BIM for Existing Construction: A Different Logic Scheme and an Alternative Semantic to Enhance the Interoperabilty

Franco Guzzetti, Karen Lara Ngozi Anyabolu, Francesca Biolo * and Lara D'Ambrosio

Politecnico di Milano, 20133 Milan, Italy; franco.guzzetti@polimi.it (F.G.);
karenlara.anyabolu@polimi.it (K.L.N.A.); lara.dambrosio@polimi.it (L.D.)
* Correspondence: francesca.biolo@polimi.it; Tel.: +39-340-551-1471

Abstract: In the construction field, the Building Information Modeling (BIM) methodology is becoming increasingly predominant and the standardization of its use is now an essential operation. This method has become widespread in recent years, thanks to the advantages provided in the framework of project management and interoperability. Hoping for its complete dissemination, it is unthinkable to use it only for new construction interventions. Many are experiencing what happens with the so-called Heritage Building Information Modeling (HBIM); that is, how BIM interfaces with Architectural Heritage or simply with historical buildings. This article aims to deal with the principles and working methodologies behind BIM/HBIM and modeling. The aim is to outline the themes on which to base a new approach to the instrument. In this way, it can be adapted to the needs and characteristics of each type of building. Going into the detail of standards, the text also contains a first study regarding the classification of moldable elements. This proposal is based on current regulations and it can provide flexible, expandable, and unambiguous language. Therefore, the content of the article focuses on a revision of the thinking underlying the process, also providing a more practical track on communication and interoperability.

Keywords: classification system; logic scheme; HBIM standard; BIM basic criteria; GIS reference

1. Introduction

In the last decade, there has been a revolution within the construction sector that aims to the digitization of the entire building process. At the base of this dynamic, there is the increasing demand for the formulation of a Building Information Model. This design and management tool of the building system sees a deep-rooted presence in some states, although its methods of use are constantly evolving. The United Kingdom, Germany and countries of Northern Europe are among the front-line players in the adoption of this system. Their work has led to the formulation of national standards for the realization of these 3D models: such as the English BS EN ISO 19650 of 2018 that was born from the homonymous ISO standard and replaces the previous BS 1192 and PAS 1192 [1–7].

According to Ministerial Decree 560/17 [8], a similar change will be necessary also in the Italian context, imposing BIM as the instrument behind any intervention, both newly built and on the existing one. However, the success of this purpose requires an important process of regulation. Thinking of the Italian context and the heterogeneity of the elements that compose its urban fabric, structured regulatory instruments are indispensable. These allow an agile use of BIM in all conditions and also in the case of HBIM. Standards, on the one hand, must have a close reference to international regulations. On the other hand, they must demonstrate maximum flexibility and interoperability with regard, in particular, to the modeling of existing historic buildings.

A first reflection could be on the principles underlying modeling and its digital tools. It is necessary to assume that BIM software was thought for new buildings, but now it is trying to expand its use also for existing ones, such as architectural cultural heritage and historic buildings in general. With these premises, it is essential to review the approach

behind the modeling. Paradoxically, for such objects, the spread of this system is leading us to think that it is not possible to talk about predefined and regular geometries. It is necessary to prepare a tool that can be adapted to all foundable cases. The current software (e.g., Autodesk Revit) and their modeling tools struggle to work with particular and unique architectural objects, which can be detected in any historical building.

A second important topic is the language, specifically related to classification and nomenclature of the objects. To provide a method, it is also essential to offer a language and an encoding model of everything contained in the BIM model. It must be easily implementable and a general, flexible, and universally understandable vocabulary. This need is the basis for strong interoperability and the dissemination of the instrument. In parallel with English legislation, standardization of language based on UNI 8290 and the relative building system breakdown could be hypothesized. With this premise, the proposal for a structure that refers to the GIS (Geographic Information System) world—specifically to the CISIS Topographic Database—and its succession "layer-theme-class" was born [9]. All this was with the aim of language standardization and solid interoperability between different entities, a fundamental concept of the BIM world and the various software that are part of it.

This text addresses both of these topics. It tries to analyze them and formulates possible solutions. The work deals with these issues following an HBIM modeling experience, which has raised questions about software standards and software difficulties. The aim is to propose a reflection on these themes and consequent solutions as articulating a new BIM tool and a common language aimed at the classification and nomenclature of moldable objects.

2. The Criteria: A Different Logic Scheme

The introduction of Building Information Modeling represents an international reform, which has led to multiple results in different countries [1–7]. Indeed, its large spread brought to intense regulatory activity. The output is the vast material of management and standardization produced and still evolving.

In this context, our country is carrying out a process of adaptation, imposing BIM as a "sine qua non" tool in the construction field, and also seeking substantial internal progress regarding building standards usage.

The characteristics of the buildings that compose the vast majority of the national building stock strongly influence this process. This because they introduce new factors, not yet structured in the logical scheme of BIM and in the consequent models [10]. For example, the realization phase, with the corresponding construction techniques, originates the need for special libraries. The state of conservation generates the necessity to manage other levels of information in the digital model of the existing. The various destination of use over time, contexts, and other aspects are factors that the BIM model must be able to handle in order to maintain the goal of organizing the entire building life cycle. Faced with numerous and various architectural case studies, it is not difficult to consider classic BIM, used for new building. There is an urgency to introduce the concept of HBIM in the legislation. It is not possible to adapt the needs of the built—understood both as new and as pre-existences—to a series of tools designed to manage, albeit excellently, only new construction projects. The latter, among other things, is set on a construction model very similar to that of industrial processes and prefabrication. Therefore, a reviewing process of the BIM method and logical scheme is essential to obtain universally applicable standards, including historical buildings.

These observations derive from a series of works and studies on complex architectures, including Palazzo Trivulzio in Melzo (MI) and the former Corpus Domini Monastery of Cremona [11]. They are, respectively, a castle of the late 1200s, characterized by centuries of expansion, overlapping and modification, and a stately palace converted in the 16th century into a monastic seat, with further uses (military barracks and residence for Jewish refugees). Working with pre-existing structures as described above, which is a very

common condition in a context such as Italian and European ones. It is inevitable to incur extra-ordinary or even unique elements or structures: articulated vaults, masonry with irregular sections, singular artifacts, structures deformed by the action of time and events have been individuated and analyzed in Figure 1.

(**a**) (**b**)
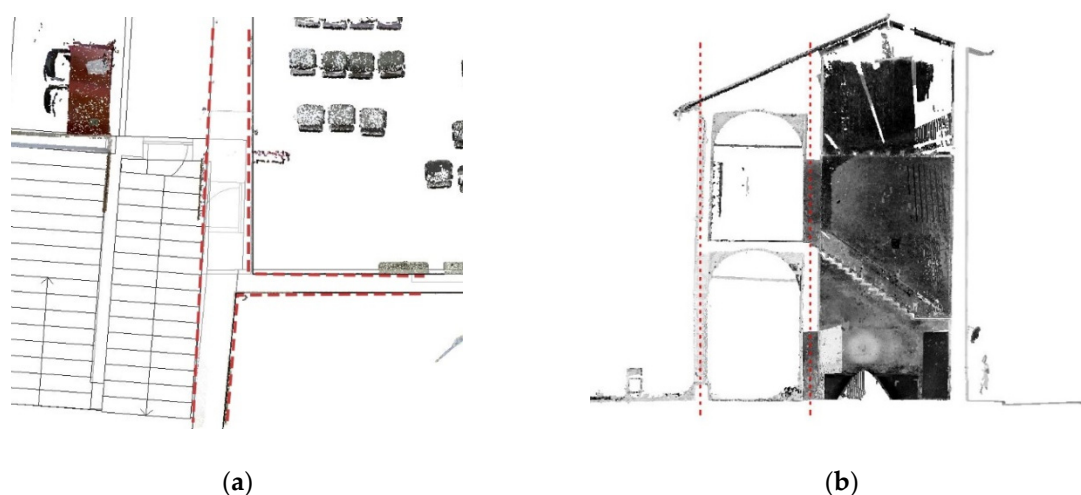
Figure 1. (**a**) A not perpendicular junction between three not regular walls in P. Trivulzio; (**b**) Section of the former Corpus Domini Monastery with tapered masonries.

The work carried out on these buildings is based on the scan-to-BIM process, for which Revit Autodesk software was used. Basing the model on the guidelines provided by the BIMgroup of the Politecnico di Milano, the challenge was to model a Cultural Heritage building, using default commands and avoiding particular local objects. Moreover, the material provided to manage the digitization process involved the use of a particular nomenclature system. This HBIM application has led to various insights on the relationship between Cultural Heritage and existing BIM software and the importance of a clear and elastic classification and nomenclature method.

The current Autodesk Revit software settings do not allow easy modeling in similar contexts, leading the operator to search for complex and inventive solutions to approximate the geometry of the existing structure as much as possible [12,13]. A possible solution is to treating particular objects with NURBS in other modelling software [14,15]. This is a consequence of the scheme and criteria on which these programs are based. Referring to of the offered commands and their functionality, the problem is clear; for instance, it is possible to create a local component as a wall with particular section but of course it is not straightforward, considering the lack of standard parameters define for typical "wall". This is because, as is known, this software is born for the design of the new and regular and standard elements.

The willingness to expand the BIM use is facing the need to change the basic criteria. It is unthinkable to continue with models that base their work on the idea of geometries with only vertical, horizontal, and regular development. During the modeling of the two buildings mentioned, the use of standard commands such as "wall" and "floor" proved as limiting. It is possible to hypothesize a more flexible and less categorized system, based no longer on the types of moldable construction elements but on objects that are ontologically volumes, surfaces, and points. The volume must have any shape (not necessarily a parallelepiped), the surface should be part of the external surface of a volume, and the point must belong to a plan or a mass. In this way, considering the modeling phase, various problems would be overcome, obtaining a system adaptable to any request in terms of shapes. Using this approach, the element identity and their specific information do not depend on geometry. This thought approaches the GIS world, where the element conformations do not determine their nature within the constructed

system. There are not horizontal, vertical, or other regular objects. The geometry is as such and is not an attribute of the individual object. In this way, there are countless possible combinations between geometric configurations and functions. All this opens up at much more elastic and adaptable modeling. In addition to the classic libraries with the predefined and parameterized geometries, typical of modern construction, there could be variable geometry libraries (the geometry is the one that derives from the survey) but with a whole series of parametrizable attributes.

3. Classification System: The Semantic Structure

Another great topic is language standards in the BIM world: the classification and nomenclature of moldable 3D objects. Based on the logical scheme that approaches the modeling of the building, it is about defining a way of organizing and naming objects. The purpose is to be sure to speak a shared language usable by all (interoperable). Additionally, in this case, is the same problem that has been raised in the cartographic framework. There were the same conditions with the transition from CAD (computer-aided drafting) models of the territory, aimed only at the cartographic representation, to the GIS models of the same, aimed at questioning the information associated with the objects and not only at its representation.

It is also essential for BIM to formalize this step as soon as possible. The reason is its imminent spread. With this diffusion, individual administrations, for example, will have to handle building models that come from different productions [16]. A municipality that manages owned buildings, on the basis of BIM models, need a significantly re-organization in order to manage a notable amount of data in an adequate way [17]. These digital tools should be created with the same logical scheme. Moreover, they need to use a standard language to identify entities of different building models.

Already, a decade ago, several countries began to work on this issue and to provide the first directives within their national standards. For example, the AEC (UK) introduced a methodology for naming activity with its BIM Technology Protocol—2015 [18]. This model affected both files, and their constituents (such as view names within models), and objects that are part of 3D (Figure 2).
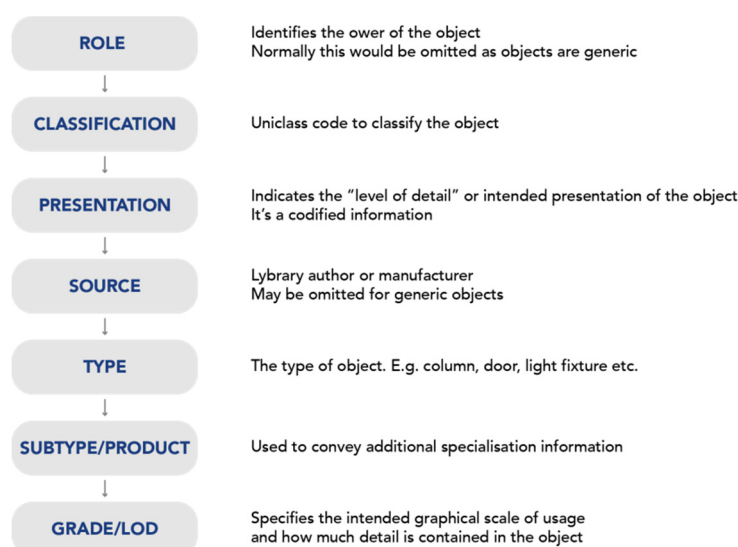
Figure 2. Nomenclature scheme for BIM element. AEC (UK) BIM Technology Protocol.

This problem is also opening up in our country. Indeed, some institutions and administrations, which have started the BIM modeling of their assets, temporarily adopted such a standard [19–21]. It is unthinkable, however, that every administration creates its own standard to prevent the production of too many data that will be than difficult to compare

and manage. What BuildingSmart has deepened as part of the Built Heritage Information Modelling/Management BHIMM is certainly a reference [22].

The basic characteristics of a logical structure and a physical scheme must be the flexibility to model the real, the implementability over time, and the applicability to each building object. The logical model must define the modeling criteria (to which the dedicated software must then adapt) to break down the building object into elementary parts, as physically happen in construction phase. Considering also the historical becoming, fundamental for using BIM for the existing without forgetting its passed life cycle.

Therefore, starting from the assumption that basic geometries are those described above, the belonging of a part of the building to a given object must correspond to their realization method and modification over time.

Inside an ancient wall, supposing in the masonry of the time, there are often, for example, buffered windows, lintels embedded in the structure, old chimneys filled with bricks, or modern building elements. In parallel, new openings have probably been inserted, with structural reinforcement elements from different eras. However, this situation is also the one that, over time, a modern building could deal with. These modifications, induced by various uses will mark the linearity and continuity of the geometries made at the construction phase. Therefore, the purpose is to think of a data model as a logical scheme but also as a physical scheme of the data, which can manage, without excessive simplifications of geometry, changes over time. This is also important to ensure the history mapping of modern buildings over time (Figure 3).

(**a**)

(**b**)
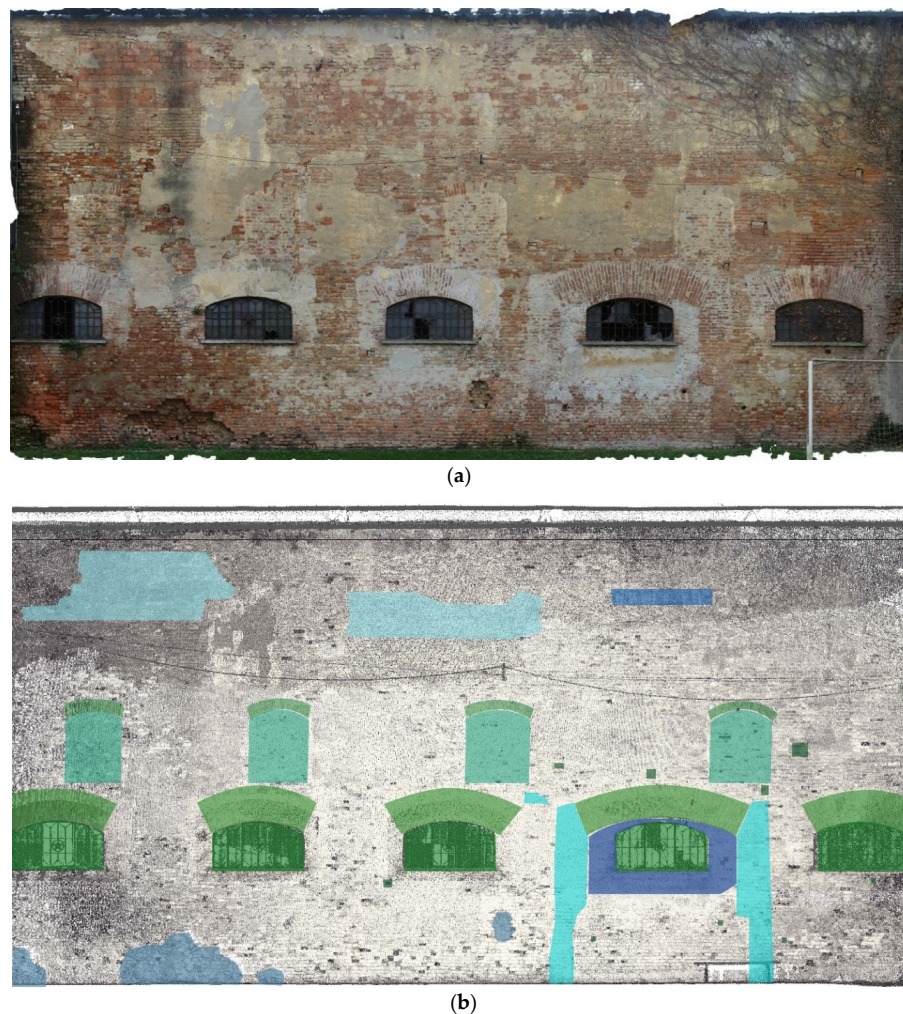
Figure 3. (**a**) A picture of an ancient masonry; (**b**) The analysis of masonry composition.

Therefore, from this perspective, what is currently happening in some models is questionable. An example is the portion of the pavement under an internal door: it is associated with the wall and not the slab because it is an integral part of the opening. The subdivision of the constituent parts of a building, each one with its irregular geometry, must correspond to the dynamics of construction and to the interventions over time.

The modeling software could be implemented in order to better manage different type of elements in a single family based on construction phases, as shown in the previous paragraph. These should not necessarily predefine standard geometries, and it would be useful if they allowed objects to be divided according to changes in the various attributes, as for this column and its parts Figure 4.

Figure 4. A particular column that could divided into basement, column shaft and capital.

Similarly, parameters such as dimensions, materials, and shapes (basically all information associated with the object) should not be considered useful factors for the composition of the nomenclature system, even if this is what is required, but not obligatory, in IFC standards. This information is associated with the individual element inserted into the specific BIM model. These will not be immediately visible in the name but still present to define the objects themselves. Therefore, within the idea of this new software, it is fundamental the functionality to search and query the model based not only on the nomenclature but also on the attributes that characterize the various elements of the 3D. In this way, the possibility of identifying the same information in the BIM space, of counting the identical elements (or with particular coincident characteristics), and the extraction of products such as abacus and tables of 3D contents are not affected.

Excessive definition of the element through its name would be counterproductive. The "speakers names" become challenging to manage in the long term, as will be taken up in the following chapter.

Based on these statements, it was decided to consider the UNI 8290 legislation [23] and its building breakdown structure due to its officiality and its elevated usage in the Italian context, as the last legal material concerning this issue. Latter uses two-digit numerical codes to identify each object class and its attributes.

The articulated system has a configuration that takes up what has been set in the GIS world. More precisely, it aligns with the organization of the CISIS Geotopographic Database [9]. The latter consists of an identification method based on three levels: layer, theme, and class [24,25]. Indeed, everything in the DBT shapefile is classified using these

tiers, with a numeric identifier to simplify their hierarchy. Therefore, each element has a name, composed of a sequence of as many numerical codes, which identify layer, theme, and class associated with it. This tool is reported in BIM, using the UNI 8290 as a working base Figure 5. According to the pondered method, still similar to GIS, it is mandatory to establish a set of coded descriptive parameters for each modeled object. They permit to characterize the element and differentiate it from the others that are part of the same class. The system should avoid inserting, into those attributes, all aspects related to the geometry that is fully supported by the geometry itself. All this is advisable if, as for the GIS software, the geometrical part has its related organization, and the Geodatabase thus generated can be queried both by the geometrical point of view and that of related information.
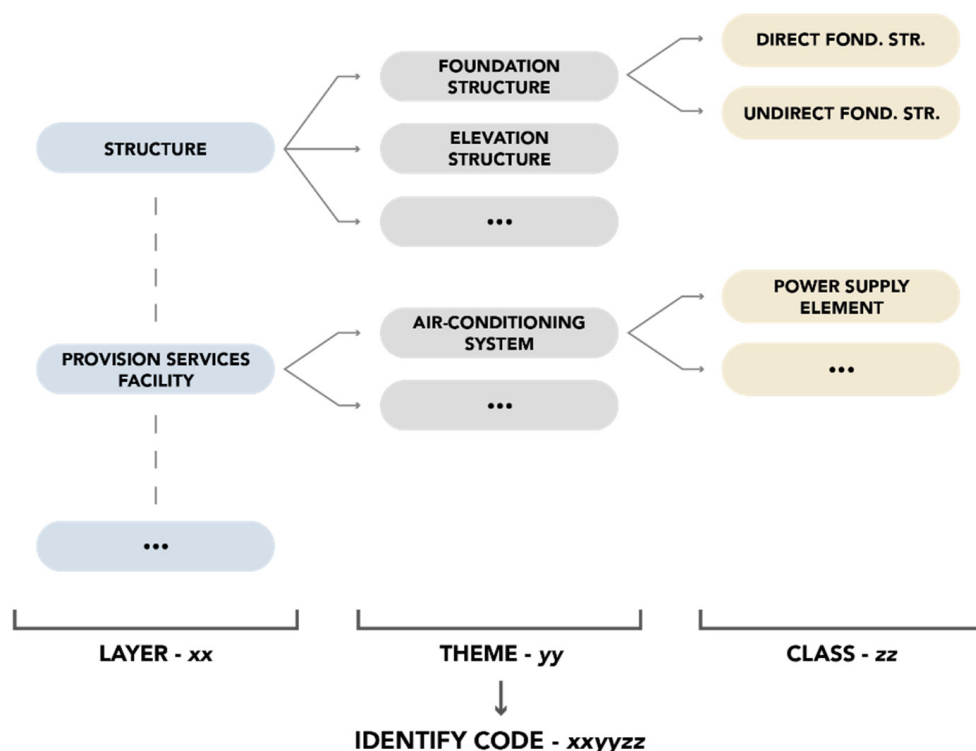
Figure 5. Structure of the classification and nomenclature scheme use for the CISISI Geotopographic Database.

It is useful to specify that this proposal does not refer to any BIM software currently present. This new classification method does not raise from today's modeling processes or from the basic criteria of the modeling programs themselves. This work is part of a broader idea, namely that of new software, which operates as indicated in the previous chapter.

Although the work starts from the breakdown present in UNI 8290, the proposed system for putting this classification process into practice allows for an almost unlimited extension of the scheme. Within the CISIS Geotopographic Database, it is possible to observe the classification of extremely different elements: geodesic information, infrastructures, buildings, and natural elements such as glaciers and vegetation. Therefore, the reported proposal aspiration is to allow the management of the classification of every component of the BIM world.

This proposal is an enumerated classification system. In such a model, the various elements are identified in a single class and have a unique location in the overall system. Therefore, each object identifies a unique path within the classification, from the widest to the most specific class. Mono-dimensional and vertical are the definitions for this type of scheme [26].

Of course, the solution described is not feasible in the immediate future because today's software has settings according to a different logic. This work aims to prepare the first conditions for the formulation of a different data organization in an hypothetic new software, starting from personal experiences with the present BIM tools (in specific Revit Autodesk).

4. An Example of Classification and Nomenclature

The classification proposal refers to the GIS world. The scheme, which is based on the unambiguousness of the elements described, is essentially divided into two parts: a system consisting of "layer-theme-class" for the instances identification and a descriptive phase in coded form for the explicitation of their characteristics.

As with the GIS world, it should be mandatory to implement a subset of data in each BIM model (corresponding to the GIS world national core). Moreover, other specific attributes and instances can be added to enrich the information of objects modeled.

The "class" notion is the basic one in this structure. It defines a series of homogeneous objects in the building organization designed by UNI 8290, also characterized by similar mandatory information content. Each class is identified by a single name, which is a numeric code that combines the three hierarchical levels of layer, theme, and class. Working this backward, a series of classes constitutes a theme and a defined number of them composes a layer. The unambiguousness of the system becomes clear. Within a precise class, a series of attributes characterize each object. Some aspects are specific for a few types of objects contained in the BIM model of a particular building (General Identification— General ID). Others qualify it based on its role, type of material, and history.

The building system breakdown reported in the UNI 8290 adapts well to this structure. With regard to its structures section, the classification method is proposed again by first introducing the numbering of the various levels.

Below, there is an example of a pillar. First, a letter will introduce its name to specify the type of geometry (V for volumetric, S for surface, P for point). Therefore, its geometry will be a volume, defined by its closed side surface. The latter is composed (if the building exists) by the modeling software based on survey with the help of sections that divide it in a robust way from a computer point of view in the continuous part with the other structural elements with which it is consistent. Returning to the name, it will correspond to a sequence of three numbers, each consisting of two digits. As already mentioned, the numbers refer to the same levels of the structure. As far as the pillar is concerned, therefore, the code will be the following: V010201. The 01 indicates the belonging of the element to the structures layer, 02 corresponds to the elevation structures theme and, finally, 01 leads us to the specific vertical volumetric element Figure 6. The term "vertical" is maintained in order to avoid modifying in UNI, but it is not intended as a strictly geometric feature of the. It attempts to classify all those structural parts of the building that serve to raise it to height, without giving rise to walkable elements or that generate "horizontal" spaces.
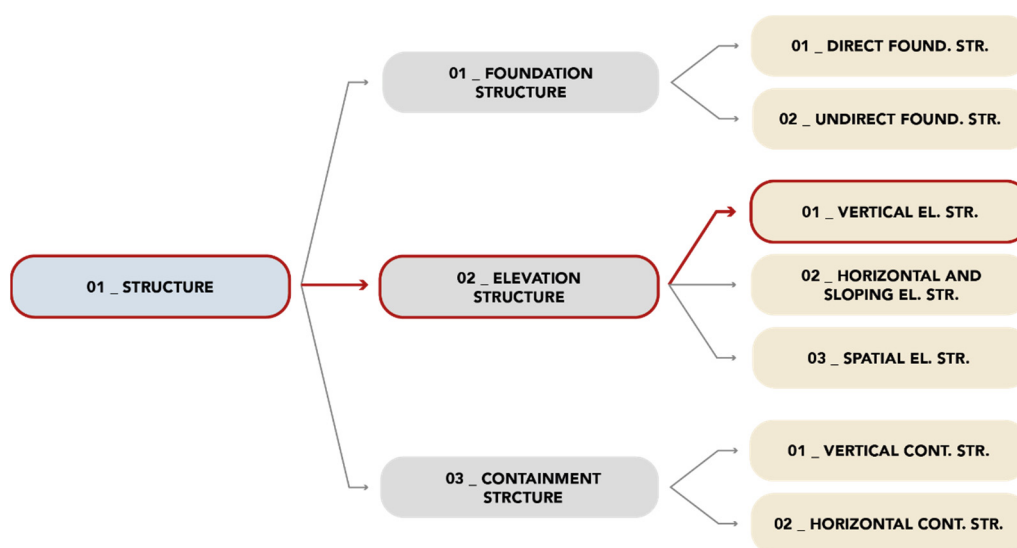
Figure 6. Nomenclature system with the UNI 8290 breakdown structure. In the scheme, the path for the pillar coded name is highlighted.

Precisely on this last observation, certain attributes will have to be defined, including those that differentiate the element from all the others in the same class. In the following part, a first provisional list of attributes to associate with the V010201 section is described:

- ID_class: a unique number within the class (progressive or random).
- Model-ID: a general identifier of the model to which the object belongs. It is possible to manage the model-ID uniquely at the territorial (national) level, and this makes the individual element exclusively defined at the country level, as it does for all GIS objects.
- Type: one item of default and complete list of all objects that can be part of vertical elevation structures. A first set will contain the following types: pillar, wall, column, capital, plinth, lintel, arch . . . ; then it will be available also the corresponding generic instances: not detected, not known, undefined.
- Material: the attribute referred to the principal material which the element consists of (in the hypothesis of a first schematic approach). It could be reinforced concrete, pre-stressed reinforced concrete, steel, cast iron, masonry, stone . . . plus generic instances.
- Start date: the date of the object construction.
- End date: the date on which the item was demolished. It is necessary to support the concept of historicization in BIMs. Therefore, it will be possible to create a query in the software, to extrapolate elements present in a specific period. With this method, the system will select and show all parts that constituted the building before a particular intervention. The end date corresponds to the demolition phase in an intervention to modify a building.
- Project information: both for the start and end date of each element, it would be interesting to be able to insert an identifier that refers to the design process or to the historical document, survey, image that documents the modification.
- State of effort: it would be interesting to insert various links to any effort diagrams on structural analyses performed. Diagrams must have information about the structural analysis: what type of load, the date of elaboration, software used, etc.
- Standard element: it is a Boolean attribute (i.e., a yes/no) that, if so, refers to modern elements or regular cases with classical information, including geometric ones, in the conventional BIM library.

Obviously, it will be essential to study and test the list of attributes for each class, using type cases of different nature. It is fundamental to remember that no geometric information should be part of the attributes, as with GIS. An exception is those associated

with any standard element characteristic. Even in an ancient building, for example, if standard fixtures are inserted after conservation, they can be characterized by their feature, recovered from the corresponding libraries.

As can be seen, HBIM objectives force us to think of models that are less standard than those normally introduced by BIMs for new construction. Returning to the bearing wall example also coded with V010201, you will have to divide it geometrically into its parts. It consists of a single and continuous element, probably with a unique type of wall (bricks, binders, and related dimensions and stratigraphies), with three openings to accommodate the windows. In the course of time (from the historical documents), there was an intervention on a window and it has been buffered. At present in that opening, there is load-bearing masonry of different ages and materials. Another window has been enlarged, so a part of the original wall is "historicized" with the end date. You have also inserted an architrave into a particular material that solves the static appearance, and then there are new openings. Therefore, it is possible to reconstruct the history of that wall, using what appears today and the existing historical documentation. Only in this way, the BIM can map the life cycle of a historic building.

Below, by analogy, there is an excerpts from Annex A of DGR 6650 Figure 7. It concerns the physical delivery scheme of the Topographic Database of the Lombardy Region. Behind this result, however, there are more than 15 years of experimentation.

02 - Immobili e antropizzazioni

01 - Edificato

02 - Edificio

A020102 - (Poligono)

Nome Campo	Formato	Lunghezza	Descrizione
STRATO	testo	2	Codice strato
TEMA	testo	2	Codice tema
CLASSE	testo	2	Codice classe
ID_ZRIL	testo	12	Identificativo univoco della porzione di territorio rilevato di riferimento
FEATURE_ID	numero	12	Identificativo progressivo univoco per la classe di oggetti all'interno della porzione di territorio rilevato
EIDIFC_TY	enumerato	10	dell'attributo tipologia edilizia
EDIFC_USO	enumerato	10	dell'attributo categoria uso
EDIFIC_STAT	enumerato	10	dell'attributo stato
EDIFC_ID	testo	12	dell'attributo identificatore
EDIFC_CASS	testo	12	dell'attributo id del cassone d'appartenenza

Figure 7. An excerpts from Annex A of DGR 6650. It shows the classification system and its use with a building.

The images show a summary of the classification model. As is shown, the element's name consists of a six-digit code, similarly to what was proposed. The corresponding features are not explicit in names but it is possible to easily deduce them from the attributes, through GIS software. In the data structure, each unique object connects to its geometric characteristics that respect the textures, adjacency, overlap, etc., manageable by different software. The system allows agile implementation at all levels. Introducing a new layer, parameter, or attribute does not alter in any way its balance or structure. The only substantial difference is that GIS is conceptually two-dimensional, although it formally extends to the entire globe.

5. Discussion

The proposed work focuses on two main themes: the standardization of Building Information Modeling and the relationship between the latter and pre-existence (Architectural Heritage and beyond). Firstly, the various needs from the pre-existing buildings lead to changes in principles and underlying BIM criteria. Conceptually, such variations allow us to also manage the future changes of new buildings. Subsequently, these reflections bring to elaborate on a new classification and nomenclature of BIM model constituent elements, the second goal of the paper.

However, these two apparently unrelated themes show a common objective: laying new foundations for a universally used instrument (not only in new construction projects), characterized by sound interoperability conditions.

The work is referring to the experience of a similar, settled, and regulated sector: GIS environment and Topographic Data Bases.

All this has been developed with the conviction that a firm standardization of the basic model can lead to further progress.

As far as the future development of these issues is concerned, there are two main options. The structure of the classification method can be improved and more formulated integrating the UNI 8290 structure with the necessary attributes that also consider the historical topic. The formulation of a possible list of attributes for one or more classes can be an option to develop the structure, another coincides with the vertical progress of the structure itself. As stated above, this system aims to manage the classification and nomenclature of each element introduced in BIM. The UNI 8290 is the starting point of this structure but neglects many situations detectable in a model. It is not uncommon for BIM to operate within infrastructure or in urban areas (or portions of them). Within a model, it is possible to trace components dissimilar from those found in the normative, as natural or contextual elements. That is why this work could be continued by verifying and demonstrating the management capabilities of the proposed system.

Another theme is the review of changes to UNI 8290. A section of the diagram could be carried out in all its parts, and the first physical diagrams of buildings could be drawn up according to the classes examined. Continuing to deepen the proposal inevitably reveals critical issues but also possibilities for its better definition. Secondly, it is possible to relaunch to the BIM software world, managing separately but coordinately the geometric aspects, fundamental for interventions on buildings, from those purely informative features, related to facility management. This second opportunity provides a possible interesting collaboration between professional figures of various kinds, fertile ground for stimulating insights.

6. Conclusions

Building Information Modeling is an extremely advanced and necessary method for the digitization process in the construction sector and its considerable diffusion is evident. These changes are even more relevant from the point of view of Italian deadlines in the BIM field. By 2025, all projects will require its use, both for new constructions as for historic buildings and Cultural Heritage. That is why the standards formulation, such as classification, and software review exhibit a certain urgency. In public procurements, these issues are even more relevant. Indeed, in this context where high-performance management of materials and information (coming from different sources) is a priority, the need for a structured use of BIM is perceived even more. The proposals outlined in this text attempt to take a step in this direction, in a more or less radical way. The idea of new software, based on completely different modeling criteria from those currently in use, could be seen as utopian. However, the fundamental issue is the requirement to understand that it is no longer possible to adapt the current functions of BIM software to HBIM, characterized by needs and features that cannot be fully satisfied through this operating method.

A huge amount of work has been done in terms of different software progresses and regulations. HBIM is an increasingly discussed theme. Therefore, in this paper, the principle aim is propose enhancement in the use of this technology and analyze a new hypothetic logical scheme to improve modeling of Architectural Heritage. This will be one of the future developments of BIM, which still needs insights, research, and new standards. However, it is not possible to proceed according to the principles on which BIM has been coined. Indeed, it was born as a design and management tool for new constructions. In summary, it is necessary to rethink the logical model and the resulting physical pattern of objects and BIM data to hold against the entire life cycle even for existing buildings. This indication also supports the possibility of managing information in the BIM model of new buildings over time.

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