A Data Dictionary for the Building Energy Modeling Domain

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Abstract
Building information modeling (BIM) holds the potential to streamline the building energy analysis process by providing geometry, materials, envelope properties, internal gains, and ventilation systems. The IFC (Industry Foundation Classes) standard facilitates data transfer for this purpose. However, the IFC scheme allows information to be organized and represented in different ways, causing interoperability challenges between software and information loss. This study addresses these issues by proposing a methodology for developing an energy modeling data dictionary. Based on the BuildingSmart Data Dictionary (bSDD) methodology, the proposed data dictionary aligns with the IFC schema and incorporates information about the building materials' thermal properties. The proposed structure includes information classification systems and allows for diverse energy code integration. In doing so, the organized and classified information can be mapped to energy analysis software. This initiative resolves current challenges and establishes a blueprint for creating data dictionaries across various domains, expanding its utility beyond energy modeling.

Keywords: Industry Foundation Classes, BuildingSmart Data Dictionary, Linked Data, Building Energy Modeling.

1 Introduction

In recent decades, attention has been significantly increased to energy and environmental issues. The construction industry has been particularly prominent, identified as an important source of global energy demand and CO_2 emissions. The Status Report for Building and Construction from the United Nations Environment Program – UNEP (UNEP 2024) highlights the need to consider the use of passive strategies in construction projects to mitigate these impacts and, where relevant, choose appropriate energy-efficient civil construction materials. Evaluating passive strategies can be achieved through building energy performance simulations, which can seamlessly integrate into the building design process via Building Information Modeling (BIM).

Efficient communication between design and energy simulation tools is critical to establishing a collaborative design environment. In the BIM approach, the design process requires clearly defined procedures to prevent communication failures and interaction conflicts between the different specializations of the models. Furthermore, ensuring that models are shared in a common read-and-write structure using the same file formats and protocols is essential. The concept of interoperability refers to the ability of different computer systems to exchange data, simplifying the workflow and eliminating the need for manual manipulation of information generated by other programs (Andriamamonjy et al. 2018; SACKS et al. 2018). The

IFC (Industry Foundation Classes) standard is a non-proprietary international protocol certified by BuildingSmart (BUILDINGSMART 2024a). This standard represents a broad support structure focused on objects, created for interoperability between different applications, being commonly used and compatible with most BIM software utilized within the professional landscape. The IFC standard translates information between BIM and Building Energy Performance Simulation (BEPS) and for other uses throughout the construction life cycle. However, there are still many challenges associated with using the IFC standard. Information loss can occur during model import and export from other tools and formats. The loss of information includes geometric data and also thermal properties of the envelope components (Chen et al., 2018). This loss usually occurs during BIM model export. In addition, some of these parameters, necessary for energy analysis, are absent in the IFC schema. These parameters refer to the thermal properties of materials – such as solar refraction, coefficient of heat transfer, and absorption coefficient (Alshehri et al. 2017).

To solve this problem of building material properties, some authors used external libraries to fulfill the need to insert or map properties of envelope materials (Choi et al. 2016; Jeong et al. 2014; Kim et al. 2016; Sanguinetti et al. 2012). These libraries are model-linked data systems. However, they are independent libraries developed for specific domains or to serve a certain system or software without specifying information classification standards. In essence, these independent libraries cannot be connected because there is no common standardization between their structures. Furthermore, as described by Venugopal et al. (Venugopal et al. 2015), the IFC standard offers multiple ways to define objects, relations, and attributes. A lack of connection and standardization between these structures prevents them from being unified and used in different analysis contexts.

The aim of this paper is to propose a specific data dictionary for the energy modeling domain, presenting a methodological approach for its structuring and subsequent development. The dictionary allows users to organize information, incorporating standards for classifying materials. Using BuildingSmart's data dictionary methodology as a basis and following the IFC structure, the proposed methodology provides a basis for developing different libraries within the domain. The linked data structure avoids interoperability issues and reduces data loss in the energy modeling and analysis domain by aligning with and linking to the IFC schema.

The paper initially reviews topics relevant to the structure and organization of the data dictionary, followed by the proposed methodology and application in a case study.

2 Background

Information required for an energy analysis model includes building geometry (including layout and space configuration), solar orientation of the building, materials used and their thermal properties, building function, lighting, occupancy, and equipment programming settings (Sanhudo et al. 2021). Furthermore, it covers the characterization of the HVAC system and local meteorological data (Wetter & Treeck 2017).

In some cases, the information required for BEPS is added to BIM models but not transferred to the energy model, for example, solar and infrared absorptivity properties in a glazing system (Jeong et al., 2014). Furthermore, it was detected that the IFC schema does not include all classes of specific elements necessary for the energy model, as exposed by Pinheiro et al. (Pinheiro et al. 2018).

Maile et al. (2013) emphasize that certain modeling aspects are difficult to address, such as defining the thermal properties of materials. More definitions and information about domain-specific requirements can lead to consistency in the IFC.

Utilizing a data dictionary to organize the information necessary for the energy modeling domain presents a promising approach. The bSDD is an openBIM standard that operationalizes the exchange of BIM information to establish compatibility and interoperability between applications from various experts in the AECO (Architecture, Engineering, Construction, and Operations) sector, BIM end-users and providers of software solutions (Böger et al. 2018). Its data schema resembles the IFC and is aligned with the international standards ISO 12006-3 (ISO 2022) and ISO 23386 (ISO 2020a). Additionally, it operates on an object-oriented principle, where each object is associated with a class possessing well-defined attributes and relationships. The service can be accessed on the BuildingSmart website or through an open Application Programming Interface (API) compatible with multiple applications (BUILDINGSMART 2024b).

A data dictionary is a centralized metadata storage repository. It covers definitions, relationships between data, origins, uses, and formats (ISO 2020a). It allows for adding classification systems, categorizing elements by construction function, materials, and properties, establishing relationships, and defining terms with synonyms and translations in different languages (BUILDINGSMART 2024b). Utilizing it ensures the standardization of information across the entire construction life cycle and accurate comprehension of the involved data. It operates as a semantic mapping tool, linking akin terms based on their meaning.

Organizing information within a specific dictionary may imply embedding codes for materials or services or domain-specific manuals. Using a classification system facilitates collaborative work because when the same defined vocabulary terms are used, the ambiguity can be excluded (Böger et al. 2018). The most used classification system in BIM domains is Omniclass. Omniclass is a classification and standardization system aimed at the construction industry. The structure is based on ISO 12006-2 (ISO 2020b), following the organizational principles of the MasterFormat and UniFormat tables. The standard classifies building components and different construction systems. It structures and names electronic databases contained in software and components of the IFC structure. There are other information organization standards beyond Omniclass, created for specific contexts. The advantage of using a specific standard instead of Omniclass is that it should adapt better to the materials and products available in the specific context of a country, for example (ABDI 2017); the same applies to regulations in other countries.

Regarding information classification, the IFC scheme classes in version 4.3 are defined in bSDD, so it is possible to create a dictionary classifying the varied materials with their thermal properties, associating them with the properties already defined in the IFC and established in bSDD. Information organizing at bSDD may involve classification systems like Omniclass or another classification system like the Brazilian classification standard.

IFC presents a very detailed level of information and is used for general purposes, while in bSDD, the organization allows internationality to libraries of reusable and shareable objects (Böger et al. 2018).

In addition to the advantage of establishing standardization of material properties, it is possible to create automation in properties relationships in models that have materials defined in the project phase but do not have the values predefined in each standard, minimizing the ambiguity of information and facilitating interoperability between different applications.

The open standards used for defining information exchange requirements combined with the provision of a well-structured knowledge base, such as a data dictionary, allows different applications or systems to collaborate, for example, defining files in IDS (Information Delivery Specification) format to starting from the information necessary for a BIM model, in a natural language (readable for humans) collected in previous phases. The Information Delivery Specification (IDS) is a standard developed by BuildingSMART to define non-geometric information delivery requirements for an IFC model, limited to names and values of properties, classes, attributes, classifications, materials, and some relationships (BUILDINGSMART 2024c).

The bSDD schema allows cross-referencing information from a specific project domain with the IFC schema. For example, understanding that there is a need for a property in the BIM model, it is possible to use the dictionary to cross-reference information about that property written in natural language 'specific heat' with the property defined in the IFC schema 'Specific thermal capacity' described in the set of Pset_MaterialThermal properties.

So, this work aims to demonstrate how a data dictionary can be used to aggregate the thermophysical properties of materials associated with construction elements. This information enriches the IFC model for analyzing the thermal-energy performance of buildings. To achieve this objective, we will rely on BuildingSMART International's freely accessible data dictionary repository, the buildingSMART Data Dictionary (bSDD). The IDS specification can serve as a supplementary repository for designers to verify definitions within BIM software.

3 Methodology

This work proposes a methodology for creating a data dictionary for the energy modeling domain, following BuildingSmart's Data Dictionary (BUILDINGSMART 2024b) methodology. The proposed approach can serve as a basis for enriching models and classifying the information necessary for the domain, supporting the development of other data dictionaries to embed different construction materials or classification systems for different energy codes.

The structuring of the dictionary followed these steps: Initially, the information requirements for energy analysis models were identified. The information requirements of a local energy code were also raised at this stage, to demonstrate in the case study that it can be applied to a specific dictionary. Likewise, information was collected about the classification system for construction components that would integrate the structure of the dictionary. The next step includes understanding the bSDD and IFC schemes so that both can be aligned and connected. Therefore, the information is organized following the bSDD structure. Finally, a case study for an energy data dictionary adapted to the Brazilian context is presented. The dictionary is connected to the IFC schema. Likewise, another generic energy dictionary can also be connected to the same IFC schema. To illustrate the relationship between the two dictionaries, the proposed methodology is shown in the conceptual diagram in Figure 1.

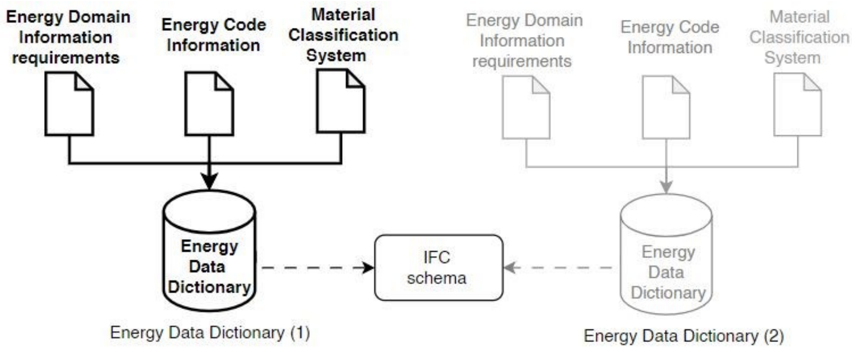

Figure 1. Proposed methodology for developing a Data Dictionary for the Building Energy Modeling domain.

The essential information to complete the energy data dictionary following the proposed methodology includes domain-specific information requirements, details from the local energy code, and the material classification system (Figure 1). This information will be added to the proposed dictionary and linked to the IFC schema. Similarly, any energy dictionary (following different local energy codes) can also link to the IFC schema, as its hierarchical base follows the bSDD structure. The energy data dictionary for the Brazilian example is shown on the left side of Figure 1. A generic structure of another energy data dictionary is presented on the right side. Both energy dictionaries are connected to the IFC schema.

The proposed dictionary structure was organized hierarchically to represent the building envelope component, specifically the materials that cover the building envelope construction system, including their thermophysical properties. For greater clarity, only one wall material will be illustrated in the dictionary, demonstrating the hierarchical relationship between the material and its thermophysical properties. The same hierarchical structure applies to the other envelope materials and building elements or systems.

The IFC schema already includes certain classes that assign properties to materials. This organizational structure can connect properties classified with codes aligned to some classification system that focuses primarily on thermophysical properties such as thermal conductivity, specific heat, and density of ceramic materials. To include a classification system in the data dictionary, it is necessary to locate the code for each construction material or element in the desired classification system.

This designed system can also be articulated in an alternative energy code, described in a different language, and used in another classification system. However, it still has the advantage of connecting to the IFC structure that underpins the data dictionary arrangement.

To gain deeper insights into the organization of the proposed dictionary and its potential counterparts within the domain, the correlation between the data dictionary designed for a specific context (using a local classification system) and another energy dictionary without a determined context is illustrated. The generic dictionary uses the Omniclass Classification system. Both structures are linked to IFC.

The bSDD provides a schema, that outlines representative classes in the dictionary, their classifications, and properties, which will be used as a guide for structuring the Data Dictionary for the Building Energy Modeling domain (Figure 2).

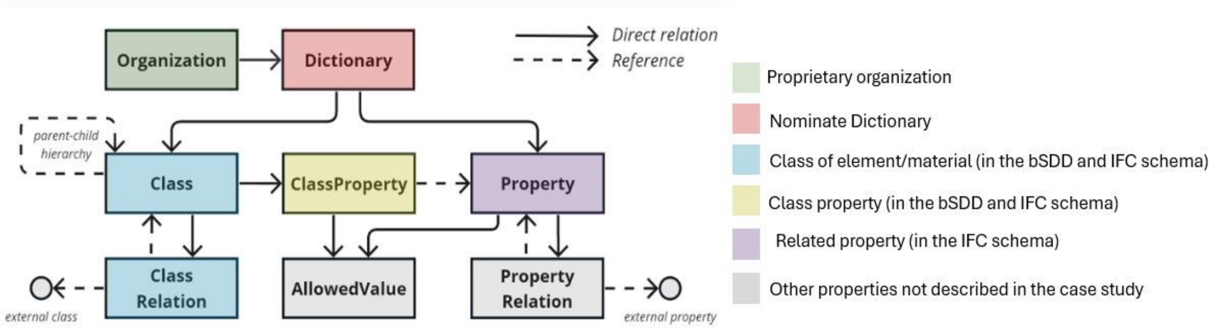

Figure 2. BuildingSmart's Data dictionary structure. Reference: Adapted by BUILDINGSMART, 2024b.

In the IFC schema, construction materials are defined by the IfcMaterial class. A linkage can be established through a set of properties (Property sets) to associate properties with these materials. This connection is made through the HasProperties attribute. Properties can also have simple values corresponding to the class they represent, defined in the schema using IfcPropertySingleValue (BUILDINGSMART 2024b), as shown in Figure 3.

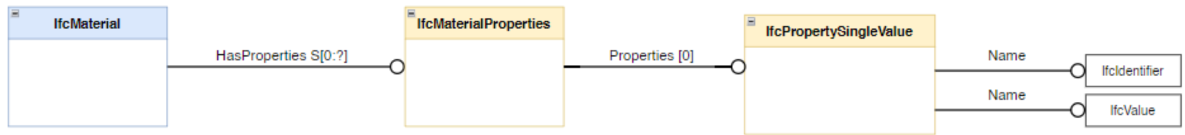

Figure 3. Material properties in the IFC schema.

4 The Data Dictionary structure

The IFC represents a standardized and hierarchically organized dataset to provide relationships and dependencies in virtual building constructions. The IFC schema encodes identity, semantics, relationships between objects (among others), characteristics, and attributes of elements, such as materials, colors, and thermal properties of materials. This information is organized into a model and can be used across various project disciplines. The IFC model was created for global interoperability, that is, to allow all information organized in the dataset to be shared.

BuildingSMART's data dictionary (bSDD) schema is connected to the IFC schema. However, it represents interoperability at a national, regional, or organizational level only, which means that only a portion of the IFC schema is shared. The information and properties outlined in the data dictionary are connected to the property set described in the IFC schema. This allows the inclusion of detailed information about construction materials, as the dictionary proposed in this work adheres to the bSDD scheme.

At the national or regional level, the dictionary describes building materials or systems used in energy codes. At the organizational level, it details the thermophysical properties of materials. Figure 4 presents the schematic of a data dictionary that follows the IFC schema, illustrating the example of a wall construction material and its relationship with the organizational levels of the data dictionary.

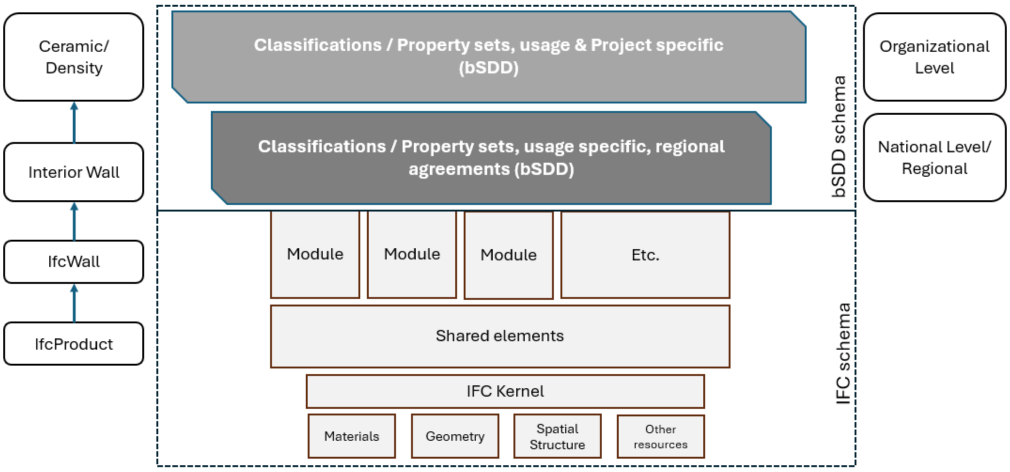

Figure 4. Data dictionary schema connected to the IFC schema.

4.1 Case Study: A Brazilian Energy Data Dictionary

The proposed data dictionary is a standardized database that enriches and organizes the necessary information into IFC models. For building designers, this facilitates the inclusion of information about construction materials. Meanwhile, energy modelers who need this information for energy simulations receive it in an organized manner, simplifying the information mapping to the software used for computational simulation. The ability to replicate this dictionary organization for different contexts, each using different local energy codes, allows the same tools to be used for reading in energy simulation software. Since the information is consistently located and defined, this simplifies its mapping.

The case study demonstrates how this application can be used in a context such as the Brazilian example, which presents a specific energy regulation and a material classification system for the country.

To demonstrate this case study, the building envelope was used as a reference, with its construction system for sealing being that of walls commonly used in Brazil. The system consisted of perforated brick masonry walls covered with mortar on both sides (Figure 5). The thermal properties for the Brazilian case study were sourced from the thermal properties catalog associated with the Brazilian Regulation on Energy Labeling of Buildings (INMETRO 2022). The thermophysical properties used to determine these thermal properties are detailed in the Brazilian standard ABNT NBR 15220-2:2005 (ABNT 2005).

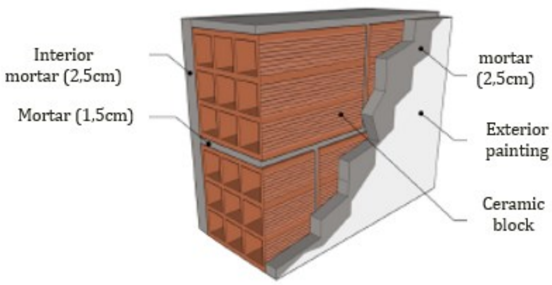

Figure 5. Wall system presented in the Brazilian building energy labeling used for the case study.
Reference: Adapted by INMETRO, 2022.

For clarity, only the ceramic block component of the wall was illustrated, though the same hierarchical structure applies to other materials. Furthermore, the thermophysical properties of the block's ceramic material were illustrated, which consist of mass density (densidade de massa in Portuguese), thermal conductivity (condutividade térmica in Portuguese), specific heat (calor específico in Portuguese) and solar absorptance (absortância solar in Portuguese).

The dictionary receives nomenclatures of the thermophysical properties of construction materials in Portuguese (indicated in the 'Brazilian data dictionary' in Figure 5) and follows the classification system proposed by the Brazilian material classification standard ABNT NBR 15965-7:2015.

Additionally, another energy data dictionary (indicated in the 'Any data dictionary' in Figure 5) was connected to the same IFC schema, detailing the descriptions of these materials in English, and aligning them with the Omniclass classification system. When connecting both dictionaries in different languages, they both have a common link with the IFC schema and material property sets (top of Figure 5).

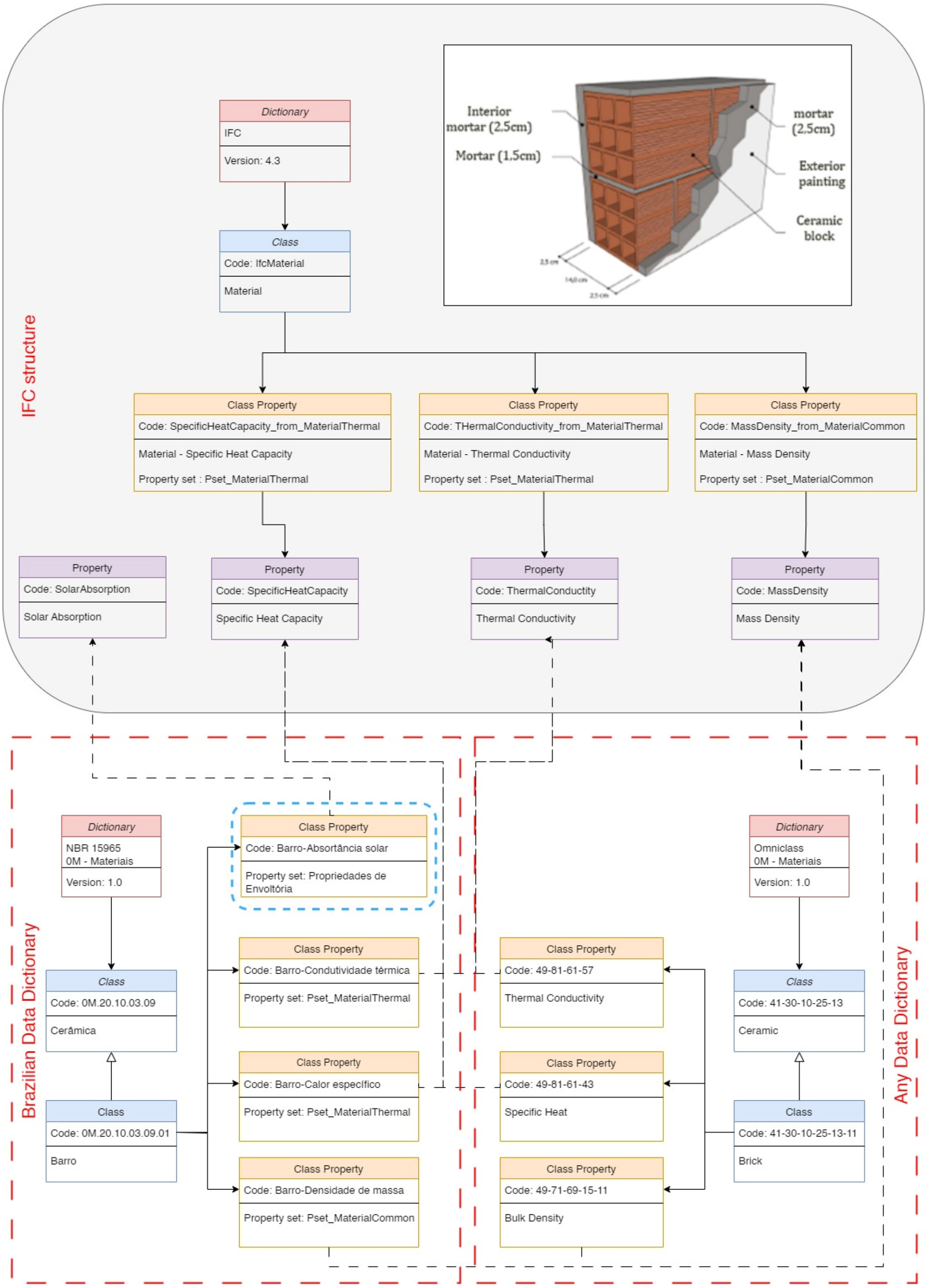

Figure 5. Proposed methodology for a data dictionary that includes the material's thermophysical properties.

The proposed methodology not only determines a code and defines the materials used in civil construction, specified in the IFC standard, but also creates relationships with the universal properties already defined in the IFC 4.3 scheme through its dictionary. This makes it possible to establish a link between the properties of more than one data dictionary.

Furthermore, this approach can be leveraged to develop alternative data dictionaries for various energy codes articulated in diverse languages. The unification of information between these libraries is based on the thermophysical properties of materials and the common IFC structure used in the BuildingSmart data dictionary. This means that equivalent information from different energy codes, expressed in multiple languages, can be linked through the IFC data schema. As bSDD functions as a service with an open API (Application Programming Interface) application can directly fetch property values from the material classification dictionary. Additionally, modeling software may have the capability to enhance an IFC model by incorporating values acquired from dictionaries and inputting the information into relevant properties along with the appropriate units. In this context, the IDS specification could also be used to validate information within IFC models (defining information requirements) and to understand the meaning and application of each property inserted in the dictionary. However, the use of this specification is not the focus of this work.

Moreover, the proposed methodology demonstrates how a data dictionary can enrich IFC models. In pursuit of this, the Brazilian data dictionary incorporates the solar absorptance property (dashed in blue in Figure 5), a missing property in the IFC schema for opaque materials, also absent in the Omniclass system. This property refers to the solar absorptance of opaque elements. Although this property is not associated with opaque materials in the IFC, the same property is present to characterize transparent elements on the doors and windows in the IFC schema. In the proposed approach a classification property associated with the materials was created. It indicated the type of IFC property that could be used in a Custom Properties set. A Classification property is a property defined for a given class in the dictionary, which can be a category (IfcWall, IfcWindow, etc.), a classification, or a material. Classification properties are related to a property, which gives meaning to its semantic term. However, it can be associated with different classes. For example, color is an independent property of any class. It may be linked to paint or the material of a window or door. In this case, when defining the paint color, we create a Classification property, which can have restrictions applied to the color. The color property will have global attributes that apply to all colors.

Once materials within a model are appropriately categorized, energy simulation software can map and retrieve necessary values for specific thermal and energy performance computations.

The proposed methodology organizes, classifies, and enriches the model with information, facilitating the mapping and reading of information by software that will carry out energy analysis, regardless of the energy code used for analysis.

It should be noted that the methodology presented is a guideline for developing an energy dictionary requires time and resources for development and validation as a national dictionary. An established material classification standard allows the dictionary to interact with other project disciplines, reducing interoperability issues. The classification system applied in the Brazilian context was used solely for illustrative purposes, as it is an outdated system needing improvement. Ideally, a specific data dictionary could have its own classification system and be linked to other dictionaries.

Similarly, when creating a new dictionary, it's highly recommended to use existing terms from the bSDD. Any missing terms should be identified, and this process can be streamlined by involving domain experts in data collection.

Moreover, the design of the proposed energy dictionary structure reduces development efforts by linking materials based on their thermophysical properties rather than specific values of the properties. The values are left to the discretion of the user. This strategy allows for the creation of a generic structure applicable to different energy dictionaries while minimizing the effort required to gather thermal properties for each existing building material. However, this strategy does not prevent the creation of new complementary dictionaries connected to it. The purpose of bSDD is precisely to establish a network structure with multiple connected dictionaries.

5 Conclusions

This work presented a methodology to enrich and classify information in IFC models to address the building energy modeling domain. The approach was created based on the BuildingSmart data dictionary, which follows the IFC schema. The library was used to incorporate information about the properties of construction materials.

The developed methodology proved to be a case for application in different contexts of local data dictionaries, relying on the common IFC structure. Furthermore, the energy data dictionary can be connected to the IDS to verify data and present concepts about the meaning of each property, working with the standardization of the set of properties.

A standardized data structure, such as a dictionary, in addition to enriching IFC models, facilitates the transfer of data by reading and conversion algorithms from the IFC format to the energy simulation format since the properties are always located in the same location and defined by the same classification structure, facilitating their mapping.

This work is important because it establishes a base for other data dictionaries that address the energy analysis domain. The study could help develop data dictionaries that intend to address different energy regulations in various contexts or languages. The proposed methodology also supports the organization of data dictionaries in other domains.

In future work, we intend to apply the methodology, testing its application in a complete BIM-BEM data transfer flow, including specific algorithms for mapping the enriched model information.

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