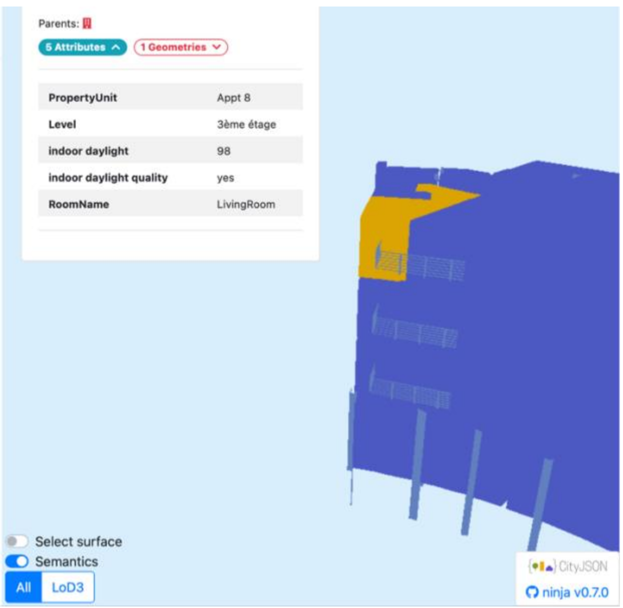

Figure 12. Data integrability results for indoor daylight test.

5. Conclusion

Modeling and integrating data for 3D property valuation is an active area of research. Within this article, we have navigated through the intricacies of it within the context of CityGML and Industry Foundation Classes (IFC) integration.

Our methodology encompasses the conceptualization, design, and development of the model, extending CityGML 3.0 enriched by IFC data. Despite encountering challenges in data integrability, highlighted by our exploration of the CityJSON standard, we persist in our pursuit of precision and specificity, developing independent ADE data models for each specific use case to ensure accuracy across diverse valuation scenarios.

By categorizing requirements into indoor and outdoor variables, we showcase the model's versatility and applicability, grounded in a modular structure that extends CityGML 3.0. This structure introduces the innovative concept of the "Property Unit" and its intricate connections to indoor and outdoor variables, ensuring flexibility and adaptability across valuation scenarios.

While progress has been made, challenges in data integrability persist. We remain committed to overcoming these obstacles, exploring alternative data formats like CityJSON. In our future work, we aim to extend the model to incorporate outdoor and interactive variables, alongside an official GitHub release and the development of an API platform.

Through a preliminary implementation using CityJSON, we have demonstrated successful integration. Future works also include polishing the implementation, uploading the extension to an official repository, and developing an essential API platform, which will facilitate the practical usability and scalability of the developed model.

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