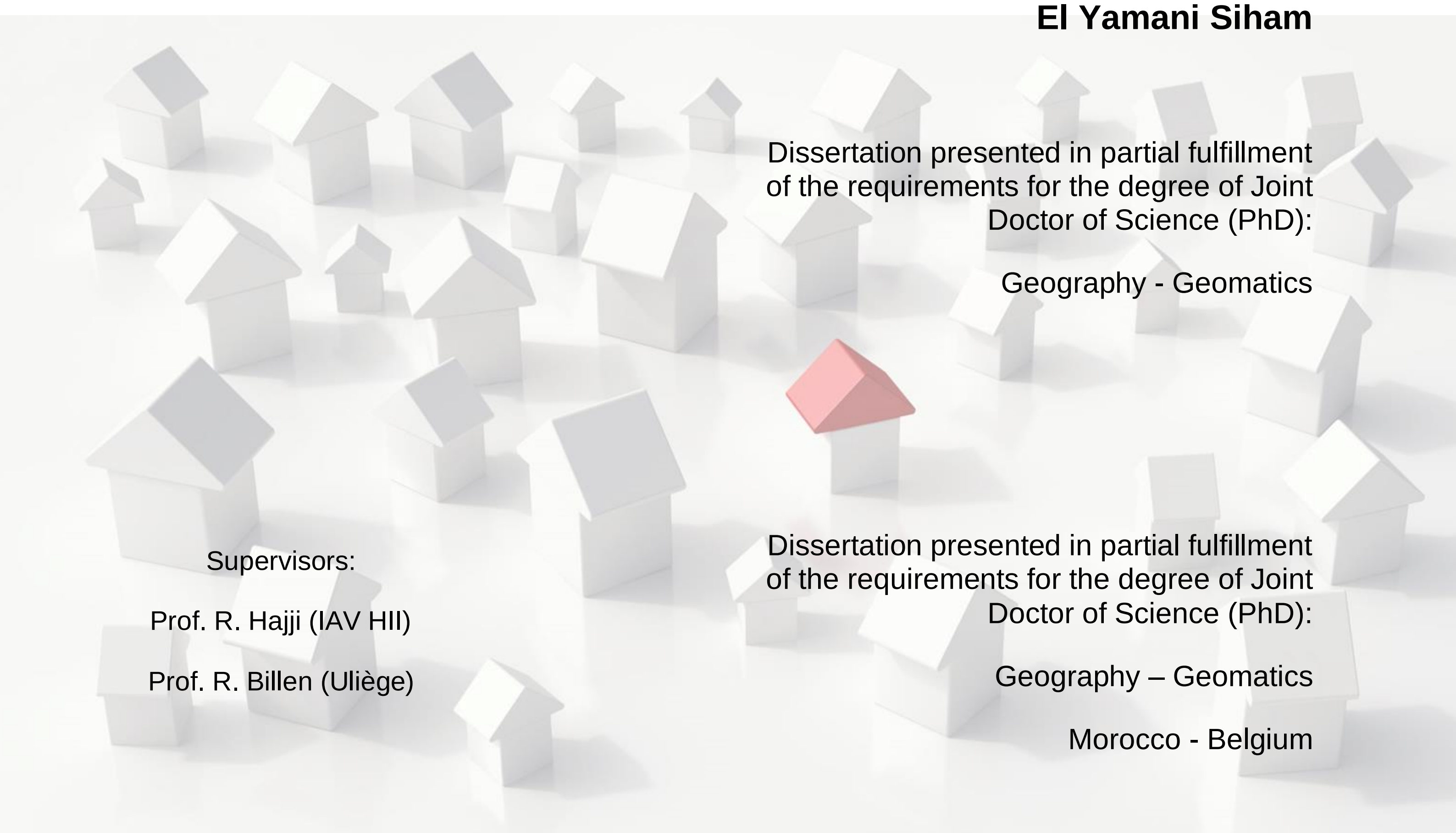
GEOGRAPHY DOCTORAL SCHOOL - Faculty of Science

COLLEGE OF GEOMATICS SCIENCE

Towards a 3D property valuation model:

Conceptualization and BIM-CIM based data integrability.

El Yamani Siham



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Abstract

The rapid urbanization and scarcity of land in recent decades have led to the emergence of vertically oriented and complex urban forms, posing challenges in accurately determining property values. The use of 3D models is crucial for accurate property valuation due to the volumetric and complex nature of these properties. However, existing literature lacks practical frameworks that consider the combination of multiple factors and their dynamic simulation at an urban scale, hindering the development of accurate valuation models.

Moreover, conventional valuation methods primarily rely on comparing sales prices with recent transactions, which limits their effectiveness in capturing the complexity of 3D building structures and accurately modeling environmental factors. To address these limitations, the integration of 3D modeling techniques such as Building Information Modeling (BIM) holds great potential in enhancing the hedonic pricing method and improving the accuracy of real estate valuation.

While previous studies have recognized the importance of indoor elements and 3D simulations of the outdoor environment for property valuation, there is still a need to simulate property valuation variables themselves. The use of industry standards like IFC (Industry Foundation Classes) and CityGML has been chosen for developing a standardized and efficient workflow to improve the accuracy of property valuation by integrating data from indoor and outdoor environments. This research explores the evaluation of indoor variables and property unit cost as an initial demonstration of the effectiveness of this approach and provides a solid foundation for future extensions in 3D property valuation.

By addressing the challenges in accurately determining property values in complex urban environments and developing a comprehensive 3D property valuation model, this research contributes to the advancement of property valuation practices. It explores suitable valuation approaches, defines 3D variables with a high impact on property value, integrates these variables into practical frameworks, and develops a feasible and generic 3D valuation model. The research findings provide valuable insights and guidance for stakeholders in the real estate industry, supporting informed decision-making processes.

The research questions addressed in this study include investigating suitable valuation approaches, acquiring 3D variables using advanced 3D modeling techniques, developing a workflow process for integrating these variables, and exploring the feasibility and adaptability of the approach for future implementation. The research encompasses four peer-reviewed publications, each focusing on different aspects of the research journey. These include an overview of property valuation approaches, the potential of BIM in real estate valuation, technical requirements of 3D variables, and data integration techniques.

In conclusion, this research successfully addresses the research questions by defining key 3D variables, exploring their acquisition through 3D modeling techniques, developing a workflow process for integration, and demonstrating the feasibility and adaptability of the approach. The developed 3D property valuation model, along with proposed research extensions, has the potential to revolutionize property valuation practices and decision-making processes in the real estate industry. By aligning with the pillars of the EuroSDR

project, this research contributes to the advancement and implementation of similar projects in the field of GEOBIM in urban applications.

The research extensions outline avenues for future exploration, including expanding the model to incorporate additional 3D variables, standardizing and ensuring interoperability, applying the model to different contexts, engaging stakeholders for industry adoption, and integrating advanced machine learning techniques. These extensions aim to enhance the effectiveness, applicability, and impact of the developed 3D property valuation model, paving the way for advancements in property valuation research.

Résumé

L'urbanisation rapide et la rareté des terrains ces dernières décennies ont entraîné l'émergence de formes urbaines complexes et orientées verticalement, posant des défis pour déterminer précisément la valeur des biens immobiliers. L'utilisation de modèles 3D est essentielle pour une évaluation précise des biens immobiliers en raison de leur nature volumétrique et complexe. Cependant, la littérature existante manque de cadres pratiques qui prennent en compte la combinaison de plusieurs facteurs et leur simulation dynamique à l'échelle urbaine, ce qui entrave le développement de modèles d'évaluation précis.

De plus, les méthodes d'évaluation conventionnelles reposent principalement sur la comparaison des prix de vente avec des transactions récentes, ce qui limite leur efficacité pour capturer la complexité des structures de bâtiments 3D et modéliser précisément les facteurs environnementaux. Pour remédier à ces limitations, l'intégration de techniques de modélisation 3D telles que la modélisation des données du bâtiment (BIM) présente un grand potentiel pour améliorer la méthode de tarification hédonique et accroître la précision de l'évaluation immobilière.

Bien que des études antérieures aient reconnu l'importance des éléments intérieurs et des simulations 3D de l'environnement extérieur pour l'évaluation des biens immobiliers, il est encore nécessaire de simuler les variables d'évaluation des biens eux-mêmes. L'utilisation de normes de l'industrie telles que IFC (Industry Fondation Classes) et CityGML a été choisie pour développer un flux de travail normalisé et efficace afin d'améliorer la précision de l'évaluation immobilière en intégrant des données provenant des environnements intérieurs et extérieurs. Cette recherche explore l'évaluation des variables intérieures et du coût unitaire des biens immobiliers comme démonstration initiale de l'efficacité de cette approche et fournit une base solide pour des extensions futures dans l'évaluation 3D des biens immobiliers.

En abordant les défis liés à la détermination précise de la valeur des biens immobiliers dans des environnements urbains complexes et en développant un modèle d'évaluation immobilière 3D complet, cette recherche contribue à l'avancement des pratiques d'évaluation des biens immobiliers. Elle explore des approches d'évaluation appropriées, définit les variables 3D ayant un impact significatif sur la valeur des biens, intègre ces variables dans des cadres pratiques et développe un modèle d'évaluation 3D réalisable et générique. Les résultats de la recherche fournissent des informations précieuses et des orientations pour les acteurs de l'industrie immobilière, soutenant les processus de prise de décision éclairée.

Les questions de recherche abordées dans cette étude comprennent l'investigation des approches d'évaluation appropriées, l'acquisition de variables 3D à l'aide de techniques avancées de modélisation 3D, le développement d'un processus de flux de travail pour intégrer ces variables et l'exploration de la faisabilité et de l'adaptabilité de l'approche pour une future mise en œuvre. La recherche comprend quatre publications évaluées par des pairs, chacune se concentrant sur différents aspects du parcours de recherche. Celles-ci comprennent une vue d'ensemble des approches d'évaluation des biens immobiliers, le potentiel du BIM dans l'évaluation immobilière, les exigences techniques des variables 3D et les techniques d'intégration des données.

En conclusion, cette recherche répond avec succès aux questions de recherche en définissant les principales variables 3D, en explorant leur acquisition grâce aux techniques de modélisation 3D, en développant un processus de flux de travail pour l'intégration et en démontrant la faisabilité et l'adaptabilité de l'approche. Le modèle d'évaluation immobilière 3D développé, ainsi que les extensions de recherche proposées, ont le potentiel de révolutionner les pratiques d'évaluation des biens immobiliers et les processus de prise de décision de l'industrie immobilière. En s'alignant sur les piliers du projet EuroSDR, cette recherche contribue à l'avancement et à la mise en œuvre de projets similaires dans le domaine du GEOBIM dans les applications urbaines.

Les extensions de recherche présentent des pistes pour des explorations futures, notamment l'extension du modèle pour incorporer des variables 3D supplémentaires, la normalisation et l'assurance de l'interopérabilité, l'application du modèle à différents contextes, l'implication des parties prenantes pour l'adoption par l'industrie et l'intégration de techniques avancées d'apprentissage automatique. Ces extensions visent à améliorer l'efficacité, l'applicabilité et l'impact du modèle d'évaluation immobilière 3D développé, ouvrant la voie à des avancées dans la recherche en évaluation des biens immobiliers.

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“They did not know it was impossible, so they did it.”

- Mark Twain

Chapter 1 - Introduction

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1.1. Context

Oscar Wilde's famous quote, "*Today, people know the price of everything but the value of nothing,"* highlights the urgency of transcending a narrow fixation on market prices and exploring the multifaceted aspects that truly underpin a property's value.

In the realm of real estate, this quote serves as a poignant reminder that many stakeholders tend to concentrate solely on financial metrics, such as market value, often overlooking the broader, intangible elements that significantly contribute to a property's intrinsic worth.

When assessing property value, relying solely on market data or price comparisons falls short. To gain a more precise understanding of a property's true value, one must delve into the intangible aspects—the quality of life and overall well-being it offers its residents. This holistic perspective encompasses various factors, including the property's physical attributes, its surrounding environment, and the experiences it affords its inhabitants.

However, these factors are complex to assess, especially in the context of intricate urban vertical expansion.

In reality, property valuation is inherently three-dimensional. It involves associating indoor parameters with the property as a 3D entity and considering outdoor parameters related to the 3D environment. Factors like views, noise levels, pollution, and sunlight for each property unit floor profoundly impact property value. With the ongoing digitalization of buildings and cities, research and practices have evolved to develop numerous urban applications that simulate these variables.

Recent research has identified specific 3D variables that significantly influence residential property values. For example, factors like noise, sunlight, pollution, and the quality of the view can impact property values by approximately 9.76% (Ricker, 2019). Solar radiation also plays a significant role in determining prices, especially for properties at higher elevations (Helbich et al., 2013). Studies have shown that using 3D modeling techniques and data sources to define these 3D variables leads to more accurate property valuations (Isikdag, Horhammer, Zlatanova, Kathmann, & van Oosterom, 2015) (Figure 1.1).

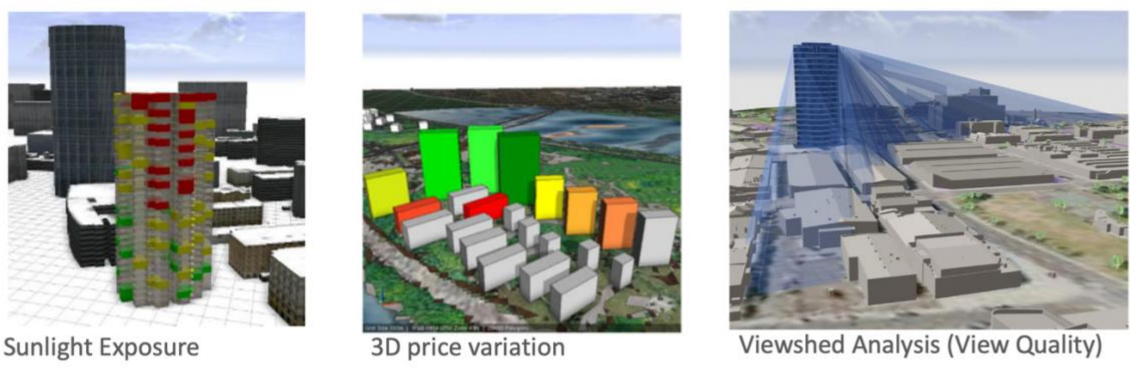

Figure 1.1: Research examples for modeling these variables with relevant impact on property value

One notable model for this purpose is the International Valuation Information Model, an extension of the Land Administration Domain Model (LADM) based on the ISO 19152:2012 standard. It serves as a foundation for property valuation, drawing data from 3D cadastral models and recording services as primary sources (Kara et al., 2020, 2018). Some models primarily use 3D models to visualize these variables, enabling experts to assess them within a 3D Geographic Information System (GIS) environment (Toppen, 2016).

Real estate valuation should also benefit from 3D technical achievements in 3D building and modeling techniques, such as BIM (Building Information Modeling) and CIM (City Information Modeling). However, the challenge lies in defining and obtaining these variables for property valuation purposes, given their use across multiple urban applications.

It's more than a technical challenge; it's about rethinking the concept of 3D variables and how feasible and interoperable it is to assess their requirements and classifications in a 3D context. Biljecki structured this approach into several requirements (Figure 1.2):

1. Distinguishing use cases based on whether they require specific semantics and/or attributes, similar to Ross's approach, but with limitations discussed in Section 2.

2. Using the required minimum level of detail (LOD) as a classification criterion for 3D city models. However, this approach faces challenges, such as inconsistent LOD reporting, dispersed LOD usage, and limited performance investigations.

3. Grouping use cases by the level of spatial granularity, considering the spatial extent of the object of interest. Yet, this approach falls short due to substantial variation within each use case.

4. Using spatio-semantic coherence, which is crucial for some use cases related to energy but is not a suitable criterion due to overlapping considerations within use cases.

5. Differentiating use cases based on the nature of their output, whether quantitative or non-quantitative. However, this criterion is excluded due to the inherent fuzziness in quantifying certain outputs.

6. Exploring the role of textures in use cases that prioritize visualization. Still, there's no clear separation between use cases, and limited research exists on the performance impact of textures in 3D city models.

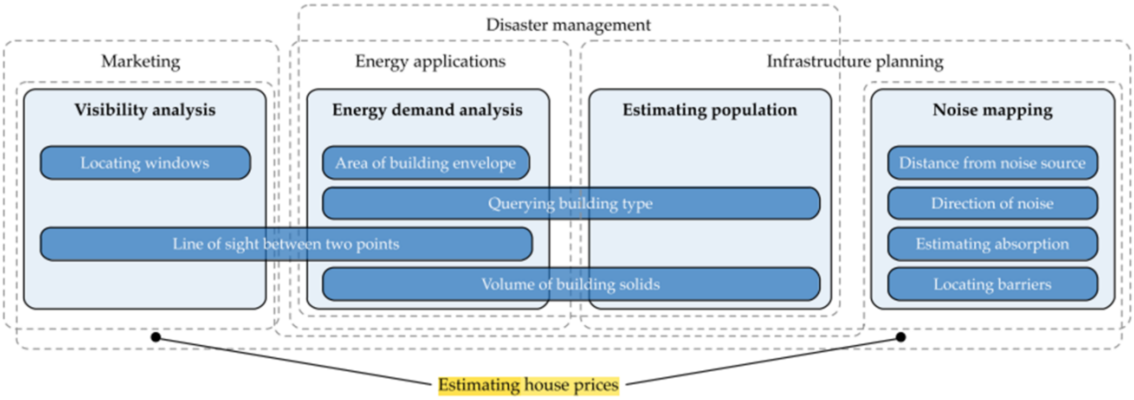

Figure 1.2: Example of the challenge of overlapping definitions for property valuation variables arises due to their shared usage in other applications, such as marketing and infrastructure planning.

In essence, the challenge is to adapt and choose among various urban use cases while addressing their overlap. Rethinking how these variables interact and defining their requirements is an underexplored aspect of research. For instance, consider noise requirements; estimating noise's impact on real estate value is crucial, but it often relies on predictions rather than on-site surveys. Integrating such factors into real estate price estimation, especially at a granular scale, is where BIM modeling approaches become indispensable. A BIM model encapsulates geometry, topology, and specific attributes of building elements, allowing advanced analysis in real estate valuation, such as quantity take-off and simulations of factors like lighting, ventilation, and noise propagation(Figure 1.3).

The core idea is not just data integration but providing a generic model where 3D variables are defined with minimum requirements to make them implementable in complex urban contexts. This poses a significant challenge that we aim to address in this study.

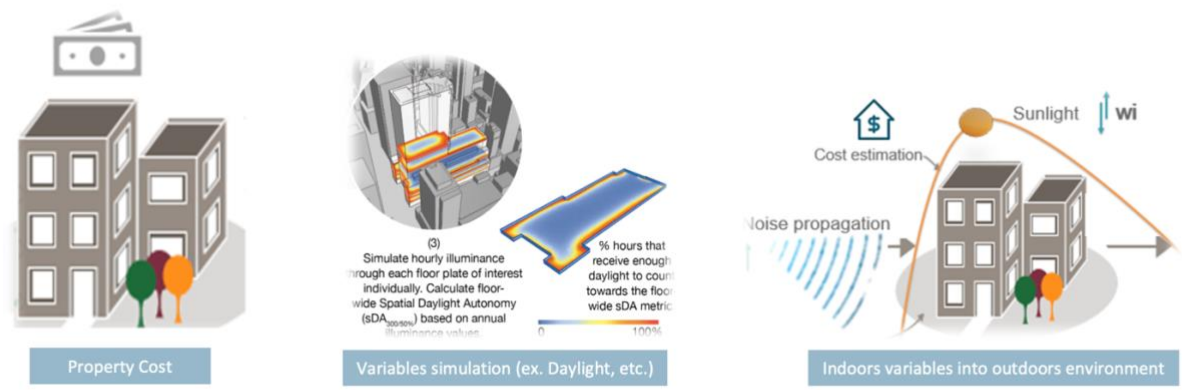

Figure 1.3: BIM and CIM capabilities to model 3D variables for property valuation.

1.2. Research questions

The current limitations faced in accurately assessing property values in complex urban environments highlight the need for an integrated approach that incorporates 3D modeling techniques, specifically Building Information Modeling (BIM). This research aims to address these challenges and answer the following main research question:

"Can a comprehensive and generic 3D property valuation model be developed using BIM and CIM data, which incorporates 3D indoor and outdoor variables to accurately determine the actual value of a property?"

To address this main research question, the following elementary research questions are proposed:

1- By investigating the suitable valuation approach for property valuation, how far can we define the 3D variables with high impact on property value?
2- Considering the current advances in 3D modeling techniques (BIM, CIM), how can we obtain these 3D variables required for property value?
3- How can a 3D property valuation model be effectively developed to incorporate the required 3D variables, towards a generic and implementable 3D property valuation extension?
4- Could we develop a data integrability approach: A use case where the feasibility of our property valuation model is demonstrated? Where 3D indoors and outdoors variables can be sourced from IFC and CityGML?

1.3. Document outlines

The research outlines are structured around four three -reviewed publications (chapter 2,3 and 5), chapter 4 is not a published publication. and each chapter is preceded by specific preambles that introduce the topic and provide additional context.

Chapter 2: 3D Property Valuation background

provides an in-depth overview of various property valuation approaches, standards, and practices. It explores the strengths and limitations of different methods and introduces the hedonic pricing approach as the most suitable for integrating Building Information Modeling (BIM) and 3D Geographic Information Systems (GIS) techniques. The chapter emphasizes the need for incorporating 3D models in property valuation to enhance accuracy and efficiency.

Chapter 3: 3D Valuation Model Requirements

delves into the technical requirements of 3D variables in the context of property valuation. It analyzes the 3D spatial and non-spatial elements of these variables to determine which ones can be derived from 3D city models and building-scale elements. The chapter explores the capabilities of BIM and City Information Modeling (CIM) in providing essential information for property valuation, both indoors and outdoors. It emphasizes the need for comprehensive data integration and highlights the potential of utilizing 3D models for accurate property valuation.

Chapter 4: Towards Extending CityGML for Property Valuation

proposes the development of an Application Domain Extension (ADE) specifically designed for property valuation within the CityGML data model. By addressing the limitations of CityGML for property valuation use cases, the need for a specialized ADE becomes apparent. The chapter justifies the design decisions and outlines the core module and packages of the ADE-Valuation model, based on enriching CityGML with Industry Foundation Classes (IFC) datasets. It presents various IFC enrichment scenarios and their integration into CityGML ADEs, resulting in a cohesive ADE that seamlessly incorporates indoor and outdoor variables for accurate property valuation.

Chapter 5: 3D Variables Data Integration use case

introduces a meta workflow for the integration of data from Industry Foundation Classes (IFC) and CityGML to enhance property valuation. The chapter presents an approach for integrating these data sources and discusses their relevance to 3D property valuation. A detailed evaluation of the proposed approach is conducted by testing it with two indoor variables, serving as a demonstration of its effectiveness and providing valuable insights into its practical application.

In summary, these chapters collectively detail the research path towards creating a comprehensive 3D valuation model for property valuation. Encompassing a wide array of topics, they explore property valuation approaches, standards, and the fusion of BIM and CIM capabilities with 3D variable integration. As a result, this body of work significantly advances property valuation practices, offering valuable insights, guidelines, and practical methodologies for seamlessly integrating 3D modeling techniques into the valuation process (see Figure 1.1). The overarching aim is to develop a versatile and generic property valuation model extension, encompassing the best practices and standards to enhance the accuracy and efficiency of property valuation in 3D urban environments.

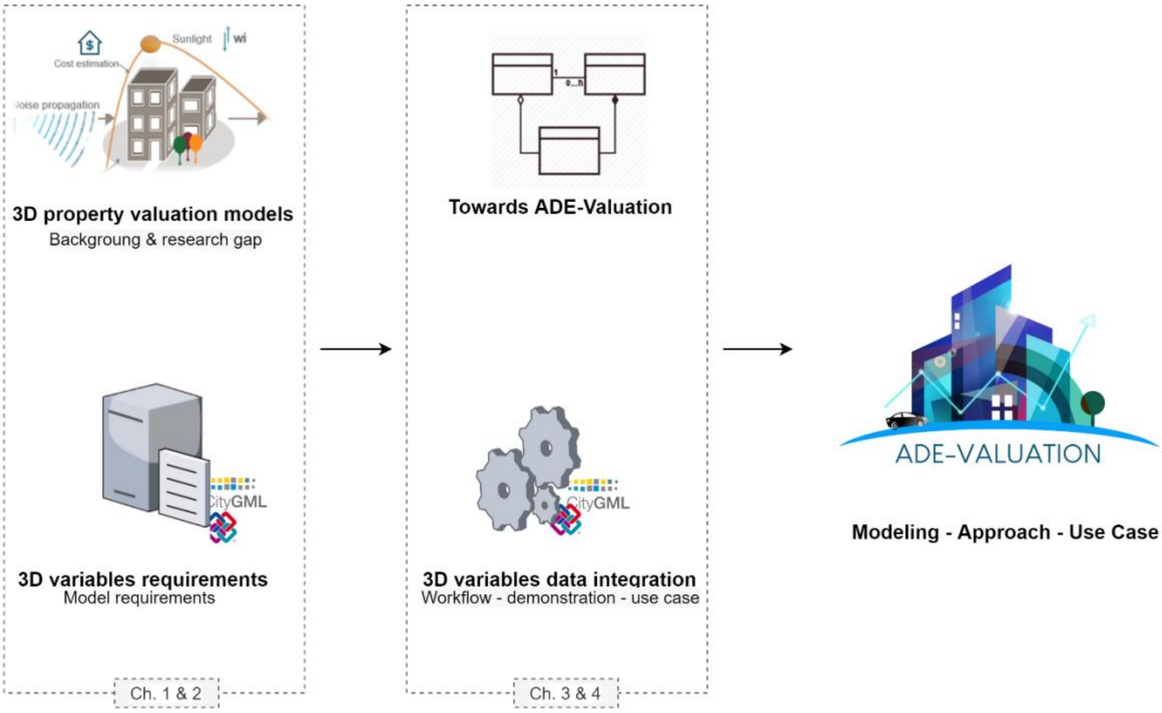

Figure 1.4: Hierarchical Structure and Transitions Between Thesis Chapters

Chapter 2 - 3D Property Valuation background

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Preface

This chapter is published in a book by ISTE Ltd and John Wiley & Sons, Inc. in the beginning of 2021. At the beginning of the thesis project, the main objective is to emphasize the importance of integrating Building Information Modeling (BIM) and 3D Geographic Information Systems (3D GIS) in the field of real estate valuation. This research aims to address the challenges posed by the rapid urbanization and limited land availability, which have resulted in the emergence of complex vertical urban forms.

The primary focus is on accurately determining property values in such intricate spatial configurations. Estimating the value of a property involves identifying and quantifying various factors that contribute to its overall worth. Recognizing the significance of three-dimensional models, the use of 3D modeling became crucial for achieving precise real estate valuations.

The motivation for this study originates from the realization that various stakeholders, including investors, developers, decision-makers, tax authorities, banks, and insurance companies, heavily rely on property valuations as key indicators for future actions such as property acquisition, construction, transfer of ownership, and value adjustment.

Recent studies have indicated that employing 3D modeling techniques for property value variables leads to more accurate estimates. Among the models explored was the International Valuation Information Model, an extension of the Land Administration Domain Model (LADM) from ISO 19152:2012. Additionally, the rising popularity of BIM in the real estate industry and the potential of 3D GIS for geospatial analysis and visualization expanded the scope of applications beyond construction engineering.

Although BIM and 3D GIS serve distinct purposes, their integration offers significant potential for creating comprehensive digital representations of urban areas. This integration would provide a 3D information base for simulating real estate values in both indoor and outdoor contexts of buildings. However, at the time of writing, research in this field is still in its early stages, and there was a lack of practical frameworks that considered the combination of multiple factors and their dynamic simulation on an urban scale.

Hence, the aim of this chapter is to investigate the concept and approaches of real estate valuation, explore the potentialities and applications of BIM and 3D GIS in this domain, and analyze the challenges associated with their integration for accurately determining property values. Furthermore, the chapter provides examples of how BIM and 3D GIS could individually or jointly contribute to 3D modeling and simulations of variables in real estate valuation.

By providing this preamble, we situate the writing of the second chapter within the broader context of the thesis project. It aligns with the overarching goal of comprehensively examining the integration of BIM and 3D GIS in real estate valuation and contributes to the ongoing discourse in this field. As the thesis project progresses, it became evident that there is a need for more advanced and accurate approaches to property valuation, particularly in the context of complex urban environments.

Based on article, Chap6 (El Yamani, R. Hajji et al. 2021)

BIM and 3D GIS Integration for Real Estate Valuation

Published by ISTE Ltd and John Wiley & Sons, Inc.

2.1. Introduction

In recent decades, accelerating rates of urbanization and land scarcity have led to the expansion of vertical and increasingly complex urban forms. This spatial configuration presents a major challenge for the accurate determination of property values.

Estimating the real estate value of a property is the process of identifying and quantifying each determinant of that value (RICS 2020). The volumetric nature of a property dictates the use of 3D models for accurately determining real estate value. Throughout the lifecycle of a residential asset, several stakeholders (investors, developers, decision-makers, tax authorities, banks and insurance companies, etc.) require the valuation of these properties as a main indicator for any future action (acquisition, construction, transfer of ownership, value adjustment, etc.).

Studies have recently shown that 3D modeling of the variables of a property value results in more accurate estimates (Işıkdağ et al. 2015). Several models have been developed for this purpose. Among them is the International Valuation Information Model, which is an extension of the Land Administration Domain Model (LADM) from ISO 19152:2012 (Kara et al. 2018, 2020).

Building Information Modeling (BIM) is one of the most recent paradigms in the real estate industry, which is becoming increasingly popular in construction engineering, but whose use also extends to several topics associated with “Smart Building”, including energy efficiency, noise propagation, urban regulation, real estate valuation and so on.

3D Geographic Information Systems (3D GIS), on the other hand, have the potential for geospatial analysis and 3D visualization, which can simulate the impact of several external factors on the real estate value of a property in a 3D urban environment.

BIM and 3D GIS have different purposes, but their integration offers great potential in the production of digital mock-ups at the urban scale. Such integration will provide a 3D information base to undertake real estate value simulations in both an indoor and outdoor context of buildings. Research in this area is still in its infancy and investigations in the literature are far from proposing a practical framework for real estate valuation that considers the combination of several factors and their dynamic simulation at an urban scale.

In the following sections, the concept and approaches of real estate valuation are presented, the main potentialities and applications of BIM and 3D GIS in real estate valuation are discussed, and the challenges that come with integrating BIM and 3D GIS in the accurate determination of the value of a property are analyzed. Also, we illustrate, through examples of uses, how BIM and 3D GIS can contribute individually or jointly in 3D modeling and simulations of variables in real estate valuation.

2.2. Real estate valuation: concepts, approaches and standards

The residential property market plays a prominent role in economic development. Thus, any inaccurate estimate of property value will have deplorable consequences for future developments in the construction industry and real estate economy (Curran et al. 2018). Many urban cores may be subject to overvalued residential property estimates that make housing prices increasingly unaffordable.

2.2.1. The concept of real estate valuation

Real estate appraisal is a complex process of determining the best price for which a property can be exchanged (Pagourtzi et al. 2003). Much research has discussed the issue of the accuracy of real estate appraisals. Some of them assume that the reliability of a real estate valuation depends on the quality of the variables considered (Mooya 2016). The choice of a valuation approach and model are also key criteria in the accurate assessment of values. These variables differ from one appraisal to another depending on the type of stakeholder (real estate expert, tax authorities, etc.) and their opinion on the value, the object of the appraisal (transfer of property, future construction, renovation, real estate credit, etc.) and the estimation approaches used (comparison item, cost approach, hedonic approach, etc.). However, certain variables are common to all use cases, such as the location of the property.

The value of a residential property is closely linked to the determination and integration of the inherent characteristics of the residential property (location, surface, accessibility, noise, age, etc.). It is dependent on several factors that can be classified into internal and external factors. The internal factors include the surface area of the dwelling, the density of the building (ratio of the habitable surface area to the sum of the floor areas), the number of rooms, the elements of comfort (sunshine, ventilation, acoustic comfort, thermal comfort), the number of floors, and so on. The external characteristics include all the attributes to do with the micro- and macro-spatial location of the dwelling, allowing us to understand the dynamics of the place (accessibility of transport, social atmosphere, etc.): the geographical location, social environment and physical environment. These variables can also be classified into subjective and objective variables (Chan and Abidoye 2019). The so-called objective variables are usually directly quantified (accessibility and structure variables). Subjective variables are determined qualitatively, either through the appraiser’s assessment as a connoisseur of the market, or through a survey that attests to the preferences of potential buyers in a small market (Zhang 2019).

2.2.2. Real estate valuation approaches

There are several real estate valuation methods. There are so-called traditional and advanced methods (Pagourtzi et al. 2003). The traditional methods consider a residential property as a homogeneous entity comparable to other similar entities in terms of selling price, income and cost. These are the comparative approach (Adetiloye and Eke 2014), the income approach and the cost approach also known as the developer balance sheet. However, the advanced methods are based on automatic modeling techniques and require a significant history of real estate transaction data to estimate the value of the property (Monson 2009). These include Artificial Neural Network (ANN) techniques (Chan and Abidoye 2019), hedonic price models coupled with geospatial analysis methods, autoregressive–moving-average (ARMA) models (Cohen and Coughlin 2008), etc.

Recent research has revealed the inability of traditional approaches to evaluate residential property objectively and accurately (Mooya 2016). The lack of available market data and the absence of models that consider the complex and heterogeneous nature of residential property leave real estate valuation practices subjective and non-transparent.

2.2.3. Real estate valuation norms and standards

There are several regional and international associations and professional bodies whose role is to establish real estate valuation standards. Some of these standards include: the European Valuation Standards (EVS – The Blue Book) (TEGoVA 2016), the International Valuation Standards (IVSC 2016) and a set of standards published by the International Association of Assessing Officers (IAAO). These standards focus more on the procedural aspects of real estate appraisal and the definition of so-called conventional methods to define the practical exercise of real estate appraisals. For example, the International Valuation Standards (IVS) set forth the broad principles of valuation.

The Land Administration Domain Model (LADM) is an international standard that defines data modeling for land administration. LADM is a conceptual model that meets the guidelines of ISO 19152:2012. This model provides an extensible basis for the development of other data models related to property management, land value and land use. The LADM Valuation Information Model provides detailed information on legal, geometric and physical characteristics for property valuation units (Kara et al. 2018).

It provides a basic model for managing data about stakeholders in appraisal practices, appraisal entities and their characteristics. Note that this model focuses only on administrative assessments related to property tax assessments and excludes other public and private sector assessment activities.

2.3. BIM and 3D GIS for real estate valuation

The literature identifies several challenges for real estate valuation (Miens et al. 2010), among which we mainly mention: the management of uncertainty in the value estimates of numerous parameters related to real estate value as well as the lack of transparency and the subjectivity of the expert. The resolution of these challenges requires the use of numerical methods that allow the integration of different variables and their simulation within the same model.

As a result of research into the identification of three-dimensional variables that influence the determination of residential value, we propose the following classification:

– Variables based on 3D data sources: 2D or non-spatial data that are potentially extracted from 3D models (e.g., 2D surface from a 3D model).

– Variables requiring 3D modeling (quantification): variables whose values can be more accurately determined through 3D modeling and simulation.

– Variables based on a 3D environment (qualification): 3D modeling is not intended to overcome the subjective assessment of certain variables but rather to provide decision-makers and evaluators with a 3D view to facilitate their evaluations.

The emergence of building information acquisition and modeling technologies, and the rich semantic and geometric characteristics of its building elements (Eastman et al. 2011), have motivated researchers to exploit the potential of BIM models in property management, taxation and valuation. BIM provides a digital building information model based on object-oriented modeling rich in geometric, semantic and parametric building data, from which views and data appropriate for the needs of different users can be extracted and analyzed to produce information that can be used to make decisions. Through this type of modeling, BIM can address several real estate assessments challenges.

– BIM allows one to integrate in the same model several parameters related to the characteristics and behavior of the building to have an accurate estimate of the value of the property, and to consider the interactions between the various parameters.

– BIM ensures a dynamic simulation of the construction cost, which is a very significant factor in the real estate evaluation.

– BIM makes it easy to more accurately determine some parameters related to certain internal characteristics of the building, such as sunlight, lighting, thermal comfort and acoustic comfort.

– BIM supports all the simulations related to the building envelope as well as the different elements to analyze the impact of a certain geometrical configuration on the real estate value of a property.

Atazadeh et al. (2017) discussed the possibility of using BIM to model 3D land administration. Their work highlighted the challenges of the current land administration process and the importance of integrating 3D information. Kara et al. (2018) identified the type of analysis that can be used for land valuation in the context of the land administration domain model. They also discussed the importance of integrating 3D analysis into land valuation and conducted analyses using a dataset from the Netherlands.

BIM models take advantage of the potential of the IFC standard in the modeling of the internal elements of the building (volumes, cost and energy simulation). However, it remains limited to applications in the field of architecture and construction. Several studies have concluded that it is possible to develop IFC extensions adapted to several domains, namely applications in terms of 3D property management. Atazadeh et al.

(2017) use the spatial element “IfcSpace” to manage 3D legal property objects and to propose a prototype that enriches BIM/IFC models with legal semantic information.

Beyond the building scale, 3D GIS adds another dimension of 3D visualization and spatial analysis, to better estimate the value of a property in relation to several parameters characterizing the external environment of the building, which can be physical, environmental, social and so on. Thus, the BIM/IFC modeling approach can be extended to the urban scale, aiming to combine its strong semantic capabilities with the spatial analysis tools offered by GIS systems to assist the real estate value simulation process (Plume and Mitchell 2011).

In real estate appraisal, the purpose of 3D visualization is to visualize the input elements for an appraisal and let the user (e.g., the appraiser) subjectively qualify the value of the composite elements of the value according to their expertise and knowledge of the area and the real estate market. This subjectivity can significantly affect the accuracy and impartiality of the results of a real estate valuation. In some cases, visualization provides additional information to the appraiser by allowing them to take into consideration certain configurations, such as the presence of obstructing buildings nearby and 3D intervisibilities. While visualization is useful for the appraiser to consider certain external factors in the space around the building in the value simulation, other elements necessary for real estate appraisal are derived from geospatial analysis. This is the case, for example, for the simulation of the building’s energy performance.

The use cases for 3D city models are numerous and cover several domains (Biljecki et al. 2018): energy simulations, noise modeling, 3D cadastral, multi-temporal analysis, flow analysis and so on. Real estate valuation can also benefit from 3D GIS models. In a broader perspective and with the advent of urban models, the insertion of the building in an urban context will make it possible to easily verify the respect of the urbanistic potentialities in front of the proposed conceptual design of the real estate and make it possible to readjust the elements of future valuation of the real estate before its construction as well as a prior evaluation and adjustment of its value. Işıkdağ et al. (2015) demonstrated that 3D GIS models could be used for the valuation of existing properties. Practically, their research aimed to identify the necessary information elements for the taxation value of real estate.

2.4. BIM-3D GIS integration: a new paradigm for real estate valuation

The possibilities to access and use 3D geographic information in very specific application areas have increased exponentially in recent years. However, many countries still do not have 3D city models, or do not allow access to the geographic information related to these models and rely on 3D visualization applications. Specifically, real estate appraisal adds another challenge, that of accessing transaction information and value estimation histories for each vertically arranged property. While this information can be accessed in some cases in administrative registration databases, it is incomplete and only reflects average values for a specific area, which is limited to taxation applications.

The 3D geometric data of buildings includes their height, floor area, roof area and orientation. This type of data is still underutilized in real estate price analysis, but research to date has shown promising results in improving predictions. Also, studies have shown that noise in a neighborhood is influenced by building size. The age of a building, an important feature of many hedonic price models, can also be estimated using 3D data. 3D data can be used to digitally represent views of apartments, considering the height of neighboring buildings and orientation.

BIM and 3D GIS integration is prominent in many applications. The previous section highlighted their promising potential in real estate valuation. Several 3D factors that make up real estate price and value have been the subject of recent research. These relate to the physical characteristics of the property as well as the environmental factors of its immediate vicinity. The integration of BIM and 3D GIS makes it possible to account for these two types of parameters (Figure 2.1) as well as the relations that can exist between them.

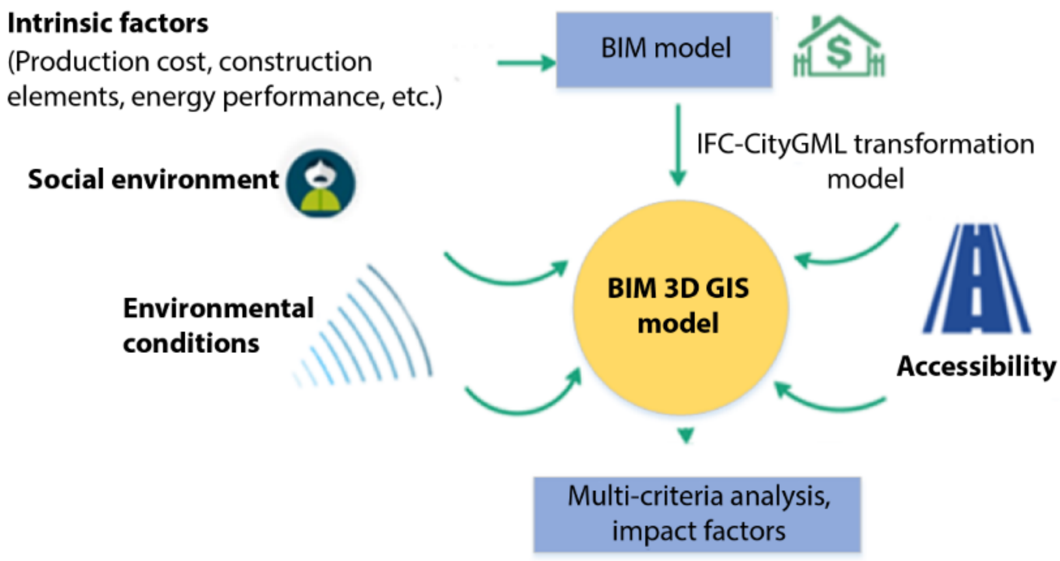

Figure 1.1:. BIM and 3D GIS integration for real estate valuation.

BIM-3D GIS integration is a complex process that presents major technical challenges, mainly due to the heterogeneities between the two information models in terms of spatial scale, level of granularity and detail (LoD), geometry representation methods, storage and access methods, as well as semantic differences between the models.

In the context of urban applications, the integration of the BIM urban model in a 3D GIS environment is an embryonic niche, particularly in real estate appraisal, for which there are mainly three integration approaches:

– Application level: real estate valuation use cases at this level are limited to visualizing the BIM model for cost estimation in a 3D GIS environment, for example (Arcuri et al. 2020).

– Process level: this level consists of setting up an architecture to integrate BIM and 3D GIS into a workflow where they are simultaneously operational but remain separate. This approach is flexible but presents several challenges in terms of interoperability. This is the most recommended level for real estate appraisals.

– Data level: this is a more flexible level of data integration where one of the two models (BIM or GIS) is extended through its standard to accommodate the data and elements of the other model. Another more advanced level of extension is the development of a meta-model that mediates between the two models at a high conceptual level. The GeoBIM extension by de Laat and van Berlo (2011) is an example of extending CityGML with BIM elements.

The challenge of interoperability between the two BIM and 3D GIS models does not allow us to take full advantage of its potential in real estate valuation. Most research is limited to the first two levels of integration, which results in significant data loss during this process. However, the third level is the most suitable in terms of accuracy, performance and applicability in real estate appraisal.

2.5. Examples of BIM and 3D GIS simulations for real estate valuation

Table 6.1 below summarizes the different use cases of BIM and 3D GIS for real estate valuation, which are analyzed and discussed in the following sections.

Use cases	Example of application in real estate value	Model	References
Simulation and quantification of internal factors of a property	Construction cost estimates Energy simulation	BIM	El Yamani *et al.* (2019), Morano *et al.* (2019) and Arcuri *et al.* (2020)
Identification of comparable units	Comparative approach	BIM/3D GIS	El Yamani *et al.* (2019) and Couto *et al.* (2021, pp. 15–19)
3D visibility analysis	Evaluation model	3D GIS	Yu *et al.* (2007) and Kara *et al.* (2018)
3D cadastral model	Real estate tax value Real estate price benchmark Real estate transactions	BIM/3D GIS	Işıkdağ *et al.* (2015) and Kara *et al.* (2020)

Table 2.1. Potential use cases for BIM and 3D GIS in real estate assessment

2.5.1. Simulation of the internal factors of a property

BIM is a detailed digital representation of geometric, semantic and parametric data of the building. It is a model that is becoming increasingly used in several fields, notably in the energy efficiency of buildings, by analyzing sunlight, illumination and ventilation. In addition to simulations of the structural and architectural elements of buildings, BIM simulations in the field of construction economics also have an important contribution for a dynamic calculation of the time and cost of construction to save budgets and optimize deadlines. BIM also allows a micro-environmental analysis of the property to be evaluated, to be able to identify the factors on which its value depends, namely indoor air quality, sunlight, acoustic comfort, humidity, ventilation, and so on (Figure 6.2). This is done by performing analyses related to the internal environmental parameters of the building.

BIM software allows an automatic and precise extraction of the elements determining the value of a property through quantity extractions (take off quantities, calculation of surfaces and volumes, etc.). The construction cost approach calculates the construction costs of a building and adds the land costs to determine the value of a property. To calculate the exact construction costs of a property, the BIM model must be characterized by a high semantic accuracy on the building data.

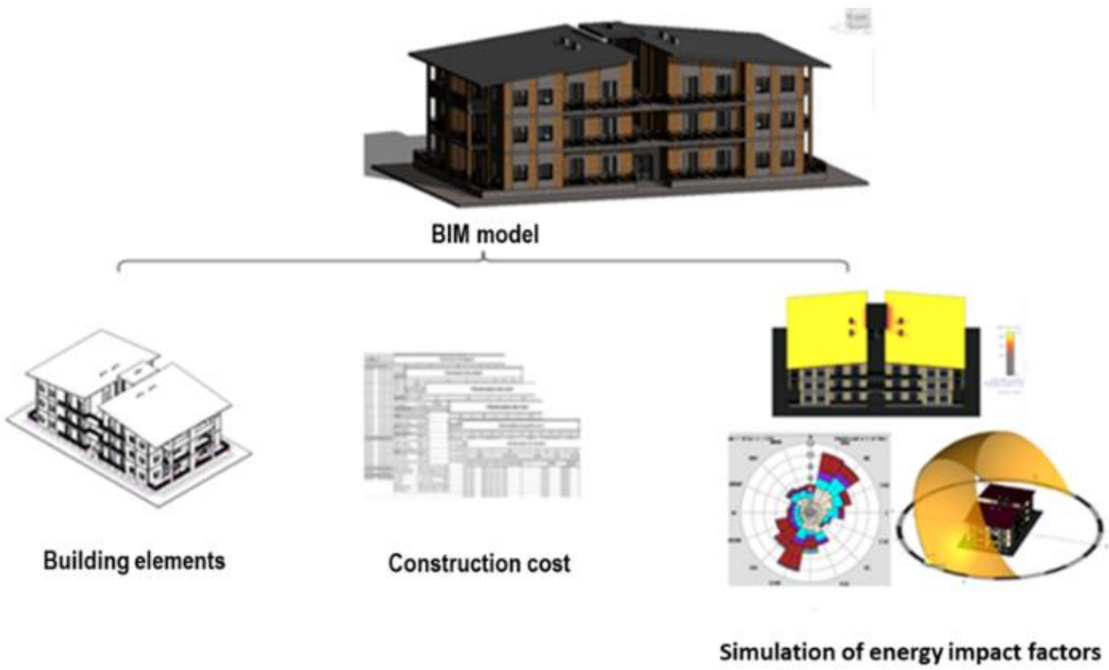

Figure 2.2. Internal factors for assessing the value of a property.

Generally, the cost estimation can be broken down into two steps. The first step consists of quantity take-off from an IFC file. The second step involves the determination of elementary prices (Figure 6.3). Three cost estimation options can be distinguished (Eastman et al. 2011): (1) exporting the quantified building elements to a cost estimation software; (2) using a BIM tool (Quantity take-off); and (3) linking the BIM tool directly to the cost simulation software. Tools for estimating the cost from a BIM model include Open BIM Cost estimate, BIM C, BIM OFFICE, BIM Estimate, Vico Office, BIM Vision, Innovaya, JustBIM, Cost X, Cost OS, Dprofiler, Autodesk Quantity Take-off and Autodesk Navisworks.

Cost estimation is strongly related to the quality, geometric accuracy and level of information of the model. In the absence of specific standards for cost estimation, the level of detailed specification for building structures generally refers to the Level of

Development (LoD). The LoD clearly defines the elements that must be included in the model. LoD 350 appears to be the most optimal for cost estimation (Vitasek and Zak 2018).

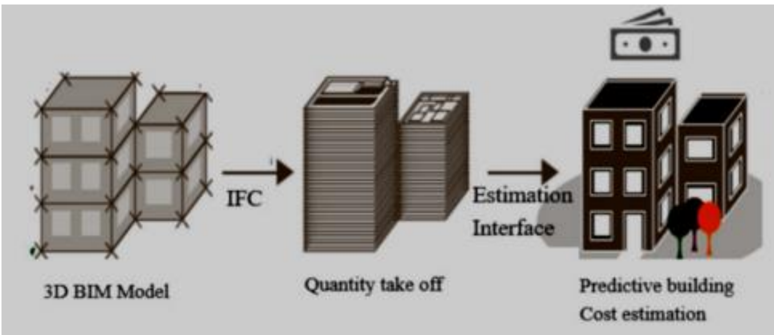

Figure 2.3. Cost estimation from an IFC model

Other internal parameters determining the estimation of the value of a property concern the thermal comfort within a building. Among these parameters, we can mention ventilation, internal noise, sunshine and so on. Indeed, air quality and ventilation contribute to the promotion of a healthy and comfortable environment. Acoustic analysis, on the other hand, through noise simulation, is very important to the comfort within a building and that should be taken into consideration when designing the form and choosing building materials (Christensen 2018).

Sunlight analyses allow us to predict the energy consumption of the future building. Determining this factor is important for real estate valuation because it allows for improved occupant comfort and health. Analyses before the construction of the building make it possible to predict the optimal design to save electrical energy consumption. The simulations are translated into several factors: the apparent sun path, shading and lighting. These analyses are very useful in the pre-construction phase, as an adequate daylighting plan can reduce energy costs and avoid unwanted heat absorption in summer. The location and dimensions of openings (e.g., windows and doors) are decided based on the result of this analysis (Khan et al. 2019).

2.5.2. Identification of comparable units of the property being appraised.

These applications primarily use previously transacted/leased or appraised properties as a comparable basis for determining the value of appraised properties. This enhanced sales comparison approach based on appraisal methods can use a 3D GIS to find comparable sales units based on various factors impacting the property value. Using a 3D city model to identify comparable sales units is primarily limited to visualization and leaves room for the subjectivity of the appraiser. Different spatial operations are used to calculate the factors mentioned above. The search for comparable properties in terms of physical, structural or environmental characteristics is mostly applicable to any real estate valuation use case: – estimating the tax liability of a property to find comparable ones; – estimating the price/value influence factors.

2.5.3. 3D visibility analysis

Geospatial analysis through 3D GIS allows for the accurate identification of real estate value in a three-dimensional environment. The research focuses on the property visibility polygon as an influencing variable on property value. The objective of a 3D model is to analyze and quantify the visibility polygon of real estate objects on large surfaces. The added value is mainly in terms of efficiency by performing the analysis and visualizing the results in a 3D space. Without the 3D model, an observing agent would have to determine the visibility polygon of a building by passing through each floor and making measurements from different positions, while respecting the level of detail required to perform the 3D simulation. In practice, visibility modeling requires the availability of openings/facades for the 3D model, or even an intrinsic/extrinsic advanced quality. Such modeling will allow the following simulations:

– estimated exterior noise level at the front of the property at different floors.

– pollution level at the window/opening level.

– air quality at property openings.

– quality of view to observe from an aperture.

– rate of exposure to natural sunlight from outside and inside the property.

– proximity to various sources of noise/pollution.

2.5.4. Valuation of tax property elements

3D cadaster 3D cadastral models are widely explored for the management and modeling of real estate registration rights. Thus, these models are introduced to estimate the factors that influence the average value of real estate according to the types of assets. This reference value is considered as a basis for taxation.

Real estate valuation is, in most countries, the basis for calculating taxes. The value depends on several factors, including physical characteristics (geometry, building materials, and other characteristics related to quality and occupant satisfaction) and legal factors (rights, restrictions and liabilities) (Işıkdağ 2015). Işıkdağ et al. (2015) discuss the use of digital building models and cadastral models when determining real estate valuation information. However, real estate appraisal stakeholders are not yet taking advantage of the potential of BIM and 3D cadaster in real estate valuation (Işıkdağ et al. 2015) Legal information modeling allows the creation of 3D legal objects. These illustrate the administrative limits of the property in volume. The fact that the space allowed for construction is larger than the size of the construction has a positive influence on its market value. In addition, other types of legal information can influence the value of a property (rights are a surplus value, easements a deficit value) (Işıkdağ et al. 2015).

The exploitation of the 3D cadastral models to estimate the basis for the tax value of real estate generally gives an average value per area. Thus, automated mass real estate valuation approaches are advocated for rather than individual property estimation. Automated mass appraisal combines large amounts of data to predict the average value of real estate in a specific zoning through 3D models (Tomić et al. 2012).

2.6. Conclusion

Real estate value estimation is a complex process that requires different data sources and can benefit from the contribution of BIM and 3D GIS. To our knowledge, there is not yet an application that takes into consideration the different use cases of valuation based on BIM and 3D GIS models.

The challenge of digital modeling methods through BIM and 3D GIS is to recover these data which are often poorly archived and dispersed, or not at all. The ideal situation would be to be able to gather all the documentation that is generated on the building to avoid redoing additional studies. The challenge is the development of a standardized digital format for the storage of data and documentation such as BIM and 3D GIS, which would allow the creation of a database on the building from its design to its operation.

Standardization allows one to structure the necessary elements for each valuation and application case, which comes from elements related to the scale of the real estate property (BIM based) and its 3D environment (3D GIS based) as well as transactional and previous valuation databases. All should be connected by well-defined geometric and semantic relationships to facilitate simulations in 3D property valuation models. However, standardization efforts are mainly focused on the use of 3D cadastral models and real estate transaction databases.

The enrichment of BIM and 3D GIS standards including concepts related to real estate applications will allow some technical constraints related to BIM and 3D GIS integration to be overcome. Recently, CityGML 3.0 adds a new concept of “space” and the possibility to include the modeling and simulation of 3D variables related to the indoor space of buildings (Tauscher 2020).

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Preface

This chapter focuses on the technical requirements of 3D variables in the context of property valuation. It aims to analyze the spatial and non-spatial elements of these variables to determine their derivation from 3D city models and building-scale elements. The chapter explores the capabilities of Building Information Modeling (BIM) and City Information Modeling (CIM) in providing crucial information for property valuation, both indoors and outdoors. It highlights the importance of comprehensive data integration and showcases the potential of utilizing 3D models for accurate property valuation.

The rapid pace of urbanization and the increasing development of vertical urban structures have highlighted the significance of geo-related variables for property units within the same building. Among these variables, the 3D indoor physical and outdoor environmental factors have a significant impact on the value of each building unit. However, existing literature primarily focuses on visualizing these 3D variables using hedonic pricing models (HPM) for property valuation, rather than utilizing them for precise 3D simulations. Furthermore, their value is often defined for specific valuation purposes, such as taxation.

This chapter seeks to investigate the 3D variables that have a substantial impact on property value, combining them with the necessary 3D technical requirements to integrate them into a future valuation model. Moreover, it analyzes the 3D spatial and non-spatial elements of these variables to identify which ones can be derived 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.

For indoor variables, BIM/IFC (Industry Foundation Classes) models serve as the primary data sources for capturing structural and living quality variables. On the other hand, for outdoor variables, such as environmental factors and information about the surrounding buildings, 3D city models (CityGML) provide the necessary data.

By investigating these 3D variables and their spatial and non-spatial elements, this chapter aims to contribute to the identification of key factors that significantly impact property value. Additionally, it explores the potential of integrating these variables into valuation models using BIM and CIM approaches. Ultimately, the goal is to enhance the accuracy and reliability of property valuations by leveraging 3D models and comprehensive data integration techniques.

Chapter 3 - 3D Valuation Model Requirements

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Based on article (El Yamani, R. Hajji et al. 2021)

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

El Yamani, S.; Hajji, R.; Nys, G.-A.; Ettarid, M.; Billen, R. 3D Variables Requirements for Property Valuation Modeling Based on the Integration of BIM and CIM. Sustainability ***2021***, 13*, 2814.*

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)

3.1. 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) (El yamani et al., 2019). Hence, property value is the process of estimating the amount of which the property will be exchanged in the market (RICS, 2020). Moreover, property valuation refers to the identification and quantification of the factors impacting its value (P. J. Wyatt, 1997). 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) (Higgins, 2019; Hussain et al., 2019; X. Li et al., 2020). 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 consider the third dimension of these variables.

Integrating 3D modeling techniques are promising to real estate valuation (Case et al., 2021; Kara & Oosterom, 2018; Toppen, 2016). 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 19,152:2012) is developed for international immovable property taxation to serve valuation practices in administration authorities based on 3D modeling of properties (Kara et al., 2020; Kara & Oosterom, 2018).

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 (Gröger & Plümer, 2012). 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 (Arcuri et al., 2020; Liu et al., n.d.). 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 (Yu, Haicong;Ying, LIU ; Cunye, 2014). 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 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.) (Edler et al., 2019).

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 (Ricker, 2019). 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.

3.2. Related Works

3D variables have a substantial impact on property valuation. Recent studies have been conducted to assess their impact on property value (Arcuri et al., 2020; Juan, 2019; Kara & Oosterom, 2018; H. Zhang et al., 2014). These variables can be classified into indoor variables (physical, inherent to the property unit) and outdoor variables (locational, environmental) (Stacy Sirmans, David Macpherson, 2005). 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 (Isikdag et al., 2015; Ying et al., 2020; S. M. Yu et al., 2007). Indeed, property size, shape, floor level, and building height have an important impact on property value. The authors of (P. Wyatt, 2010) 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, (Jingxuan Zhang, 2019) 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 (Turan et al., 2020).

Another factor related to indoor variables is energy performance of residential buildings which was proved to be significant for property valuation. Kim and Berber (Kim et al., 2017) pointed out that high energy consumption raises the apartment value by 13%. Li and Chen (X. Li et al., 2020) 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 (Šujanová et al., 2019). Another energy related variable is the building solar potential. Helbich et Jochem (Helbich et al., 2013) 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, (Turan et al., 2020) 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 (Wen et al., 2020). 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 (Kim et al., 2017)). Additionally, the proximity to the road network and industries negatively impacts the apartment price (Szczepańska et al., 2020) (Figure 4.2).

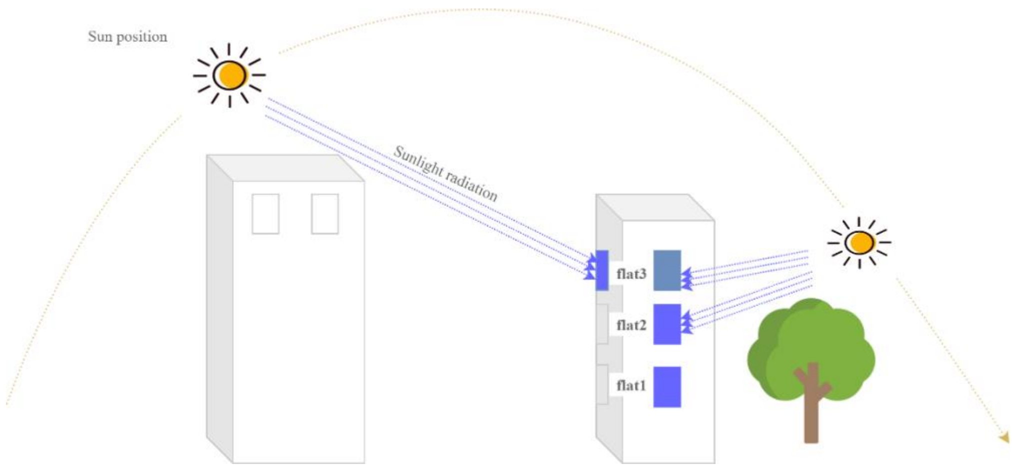


Figure 4.1. 3D sunlight exposure for the flat’s level.

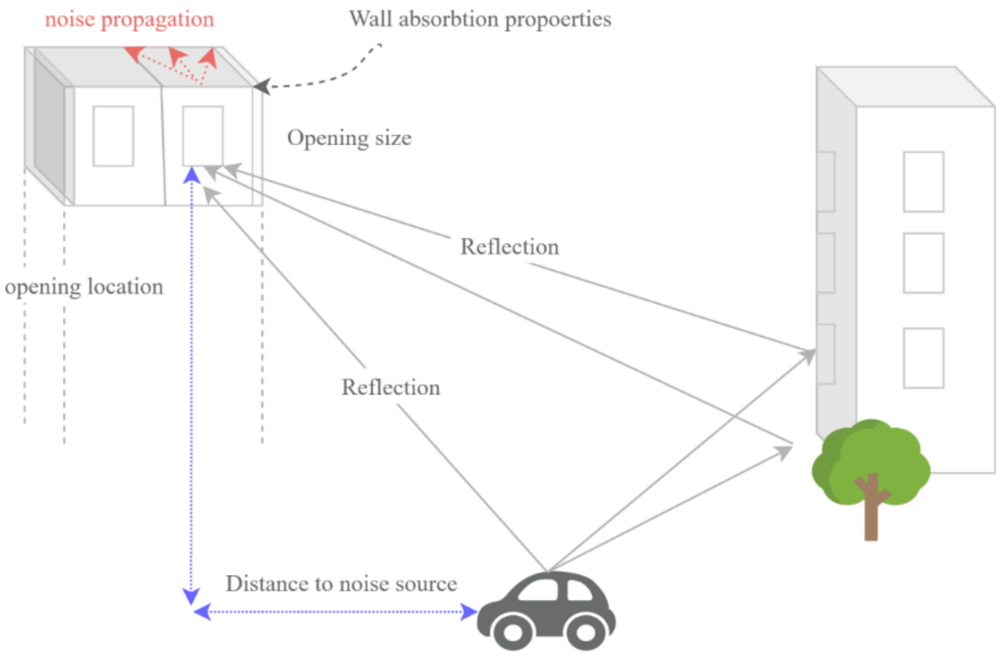


Figure 4.2. Illustration of noise level effect on outdoor and indoor spaces.

Moreover, authors assumed that flats with open view perceived from a high-rise building have a high property value. Fleming et al., (Fleming et al., 2018) 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., (Helbich et al., 2013) 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) summarizes all the sunlight definitions significant to 3D property valuation based on literature review analysis. Wen et al., (Wen et al., 2020) 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, (H. Zhang et al., 2014) generated 3D outdoor buildings based on extruding existing 2D building footprints. They concluded that procedural models can quantify sunlight factors. (Isikdag et al., 2015) 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 19,152:2012) 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., (Kara et al., 2020) 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 several 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 (Xu et al., 2019). 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.

3.3. 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.

3.3.1. 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 3.3 above shows variables impacting the value at the property unit scale.

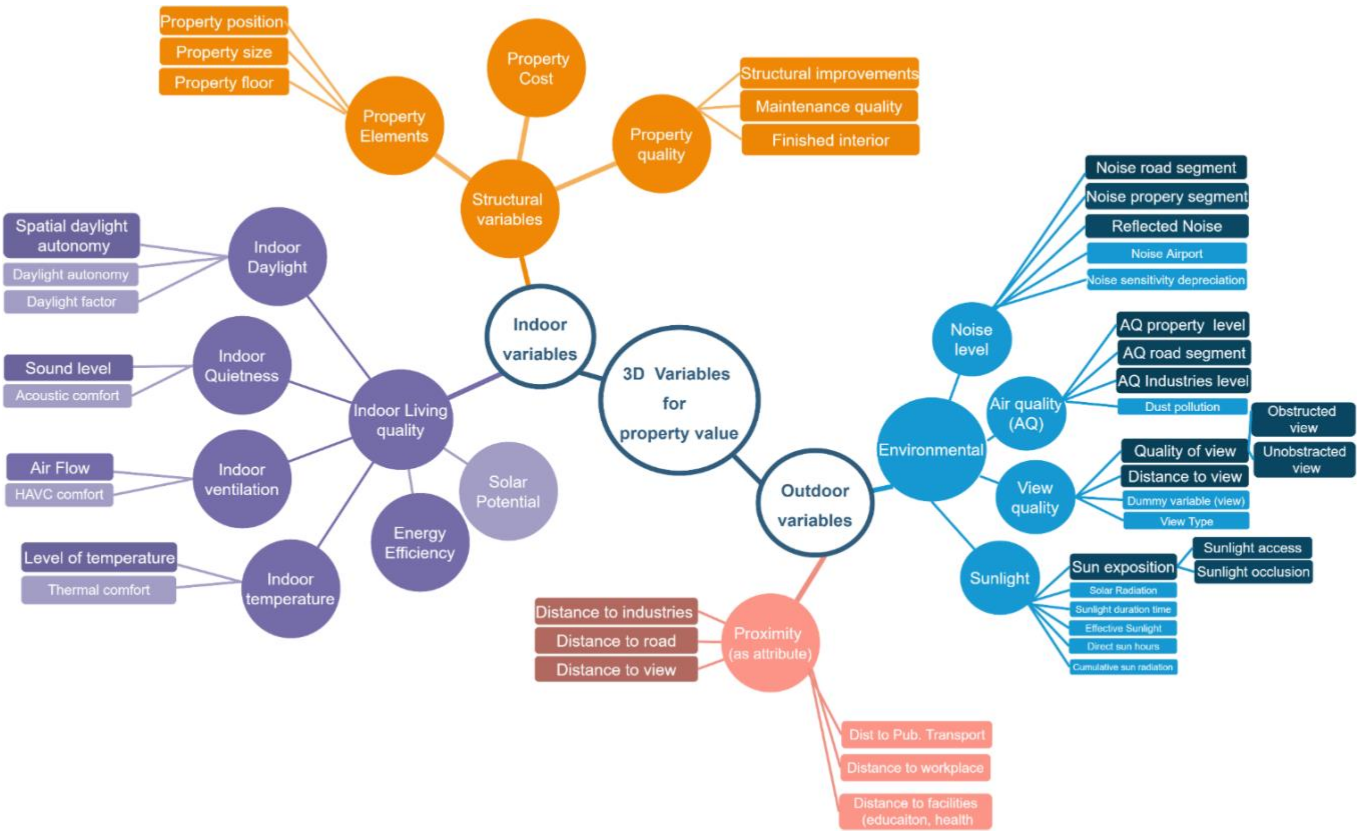


Figure 3.3. 3D selected variables for property units' value. (Dark color represents the relevant 3D variables to our valuation; the light color corresponds to the non-included 3D variables into our model).

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 opening 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 3.4 below presents the proposed structure.

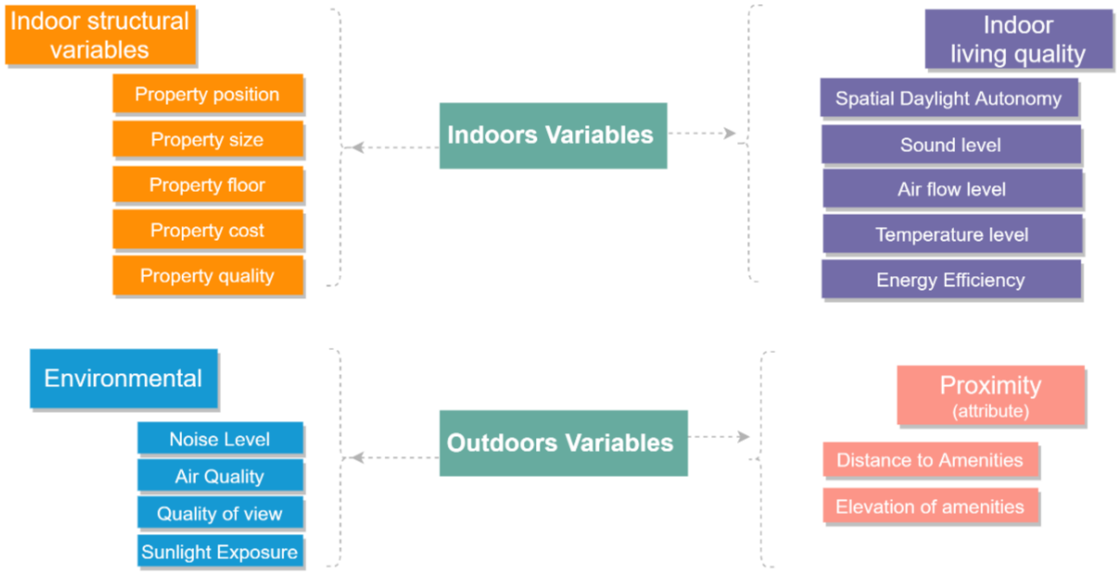


Figure 3.4. The 3D selected variables for property valuation model from indoors and outdoors 3D space.

3.3.2. 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 negatively impacts 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 3.5 below illustrates the use of 3D spatial and non-spatial elements for 3D noise estimation.

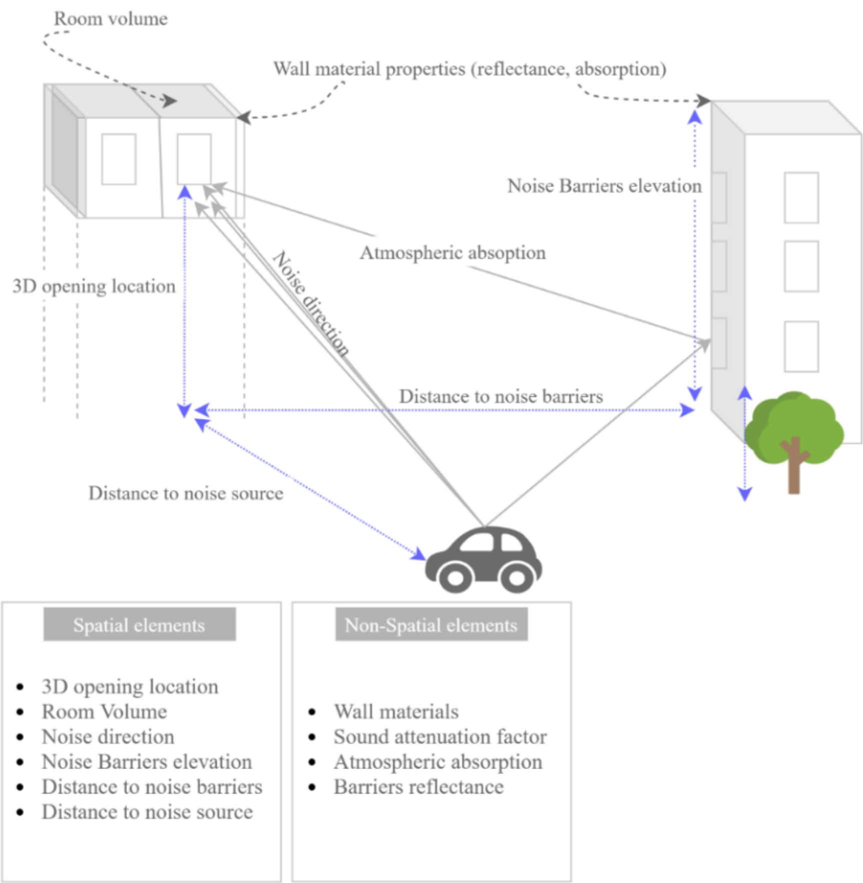


Figure 3.5. Illustration of noise level classified to spatial and non-spatial elements.

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 also contain 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.

Table3.1. 3D variables elements are 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 opening's 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 the value of a variable. 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.

3.4. CIM and BIM Capabilities for 3D Property Valuation

The 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 in Tables 2 and 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.

Table 3.2. 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**	**Openings properties**	**Installation quality**			

		Materials *quantities*		**Installation type**		
	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*
Indoor Living **Quality** **(ILQ)**	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**			
Outdoor environmental	Level of temperature	**Materials properties**	*Openings 3D location* and **properties**	*Thermal Space* **Temperature Value**	**External Wall material properties**		**Temperature degree**
	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*

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 and extensions).

3.4.1. 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 (Kitsakis et al., 2019) such as the volume of the property legal space (Atazadeh et al., 2017, 2019) and for cost estimation (Arcuri et al., 2020). 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.

3.4.2. 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 (Gröger & Plümer, 2012). 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) (Biljecki et al., 2018) 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.

3.4.3. 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 (Kutzner et al., 2020) 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.

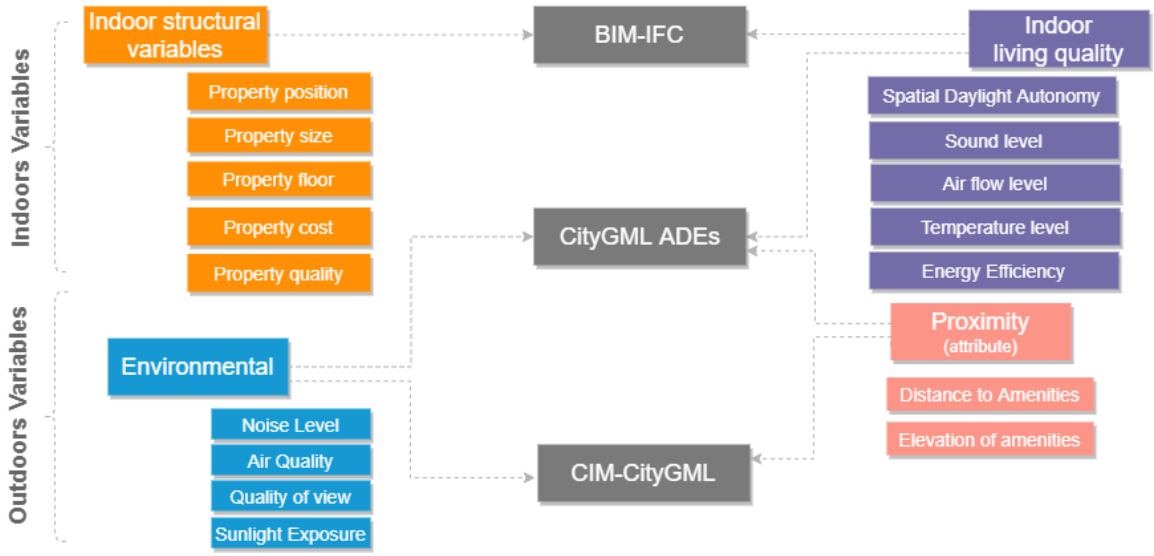


Figure 3.6. Classification of 3D variables based on their potential 3D data sources: For indoors variables: Indoor structural variables are driven BIM/Industry Foundation Classes (IFC) elements while Indoor living quality are provided from both BIM and CityGML elements. Outdoor variables and the proximity 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 [47]

3.3.3.1. 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 (Plebankiewicz et al., 2015b). 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.

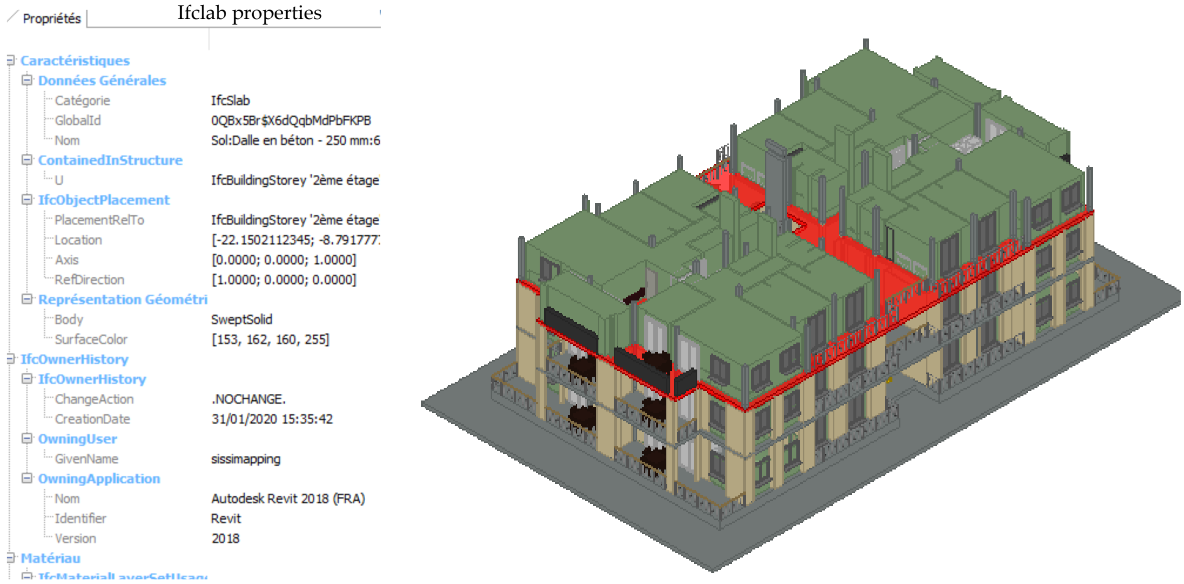
Table 3.3. Cost estimation-based BIM of constructive elements for residential building property.

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

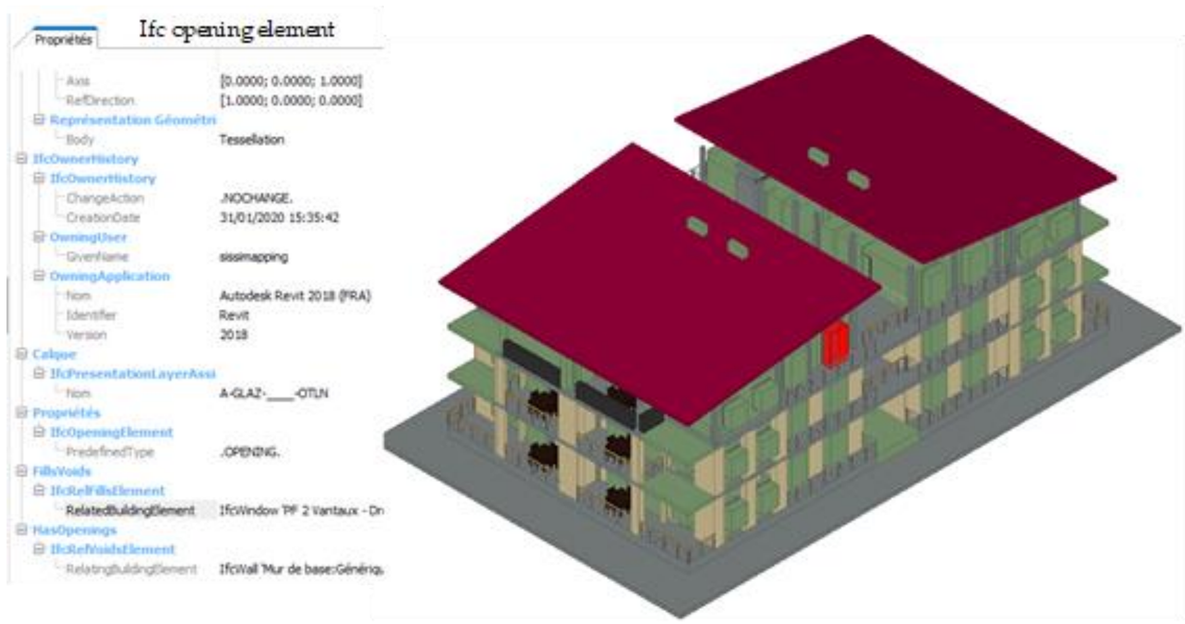
- However, the process to estimate cost variable for each property unit is not an automated process. That is why the extraction based IFC classes need to be explored.

3.3.3.2. 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. Figure 7,8 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.



(**a**)



(**b**)

Figure 3.7. 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.).

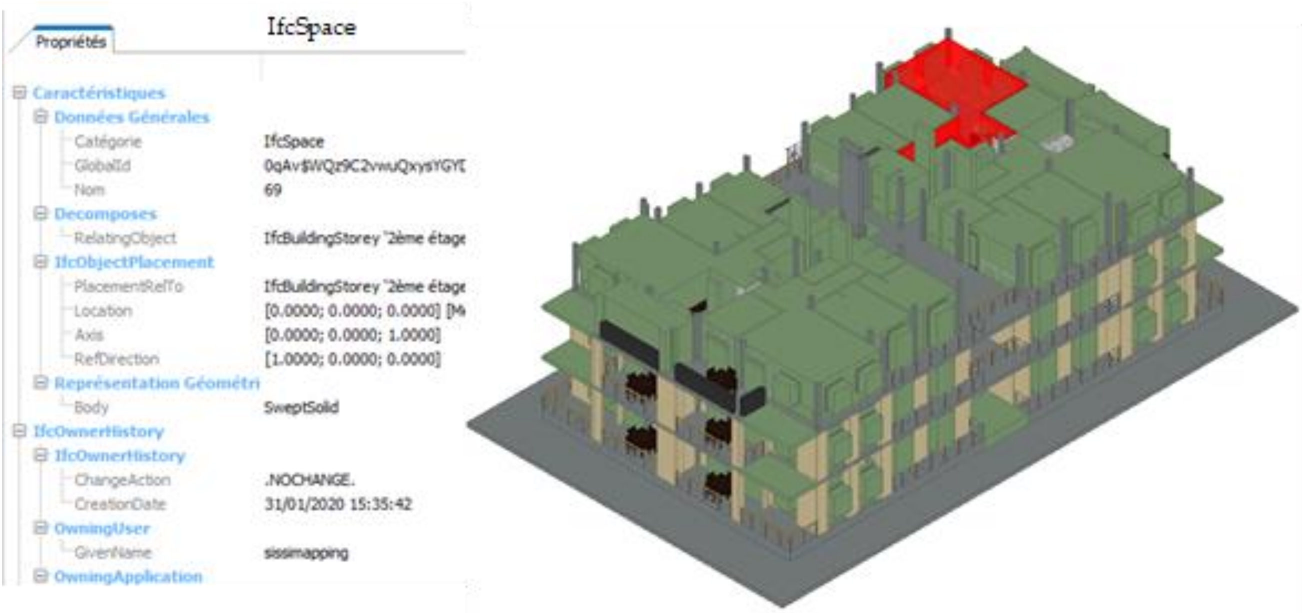
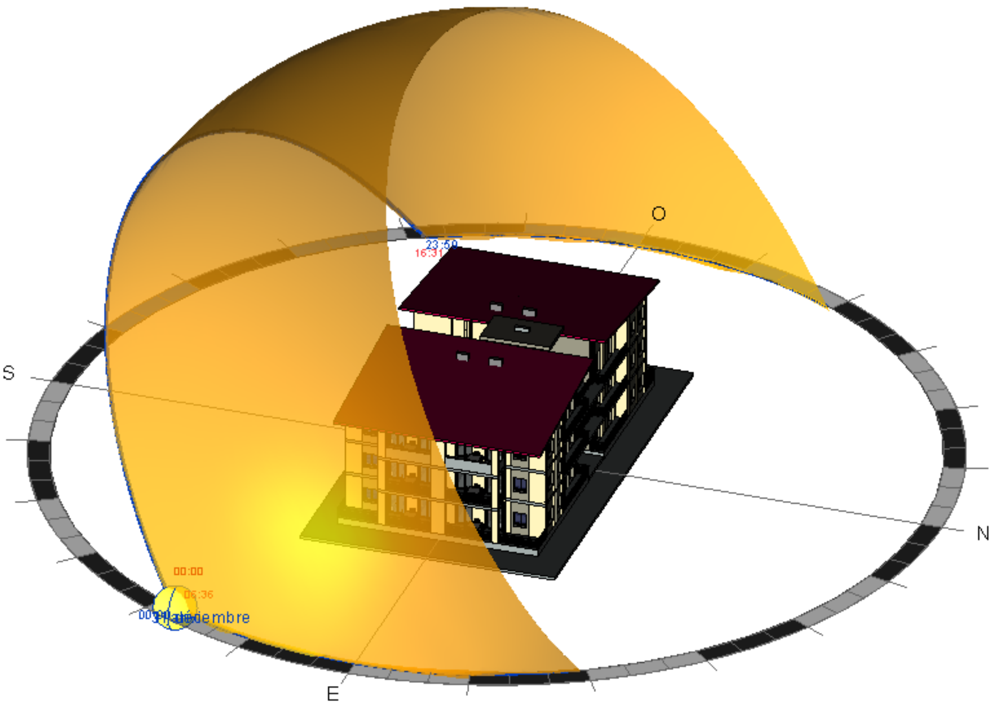


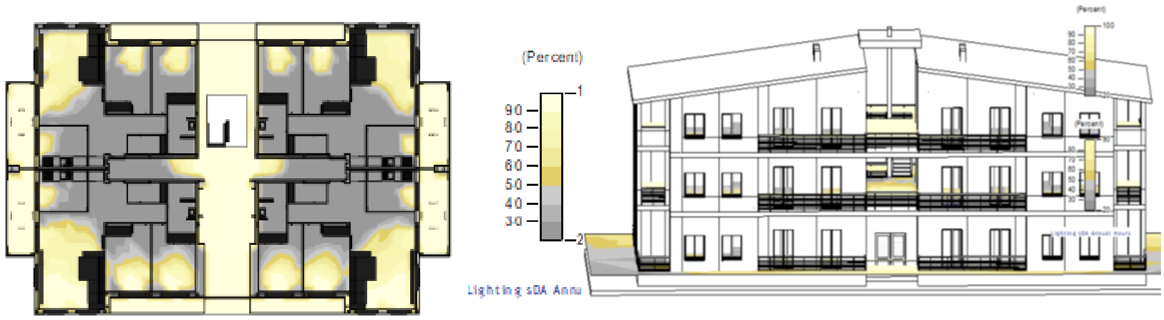
Figure 3.8. BIM capabilities to generate property indoors spaces based on IFC standard that can be used for modeling property unit indoors 3D size and volume.

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 9 a, b, shows the use of BIM to simulate the sun position (a) 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**)



(**b**)

Figure 3.9. (**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.

4.3.3.3. 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 (Kutzner et al., 2020). Besides, outdoor variables can be derived from existing CityGML ADEs advances in terms of modeling environmental parameters in 3D outdoor urban applications (Kumar et al., 2017). 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 (Kumar et al., 2017), “Air Quality ADE” for (Arco et al., 2016; Casazza et al., 2019) and 3D solar rights for modeling the sunlight exposure based on the neighboring conditions of shadowing and building obstruction (L. Li et al., 2019).

This information based on existing ADE will provide a basis for standardized information related to our valuation model.

3.5. Conclusion

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) (Biljecki et al., 2018) 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 (Kara et al., 2020) 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 (Case et al., 2021). 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.

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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 unit depending to the longest/lowest sun exposure 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 4.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	---	(Helbich et al., 2013)
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	(H. Zhang et al., 2014)
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		(Fleming et al., 2018)
Sunlight quality	Based on Fleming sunlight definition but determined by qualitative survey	Apartment (2.5D)	People's Preference (contingence)		(Ricker, 2019)
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)	(L. Li et al., 2019)
Sunlight duration (Every hour)	-Openings (Windows) -Buildings blocks -Sun duration -Surrounding building -View of vegetation	Room based sunshine quantification.	-Viewshed analysis -Sun volume analysis (every 1h the volume is generated)	-No less than 2 h per a day - blocked app = 1 -unblocked app = 2 (Sunshine duration from short to long	(Jingxuan Zhang, 2019)

	-View of water				
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	---	(Amoruso et al., 2019)

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.	(Kim et al., 2017)
Reflectance	Some types of materials dispose of high reflectance for solar radiation, sound, and noise level such as glass.	(Amoruso et al., 2019; Rosser et al., 2019)
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)	(OGC; SIG 3D, 2016)
Conductivity	The thermal conductivity of the material (W/mK)	(Rosser et al., 2019)
Specific heat	Specific heat capacity of the material (J/kgK)	
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.	(Warren-Myers et al., 2020)

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Preface

In the realm of 3D property valuation, the advent of CityGML—a versatile data model designed to encapsulate 3D urban data—has marked a significant stride in the advancement of property assessment methodologies. However, while CityGML offers a rich array of modules and tools for the spatio-semantic modeling of urban and landscape features, its generically structured nature imposes limitations when applied to specific use cases, such as property valuation. Recognizing this need for a tailored solution, a specialized Application Domain Extension (ADE) becomes imperative—an extension that adeptly bridges indoor and outdoor variables integral to property valuation.

This chapter embarks on a journey to develop a comprehensive Property Valuation ADE that transcends individual use cases, offering a unified approach to the modeling of property valuation. By harnessing the capabilities of existing ADEs, schemas, and models, and imbuing them with semantic information, this specialized ADE enriches CityGML's capabilities, allowing for the coherent simulation of multiple variables within the context of property valuation. Of particular importance is the seamless integration of Industry Foundation Classes (IFC) and CityGML schemas, as they jointly cater to the prerequisites of 3D property valuation modeling.

In this chapter, we delve into a comprehensive exploration of the integration of IFC into CityGML ADEs—a critical facet of 3D property valuation. While previous studies have ventured into enhancing CityGML ADEs with IFC enrichments, these endeavors often remained confined to specific use cases, failing to address the holistic requirements of property valuation. Our approach transcends these limitations, aiming to propose a novel ADE that cohesively amalgamates various urban aspects. This unified model is explicitly designed to cater to the multifaceted requirements of property valuation while harnessing the potential of IFC datasets for indoor variables.

Our mission extends beyond merely addressing individual use cases, instead, we seek to connect multiple aspects and establish a comprehensive ADE engineered explicitly for property valuation. By amalgamating existing ADEs, we aspire to incorporate both indoor and outdoor urban prerequisites into a singular ADE. In this pursuit, we enrich CityGML with semantic information and enable the seamless simulation of diverse variables.

This chapter significantly contributes to the advancement of property valuation processes by capitalizing on the wealth of 3D urban data and domain-specific extensions. Through our research, we endeavor to enhance decision-making and promote sustainable urban development, ultimately providing accurate valuations that benefit all stakeholders, from contractors to valuers.

Chapter 4 - Towards Extending CityGML for Property Valuation: Property Valuation ADE

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4.1. Introduction

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 spatio-semantic modeling of urban and landscape features, its generic nature may limit its applicability for specific use cases, such as property valuation. To address this limitation and cater to the specific requirements of property valuation application, there is a need for a specialized Application Domain Extension (ADE) that seamlessly integrates both indoor and outdoor variables related to property valuation.

In the context of CityGML 3.0, a comprehensive data model has been established, one that remains application agnostic. However, various applications necessitate specific data that is not covered by the CityGML Conceptual Model (CityGML CM). 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 (Shen et al., 2020; Biljecki et al., 2018). The former method presents certain challenges, such as difficulties in maintaining 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 latter approach leverages ADEs to systematically and structurally incorporate application-specific data within CityGML.

Typically, independent ADE data models are crafted for individual use cases, each featuring unique data packages, classes, and attributes. Consequently, overlaps may occur, given that multiple use cases may require the same subset of information. This is one of the main approaches to develop ADEs research, as they are tailored to specific use cases and domains, such as the EnergyADE [58]. This data model can be extended to accommodate the data needs of a particular domain or application while upholding its core concepts and semantic structure (Kolbe et al., 2021). However, no ADEs were developed to integrate 3D variables (indoor, outdoor) for Property valuation application with an enrichment sourced IFC.

Therefore, this chapter aims to develop an ADE within CityGML 3.0, termed the Property Valuation ADE, with the objective of incorporating 3D variables essential for property valuation purposes. The data requirements have been identified and categorized in accordance with the findings from our previous chapter. The ADE is conceived and constructed at a conceptual level, with implementation illustrated in the data integrability assessment section to showcase its challenges and a preliminary implementation test illustrated by the emerging CityJSON format.

The ADE-`Property Valuation model is going beyond the scope of individual use cases and offering a unified approach to property valuation modeling. By leveraging existing ADEs, Schemas and models, and incorporating semantic information, this specialized ADE will enrich CityGML, allowing cohesive simulation of multiple variables in the context of property valuation. One of the main aspects to address with this regard is the integration of IFC and CityGML schemas as they are complementary in fitting the requirements of 3D property valuation modeling.

In this chapter, 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 often been tailored to specific use case scenarios and did not sufficiently address the comprehensive requirements of property valuation. Our approach seeks to propose a new ADE that seamlessly combines various urban aspects, specifically designed to serve property valuation needs while harnessing the potential of IFC datasets for indoor variables.

This chapter contributes significantly to the advancement of property valuation processes by leveraging the interest of 3D urban data and domain-specific extensions. Through enhanced decision-making and planning for sustainable urban development, our research seeks to make valuable contributions to the research in property valuation and provide an accurate valuation for all the stakeholders (Contractors, valuers etc.) (figure 1)

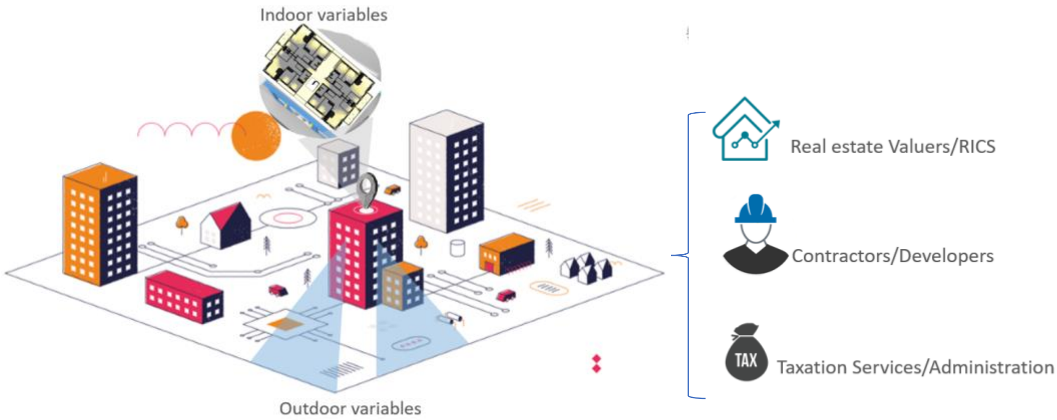

Figure 4.1: Potential users of ADE-Valuation

4.2. Background and Related Works

4.2.1. ADEs for CityGML urban applications

CityGML extensibility through the Application Domain Extension (ADE) mechanism allows tailored enhancements for specific urban use cases. This mechanism allows for augmenting and expanding the CityGML data model to cater to 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.

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), has been instrumental in refining 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.

However, despite the successful implementation of these ADEs in addressing specific urban challenges, they often face significant challenges in terms of integration with Industry Foundation Classes (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 navigate the complexity of merging these ADEs with IFC datasets to create a more cohesive and comprehensive framework for property valuation.

4.2.2. Integration of IFC in CityGML ADEs

Extensive research has explored the integration of Industry Foundation Classes (IFC) into CityGML ADEs. These 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 (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 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.

Kutzner et al. (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 invaluable, 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 provided inspiration for 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 with semantic datasets from IFC.

4.3. Methodology and approach

4.3.1. 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:
"

- ***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 [59].*

- ***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 (e.g. [44,61]).*
- ***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. [62], and it is akin to developing ADEs extending existing ADEs [63,64]. "*

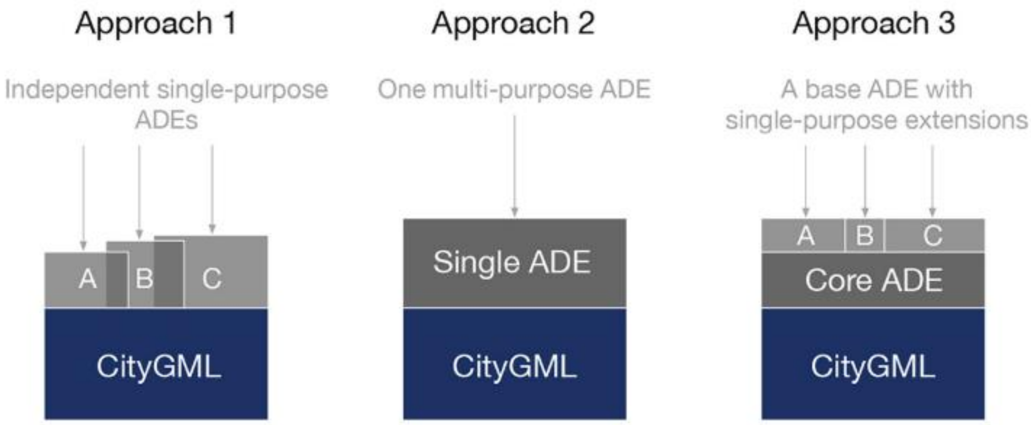

Figure 3.3 : Different Approaches to Design an ADE for a specific or multiple use case application derived from (Biljecki et al., 2021b)

In our work, we have opted for the first approach (Figure 3.3) 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:

1. 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.

2. 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.

3. 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.

4.3.2. ADE's requirements

In this subsection, we present the requirements of the ADE-Valuation model concerning indoor and outdoor variables, Figure 2 shows the classification of these requirements.

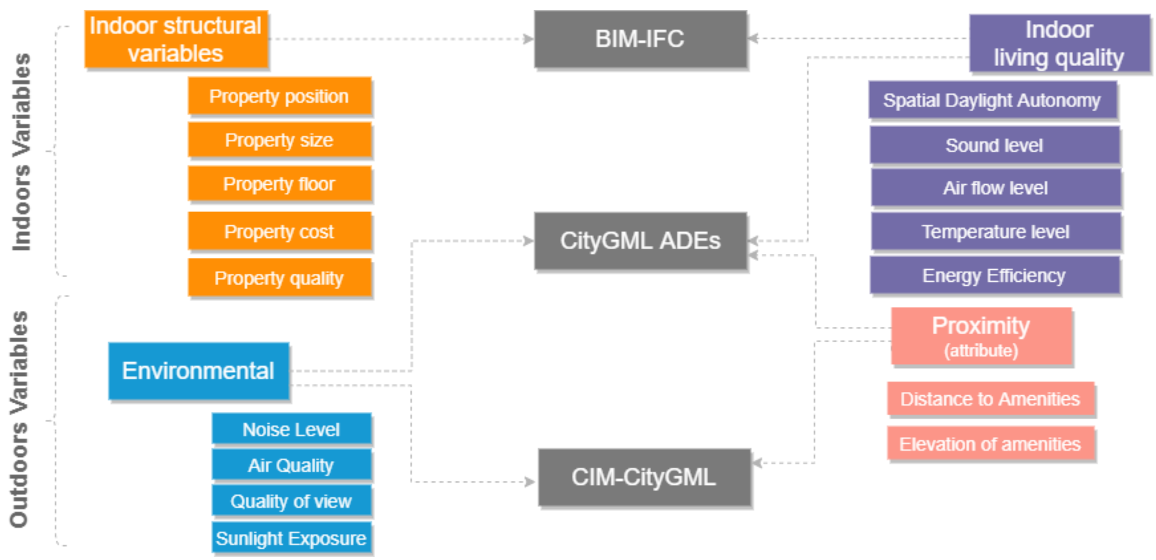

Figure 2 : ADE's requirements classification

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 1 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 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 a more comprehensive property valuation. Furthermore, by combining BIM data on structural materials and their thermal properties with the cost information, we can estimate property costs effectively. 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 "ADE Energy," 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 amalgamate information pertaining to 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 requisite 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, the ADE-Valuation model can effectively integrate and analyze the 3D variables requirements necessary as an input to the 3D property valuation model.

4.4 Property Valuation ADE:

4.4.1 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; outdoors). Although the 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), 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 in the very near future. 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.

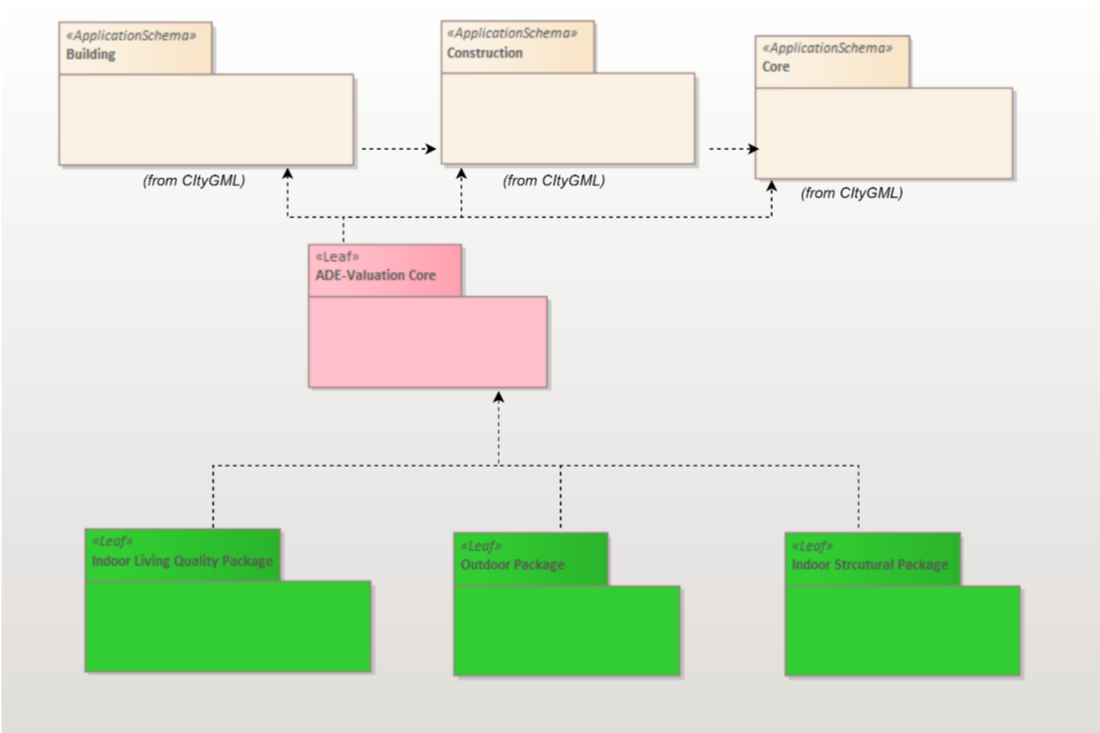

Figure 4.4: Colour-coded modular structure of the ADE valuation UML diagram embedded into CityGML core. (Beige: existing CityGML schema required; rose proposed ADE valuation generic core; green: leafs are the variables independent packages for indoor and outdoor requirements)

Figure 4.4 reports and describes each package of the ADE.

- **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 crucial generic class closely associated with the concept of valuation unit spaces. These spaces serve as the central hub 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 facilitated via the IFC, utilizing the enrichment options discussed in the preceding subsection. This feature seamlessly extends the CityGML "Building Parts" class and establishes connections with "openings," which are vital for handling outdoor variables. Additionally, it is linked to "rooms" where simulations for indoor living quality packages take place (refer to Figure 4.5 for schema).

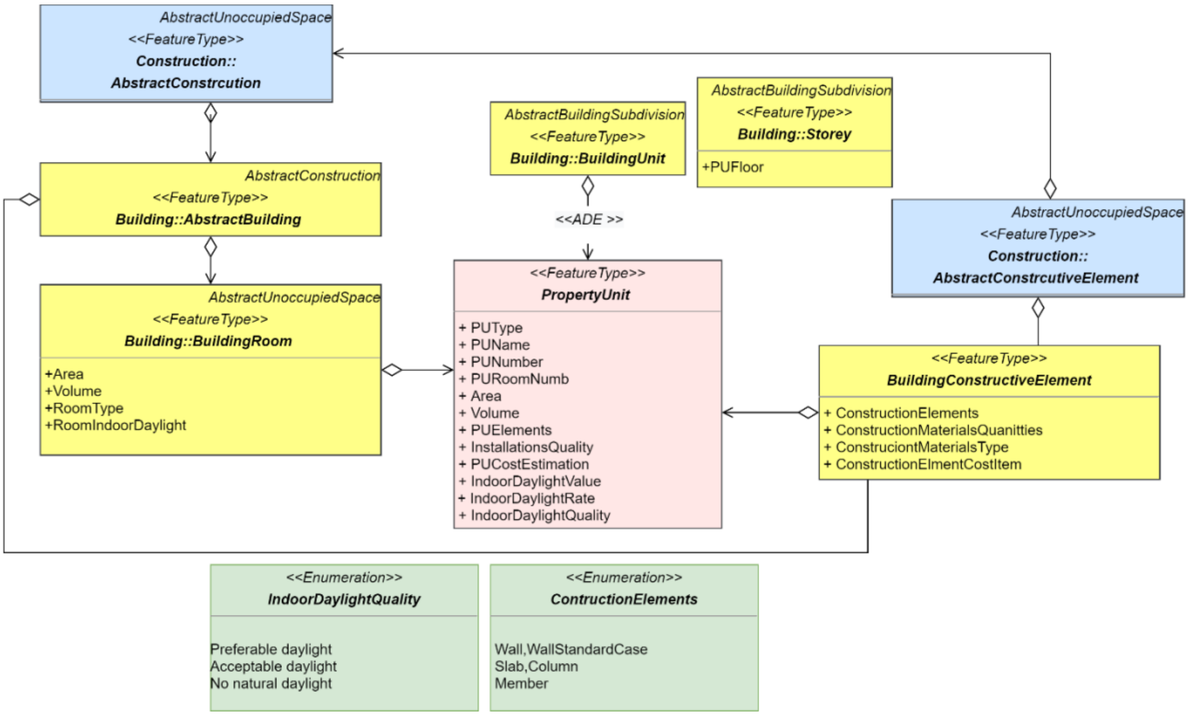

Figure 4.5: Schema model of the ADE-Valuation core model (blue: .., yellow;.., Rose : new ADE feature, green ; code lists)

- **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 class “building”, “buildingunit”, “buildingconstructiveelements” and stored as “propoertyUnit” 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 enriching process, we transform and merge relevant data from: IfcSlab”, “IfcColum”, “IfcWall”, “IfcRoof” to “Buildingconstructiveelements” and the parents/child hierarchy to “propoertyUnit” as a child of buildingunit.

- **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 enriching 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 enriching 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.

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

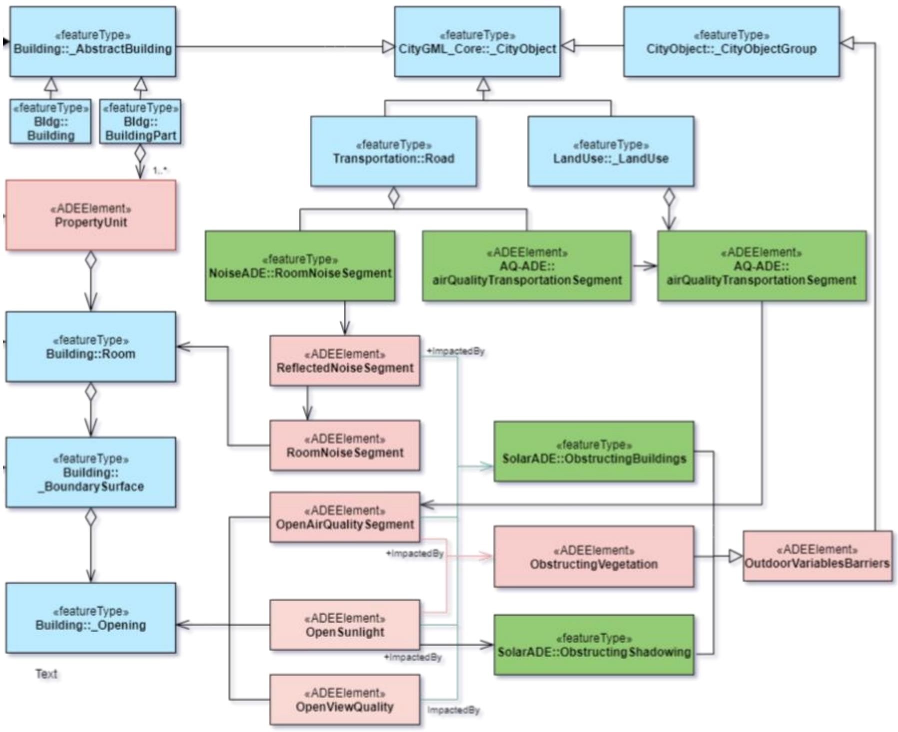

Figure 4.6: The conceptual model of Outdoor Variables Package

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):

1. 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 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.
2. 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.
3. 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.
4. Noise Assessment Class: For the noise variable, the "Room" and “openings” class 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 4.7).

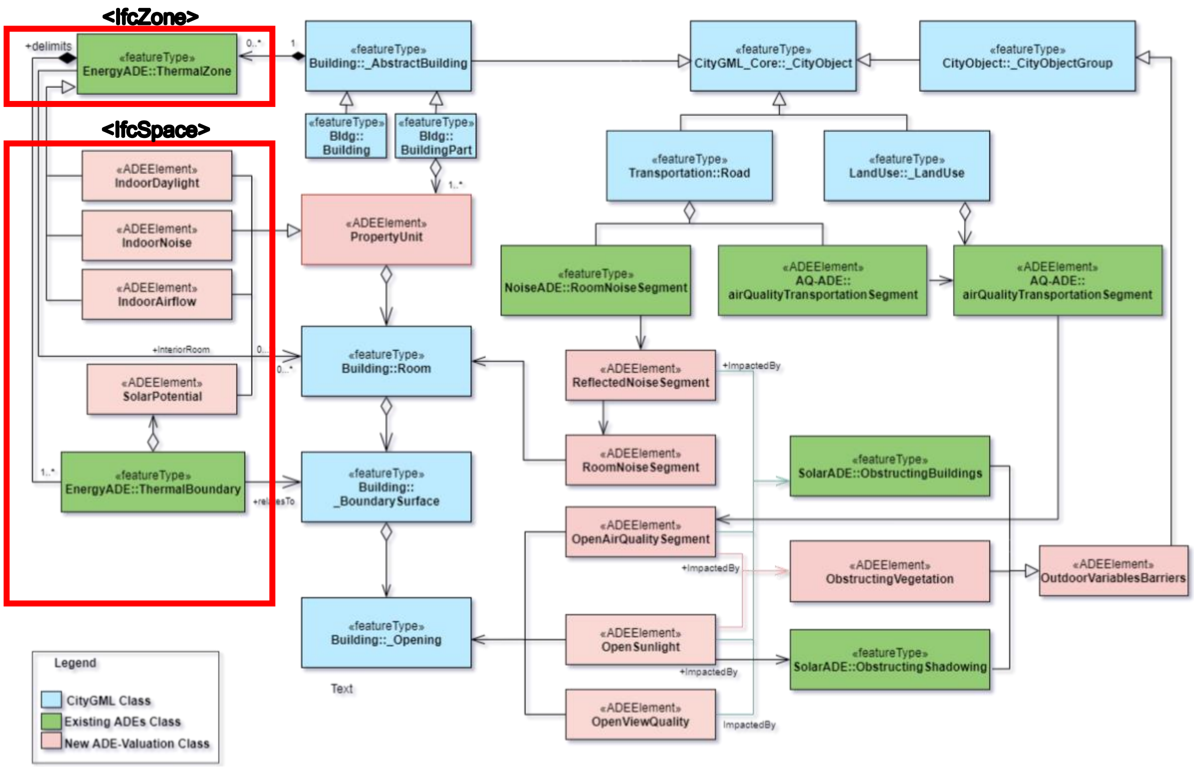

Figure 4.7: Detailed classes of ADE Valuation model

4.4.2 ADE-Data Integrability challenges

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

Firstly, the inherent complexity arising from the development of an ADE tailored specifically for CityGML 3.0. This complexity is deeply rooted in the intricate structure and interdependencies inherent in the CityGML 3.0 standard (buildingsmart, 2021). 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 pertains 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 seamlessly 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 (Interoperability, 2021). Given the inherent complexities of CityGML and the potential intricacies involved in developing our ADE, it may be advantageous to explore alternative data formats, such as CityJSON, as part of our future work (CityJSON, 2021). 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 (CityJSON, 2021).

Furthermore, the integration of our Valuation ADE with IFC (Industry Foundation Classes) data presents unique 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 (buildingsmart, 2021). 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 (buildingsmart, 2021).

Considering these limitations and challenges, the exploration of alternative data formats like CityJSON could be a promising direction for future work (CityJSON, 2021). CityJSON, a JSON-based encoding designed for storing 3D city models or digital twins, aims to provide a compact and developer-friendly format (CityJSON, 2021). This format facilitates easy visualization, manipulation, and editing of files and is specifically designed to support programmers, enabling the rapid development of tools and APIs (CityJSON, 2021). Multiple open-source options are available (CityJSON, 2021). In a similar manner, 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; in the CityGML world, these are called ADEs (application domain extensions).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 main stages:

1) Property valuation integrability based on CityJSON and
(2) Testing the data integrability for indoor daylight data (CityJSON, 2021).

For the first stage, specifications are provided from the ADE valuation model (core and packages) and mapped to CityJSON classes. The 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).

```json
{
  "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 executed 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.

Data Transformation: We employed two conversion processes, namely IFC2CityJSON and CityGML2CityJSON.

- IFC2CityJSON: We used a Python tool called "ifcenveloppeextractor" for this transformation step, which holds significant importance (refer to Figure 4.9). This stage was selected for demonstration purposes to automate the conversion of IFC files into CityJSON format. However, it's 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 4.10).

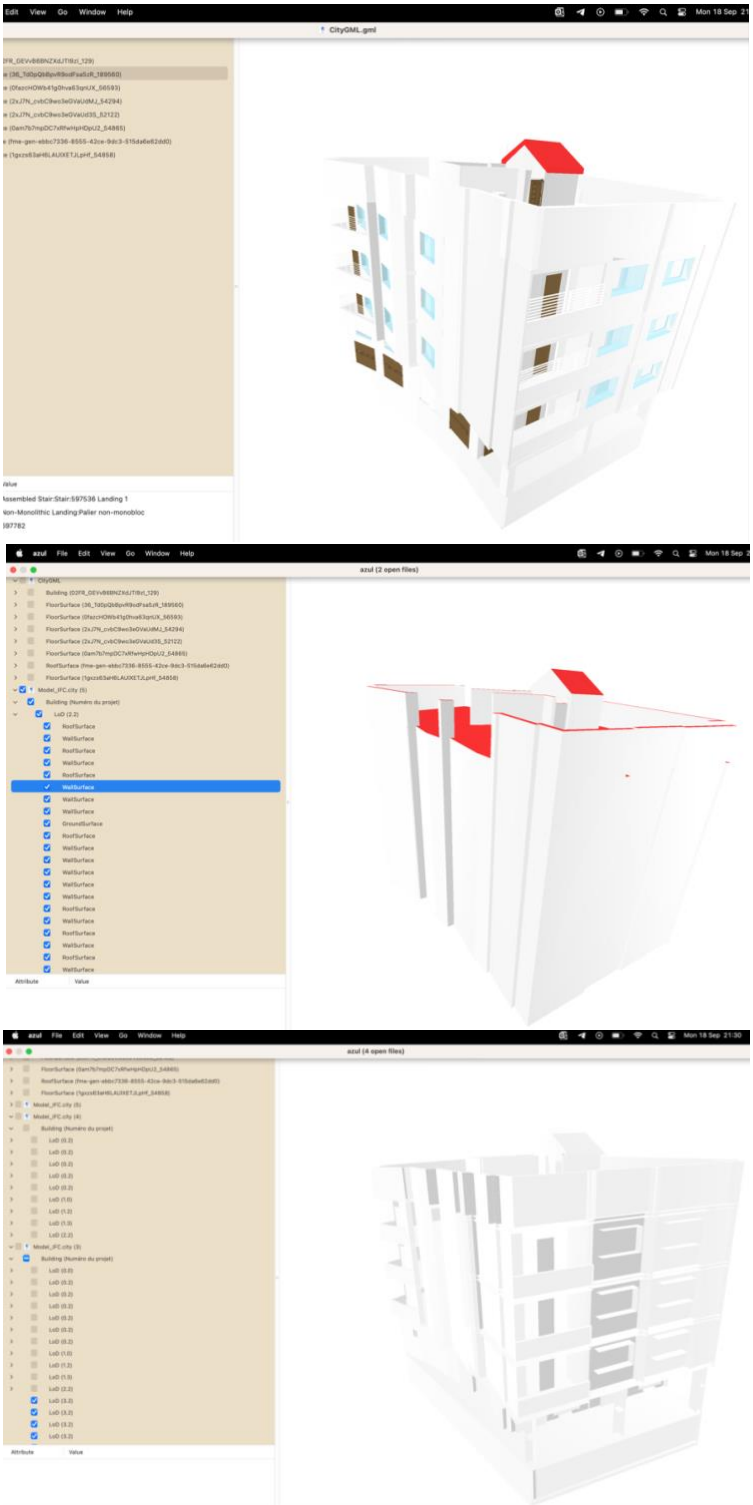

Figure 4.9: IFC2CityJSON automatic transformation results (from left to right: input file, output LOD 2.2 and LOD3.2.

Figure 4.10: Results validation IFC2CItyjson through cjval

- CityGML2CityJSON: we use the Python tool "CityGML-tools," we employed the "to-CityJSON" command within its command interface for an automated conversion of CityGML files (refer to Figure 11).

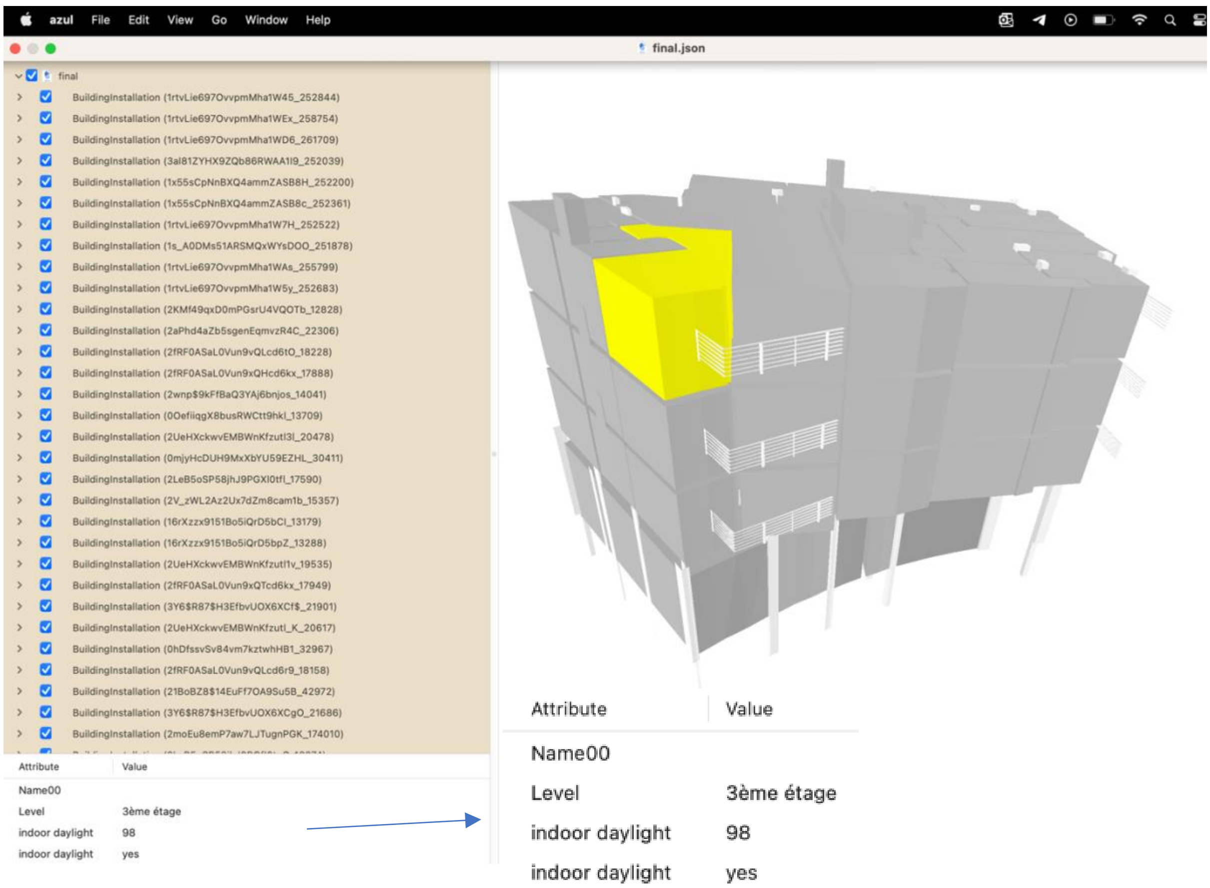

Figure 4.11: from CityGML to CityJSON results

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.

2- Data Implementation: The final step encompasses 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 Ninga visualization software, as depicted 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.

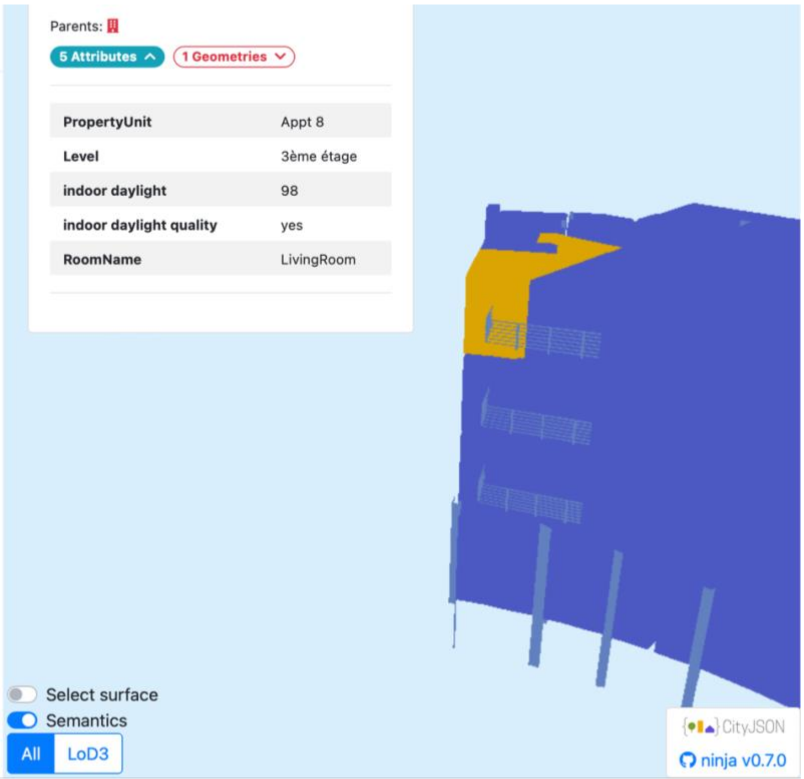

Figure 12: Data integrability results for indoor daylight test: (a) data scripts file (b) building model visualized in Ninga.

4.5. Conclusion

In conclusion, this chapter has provided a comprehensive overview of the background and related works, the methodology and approach, as well as the core components of the Property Valuation Application Domain Extension (ADE) within the context of CityGML and Industry Foundation Classes (IFC) integration.

In the realm of ADEs for CityGML urban applications, it is evident that numerous ADEs have been developed to address specific urban challenges, such as immovable property taxation, air quality assessment, 3D solar rights modeling, noise pollution management, and energy modeling. While these ADEs have successfully catered to their respective use cases, they often face challenges when it comes to seamless integration with IFC datasets, which is a critical requirement for our Property Valuation ADE. Therefore, our research seeks to bridge this gap and consolidate various urban requirements into a unified model designed explicitly for property valuation.

The methodology and approach section have outlined our strategies for designing the ADE-Valuation model, emphasizing the three identified approaches for ADE design. We have opted for the first approach, which involves developing independent ADE data models for each specific use case, ensuring precision and specificity for each property valuation variable.

Additionally, we have presented the ADE's requirements, categorizing them into indoor and outdoor variables. The integration of these variables into the ADE-Valuation model involves leveraging BIM/IFC capabilities, CityGML ADEs, and existing ADEs for indoor and outdoor variables, ensuring that the 3D variable requirements are met for property valuation.

In the core section of the Property Valuation ADE, we have proposed a modular structure that extends the CityGML 3.0 framework. This core module introduces the concept of the "Property Unit" and its connections to indoor and outdoor variables. The modular structure ensures flexibility and adaptability to various property valuation scenarios.

However, challenges related to data integrability within the ADE-Valuation model have been highlighted. These challenges encompass the complexities of CityGML 3.0, limited software support compatibility, and the need for tailored data extraction processes from IFC files. To address these limitations, we have explored the potential of alternative data formats like CityJSON, which offers a more streamlined and developer-friendly approach.

Finally, a preliminary implementation of the ADE-Valuation model using CityJSON was showcased. This implementation demonstrated the integration of indoor daylight data and highlighted the potential benefits of using CityJSON as an alternative data format. The results of this implementation were validated for syntax and schema compliance, ensuring the robustness of the data integration process.

In the subsequent chapters, we will delve deeper into the technical aspects of the ADE-Valuation model, including its architecture, data integration mechanisms, and case studies to validate its effectiveness in the context of property valuation.

Preface

This chapter proposes a workflow for integrating Industry Foundation Classes (IFC) and CityGML data to enhance property valuation. It focuses on the integration of 3D variables relevant to property valuation, specifically highlighting indoor variables. The chapter presents an evaluation of the proposed approach using two indoor variables as a demonstration of its effectiveness.

Urban areas are becoming more complex, demanding efficient property valuation strategies. 3D urban models and City Digital Twins (CDTs) have been developed to address these challenges. To accurately assess property value in complex urban environments, it is important to consider 3D variables related to the property and its outdoor environment.

Previous chapter has identified relevant 3D variables that impact property valuation. BIM and CIM provide valuable sources of these variables, representing indoor and outdoor data, respectively. However, integrating IFC and CityGML data poses challenges due to discrepancies in geometric and semantic coherence.

Efforts have been made to bridge the gap between IFC and CityGML, enabling their integration. This chapter focuses on integrating IFC and CityGML for property valuation. It proposes a data integration approach based on BIM and CIM, considering the specifications and requirements of property variables.

The main contributions of this research are analyzing property variables within an integration approach, proposing a workflow based on IFC and CityGML for simulating 3D property variables, and evaluating the approach through a case study on indoor daylight and property cost.

The chapter reviews previous research on IFC-CityGML data integration, presents the proposed integration approach, and describes the case study evaluating indoor variables. The findings demonstrate the potential and limitations of the approach. Further work is planned to enhance the workflow and test it with additional variables.

In conclusion, this chapter proposes a workflow for integrating IFC and CityGML data in property valuation. It offers a structured approach for data integration, enhancing accuracy and comprehensiveness. The evaluation demonstrates the effectiveness of the approach in simulating indoor variables, contributing to the advancement of property valuation practices.

Chapter 5 - 3D Model Data Integration Use Case

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IFC-CityGML data integration for 3D Property Valuation

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Abstract: The accurate assessment of proper ty value in complex and increasingly high-rise urban environments is a significant challenge. Previous research has identified property value as a composite of indoor elements, such as volume and height, and 3D simulations of the outdoor environment, including variables such as view, noise, and pollution. These simulations have been preliminary performed in taxation context, however, there has been no work addressing the simulation of property valuation. In this paper, we propose an IFC-CityGML data integration approach for property valuation and develop a workflow based on IFC CityGML 3.0 to simulate and model 3D property variables at the Level of Information Need. We evaluate this approach by testing it for two indoor variables, indoor daylight and property unit cost. Our proposed approach aims to improve the accuracy of property valuation by integrating data from indoor and outdoor environments and providing a standardized and efficient workflow for property valuation modeling using IFC and CityGML. Our approach represents a solid base for future works toward a 3D property valuation extension.

Keywords: Property valuation; Level of information need, Variables requirements, cost, indoor daylight, IFC, CityGML, BIM, CIM, FME.

5.1. 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.

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, 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 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.

Such 3D variables can be acquired from Building Information Models (BIM) and/or City Information Models (CIM). BIM and CIM allow rich geometric and semantic modeling related to the building or the whole city, respectively (Amirebrahimi et al., 2016; Jusuf et al., 2017; Francesca Noardo et al., 2020). Specifically, in the scope of our research, BIM offers rich information required for property valuation both for spatial and non- spatial elements at the building level, while CIM allows simulating outdoor variables requirements at the neighborhood or the city scale.

The Industry Foundation Classes (IFC) and CityGML are among the most advanced data models data models for indoor (building elements) and outdoor (building’s-built 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)

In recent years, several research studies have been conducted to bridge the gap between these two standards and make it possible to integrate them for indoor and outdoor modeling and simulations, under many use cases, frameworks and concepts (Hajji et al., 2021; Noardo, 2021; Noardo et al., 2022). Specifically, developments have been made to address the semantics mismatches and the geometry conversion problems between IFC and CityGML (Beck et al., 2020; Biljecki et al., 2021).

Various studies have explored the integration of IFC and CityGML, which can be classified into two approaches: generic integration based on IFC-CityGML, and specific integration based on IFC-CityGML use cases, such as energy or indoor navigation (Biljecki et al., 2021). For example, Noardo et al. (2020) developed an IFC-CityGML schema model for permit checking, while Ohori et al. (2018) created workflows for bi-directional conversion between IFC and CityGML. Berlo and Laat (2011) proposed a meta-model to preserve IFC semantics and properties in CityGML without a specific use case. Although some studies have proposed IFC-CityGML integration for different use cases, including energy, urban planning, and indoor navigation, there is still a lack of generic use cases, such as real estate valuation (Biljecki et al., 2021).

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.) (Kara et al., 2020).

While literature has acknowledged the importance of indoor elements and 3D simulations of the outdoor environment for property valuation, a work needs to be done to simulate property valuation variables itself. The use of for the two prominent standards: IFC (Industry Foundation Classes) and CityGML is inevitably chosen for property valuation model. By developing a standardized and efficient workflow based on IFC CityGML 3.0, to improve the accuracy of property valuation by integrating data from indoor and outdoor environments. The evaluation of indoor variables, such as indoor daylight and property unit cost, serves as an initial demonstration of the effectiveness of this approach and provides a solid foundation for future extensions in 3D property valuation.

Therefore, there is a need to address integration of IFC and CityGML for property valuation purposes. Therefore, this paper aims to propose a data integration approach-based BIM and CIM for 3D property valuation. The main contributions of our research are:

- Analyzing the property variables specifications and requirements within an integration approach for property value simulation.
- Proposing and implementing a workflow based IFC CityGML for simulating property 3D variables (cost and daylight).
- Analyzing and discussing the study case outputs towards a future data valuation model extension.

The paper is structured as follows: Section 2 reviews prior research on data integration methods based on IFC-CityGML, highlighting the challenges they encounter. Section 3 proposes an integration approach. Section 4 presents a case study in which we propose and evaluate the integration workflow, focusing on two indoor variables: indoor property daylight and property cost. Lastly, Section 5 discusses the strengths and limitations of our approach and provides recommendations for developing a 3D property valuation model.

5.2. Related Works

Several authors have proposed workflows to integrate IFC and CityGML for specific use cases. Isikdag et al. (2013) converted IFC to CityGML for indoor navigation. For 3D cadaster, Kalogianni et al. (2020) and Kara et al. (2020) extracted legal boundaries from IFC before integrating the property building in its surrounding 3D urban environment to assess outdoor urban regulations and extract 3D overlooking and visibility. The literature suggests that the schema-based approach is one of the most commonly used integration methods (Zhu & Wu, 2022). Other integration approaches include the system-based and ontology-based approaches (Beck et al., 2020; Berlo & Laat, 2011; Cheng et al., 2013; L. Li et al., 2019; Noardo et al., 2022).

These approaches can be used separately or in combination to integrate data from IFC to CityGML for specific use cases.

To determine the appropriate integration approach and the necessary level of information for a given use case, it is crucial to consider the specific requirements and applications. In this section, we will first examine the previous research regarding 3D property valuation then second, Additionally, we will discuss the concept of "Level of Information Need" and its significance in the context of property valuation.

5.2.1 3D property valuation background

In the context of property valuation, the previous research has predominantly centered on fulfilling the 3D cadastral taxation criteria, often adopting the Land Administration Domain Model (LADM) as the foundational reference [6]. To elaborate, researchers such as Çağdaş et al. [21] have extended this model to accommodate the intricacies of taxation valuation, introducing the concept of "ADE Taxation" and employing the CityGML framework. Similarly, other scholars have been focused on extracting relevant specifications of variables from the Indoor Facility Concept (IfcSpace) component within the Industry Foundation Classes (IFC) framework for applications that center on indoor considerations [7,22,23]. Moreover, investigations have delved into parameters like indoor daylight, employing simulations based on Building Information Modeling (BIM) data [24]. Further studies have ventured into aspects beyond the building's physical attributes, such as evaluating view quality through comprehensive geographic information system (GIS) analyses [6].

Notwithstanding these existing explorations, there exists an unmet need in the realm of property valuation – the integration of the Industry Foundation Classes (IFC) and CityGML standards, specifically aimed at enhancing property valuation procedures. Consequently, the primary objective of this research paper is to introduce and establish a novel data integration approach. This approach is founded on the principles of Building Information Modeling (BIM) and City Information Modeling (CIM), with the overarching goal of enabling the comprehensive 3D valuation of properties.

5.2.2 IFC-CityGML integration approaches

- System based approach: it consists in a web system-based approach, where building information are not stored, but directly integrated into an information system for visualization purposes. This approach provides the possibility to extract a part of IFC semantics and performs full geometry conversion into an intermediate format (e.g., WebGL, B3M (batched 3D model) or into 3D city models standards (e.g., CityGML or recently CityJSON) before their integration into a web-visualization platform. The geometry and semantics are stored in separate databases (IFC/BIM, CityGML/GIS). As an example, Xu et al., (2020) integrated directly IFC data into a WebGIS system and visualized the results with Cesium. Emamgholian et al., (2021) used this approach in the context of 3D urban regulations.

This approach is mainly used for specific use cases. However, it is challenging at the level of storing information. Besides, it requires open data to be visualized in a web platform, which can be problematic when it comes to sensitive or personal data (e.g., property value, private property, etc.).

- Ontology based approach: it consists of translating IFC and CityGML semantic classes entities into a new UML (Unified Modelling Language) ontological model based on RDF (Resource Description Framework) and OWL (Ontology Web Language). The integration of IFC and CityGML can be done in two ways: (1) recognizing similar concepts/entities and merge them, or (2) connecting all the classes from IFC and CityGML into a unified model thanks to an ontology tool (OWL). Information can be extracted from RDF triples based on an ontology query language (e.g., SPARQL etc.).

  We also refer to this approach in literature as semantics-web based or linked-data based approach. Under this approach, we can cite the work of El-Mekawy et al., (2011) who proposed a UBM (Unified Building Model) as an intermediate data model to combine IFC and CityGML classes and terminologies. In the same trend, Tauscher, (2019) introduced the Triple Grammar Graph (TGG) as an automated ontology tool for IFC2CityGML mapping rules. However, such an approach is mainly based on full semantics mapping and doesn't allow to extract specific information needed from IFC to CityGML that can be required for a specific use case application.
- Schema based approach: it consists of mapping between schemas or data; the process is referred to as "schema matching" and "data matching", respectively (Olteanu, 2008).

Schema mapping techniques are divided in two approaches: (1) developing specific workflows conversion based ETL (Extract Transform and Load) tools or (2) extending CityGML or CityJSON schema, respectively based on ADE and extensions. The latter approach provides the capability to extract the needed semantic and geometric information from IFC and map it to the corresponding CityGML/CityJSON classes and semantics. This approach is however not fully automated since it requires a one-to-one mapping process for every specific use case. Under this approach, Krijnen (2021) developed an application to address the automation process of IFC-CityGML (precisely CityJSON), referred to as "GEOBIM" application which is a recent implementation of (Dunkers et al, 2016) work. They developed an open-source application for an automatic transformation for building geometric elements from IFC to CityJSON which is a not applied yet to a specific application requirement.

Table 5.1. IFC2CityGML data integration approaches: capabilities and challenges

Approach	Capabilities	Challenges
System based approach.	- 3D Data visualization. - Direct use of BIM in GIS.	- Only web-based GIS systems and platforms (e.g., Cesium). - Limited implementation possibilities (Databases) - Semantic selection is challenging.

Ontology based approach.	- Automatic integration approach. - Semantics mapping - Generic data integration approach.	- Complex process of semantic mapping. - Extracting specific information is not possible. - Limited at the geometric conversion.
Schema Model based approach.	- Possibility to extract requirements for a specific use case. - Non looseness of information. - Possibility to extend schemas. - Schema mapping based on semantics. - Geometrical errors detection - New flexible data model for geometry encoding (CityJSON).	- Complex information extraction from BIM (mainly IFC schema). - Limited control during the conversion process: limitation due to the opaque ETL interfaces. - Mature-less city models at the level of implementation and software support (CityGML 3.0). - Geometric and semantic mismatches not all solved. - Limited usability, and implementation of ADEs

Table 5.1 shows that the three data integration approaches have their own advantages and limitations. The selection of the most appropriate approach depends on the specific application context, which determines the integration purpose and the necessity of preserving or not the source schemas. Moreover, the integration process can either focus on enriching the semantic content of IFC data in CityGML (Ontology approach) or on extracting geometric features (Adouane et al., 2019; El Mekawy, 2011), or on converting IFC data into CityGML to add generic features and entities both geometrically and semantically (Geobim, 2019), depending on the application context.

1.1.1. LoIN (Level of Information Need)

In the field of property valuation, it is crucial to have specific information at the property elements level, such as cost data, which is not always included in generic integration workflows. This requires a suitable data integration paradigm that can be performed at different information levels, from various data sources, and enriched with external data related to building elements or environmental data. Noardo (2022) emphasized that the user requirements should be clearly defined to ensure a successful integration process that is suitable for multiple use cases, which can be challenging given the specificity of each application.

Although IFC and CityGML provide rich semantics information at the building and city scales, not all this information is necessary for specific use cases. Both data models provide information based on the concept of level of Detail (LoD), which represents the level of granularity of geometric and semantic information of objects. CityGML proposes a classification of LoDs that has recently been updated in version 3.0 to address various applications (Billen et al., 2016; Kutzner et al., 2020). In the BIM context, several concepts such as Level of Development, Level of Accuracy, and Level of Information have been proposed to extend the concept to the model (Hajji et al., 2021), but these concepts are sometimes confusing and lack standardization, leading to different interpretations of the requirements of each level of granularity.

To address this issue, a new concept called the Level of Information Need (LoIN) has been introduced by BuildingSmart as a new standard EN 17412-1 (BuildingSmart, 2021). The LoIN concept suggests that the granularity of information should be tailored to meet the specific needs of information exchange based on the context of use. This is especially crucial in property valuation, where building elements information must align with technical requirements for each variable at both geometric and semantic levels. While this concept has been introduced in dictionary descriptions, there is currently no technical implementation developed at the BIM&CIM level.

5.3. Method

In this section, we describe the methodology used to simulate and model 3D property variables using an integrated BIM and CIM approach. Figure 5.1 illustrates the meta-workflow, which is broken down into steps that we analyze in the following subsections.

As discussed in the related work section, the schema model method is the most appropriate approach for our work. It requires operating at the schema level to extract information based on the level of granularity required for each indoor and outdoor property variable.

Additionally, to enable further analysis at the neighborhood or city levels, the BIM and CIM should be maintained as reference models. IFC and CityGML are the most suitable data models for the proof of concept of our approach.

The recent version of CityGML 3.0 offers some improvements and new concepts related to modeling of constructions such as Buildings that are divided into Constructive Elements. Buildings as well as BuildingParts and ConstructiveElement classes allow mapping constructive elements from BIM data sets given in the IFC standard (e.g., the IFC classes IfcWall, IfcRoof, IfcBeam, IfcSlab, etc.) onto CityGML (Kutzner et al., 2020). These improvements are relevant to integrate variables requirements mainly cost and materials for property valuation purposes. However, the task is not trivial until we must deal with some mismatching issues that are analyzed and discussed in our case study.

We adopt a recent method proposed by Kutzner & Kolbe (2021) to convert IFC to CityGML3.0 in our conversion workflow. Their approach utilizes a data integration-based schema mapping, and the conversion is conducted with an ifc-to-citygml3 conversion tool available on GitHub. However, their method has certain limitations: (1) it employs a generic mapping for IFC/CityGML 3.0 classes without considering specific application requirements, and (2) it uses different data formats as inputs, such as IFC and Revit format. Using separate readers for IFC and Revit in an IFC to CityGML 3.0 conversion can create problems due to compatibility issues, increased complexity in the workflow, possible data loss, and increased risk of errors. This may result in incomplete or inaccurate conversions. Therefore, we propose an adjusted workflow tailored for property valuation purposes.

Numerous studies have underscored the pivotal role of property unit cost and indoor daylight as influential factors in property valuation. For instance, research has delved into the impact of property unit cost, demonstrating that the choice of building construction materials significantly affects property value. Buildings constructed with superior materials not only tend to incur lower maintenance costs but also boast reduced energy consumption, leading to potential savings.

Similarly, indoor variables, particularly indoor daylight within residential buildings, have emerged as noteworthy determinants of property valuation. Researchers such as Li and Chen [49] have stressed the importance of properties that are naturally illuminated. Such features contribute to reduced energy consumption and lower operational costs. Recent investigations have gone further to explore the profound influence of energy performance on the quality of life for occupants. While these studies did not rely on 3D simulations but rather conducted interviews with residents across various property storey levels, the findings elucidate a clear trend: properties with ample natural daylight tend to be preferred over their counterparts within the same building [50].

Another energy-related variable of significance is a building's solar potential. As illustrated in the work of Helbich et Jochem[51], varying levels of sunlight exposure impact individual property units. Their research established a positive correlation between solar radiation and residential property value, as higher solar potential translates into reduced energy consumption and heightened property value. Properties equipped with abundant roof solar potential, in particular, command higher market values.

Furthermore, it's crucial to acknowledge that indoor living quality exhibits considerable disparities across different apartment units within buildings. For instance, findings presented by Turan [48] suggest that floors characterized by abundant daylight illumination can increase property values by a notable 5% to 6%.

These insights collectively underscore the paramount importance of considering property unit cost and indoor daylight as pivotal variables with substantial impact on property valuation. Which justify the choice of these two variables to demonstrate the viability and the feasibility of our approach.

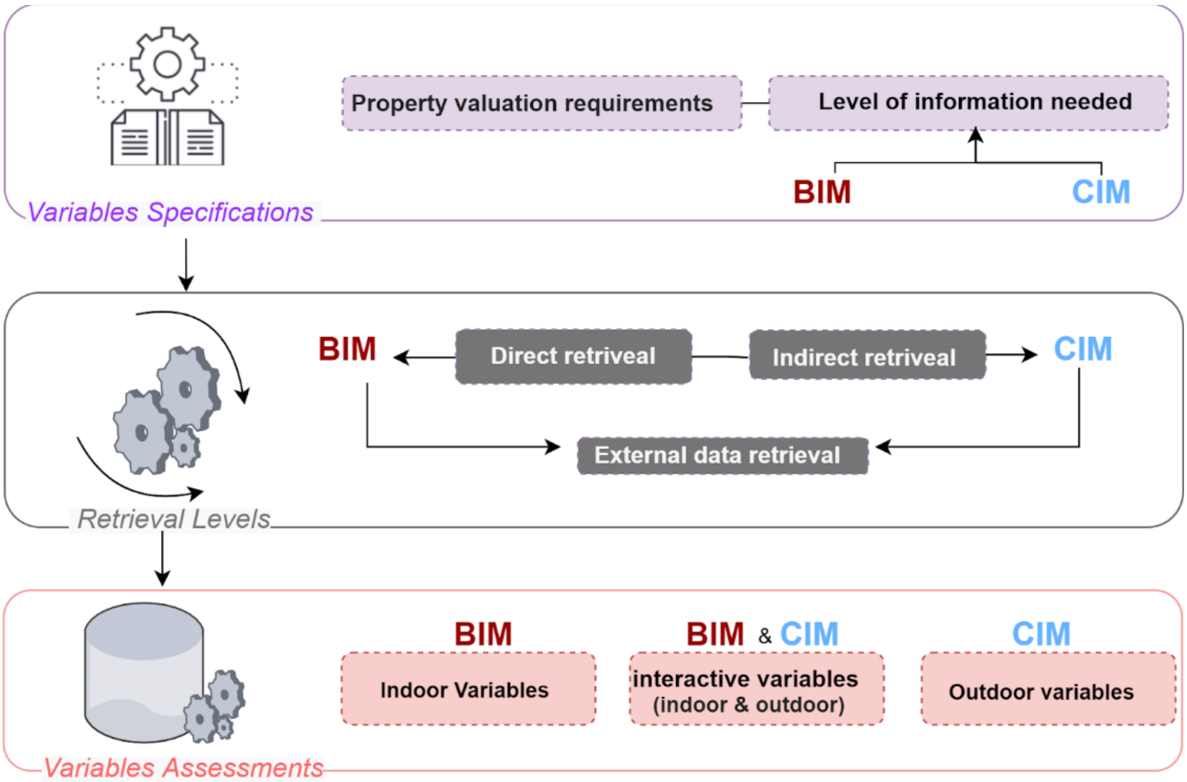


Figure 5.1: The proposed meta-Workflow for variables data integration-based BIM and CIM

The proposed workflow is divided into three stages, as illustrated in Figure 1:

(1) Variables specifications - This stage aims to identify, classify and select the relevant data specifications needed for 3D property valuation.

(2) Variables retrieval levels - The suitable data sources are defined (Building models and city models), and the process needed to retrieve each specific requirement based on spatial and non-spatial elements from the selected 3D models or other external data sources is defined.

(3) Variables Assessment - The final stage involves assessing the variable values required for property valuation.

5.3.1. Variables specifications definition

Accurate simulation of 3D property value requires identification of relevant variables for property evaluation and selection of appropriate data sources to simulate them. El Yamani et al. (2021) proposed a comprehensive analysis of such variables.

The identification process involves defining the property valuation requirements for each variable and specifying the required level of information, including the granularity of the geometric and semantic data, for variable estimation. A graphical representation of this process is shown in Figure 3.

5.3.1.1. Variables requirements

Through a deep literature review and analysis, a set of relevant 3D variables for property valuation have been identified and defined. Technical requirements for these variables were analyzed and classified based on building and city scale elements. The identification process was based on the analysis of 3D variables with high relevance to property valuation determination, with some variables being proposed due to their potential impact on the valuation process.

The identified variables were then summarized and classified according to indoor, outdoor, and interactive categories. (Figure 2).

The interactive variables can be used to predict changes in the value of residential properties in relation to the surrounding neighborhood (e.g., indoor daylight, air flow, sunlight exposure, and air quality).

The influence of the surrounding built environment on the building property can affect the interactive variables, such as indoor daylight, which is typically simulated at the scale of the building model. The obstruction of sunlight by surrounding buildings can significantly impact the accuracy of indoor daylight simulations, underscoring the need to consider neighborhood characteristics in 3D property valuation.

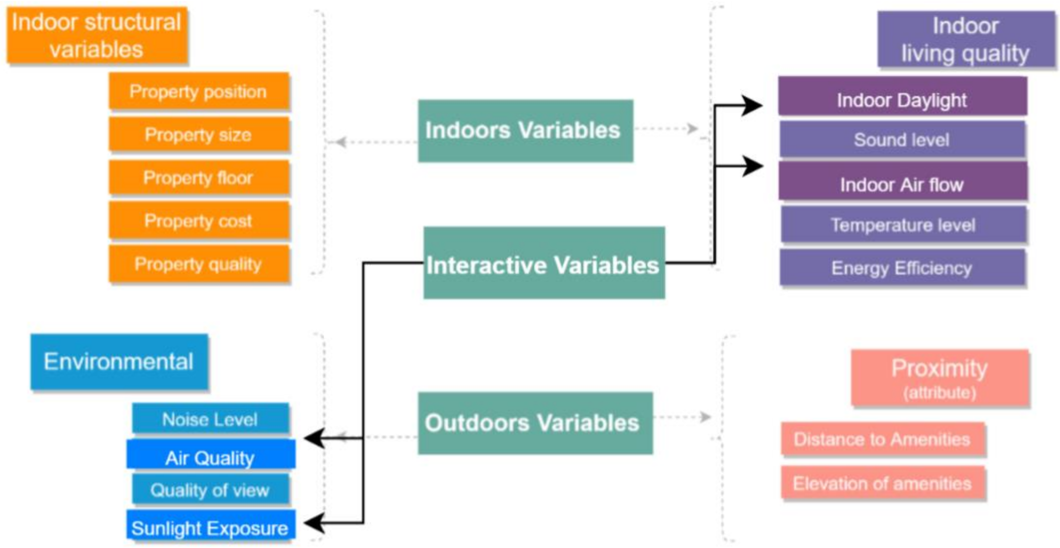
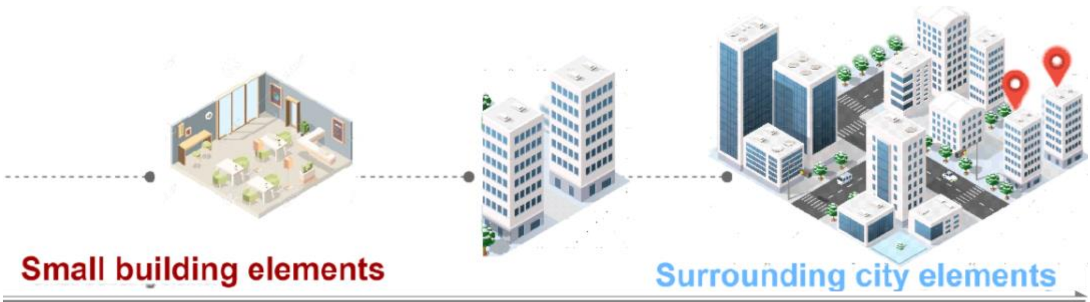


Figure 2: Variables classification (indoor/outdoor and interactive variables).

5.3.1.2. Level of Information Need

As stated before, 3D variables can be obtained from BIM, CIM or other data external sources. For each data source, integration workflows should be developed to retrieve the precise information. For each scale of the analysis (building or city or both), the degree of granularity should consider the smallest part/element of the model that holds significant information for simulating the property value (Biljecki et al, 2015). For example, indoor sunlight requires attributes at the level of IFC (IfcSpace) and the value is stored in a CityGML class (Room).



Var. Type	Requirements Elements Variables	Construction Materials	Openings	Building Part	Building Envelops	Building Surrounding Amenities	Atmospheric Conditions
Indoor variable	Property cost	**Materials cost** *Materials quantities*		*Building part cost (wall, column, slab etc.)* **Building unit : Cost estimation**			
Interactive variable	Indoor Daylight	**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*
	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*
Outdoor variable	View quality		*External openings 3D location*	**View Quality Value View type**		*Distance to Amenities Elevation of Amenities (building, vegetation)*	

Figure 3: Variables specifications-based LoIN - variables examples: Indoor (e.g., Property cost), Interactive (e.g., Indoor daylight, Sunlight exposure) and Outdoor (e.g., View quality) (italic: spatial elements; bold: non-spatial elements) (El Yamani et al. 2021).

In the following, we propose two information specification levels for property valuation, named LoIN-1 and LoIN-2, for property valuation, which are described below.

- LoIN-1 :

The specifications at this stage focus on the fundamental and generic entities and attributes that are necessary in any initial step for property valuation simulation and modeling. One such example is the Property Unit, which has boundaries that are required for defining other variables. The Property Unit can be defined as a boundary of space, volume, or building elements, and it can be obtained from either the IFC building elements or the IfcSpace (Appendix).

- LoIN-2 :

At the second level of the approach, detailed information is obtained for each variable by analyzing the input/output specifications of entities, attributes/Pset_properties, or relationships. The IFC/CityGML schema is used to select relevant classes or subclasses to retrieve the required variables.
The Pset_properties, which are attributes generated during the building modeling process according to IFC schema specifications, are used to provide more comprehensive information for each variable. For instance, indoor daylight is modeled as a Pset_properties, which is created during the BIM modeling stage and is not exported as IFC parameters by default. This approach allows for a more granular and accurate simulation of 3D property valuation variables (Appendix).

5.3.1.3. Retrieval levels

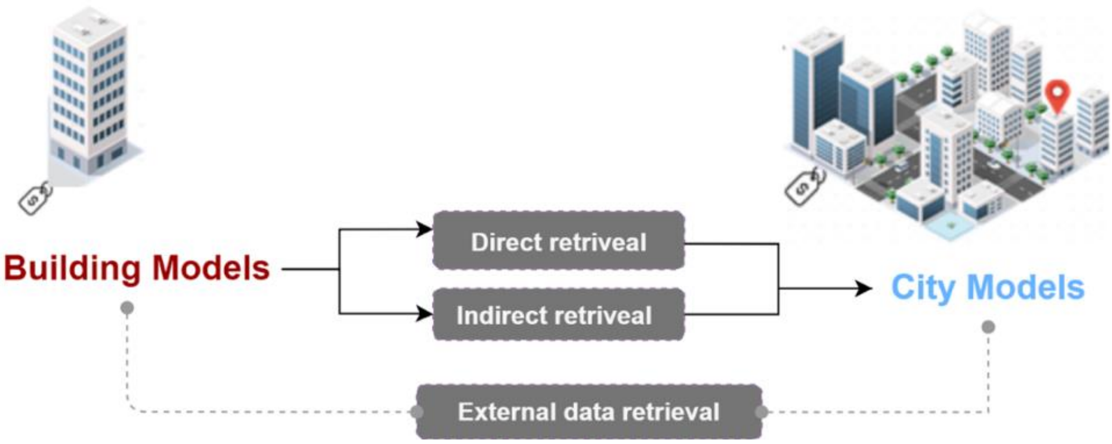


Figure5. 4: Methods for variables retrieval

Recent research has identified different approaches for retrieving variables based on data integration from 3D building and city models, however, to our knowledge, none of them studied their usability in property valuation. As presented in Figure 4, retrieval levels for variables requirements provided from 3D data models (city and building levels) can be classified into two major classes:

1. Direct retrieval: in this level, variable requirements can be directly mapped from building or city models based on an integration and conversion workflow. For example, the conversion process allows mapping features from IFC to CityGML or it can be created as a feature CityGML ADE.

2. Indirect retrieval: this level requires further processing for data integration workflow to extract variables values or requirements either from IFC or CityGML. It can be performed through two main stages. The first step is to transform variables requirements from IFC to CityGML in order to provide their composite elements; the second step is to extract their final value (example attribute) from the CityGML classes.

Another level of extraction concerns retrieving information from external sources (climate databases, real estate transactions, standards cost elements, etc.). Within the scope of this paper, cost elements have been integrated into BIM as external data to each building element (wall, column, slab and roof). Besides, further data need to be retrieved from external data sources such as climate dataset for modeling indoor daylight.

5.3.1.4. Variables assessment

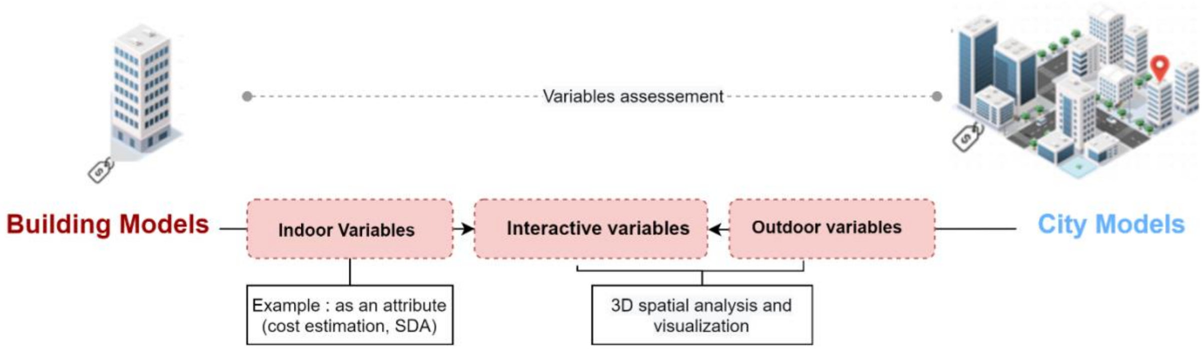


Figure 5.5. Variables assessments classes: indoors, interactive and outdoors variables.

The final stage of our workflow consists of assessing the variable values required for property valuation. Regarding the requirements retrieval levels, this subsection considers analyzing the variables assessment in terms of data structure, standardization and storage possibilities for property valuation (figure 5.5).

Therefore, we mainly classify the process of variables assessment in terms of:

3.1.1. Indoor variables: refer to variables simulated/extracted from BIM/IFC entities and stored as attributes extending the IFC property sets. These variable simulations can be done in two ways: (a) directly simulated in BIM then extracted to IFC as an input to the integration workflow or (b) assessed from IFC elements during the transformation and the mapping process from BIM to CIM.

3.1.2. Outdoor variables: outdoors variables are simulated after the retrieval step and when the transformation workflow from BIM to CIM is achieved. This process is required if further geospatial queries are needed to assess the final variable value at the level of information need. This can be done through storing the retrieved information into a 3D database and then executing queries for information extraction or through further processing by using for example 3D geospatial analysis.

3.1.3. Interactive variables: These variables simulation can be sourced from indoor quality variables such as the indoor daylight, indoor air quality and indoor noise and impacted by the outdoor built environment, such as the surrounding building amenities (building elevation, etc.). For example, indoor daylight is determined based on building requirements such as room physical boundaries, building thermal properties and the simulation of the amount daylight assessed from windows and the sun position.

5.4. Study case

The study case aims to demonstrate the feasibility of our proposed workflow for simulating 3D property variables. We tested and validated how to simulate and model two property valuation variables: indoor spatial daylight and property unit cost. We choose a residential building composed of multi-property units for which a BIM model has been created.

Beyond the technical aspect of data integration, we attempt to prove the feasibility of using IFC and CityGML to extract the level of information need to assess property valuation variables. Figure 5.6 summarizes the study case framework.

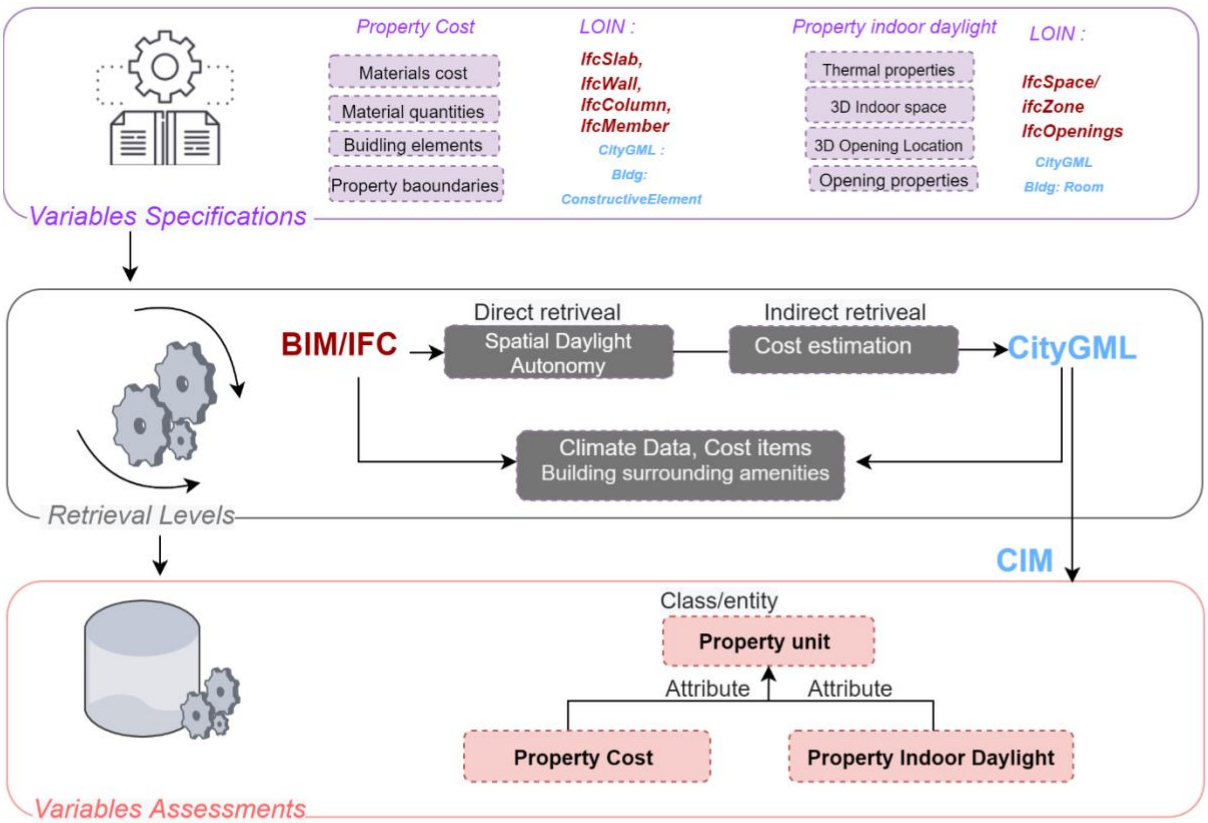


Figure 5.6. Workflow for variables simulation based IFC-CityGML 3.0 integration. The variables results are structured into three classes: Attribute (Property cost, Property Indoor daylight), new CityGML class (Property Unit).

5.4.1. Variables specifications

In the previous sections, we classified the property valuation requirements according to the LoIN specifications, and determined how each requirement can be extracted, either from an IFC entity, attribute or an additional "Property Set," or enriched from IFC to CityGML, or mapped to a CityGML class or class's attributes. These choices are elaborated upon in greater detail in the following section.

This subsection discusses the LoIN specifications for each variable, which include both geometric and semantic requirements as well as the data models used to source the specifications (IFC LoIN, CityGML 3.0 classes, and external data formats).

Table 5.2 summarizes the specifications required for determining the generic feature of a property unit (LoIN-1) and assessing two specific variables (property unit cost and indoor daylight) (LoIN-2).

Variable specifications Levels	**Input property valuation requirements**		**Data models integration specifications**		
	Geometric Specifications	**Semantic Specifications**	**IFC LoIN**	**CityGML 3.0/ classes**	**External data format**
Property unit (PU)	- sweep volume: for property unit boundaries, - solid: for building elements composing the property unit.	-PU Area; Volume, -PU Name; Number -PU materials and building elements type and installations	From class: IfcSpace IfcBuildingStorey IfcSlab, IfcColumn IfcMember IfcWall Attributes: Area, volume, number, Item Cost Property sets Pset_Materials Quantities	To class: building unit constructive element Attributes + Area; +Volume, +PropertyUnitName. +PropertyUnitNumber +PropertyUnitelementstype	-2D conceptual plans

			Pset_ cost InstallationsType		
Property unit cost	- Materials quantities (thickness, width, height) (solid in IFC) B-Rep: for building elements converted to CityGML	- Building cost at the level of apartment (mapping)	From class: IfcSlab, IfcColumn IfcMember IfcWall IfcbuildingStorey (Composition Type: Partial) Attributes: IfcMaterial Property sets PSet_Cost	To class building Parts/building unit Attributes +Property Unit Cost	- Cost items libraries based material types - Construction materials categories and families
	-Property unit boundaries (B-rep)	Materials type			
Indoor Daylight	- Room's physical space 3D (B-rep) - Openings size - Openings location	- Thermal properties (from BIM) Spatial Daylight	From IfcSpace Or IfcZone	To Bldg.: room Bldg: Building parts. +Attributes	Climate data
	- Property unit physical boundaries (B-rep)	autonomy (attribute) (extraction)	Attributes IfcThermalTransmittance	-Indoor daylight value - Indoor Daylight quality	Building thermal properties

Table 5.2. Variables specifications levels for Property unit cost, Indoor daylight variables Property unit feature.

5.4.2. Retrievals levels & assessement

An algorithm was developed to convert the chosen variables (property unit cost and indoor daylight) from IFC to CityGML by retrieving the necessary information from the former and performing geometrical and semantic mapping.

All data transformations and algorithms in this study case are performed using the Software 'Feature Manipulation Engine' (FME version 2022.2). Property valuation requirements from different formats can be imported into FME using the so called 'Readers' and the relevant attributes and entities can be selected and extracted, mainly IFC format in our approach, then manipulated using 'Transformers'. After the manipulation is complete, the newly generated output is exported to CityGML 3.0.

Since FME cannot recognize the last version of CityGML 3.0, we had to add the CityGML required classes by importing the "GML" schema of the building core classes to FME, specifically "Building" "BuildingConstructiveElements", "Room", "BuildingParts" and "BuildingUnit''.

It is also essential to mention that the IFC file need to be georeferenced before it's imported to FME. Storing the georeferencing properly is a compulsory step, without which it is impossible to proceed to the integration with the city context for simulating outdoors variables. Therefore, the IFC file was georeferenced according to the approximate address specifications. Otherwise, in the best scenario, the coordinate system should be specified during the building modeling (Noardo et al., 2021).

During the data integration process, we need to check and visualize the mapping results by using "FME inspector "and the "FZK viewer". In the next subsections we describe the integration process we performed to retrieve variables either indirectly (property unit cost) or directly (the indoor daylight).

5.4.2.1. Property unit cost

To retrieve property unit cost specifications, a two-step conversion process is employed during the IFC-CityGML integration: BIM2IFC and IFC2CityGML.

- **BIM2IFC:** the necessary features and attributes are extracted at the building model level and exported to IFC. These extracted requirements for cost can be classified as entities/classes (such as IfcBuildingStorey, IfcWall, IfcSlab, IfcColumn, and IfcMember), attributes (including material quantities, thickness and type), and Property Sets (defined as newly assessed attributes, in this case the calculated cost of building elements as shown in Figure 7).

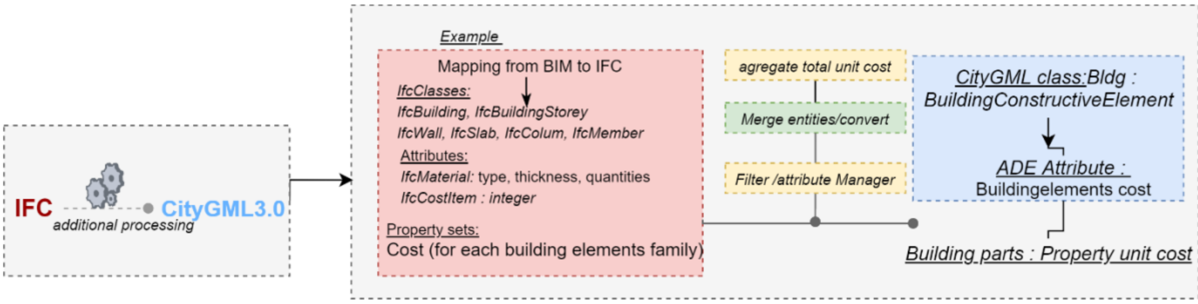


Figure 5.7: Property unit cost's retrieval step.

- **IFC2CityGML:** the first approach of this conversion process, involves retrieving the property unit cost requirements by mapping them to CityGML classes through a transformation algorithm. The property cost variable comprises spatial and non-spatial elements, which can be obtained from the IFC file's four main separate classes composing the building elements. To determine the cost estimation of the property unit, input information is required at the level of small building parts elements, such as materials quantities and cost, which can be extracted from IFC entities such as IfcBeam, IfcWall, ifcmember, and IfcSlab. However, to extract the spatial extent of the property physical boundaries and determine the building cost at the level of CityGML BuildingConstructiveElement and the whole Building cost, the data from wall, slab column elements, etc., need to be merged geometrically and semantically to the level of the building parts extent.

The second approach involves structuring the building floor to model building property units based on the building constructive elements boundaries for each floor, which enables the extraction of building elements, materials quantities, and cost at the level of the property unit boundaries. The IFC schema allows spatially grouping building elements within the same floor into one group of building units, making it possible to extract the necessary information.

To store the property cost in CityGML, it is first stored in the BuildingConstructiveElement class, then stored in the Buildingunit class by hierarchy, as an attribute. The geometry conversion is done using a customized ConvertGeometry tool that converts the hierarchical solid geometries present in the IFC file to composite surfaces of CityGML. The semantics conversion is carried out using an Attribute Manager tool that matches attribute from IFC to CityGML corresponding class and attribute, deletes unrequired attribute for ifcBuilding elements, and defines their type, such as cost estimation (valuetype: integer).

The conversion process faces two main limitations: (1) the need for a suitable method to extract cost from different IFC classes and (2) the inadequacies of IFC and CityGML classes for storing data at the building unit level. These limitations justify the need to create a new element in the CityGML schema called the Property Unit class.

5.4.2.2. Indoor Daylight

In this section, we aim to transform indoor daylight information from IFC spaces to CityGML3.0 building units. To achieve this, we first simulated indoor daylight using the Insights plugin in Revit and BIM software. We used various input data, including climate data, building location, glazing materials, and thermal properties to assess the value of the variable.

Indoor daylight specifications are retrieved directly during the conversion stage from ifc2citygml 3.0 (Figure 8) through a simulation in BIM software and then retrieved from IFC to CityGML-ADE.

We chose Spatial Daylight Autonomy (SDA) as the primary factor to evaluate indoor daylight. SDA measures the percentage of the floor area of a property unit that receives sufficient natural light, and the values are represented as a rate from 0% to 100%. The SDA value of 75% is the preferable natural sunlight by property occupants, while a value between 55% to 75% means that the indoor space daylight is "acceptable." However, when the value is under 55%, artificial lighting is necessary.

The variable attribute "IndoorDaylightQuality" was assessed based on the spatial distribution of illuminance levels in each floor area. The researchers used the SDA value for each building floor level to determine the existing definition-based energy performance. The results were spatially visualized in BIM software and stored as an attribute (El Yamani et al., 2021)(check figure 5.10).

To map the indoor daylight from "IfcSpace" to CityGML "Building: Room," the Room class needed to be extended with the indoor daylight attribute (Figure 5.8). We used FME transformers to store the variables, which consisted of three steps: "Expose Attribute," "Convert geometry," and "Attribute manager" (Geobim, 2019). These transformers were used to extract hidden IFC features and property sets, convert geometry, and create the correct CityGML hierarchy. Finally, we used the "AttributeManager" to create a new attribute in the BuildingRoom class named "IndoorDaylight" and its value type (see Figure 5.9).

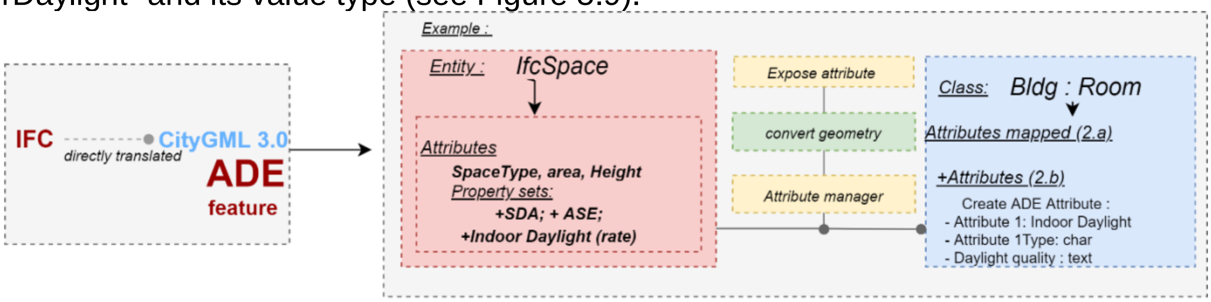


Figure 5.8. Retrieval process for indoor daylight variable from IfcSpace to Building Room.

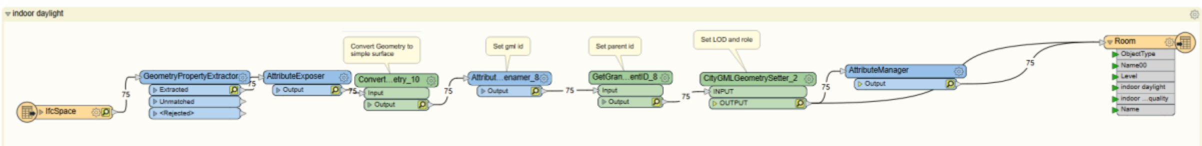


Figure 5.9. Indoor daylight Workflow retrievals.

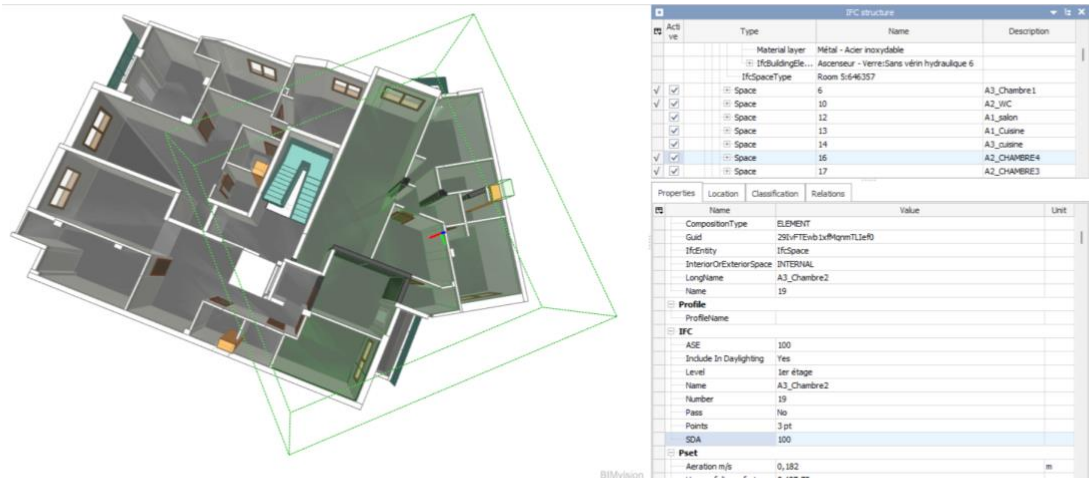


Figure 5.10: Indoor daylight value (called SDA (spatial daylight autonomy) in Ifc properties) value simulation example at the first-floor level building unit**.**

5.5. Discussion

In this paper, we proposed a data integration approach-based BIM and CIM for a property valuation purpose. A deep analysis of variables requirements in terms of Level of Information Need has been supported by a case study addressing the simulation case of two variables (cost and indoor day light).

The proposed workflow has addressed the potential problems and errors that can arise during the transformation process between IFC and CityGML. Based on the results, we recommend some guidelines and recommendations to be considered when dealing with IFC CityGML conversion in the context of property valuation to allow accurate simulations.

The section also highlights the need for a validator tool to test the transformation process and validate the resulting data and suggests expanding the methodology to incorporate outdoor and interactive variables for a more comprehensive property valuation.

5.5.1. Validator Tool Recommendation

The process of transforming indoor daylight information from IFC spaces to CityGML Building units can lead to several geometric and semantic errors. These errors can result in data loss or incorrect data during the transformation process. To minimize these errors, it is recommended to carefully validate the original IFC model and ensure that it adheres to the requirements of the CityGML standard. In addition, future works should develop a check validator tool for Property valuation LoIN through the proposed workflow approach. This tool will help to thoroughly test the transformation process and validate the resulting data to ensure that it is accurate and complete. Such a tool is necessary to ensure the reliability of the data integration process and to avoid errors that may impact the accuracy of property valuation results.

5.5.2. Software’s and technologies limitations

Using the latest version of CityGML 3.0 rises some limitations, such as SQL encoding and a lack of software support for CityGML ADEs, since it is still under development. However, our approach has the advantage of being generic and able to define the necessary information for each valuation variable specification, regardless of the standard version or technology used. Future investigations could be carried out on the CityJSON data model, which is aligned with the CityGML 3.0 schema, but it should be noted that it is not yet compliant with FME software.

5.5.3. BIM modeling requirements

We recommend guidelines to follow during the modeling stage to overcome the difficulty of obtaining specific requirements for valuation purposes at the BIM stage. One guideline is to group all building floor units into specific groups for practical export of property unit building elements for each apartment to the IFC file. This can help avoid a time-consuming extraction process. Another guideline is to specify thermal zones for simulating indoor daylight variables so they can be exported to the IfcZone for the simulation space of the property unit. Lastly, the cost for each building element entity needs to be integrated and delivered by the construction stakeholders to allow an accurate simulation of the whole building cost.

5.5.4. Method Generalization

In a more boarder perspective, to incorporate outdoor and interactive variables into our proposed approach, additional specifications and data sources need to be identified and integrated into the workflow. For outdoor variables like view quality and noise level, the specifications and data sources can be identified. Some required data need to be retrieved from external data sources, such as digital elevation models or noise maps (Appendix)

The incorporation of outdoor and interactive variables into the workflow would require additional data sources, specifications, and assessment methods, but it could result in a more comprehensive and accurate assessment of the property unit's value. Developing a specific simulation model for interactive variables such as indoor daylight and outdoor sunlight exposure would be necessary, which could consider the building's geometry and materials, as well as the surrounding outdoor environment. BIM and city models, as well as external data sources such as weather data and solar radiation models, could be used as data sources.

The results of the study demonstrate that the proposed workflow is both feasible and reliable. The study's focus is specifically on two variables: property unit cost and indoor daylight. It demonstrates how these variables can be simulated using a schema mapping process between IFC and CityGML. The process involves defining the specifications for the variables from both IFC and CityGML in terms of LoIN and using an effective conversion process to extract the specifications from both IFC and CityGML.

This methodology can be applied to other variables beyond property unit cost and indoor daylight, as demonstrated by the study's findings.

5.6. Conclusion

In this paper, we have proposed a generic workflow for supporting data integration in property valuation based on IFC and CityGML 3.0. We presented a coherent approach for data integration, which involved identifying specific requirements for valuation variables based on the LoIN. We mapped these requirements for both IFC and CityGML and proposed a structured approach for specifying the needed features, attributes, and property sets. We also proposed simulation approaches for all variables during the retrieval process.

Our proposed workflow was applied to a case study, where we successfully assessed two variables: indoor daylight and property unit cost. We defined and tested the specification levels for these variables and structured them as follows: Property Unit as a new feature class, and Indoor Daylight and Property Unit Cost as property unit attributes. We discussed the potential of our method and the results of the case study and highlighted some technical limitations.

It's important to acknowledge that our study case focuses on a subset of required in property valuation process. However, our proposed approach, when implemented as outlined, has the potential to mitigate valuation uncertainty by systematically integrating these data aspects. It's important to recognize that property valuation is an intricate process influenced by a multitude of factors environmental urbanistic, financial, social, and legal. While our approach focuses on 3D data to enhances accuracy and comprehensiveness through structured data integration, it's essential to remember that the estimated property value is inherently shaped by property markets.

In the IFC-CityGML data integration process, we found that a one-to-one mapping from IFC to CityGML classes/attributes was possible, allowing us to extract requirements and structure them hierarchically in the two models. However, this is not an automatic process, as some features require manual acquisition or substantial processing. Recent work has investigated automatic building features detection from IFC models using IfcOpenShell, such as the detection of apartments (Vaart, 2022), which may address some of the complexity and issues with the IFC model.
To enhance our approach, we plan to test our workflow with further outdoor variables to improve the specification levels for outdoor requirements and prove the feasibility of our approach. We also aim to propose a 3D property valuation extension and its implementation as a CityGML ADE, while addressing the limitations of SQL encoding in CityGML 3.0. Then, we plan to investigate the adaptability of our generic model to other data models such as CityJSON (Ledoux et al., 2019).
Finally, our proposed workflow offers a valuable contribution to property valuation by providing a structured approach for data integration that enhances accuracy and comprehensiveness. Our findings suggest that additional work is required to integrate other variables data requirements into the proposed workflow.

Appendix

Interactive variables	**Input Data requirements *(IFC)***	**Output destination data requirements *(CityGML3.0)***
Entities	Indoor Daylight → IfcZone/ IfcSpace	- Bldg::Room - Bldg::BuildingUnit
	Sound level → IfcSpace	
	Air flow level →IfcSpace	
	Temperature Level→IfcZone/IfcSpace	
	Energy Efficiency→ IfcZone,	
Attributes/ Pset_properties	IfcSpace/IfcZone : +Rate	- Bldg::Room - Bldg::BuildingUnit
Relationships	---	Room is child/parent hierarchy with Building unit

Indoor variables	**Input Data requirements *(IFC)***	**Output destination data requirements *(CityGML3.0)***
Entities	IfcBuilding, IfcbuildingStorey : PU Position PU Size PU Floor	To BuildingFloor and Building class
	PU Cost → Ifc building elements, a semantic attribute to Property Unit mapping	- Bldg::BuildingUnit
	PU Quality	- Bldg::BuildingUnit
Attributes/Pset_properties	*IfcBuilding:* +Address of Building *IfcBuildingStorey*: +PU Height +Floor Number *Ifcwall,ifcslab,ifccolumn:*	BuildingConstructiveElement : +PU Cost estimation +PU Materials Type +PU Materials Quantities

	+Item Cost +Pset_Materials Quantities +Pset_ cost *IfcInstallations :* + Installations Type	
Relationships	----	From BuildingConstructiveElement to Building unit : a part of
"PropertyUnit" **Specifications:**	**Input Data requirements (IFC)**	**Output destination data requirements (*CityGML3.0)***
Generic Entities	*IfcSite*	*CityModel*
	IfcBuilding	*Building*
	IfcbuildingStorey	*BuildingFloor* *Building Unit*
	Ifc building parts:(IfcWall, IfcSlab, IfcColumn, IfcMember)	*Building Constructive Element*
	Ifc installations	*Building*
	Ifc opening (door, window)	*Building*
	IfcSpace	*Bldg:: Room*
Generic Attributes	*IfcbuildingStorey :* + CompositionType : Partial	*Building Constructive Element* +BuildingElementType

	IfcSpace: +Area; +Volume, +PropertyUnitName; +PropertyUnitNumber	*Bldg:: Room*
Relationships	*Ifc building parts:* Merge *IfcbuildingStorey:* Spatial Structure	From *Building Constructive Element* To *Building Unit :* A part of From *Blding: Room to Building Unit :* A part of

Outdoor variables	**Input Data requirements *(IFC)***	**Output destination data requirements *(CityGML3.0)***
Entities	Sunlight Exposure → ---	- CityGML_Core::_CityObjects - CityGML_Core::_CityObjectsGroup - Bldg::Room - Bldg::BuildingUnit - LandUse::_LandUse
	Noise Level → ---	- CityGML_Core::_CityObjects - CityGML_Core::_CityObjectsGroup - Bldg::Room - Bldg::BuildingUnit - LandUse::_LandUse - Transportation::Road
	Air Quality → ---	- CityGML_Core::_CityObjects - CityGML_Core::_CityObjectsGroup - Bldg::Room - Bldg::BuildingUnit - LandUse::_LandUse - Transportation::Road
	View quality → ---	- CityGML_Core::_CityObjects - CityGML_Core::_CityObjectsGroup - Bldg::Room - Bldg::BuildingUnit - Bldg::_Opening - LandUse::_LandUse
Attributes	*IfcOpening :* +Opening dimensions	Bldg::BuildingUnit: +Sunlight Value

	+Opening thermal properties *Ifcwall:* +Materials Type +Thermal properties	+Sunlight Quality +Noise Value +Noise Quality +Air quality +View Type +View Rate +View Quality

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Chapter 6 - Conclusion

5.1. Research questions 121
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The research aimed to investigate the suitable valuation approach for property valuation and define the 3D variables with a high impact on property value. We now conclude by reviewing, the research questions that were addressed through a comprehensive analysis of different valuation approaches, the integration of 3D modeling techniques, and the development of a workflow process for integrating 3D variables.

Chapter 2 provides an overview of various property valuation approaches and identified the Hedonic pricing approach as the most suitable for integrating Building Information Modeling (BIM) and 3D Geographic Information Systems (GIS) techniques. The chapter discuss the need for incorporating 3D models in property valuation to enhance accuracy and efficiency.

Chapter 3 investigates the technical requirements of 3D variables in property valuation and explored the capabilities of BIM and City Information Modeling (CIM). The chapter highlighted the need for comprehensive data integration and proposed a meta workflow for integrating data from Industry Foundation Classes (IFC) and CityGML (chapter5).

The foundation of this research lies primarily within Chapter 4, where we have meticulously crafted and evolved our model from its conceptualization to the demonstration of data integrability using the CityJSON standard.

Based on the findings from the preceding chapters, the research successfully addresses the research questions by determining the extent to which 3D variables with high impact on property value could be defined, exploring the acquisition of 3D variables through current research advances in 3D modeling techniques, and developing a workflow process for integrating 3D variables and their requirements.

Furthermore, the research extensions outline several avenues for future exploration and enhancement of the developed 3D property valuation model. These extensions included expanding the model to incorporate additional 3D variables, standardizing and ensuring interoperability with existing standards, applying the model to different geographic contexts, engaging stakeholders for industry adoption, and integrating advanced machine learning techniques.

In summary, this research makes significant contributions to the field of property valuation by addressing the research questions and proposing avenues for further development. The developed 3D property valuation model, along with the research extensions, holds the potential to revolutionize property valuation practices and decision-making processes in the real estate industry. By aligning with the pillars of the EuroSDR project, including process, technology, interoperability, scalability, and education, this research contributes to the advancement and implementation of similar projects in the field of GEOBIM in urban applications.

5.1. Research questions

"Can a comprehensive and generic 3D property valuation model be developed using BIM and CIM data, which incorporates 3D indoor and outdoor variables to accurately determine the actual value of a property?"

By investigating the suitable valuation approach for property valuation, how far can we define the 3D variables with high impact on property value?

The research question 1 aims to determine the extent to which the 3D variables with a high impact on property value could be defined by investigating the suitable valuation approach for property valuation. In **Chapter 2**, an in-depth overview of various property valuation approaches, standards, and practices are provided. The chapter critically examines the strengths and limitations of different methods and identify the Hedonic pricing approach as the most suitable for integrating Building Information Modeling (BIM) and 3D Geographic Information Systems (GIS) techniques. The discussion highlighted the need for incorporating 3D models in property valuation to enhance accuracy and efficiency. **In Chapter 3,** we also highlighted that Hedonic method is most suitable for computing variables driven property value.

Since studies, confirmed the impact of 3D variables on the property value based on their correlations to the property price. Our research focus is modeling and simulating 3D variables elements for the purpose of an accurate value. The computation part into the statistic hedonic model is out of the research scope. In this chapter, these variables were defined as indoor and outdoor variables based on their spatial and non-spatial elements (one dimension) and based on their granularity (from the small building elements where they can be defined until the environmental neighborhood elements) for property valuation uses case, since they are mainly defined for urban applications. These two chapters addressees well this research question 1.

Considering the current advances in 3D modeling techniques (BIM, CIM), how can we obtain these 3D variables required for property value?

Research question 2 focuses on exploring how the current research advances in 3D modeling techniques, specifically BIM and CIM, enable the acquisition of 3D variables. **Chapter 4 and 5** extensively examined the potential of BIM and CIM in real estate valuation, with a specific emphasis on which variable can be obtained and the classification of the spatial and non-spatial elements required to be sourced from these models.

Chapter 3 investigates the technical requirements of 3D variables in the context of property valuation. It analyzed the spatial and non-spatial elements of these variables, determining which ones could be derived from 3D city models and building-scale elements. Additionally, the chapter explored the capabilities of BIM and City Information Modeling (CIM) in providing essential information for property valuation, both indoors and outdoors. The discussion emphasized the need for comprehensive data integration and highlighted the potential of utilizing 3D models for accurate property valuation.

Collectively, the progression of these four articles has led to a comprehensive response to this question, advancing it from its initial conceptualization to a mature reflection. The research offers an approach for acquiring 3D variables by first defining them, establishing their prerequisites, and determining the suitability of 3D modeling technologies, as detailed in Chapters 4 and 5. Additionally, it proposes specifications based on urban and building information modeling standards, such as IFC and CityGML, to address information needs. This encompasses an assessment of the extent to which these standards can supply the necessary data for assessing property valuation variables.

How can a 3D property valuation model be effectively developed to incorporate the required 3D variables, towards a generic and implementable 3D property valuation extension?

This question is the basis socle of our research project: to come up with a new generic and comprehensive model tailored to integrate 3D indoors and outdoors variables with high impact on property value.

The discussion of **chapter 4** emphasized the need to develop a 3D property valuation model-based BIM and CIM and in **chapter 5**, this model was designed and developed as a form of CityGML core extension, (property valuation ADE).

The big picture of the research is towards a generic property valuation model, where we aim to provide a **generic standardized model** that integrate indoor and outdoor variables**.** Taking the example of **the cost approach,** we provided one of the main variable's property cost elements; quantities etc.; for **the comparative approach**, sales are compared based on real estate characteristics (area, property quality etc.) and proximity to amenities. Such variables could be extracted from our model too.

In other terms, it's a **generic valuation model** that could be applied for any users/or valuations purposes it can be for sales comparative approach, a cost or for taxation basis. Since the identified variables a generic and that's the **purpose of standardizing the information related to valuation.**

Could we develop a data integrability approach: A use case where the feasibility of our property valuation model is demonstrated? Where 3D indoors and outdoors variables can be sourced from IFC and CityGML?

The discussion regarding data integrability challenges for our model (section 4, the chapter 5), in terms of standards (IFC, CityGML 3.0) complexity and flexibility are sufficient to investigate the development of a workflow process to integrate the identified 3D variables and their requirements, as well as demonstrate its feasibility through a demonstration of selected variables. That's why, Chapter 5 proposed a meta-workflow for integrating data from Industry Foundation Classes (IFC) and CityGML. By proposing a meta-workflow to integrate data requirements through three stages: (1) from their specifications at the level of information need either into IFC or CityGML classes (2) defining the retrieval stage to extract their specifications (3) to the assessment stage where these variables are stored either as new features or new attributes into our property valuation model. This approach is evaluated by testing it with two indoor variables (indoor daylight, property unit cost), serving as a demonstration of its effectiveness.

The research has successfully addressed research question 4 by developing and demonstrating a workflow process for integrating 3D variables and their requirements.

5.2. Research extensions

This research opens several avenues for further exploration and enhancement. The following research extensions aim to expand the effectiveness, applicability, and impact of the developed model, paving the way for advancements in property valuation research:

5.2.1. Better Standardization and Interoperability

After developing the proposed extension of the 3D property valuation model, a crucial step would be to align it with existing standards and ensure interoperability with other systems and applications. Specifically, efforts can be made to integrate the developed model with widely recognized standards such as CityGML and IFC, which are commonly used in the field of geospatial and building information modeling.

To achieve this alignment, future research can focus on studying the specifications of CityGML and IFC and identifying the necessary modifications or adaptations required to incorporate the extended 3D valuation model seamlessly. The aim would be to establish compatibility and harmonization between the developed model and these established standards.

Furthermore, it is important to consider the broader context of international standardization. Research efforts can be directed towards submitting the extended 3D valuation model to international standardization bodies, such as the Open Geospatial Consortium (OGC) and the International Organization for Standardization (ISO). By engaging with these organizations, the model can undergo rigorous evaluation and potentially be adopted as an official standard within the industry.

The focus on standardization and interoperability aims to ensure that the developed model can effectively communicate and integrate with other systems and applications used in the field of property valuation. This alignment with international standards not only enhances the credibility and wider acceptance of the model but also enables seamless data exchange and collaboration among different stakeholders in the real estate industry.

By pursuing this research extension and actively participating in standardization efforts, the developed 3D valuation model can make significant contributions to the field of property valuation and become a widely recognized and adopted framework for accurate and comprehensive property assessments.

5.2.2. Integrability generalization

In a more boarder perspective, to incorporate outdoor and interactive variables into our proposed approach, additional specifications and data sources need to be identified and integrated into the workflow. For outdoor variables like view quality and noise level, the specifications and data sources can be identified. Some required data need to be retrieved from external data sources, such as digital elevation models or noise maps.

The incorporation of outdoor and interactive variables into the workflow would require additional data sources, specifications, and assessment methods, but it could result in a more comprehensive and accurate assessment of the property unit's value. Developing a specific simulation model for interactive variables such as indoor daylight and outdoor sunlight exposure would be necessary, which could consider the building's geometry and materials, as well as the surrounding outdoor environment. BIM and city models, as well as external data sources such as weather data and solar radiation models, could be used as data sources.

The results of the research demonstrate that the proposed data integrability approach is both feasible and reliable.

5.2.3. Stakeholder Engagement and Industry Adoption

An essential aspect of furthering the impact of this research is engaging with relevant stakeholders and promoting the adoption of the 3D valuation model within the real estate industry. Future research can involve collaborating with industry professionals, policymakers, and valuation experts to gain insights and feedback on the model's practicality and usability. By actively involving stakeholders, the research findings can be translated into tangible benefits for the real estate industry.

5.2.4. For a better implementation and expansion

To enhance the implementation of this research extension and broaden its scope, several crucial steps are planned. Firstly, the project will undergo a comprehensive implementation phase, and its official GitHub repository will be established. Secondly, the development of an essential API platform will be undertaken. These endeavors mark the continued evolution of this remarkable work in terms of conceptualization and data integrability within the context of bridging BIM and CIM into an adaptable and all-encompassing generic model suitable for diverse 3D variable simulation use cases. The transition from a novel approach to practical usability represents the imminent progression of this model's expansion. Importantly, this initiative is a collaborative effort, not an individual endeavor. It necessitates the collective teamwork of numerous PhD candidates and researchers. As we move forward, this project will persist in terms of development and growth. This thesis serves as the initial step towards embarking on the substantive work associated with the project itself.

The developed 3D property valuation model and the proposed research extensions provide valuable contributions to the advancement of the field and support the implementation of similar projects in this research context.

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Curriculum

Siham El Yamani is born on 26 January 1990 in a small village in the south of Morocco/Agadir called Belfaa.

Siham El Yamani - GEOBIM Wizard | Unravelling the 3D Valuation Mystery! 💁‍♀️

🔭 Exploring the Geomatics Galaxy | Property Valuation Guru | 🏙️3D Urban Modeling Enthusiast

Hey there! I'm Siham El Yamani, a fearless Joint-Ph.D. student in Geomatics Science 🎓, on a mission to crack the code of 3D property valuation! 🏠✨ Armed with my trusty BIM/IFC & CIM/CityGML elements, 3D spatial analysis, CityJSON CityGML ADE, 3D citydB, and 3D geovizualisation. I'm weaving magic to reveal the hidden magic of the 3D indoors and outdoors 3D variables that compose the Property-value.

💼 As a savvy GIS consultant, I've conjured up some wickedly clever insights for property valuation projects. 💁‍♀️💡 My geomatics background as a surveyor engineer gives me a unique perspective, blending academic prowess with real-world wizardry.

📚 My baby Ph.D. project is an enchanting journey, introducing an innovative approach to 3D property valuation modeling, perfect for the realm of urban digital twin tech! 🏙️💥 It's been a whirlwind adventure collaborating with IAV Hassan II institute and the University of Liège's Geomatics unit.

🎓 Ready to soar into a thrilling new chapter! Soon, I'll embark on an exciting postdoctoral quest, where I'll continue my magical exploration of GEOBIM, Urban application enthusiastic project🖊️✨

List of publications

Publications

- **El Yamani, S**.; Hajji, M.; Billen, R. IFC-CityGML data integration for Property Valuation. at ISPRS International Journal of Geo-Information.

- **El Yamani, S**.; Hajji, R.; Nys, G.A.; Ettarid, M.; Billen, R. 3D Variables Requirements for Property Valuation Modeling Based on the Integration of BIM and CIM. *Sustainability*, **13**, 2814. Doi : 10.3390/su13052814.

- **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. Doi: 10.2495/BIM190261.

- **El Yamani, S**.; Hajji, R., *BIM and 3D GIS Integration for Real Estate Valuation*, ISTE Ltd, UK, December 2021, chapter 6, pp. 95-109. Doi: 10.1002/9781119885474.ch6.

- **El Yamani, S**.; Hajji, R., Intégration BIM et SIG 3D pour l'évaluation immobilière, ISTE Ltd, UK, Septembre 2022 Link : https://hdl.handle.net/2268/294663

- El Yamani, S. ; J. Stoter[1] F. Noardo[2], A.Hakim[1], K. Arroyo Ohori[1], J.van der Vaart[1], **Geometry level of information needs for digital building permit regulation, DBP 24 conference proceedings, April 2024**

Communications

- Doctoriales 2019 – SIAM : « L'intégration des BIM et SIG 3D dans un système d'évaluation immobilière par la méthode des prix hédoniques »
- Séminaire sur « Building Information Modeling, Construire grâce à la maquette numérique » ;
  Casablanca le 09 janvier 2018, organisé par l'École des Hautes Études des Sciences et Techniques de l'Ingénieur et du Management (HESTIM).
- Intervention et modération de la table ronde à la journée de l'ingénieur génie civil intitulée
  « BIM, quel avenir et quelles perspectives ? », 2018 Rabat le 05 Mai à l'École Marocaine du Science de l'Ingénieur.

- Participation aux Conférences et ateliers de la 4ème édition du Salon BIM World/ Smart data 2018; Paris le 28-29 mars 2018 à l'Arche de Défense.
- Participation ma Thèse en 180s Uliège : « Nouveau voisin, suis-heureuse ? »
- Oral presentation at 3 Minute Thesis, "Your House has a 3D value", September 2021.
- Séminaire GISt "Towards a CityGML 3D Property Valuation Model based on BIM", Université de Delft, Pays-Bas, 02/07/2020 ;
- Oral presentation at the 3rd International Conference on Building Information Modelling (BIM) in Design, Construction and Operations, Seville, Espagne, 9 – 11 October 2019.
- Oral communication at the 5th International Conference on Geoinformation Science, "3D Geoadvances Conference", ISPRS, Morocco, October 2018.
- Poster and Oral communication at ARGDT Conference, IAV Hassan II, Morocco, October 2018.
- EuroSDR Grant – GEOBIM Ecole doctorale du 06 – 17 Mars 2023 : Conference 3Dgeoinfo – 2022 : 7th Smart Data Cities & 17th 3D GeoInfo.