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Standard for geometric and informative reliabilities in HBIM models

The modelling of a historic building constitutes a restitution of the architectural object, result of a critical reading made by the researcher.
For a valid scientific representation of the architectural heritage, issues relating to the "transparency" of information sources and the "reliability" of modelling become fundamental.
Through the development of same case studies, the paper proposes and tests a procedure by which it is possible to transparently declare the sources that have substantiated the modelling and, at the same time, evaluate and communicate the reliability of the digital reconstruction.
Aim of the paper is the definition of a standard for the evaluation of the reliabilities which is dependent from the LoD of the objects.
Taking into consideration the dual meaning of 3D representation and heterogeneous information system of BIM models and the peculiarities of built heritage (importance of the declaration of sources; availability of information that is often not exhaustive and non-uniform for all elements; modelling based on the critical interpretation of data, etc.), the developed standard was divided into different types of reliability and sub-reliability, depending on LoD and, in the case of non-geometric information, on the type of source.
The obtained result is a standard that can make the HBIM an effective procedure to be used for the survey and for the evaluation of the restoration project.

Keywords:
Architectural Heritage; HBIM; Reliability; Levels of Development

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1. INTRODUCTION

The modelling of a historic building constitutes a restitution of the architectural object, result of a critical reading made by the researcher.
Knowledge in historical buildings derives from direct or indirect sources, which are often partial and incomplete and frequently, even at the end of the cognitive process, does not allow to reach a uniform level of development for all the elements that make up the model.
The interpretative nature of the model is amplified in the HBIM case, in which the informative aspect plays an important role and the geometric representation is combined with various kinds of information enrichment (technical-constructive, historical, etc.).
In the BIM environment the geometric representation and the information enrichment are defined inside the level of development of the digital objects, whose growing corresponds to a linear increase in the quantity and quality of the information contained within the BIM objects.
However for historic buildings, whose knowledge is usually inhomogeneous, often it is not possible to meet these standards (because of the lack of information and the complexity of the geometric shape).
Furthermore, these levels do not concern all the information necessary for the knowledge and documentation of the architectural heritage: the HBIM models must in fact include, for example, also information of a historical nature that is not considered in traditional BIM processes.
The new international standard UNI EN ISO 19650:2019 propose to replace the LODs with the Level of Information Need (LoIN). The latter establish that only the necessary information, based on the purposes and uses of the model, should be requested and contained within the models.
LOINs can help overcome some of the limits deriving from the extension of the BIM procedure to historic buildings. In fact, instead of trying to reach and fulfil specific LoDs classified and defined for new constructions, it is possible to establish, according to the model's purposes, which information is necessary (and therefore, in case of absence, investigable, for example the construction technologies) and which ones is available (for example, the historical ones deriving from archival and bibliographic research which, if absent cannot be recovered).
For a valid scientific representation of the architectural heritage, issues relating to the "transparency" of information sources and the "reliability" of modelling become fundamental.
Therefore, the definition of a specific procedure constitutes a pivotal issue for the development of Historic Building Information Modelling [1].

2. AIMS

The declaration of the sources and the "interpretative" level of the information obtained with respect to the available data are two essential themes in the context of the representation of the architectural heritage.
In order to have a scientifically valid representation, it is in fact necessary that the modeling process be methodologically founded and that this be made known, offering the opportunity for reply to other scholars (Centofanti, 2018; Bianchini, 2014).

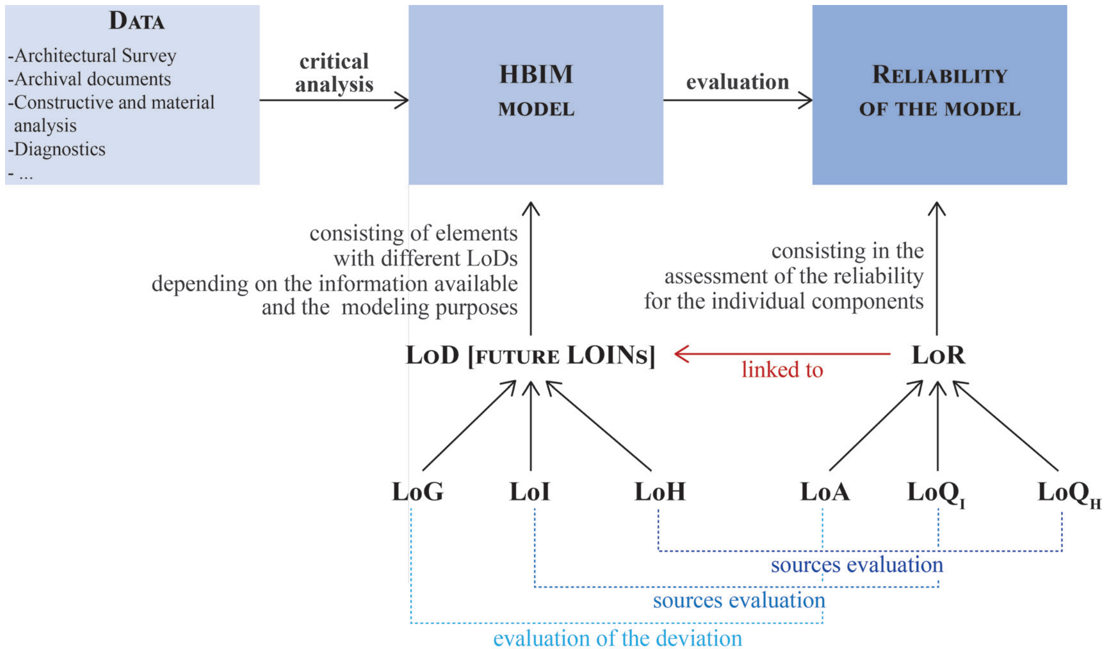

Fig. 1 - HBIM procedure: from data collection to realization of the critical model and its validation through the reliability evaluation. In particular, for the measurement of the LoG, LoI and LoH reliabilities, respectively the LoA (Level of Accuracy), the LoQI (Level of Quality) and LoQH (Level of Quality for historical information) are defined.

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Therefore, the issues of "Transparency" and "Reliability" become fundamental, taking on an even greater value in the case of HBIM where the geometric representation is enriched by heterogeneous information attributes (construction technology, historical phases, etc.).
From an operational point of view, it is therefore necessary to define specific standards that can ensure the effectiveness of the HBIM process for the documentation and restoration project of historic buildings. Through the development of some case studies, the paper proposes and tests a procedure by which it is possible to transparently declare the sources that have substantiated the modelling and, at the same time, evaluate and communicate the reliability of the digital reconstruction.
As is known, the information foundation of the BIM process refers to the ability to manage and analyze large amounts of data and information within an interoperable and interactive environment.
In order to ensure the transparent presentation of the entire elaboration processing underlying the modeling, the research aims to use the potential of BIM to offer the possibility of philologically reconstructing the choices made in relation to the sources. In particular, we want to exploit the information base implicit in BIM platforms to insert into digital environment the documents which, once analysed and interpreted, led to the elaboration of the BIM model in all its aspects (architectural, structural, historical, etc.).
At the same time, we want to tackle the problem of the reliability of the virtual reconstruction, referring not only to the geometric-dimensional aspect –i.e. the relationship between the restitution model and measurement–, but also to all the issues inherent to the knowledge of a historic building, including the construction technology.
Based on a reflection of the information contents of an HBIM model (geometrical, informative, historical), the paper aims to define a standard for the evaluation of the reliabilities of the model (fig. 1). Furthermore, we intend to use BIM information system for the assessment and declaration of the reliability of the digital representation.

3. HBIM INFORMATION CONTENT: THE LEVEL OF HISTORY

Historic Building Information Modeling cannot be considered an automatic extension of the consolidated BIM process –developed for the new– to historic buildings. The specific characteristics of the architectural heritage, in fact, mean that the application of the BIM procedure in the field of built requires special reflections and attention. First of all, the complexity of the geometric shapes of historic architecture, together with the uniqueness of its constituent elements, means that the three-dimensional modeling of the building components of the heritage poses important problems that are not easy to solve.
Added to this there is the need to manage a large amount of information that goes beyond normal BIM procedures. The knowledge and representation of a historic building, in fact, includes a series of information that is not contemplated in normal BIM processes, designed for new constructions.
From these considerations it follows that Historic Building Information Modeling, even if borrowed from the more well-established BIM, must include its own approach based on the peculiarities and needs of the architectural heritage. In this sense, the traditional levels used to describe the information content of the model, geometric and not, are not sufficient in the field of HBIM.
Well-known LoDs constitute a measure of the "nature, quantity, quality and stability of the data and information" associated with each digital element that constitutes the model (UNI 11337). In national and international regulatory references (such as the English system PAS 1192-2 and American BIMForum), the Levels of Development consist of both the graphic attributes (geometric attributes - LoG) and the non-graphical ones (information attributes - LoI).
Both levels refer to aspects concerning the physicality of the architectural element (e.g. dimensions, materials, etc.) or that, in any case, can be quantified and computable (e.g. costs, etc.) (fig. 2). The current LoDs, therefore, do not include all those information of a more general nature (such as information regarding the author of the work and the cultural context, or derived from archive drawings, historical images, etc.) which, although fundamental in the process of knowledge of a cultural asset, are not directly correlated to the physical consistency of the architectural element.
So, if an expansion of the current BIM databases is necessary to receive unscheduled information, it is equally essential to introduce an additional level of development that takes into account the

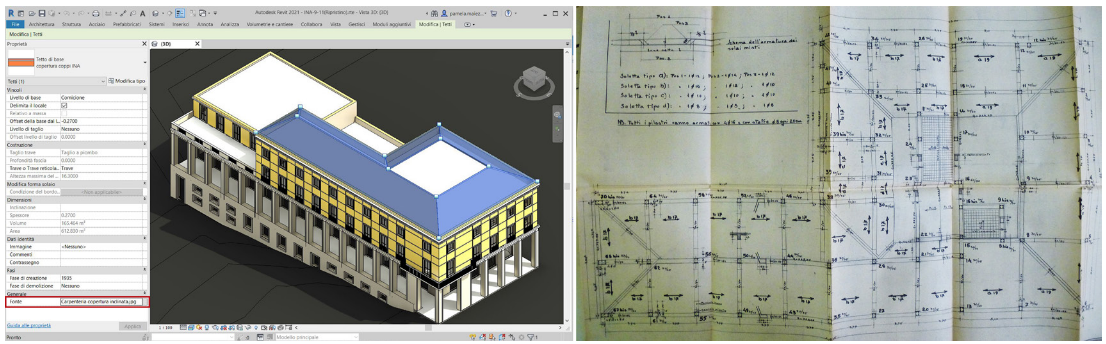

Fig. 2 - HBIM model of the INA Palace in L'Aquila (1935-1938) in its current configuration, and archival document relating to the construction equipment of the roof.

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non-computable information of the HBIM model (Brusaporci, Tata, Maiezza, 2020). This level, defined as Level of History (LoH), refers to all information of a historic nature relating to the modification and stratification process that has led the building to the present day (for example, dates, author, historical phases, etc.) (fig. 3).
Since the information concerning the historical knowledge of an architectural element can be more or less exhaustive, there can be three different Levels of History: high, medium or low. Therefore, the wealth of information of each architectural element of an HBIM model is described by three Levels: the Level of Geometry and the Level of Information, as occurs in the usual BIM models, to which the Level of History, specific to the architectural heritage, must be added.

4. BACKGROUND

Transparency in the beginning was a concept born in the field of archaeology that was the first to investigate digital representation as a research method. The main references for transparency, developed for the archaeology, are the London Charter (2009), which aims to establish a series of principles to ensure that the digital visualization of cultural heritage is intellectually and technically rigorous and reliable, and the Seville Principles (2012) which establishes principles and criteria for measuring the quality of projects carried out in the field of virtual archaeology with the aim to increase the conditions of applicability of the London Charter in order to improve its implementation. Both emphasize the importance of scientific transparency, understood as the identification, evaluation and documentation of the sources used to ensure the intellectual integrity of the methods and results of digital visualization.
The importance of the concept of transparency have also been confirmed in architectural field (Brusaporci, 2017). Historical buildings, in fact, have peculiar characteristics compared to other types of built heritage, as regards materials, construction and historical aspects, spaces, uses and available documentation.
Each representation, whether it is of buildings in their current or past configuration or of buildings that no longer exist, is the result of a critical interpretation of heterogeneous materials, often not exhaustive, deriving from archival and documentary research and from the survey.
Scientific transparency, understood as the transparent collection and presentation of the entire modelling process, starting from the declaration of the sources of the information and documentation of the interpretative process operated on their basis, is therefore an indispensable premise for the digital restitution also in the architectural field.
BIM modelling consists of the twofold aspect of geometric and informative. Therefore, the BIM model cannot be just a geometric representation but must also contain all the information relating to materials, construction equipment, historical and structural characteristics, etc. The transparency and reliability of the virtual reconstruction, thus, cannnot only be referred to the geometric-dimensional aspect, but also to the themes inherent to knowledge.

4.1. THE GEOMETRIC RELIABILITY

As regards the geometric reliability, it is measured by comparing the three-dimensional model and the point cloud deriving from the survey. The bigger the distance between the two, the closer the model is to an ideal model, the shorter the distance and the closer the model is to the real object and it is called as-built model (Maiezza, 2019; Apollonio 2017). Quattrini et al. (2016), to ensure the accuracy, adherence and quality of the representation of models HBIM, develop two case studies in which they

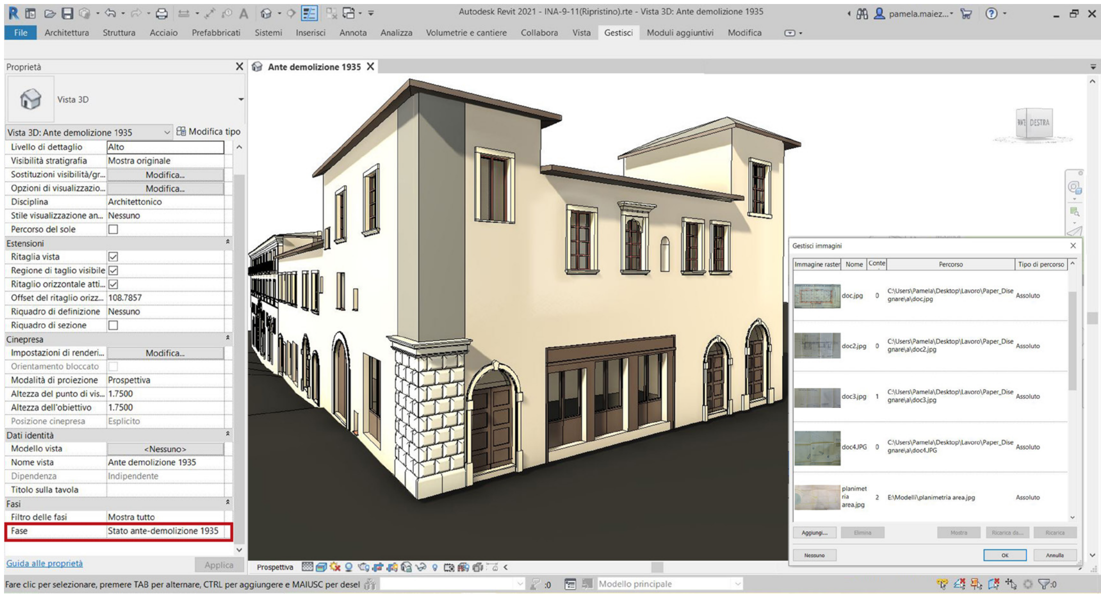

Fig. 3 - Digital reconstruction of the Quattro Cantoni corner in L'Aquila before the demolitions of 1935. In the BIM environment, historical information is part of the Level of History, specifically proposed as an integrative Level of Development for the architectural heritage.

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create semantically structured models in the first by importing the point cloud into the BIM modelling environment and modelling directly on it; in the second, using the slices of the point cloud instead. The purpose, especially by modelling directly on the cloud, is to try to minimize the steps and avoid excessive simplification and the consequent loss of information. Finally, they validate the geometric accuracy of the model by carrying out both a qualitative control inherent to the overall deviation of the models, and punctual controls inherent the deviation on individual elements.
Apollonio (2017) combines low-cost automatic photogrammetric data acquisition techniques with parametric BIM objects constructed on the basis of the treatises. The accuracy of the as-built BIM, modelled starting from the point cloud, is evaluated measuring the deviation between as-built model and ideal model.
Brumana et al. (2019) underline the importance of defining specifications and protocols, which are currently absent, in order to reach a common language for the modelling of built heritage. In their paper they propose and adapt the conventionally adopted specifications for the survey in terms of detail and accuracy to the HBIM modelling introducing the Grade of Accuracy (GoA), which should be respected in the modelling phases according to the virtual scale chosen based on the aims and objectives of the model. The GoAs do not replace the LoDs but accompany them and have the main purpose, together with the GoG (Grades of Generation), to describe how the modelling of objects took place starting from the survey.
Moreover, in 2019 the U.S. Institute of Building Documentation has defined guidelines to allow professionals in the fields of architecture, engineering, Construction, Owner (AECO) to clearly specify the accuracy with which to represent and document the state of the buildings. The framework defines different levels of geometric/spatial accuracy in terms of standard deviation; each level (LOA) consists of a range of accuracy and is related to the individual elements which constitutes the building. The guidelines define both measured, i.e. relative to the data, and represented accuracy,

LEVEL OF ACCURACY (LOA) OF LOG - EVALUATION OF THE DEVIATION

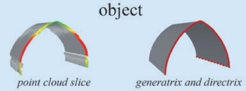
LEVEL OF GEOMETRIC DEVELOPMENT	DEVIATION EVALUATED WITH RESPECT TO:	RANGE OF DEVIATION VALUES (D)		LEVEL OF ACCURACY (LOA)
LoG A, LoG B } Low LoG	whole element (wall, roof, vault ...) 	D > 70 mm		Low LoA
		50 < D < 70 mm		Medium LoA
		D < 50 mm		High LoA
LoG C, LoG D } Medium LoG	generatrix and directrix of BIM object 	D > 50 mm		Low LoA
		20 < D < 50 mm		Medium LoA
		D < 20 mm		High LoA
LoG E, LoG F, LoG G } High LoG	generatrix and directrix of BIM object  surface of the element 	GENERATRIX AND DIRECTRIX	SURFACE	
		D > 20 mm	—	Low LoA
		D < 20 mm	D > 50 mm	Low LoA
			20 < D < 50 mm	Medium LoA
			D < 20 mm	High LoA

Fig. 4 - The geometric reliability of the architectural element (LoA) is evaluated according to the LoG through the measure of the deviation (the range of deviation must be respected in the majority of the surface).

i.e. relative to the restitution. They also define a LOA framework template that professionals can use and adapt to their needs in which, in order to view the suggested LOAs, they should also specify whether they are using the Standard framework the Heritage one.
Based on the three-dimensional representation purposes, depending on the level of detail and the accuracy to be achieved, different modelling methods can be adopted: parametric modelling (Brusaporci, Maiezza & Tata, 2020); modelling of complex objects and irregular shapes through the use of NURBS which then, thanks to interoperability, can be imported into BIM software (Oreni et al., 2014); semi-automatic modelling using scan-to-bim techniques (Garagnani, 2013; Banfi 2019); the creation of ad-hoc libraries of parametric objects for historic buildings (Lo Turco, Santagati, & D'Agostino, 2017).

4.2 THE INFORMATIVE RELIABILITY

The importance of the reliability of other informative contents within the three-dimensional model is underlined by numerous studies that focused on the declaration of the sources used in the attempt to ensure a scientifically rigorous digital reconstruction.
Stefani et al. (2009) underline how knowledge about an historical site is often contradictory and uncertain, characterized by the study of heterogeneous documents, often incomplete and dubious. In their paper they focus on the problems of visualizing the historical transformations of the building. They also highlight how the semantization and granularity of the 3D model allow the representation of spatial and temporal uncertainties.
De Luca et al. (2011) propose a semantic-based platform to manage the digital representations of architectural heritage to the analysis and the

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documentation. The uncertainty degree is expressed using colour tones concerning spatial (shape or position) and temporal uncertainties. As for the building transformations, authors describe changes using a system of graphic notation (creation, destruction, alteration, union, division, reconstruction). Regarding the geometric entity four levels of reconstruction method are defined: based on survey data acquisition; based on images in conic or cylindric projection; based on images in pseudo-perspective, pseudo-axonometry or sketches; without iconographic support or survey data. Moreover, they associate a transparency parameter with the model to differentiate the hypothetical shapes (existing or destroyed) whose iconographic sources are known and to distinguish the various assumption.
Studying different kinds of architectural heritage, Apollonio e Giovannini (2015) present a methodology to describe the data-processing with the aim di describe the 3D model creation keeping tracks of the complete modelling process. In their paper they propose the use af a colour scale to define the reliability related to different sources: laser scanning survey; original survey drawing; original sketches and uncomplete survey drawings; coeval design reference; data deducted from previous levels; failing references.
In the specific HBIM field, however, the issue of the declaration and evaluation of the sources used for modeling led to the introduction of new reliability levels associated with the digital three-dimensional objects.
Bruno and Roncella (2018) to certify and validate the quality and accuracy of the BIM model from an informative point of view, introduce a new level of evaluation of the data relating to the knowledge of objects, the Level of Knowledge (LK), which can be compared with that provided by the Italian NTC of 2009. This level is divided into geometry, materials and structures and, for each of these areas, provides for 4 levels of knowledge (assumed Lk0, limited LK1, LK2 Appropriate, LK3 Accurate).
Bianchini and Nicastro (2018), on the other hand, with the aim of measuring and explaining the level of reliability of digital objects, introduce and codify a new parameter, the Level of Reliability (LOR). The LOR is the result of a weighted average, ranging from 0 to 10, between factors, more or less influential, which take into account both the geometric correspondence and the ontological reliability of the model compared to the reality. Furthermore, for a more immediate visualization of the model reliability, the numerical scale of the LOR is expressed in a simplified chromatic scale with three levels of reliability (low, medium, and high).

Level of Quality (LoQ) - sources evaluation

Non-geometric information level: Level of Information		Level of History	Types of sources	Level of Quality (LoQ)	
LoI A, LoI B	Low LoI	Low LoH	—	—	—
LoI C, LoI D	Medium LoI	Medium LoH	indirect	Low LoQ_I	Low LoQ_H
			direct but not exhaustive	Medium LoQ_I	Medium LoQ_H
			direct and exhaustive	High LoQ_I	High LoQ_H
LoI E, LoI F, LoI G	High LoI	High LoH	direct but not exhaustive	Medium LoQ_I	Medium LoQ_H
			direct and exhaustive	High LoQ_I	High LoQ_H

Fig. 5 - The informative reliability of the architectural element (LoQ) is evaluated according to the type of sources (indirect, direct but not exhaustive, direct) and to the LoI or LoH. For a low LoI or LoH, no information is provided and reliability is not considered.

5. METHODOLOGY

The proposed procedure is based on the declaration of the sources of information, inserted in the BIM database as an additional parameter, and on the introduction of a specific level that expresses the reliability of the model.
This level (high, medium or low) is referred to individual architectural components because a single level of reliability of the entire model would be not significant, indistinctly bringing together elements characterized by good knowledge with the ones of which there is very little information.
Since the introduction of LoINs has not yet been officially defined and adopted at a regulatory level, the definition of the reliability levels is based on the Italian Level of Development which are defined and classified by the UNI 11337: 2017, which is the only one that also considers LoDs for restoration. Despite the presence of the LoD G for restoration, the current classification was conceived for the design of new buildings, a field in which there is a gradual and uniform increase in the definition and information wealth of the building elements. In the architectural heritage this does not happen and, frequently, HBIM models are made up of components characterized by LoDs that are extremely different from each other, because of the disparity in the availability of information.
Therefore, the articulated classification into seven levels, each with its own definition of information content, is not so significant for historic buildings when we have to evaluate the reliability of the

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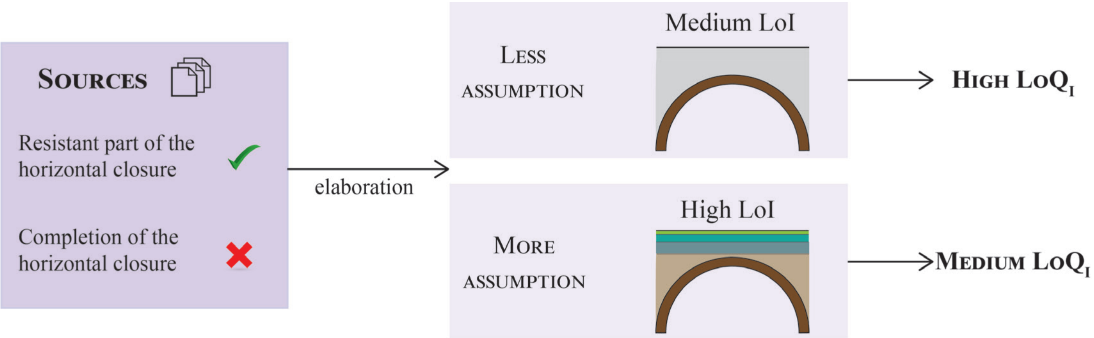

Fig. 6 - With the same information available (e.g. knowledge of only one part of the element), a higher LOD requires more hypotheses and therefore a lower reliability level; while a lower LOD guarantees a higher reliability given by the lower level interpretative of the modeler.

model.
For this reason, in this procedure the LoDs provided for by the UNI standard were grouped into three categories:
- Low LoD (LoD A, LoD B);
- Medium LoD (LoD C, LoD D);
- High LoD (LoD E, F and G).

In addition to the LoDs codified by the legislation, the Level of History is considered, to take into account the historical information attributes specific to HBIM.
For the evaluation of the reliability, we introduce the Level of Accuracy (LoA) for the geometric attributes (LoG) and the Level of Quality (LoQ) for the non-graphical attributes (Maiezza, 2019), with a different subscript to indicate whether it refers to the informative attributes (LoI) or to the historical ones (LoH). In particular, it is proposed:
1. Geometric reliability (LoA): it expresses the accuracy of the three-dimensional representation compared to the real object, evaluated in terms of deviation between the restitution model and the point cloud [2].
2. Informative reliability (LoQ_I): it is relating to the non-geometric contents of the model. In turn, it is divided into several sub-levels, as many as the different types of information entered in the model: reliability of the construction equipment; reliability of the plant system; etc.
3. Historic reliability (LoQ_H): it refers to the specific information content of the architectural heritage, that is, to all historical information concerning the process of formation and modification of the building.

Three possible levels have been identified for each type of reliability: low, medium and high.
The Level of Accuracy (LoA), given by the deviation measured on most of the element considered (D), depends on the Level of Geometric Development (LoG) (fig. 4):
- In the case of a low LoG, the LoA is evaluated on the basis of the deviation between the entire surface and the model of the architectural element. Depending on the range in which the value falls –measured, on average, over most of the surface– the Level of Accuracy can be low (D>70mm), medium (50<D<70mm) or high (D<50mm).
- For the medium LoG, in consideration of the greater attention to the geometric construction of architectural elements, the comparison is made between the generatrix and directrix of the surface, and the slices extracted from the point cloud. The testing result can be: low LoA if D> 50mm; medium LoA for 20 <D <50mm; high LoA in the case of D<20mm.
- For the high LoG, the deviation is evaluated both with respect to the generatrix and directrix and with respect to the entire surface. If the deviation relative to the generatrix and directrix is greater than 20mm, the measurement with respect to the surface is omitted and the LoA is low. If, on the other hand, this deviation is less than 20mm, the determination of the LoA depends on the deviation measured with respect to the surface: for D> 50mm the LoA is low; if 20 <D <50mm the LoA is medium; for D <20 mm the LoA is high.

The LoQ concerns all those information contents that cannot be traced back to a directly measurable geometric shape and, therefore, cannot be evaluated in terms of deviation between the model and the point cloud. In this sense, also the stratigraphy of the architectural elements, the knowledge of which is mainly linked to the diagnostic campaign and archival-document research (Centofanti, 2010), can be ascribed to the non-geometric contents, whose reliability is of an informative type (LoQ_I for the construction technologies).
The informative reliability depends on both the LoI and the sources on which the modelling is based (direct, indirect, exhaustive or not) (fig. 5). So, for a given quantity of sources only a certain LoI can be achieved because it would be meaningless to have a higher level of development but a very low reliability.
Therefore, with the same information available, a higher LoI requires more assumptions (and therefore a lower reliability level), while a lower LoI guarantees a higher reliability given by the lower interpretative level of the modeller (fig. 6).
In the same way, just as it happens for informative reliability, the LoQ_H depends not only on the sources but also on the Level of History itself.
In the assessment of the Level of Quality, only the medium and high LoI and LoH are considered, because of the absence of information attributes in the low level:
- In the case of medium LoI / LoH, the reliability (LoQ) can be low, medium, high, depending on whether the sources are, respectively, indirect, direct but not exhaustive, or direct and exhaustive.

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- For high LoI / LoH: if the sources are direct but not exhaustive, LoQ is medium; if the sources are direct and exhaustive, LoQ is high; if, instead, there are only indirect sources, a high LoI / LoH is considered unreachable because of the excessive need to hypothesize.

6. RELIABILITIES EVALUATION AND VISUALIZATION PROCEDURES

With the aim of assessing and declaring the reliability of the digital representation inside the BIM informative system, two different procedures have been developed depending on whether these are the informative or the geometric reliabilities of the elements.
To carry out the semi-automatic assessment of geometric reliability directly in the BIM environment the visual programming has been used.
The VPL is a language that allows programming not by writing codes but by graphically manipulating elements called nodes. Each node performs a specific task and is connected to the other nodes using wires, according to a logical sequence. The programming result is a graphical representation of the flow of data and of the steps required to achieve the final result [3].
The programming created for the evaluation of the geometric reliability can be divided into five functional blocks.
The first consists of the programming input data, i.e. the points of the point cloud deriving from the survey and the surfaces of the BIM model whose deviation is to be measured.
The points are created directly within VPL software (Dynamo) starting from their coordinates, which were imported into the visual programming environment within an Excel file. As for the BIM element, the selection of the surfaces takes place using direct selection nodes which connects directly with the project file.
In the second part of programming, the normals of the points with respect to the surfaces of the element are calculated. The latter are then used to project the cloud points perpendicularly onto the surfaces using the normals previously calculated as directions. Finally, only the projected points that actually intersect those surfaces were selected.
The third part is inherent in the calculation of the distances between these last projected points and the corresponding ones belonging to the initial cloud. Since some points can be projected perpendicularly and can intersect multiple surfaces, the minimum distance constraint has been set to make sure that the points are applied to the right surfaces. Therefore, the distances of the points with respect to all the surfaces were compared and, in the case of the presence of more distances, the smaller one was selected for each point.
Finally, a check of the lists was carried out to definitively understand which points were applied to which surfaces, according to the constraints set previously, and to select the points of the cloud based on the distances selected.
The fourth part of the programming is dedicated to the calculation of the reliability based on the ranges defined in the standard.
In the case of the reliability of the niche (fig. 7) the evaluation was carried out on the basis of the standard for low LoD. Hence, the distances were then filtered for distances greater than 7 cm, intermediate between 7 and 5 cm, and less than 5 cm.
Finally, in the fifth and last part of the programming, the previously filtered points have been coloured, according to the range they belong to, respectively in red, yellow and green.
The advantage in using visual programming is that once the programming has been set up, it can be reused several times for different elements. In fact, with the update of the three inputs (Excel file for point clouds, surfaces of the BIM element and values for the reliability ranges) it is possible to semi-automatically calculate the geometric reli-

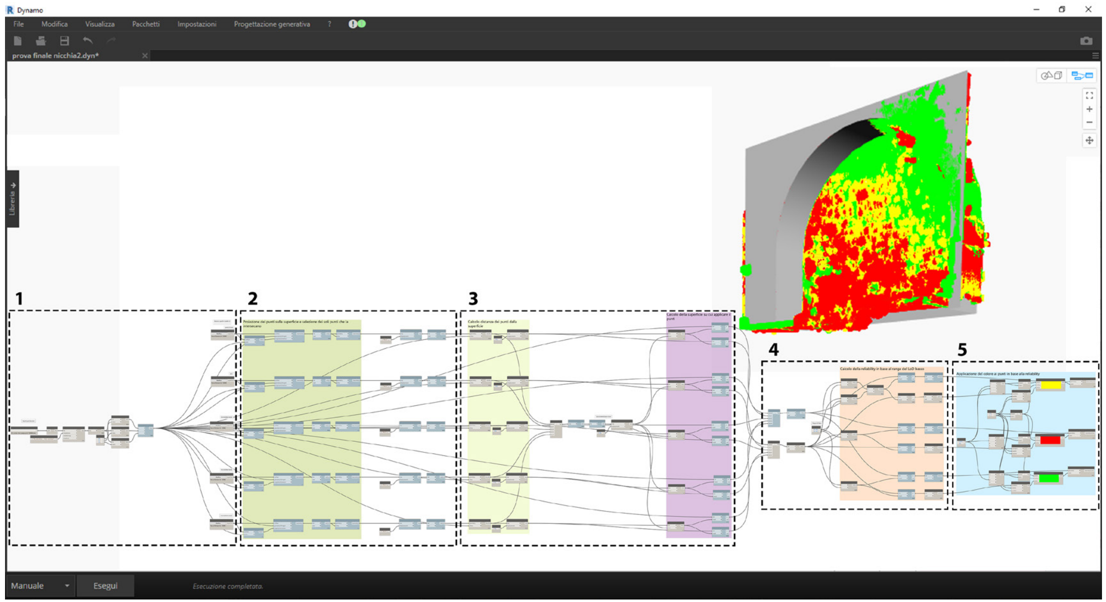

Fig. 7 - Evaluation of the geometric reliability of a niche with a low LOD through the use of the visual programming language (VPL).

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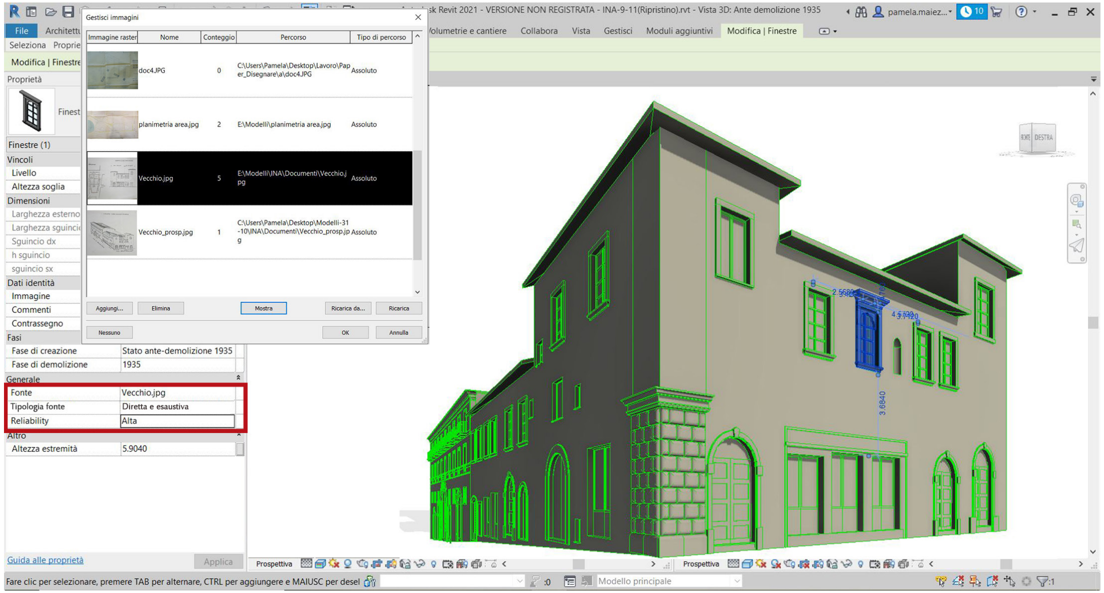

Fig. 8 - Evaluation of the reliability of the historical reconstruction within the BIM platform: the green display of the various architectural elements indicates a high LoQ_H due to the availability of direct and exhaustive sources (that is the survey of the buildings expropriated and then demolished).

ability of the three-dimensional objects, , depending on LoD.
The informative reliabilities, instead, are evaluated directly in the BIM modelling environment through the creation of view filters (fig. 8).
For each informative reliability three parameters have been created and assigned to the concerned families: source, type of source (direct or indirect, exhaustive or non-exhaustive), reliability.
Then more view filters, directly linked to the corresponding "reliability" parameters, were created for the different informative reliabilities.
These filters have then been applied to the views and for each reliability filter the graphic substitutions were used to automatically apply the colours red, yellow and green to the three-dimensional elements, based on the filtered reliability and their values (low, medium or high reliability).
Once created, these filters can be activated or deactivated in the views, depending on the type of informational reliability you want to see and communicate.
Also in this case, once the reliabilities filters have been created and applied to the views, the graphic replacements take place and are automatically actualized if the reliability parameters are modified or updated.

7. RESULTS AND CONCLUSIONS

The innovative result of the research is the definition and related testing of a procedure for the evaluation and declaration of the reliability of HBIM representation.
Taking into consideration the dual meaning of three-dimensional representation and heterogeneous information system of BIM models and the peculiarities of built heritage (importance of the declaration of sources; availability of information that is often not exhaustive and non-uniform for all elements; modelling based on the critical interpretation of data, etc.), a standard was developed divided into different types of reliability and sub-reliability, depending on the level of development of the digital objects and, in the case of non-geometric information, on the type of source.
Taking into account the non-computable information of the HBIM model relating to the historic knowledge of del built heritage, expressed by the Level of History (LoH), a new level of reliability has been introduced (LoQ_H).
In order to guarantee the model transparency, information and documents are linked to each digital object, together with the declaration of the relative reliability level, concerning the geometric (LoA), informative (LoQ_I) and historical (LoQ_H) aspects.
Furthermore, by inserting the level of reliability within the BIM environment as an attribute of the individual architectural components, transparency and interoperability between the various stakeholders is promoted.
The proposed procedure, developed today on the basis of the Italian current regulations, using three levels of development for the evaluation of the reliabilities, can be adaptable also for the foreign regulations and for LoINs when their introduction will be official.
The obtained result is a standard that can make the HBIM an effective procedure to be used for the survey and for the evaluation of the restoration project.
Future lines of development will concern the definition of the minimum levels of geometric and informative reliability to be satisfied in relation to the different objectives of HBIM modeling.
From an operational point of view, however, it will be interesting the implementation of the algorithm to automate the display of the results of the reliability assessment, processed in Dynamo, directly within the BIM software. In this sense, it will be essential to test the procedure on one or more case studies, to validate the proposed standard in its various aspects.

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NOTE

[1] Although the paper was conceived unitedly, Maiezza is the author of "Introduction", "HBIM information content: The Level of History", "Methodology" and "Results and conclusions"; Tata is the author of "Aims", "Background", "The geometric reliability", "The informative reliability" and "Reliabilities evaluation and visualization procedures".

[2] It is well known that even point clouds are characterized by a more or less high accuracy, defined by the U.S. Institute of BUILDING DOCUMENTATION as "Measured Accuracy", i.e. "the standard deviation range that is to be achieved from the final measurements taken regardless of the method used to acquire those measurements" (p. 9). For the purposes of our study, it is assumed that the point cloud used for the deviation assessment has a sufficient accuracy, corresponding to a LOA 30, or LOA 40 or LOA 50 (i.e., according to *Level of Accuracy (LOA) Specification Guide*, a standard deviation between 5 and 15 mm, 1 and 5 mm, and 0 and 1 mm, respectively, with a confidence level of 2 sigma, or 95%).

[3] The experimentation was carried out using Autodesk Revit 2021 software and Dynamo plug-in which is the Autodesk's BIM visual programming tool that collaborates with Revit and allows to have a bidirectional link directly with the data and three-dimensional objects that are within the project file.

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