HBIM LIBRARY DEVELOPMENT FOR A DORIC TEMPLE COLUMN

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ABSTRACT:

The growing interest within the construction industry in the preservation, rehabilitation, and conservation of heritage-value buildings has led to the implementation of Historic Building Information Modelling (HBIM). Especially in Greece, where the number of historical buildings is considerably large, having efficient and standardized processes of Cultural Heritage management and conservation becomes a prerequisite. The rigorously accurate representation of old constructions requires specific geometric modelling processes in order to generate the necessary relevant libraries of parametric objects. This paper describes the development of a parametrized library for the main parts of a Doric Temple to be used for introducing such parts in an HBIM system. Moreover, to verify the correctness of the parametrized column an application is performed in which the dimensions of a real column are compared with the dimensions of the standard one. The study improves the potential of the BIM process for its application to buildings with distinctive architecture in the context of the preservation or conversion of heritage buildings. In first section the term HBIM is explained and its usefulness to cultural heritage (CH) is justified. Section 2 describes previous attempts to create HBIM libraries for historic structures. After that, the construction of parametric model, which was created with visual programming Dynamo, is presented. Finally, the efficiency of the adjustment of a standard column to a given point cloud is described and in the end the results of the application are compared and discussed.

1. INTRODUCTION

Historic or Heritage Building Information Modelling (HBIM) is designed for use in the maintenance of historical buildings and can be used in a variety of technical fields, including archaeology, architecture, historic studies, conservation, and engineering in general. The assemblage of information in a combined digital model, and the easy and intelligent access to its database, contributes to the support of this type of multidisciplinary work. Creating a BIM model that represents a historic or cultural heritage building can also be considered as contributing an important collaboration platform.; however, for this purpose, the model must include all information required by the professionals involved.

The libraries of parametric objects available in the mostly used BIM-based modeling systems are extremely limited for a rigorously accurate representation of the architectural geometry and the construction solutions adopted in historic buildings. With regard to HBIM, the main difference in relation to new constructions lies essentially in the need to create the necessary families of specific parametric objects. A first collection of historical documents is fundamental to following a proper architectural modelling process. The establishment of appropriate parametric objects requires a specific approach to the identification of the most representative architectural configurations of each era. Therefore, standards, patents, and specifications are essential in the provision of support for the development of new object libraries of elements alike to similar buildings.

The construction of a historic building normally reveals a sequence of phases because the building is submitted to different interventions over time, thus incorporating many architectural trends. To determine the historic evolution of the construction solutions, all the available documentation must be accumulated, studied, and then archived, forming the documentation that will serve as the basis for the development of projects, either for maintenance or restoration of buildings.

2. RELATED WORK

2.1 State-of-the-art

Although the classical use of BIM technology for new buildings is almost well established, the particular characteristics of historical buildings, like the uniqueness of their building blocks and the absence of the concept of life cycle makes BIM implementation in the field of CH not a very popular task (Volk et al., 2014). In fact, an historical building is the product of a non-industrial process of construction and all the uses of a management tool are motivated by analysis, conservation, and maintenance purposes. However, the use of (H)BIM is growing its interest among the researchers dealing with Cultural Heritage. So, there is a technique, which is based on the use of pre-designed libraries of basic architectural and structural elements, so-called "smart objects". A lot of professional publications engage in the creation of libraries for HBIM (Figure 1). They have plenty of advantages such as: review of the building's exterior and interior and assistance of availability to survey renovations and changes that took place through different time periods.
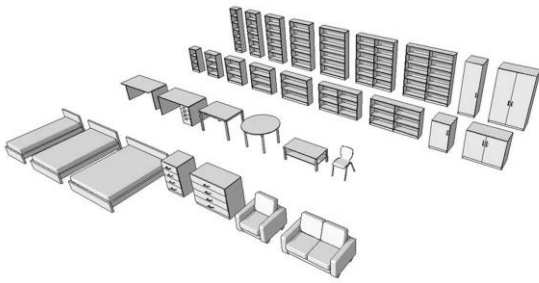
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Figure 1. Graphisoft ARCHICAD Library Part Maker. (source: https://www.thenbs.com/knowledge/graphisoft-archicad-library-part-maker-the-easy-way-to-create-data-rich-objects).

There have been numerous previous attempts to create such libraries which produced significant and remarkable results. An interesting research project was conducted by Dore and Murphy, (2012), where the idea comes from integrating HBIM and 3D GIS. The proposed method consists of two main phases; the first one is to create a 3D model by using HBIM architectural library and the second one is to integrate this 3D model in a 3D GIS for more advanced analysis. A theory is presented based on the creation of a library of interactive parametric objects based on historical architectural data, illustrating the sourcing and analysis of historic architectural data and how the parametric architectural elements are coded using geometric descriptive language (GDL). Such as the attempt of Baik, (2015) to integrate 3D Building Information Modelling (BIM) with 3D Geographic Information System (GIS) to provide semantically strong models. This research creates an interactive library of heritage elements controlled by Shape Grammar, i.e., a generation of 3D heritage objects requiring the application of computer algorithms in combination with architectural rules based on a grammar and a vocabulary of shapes, used in the documentation, restoration, education and information interchange (Stiny and Gips, 1971). In addition, a successful attempt has been made for a mathematical approach and modelling of complex geometric objects of Doric order from Siopis (2016). GDL (Geometry Description Language) is the programming language which is used by ArchiCAD software to design objects. In the possibilities of this language, apart from the creation of geometry, is the definition of all the properties of the object (materials, additional properties) and the design of the user interface surface. In addition, this work showed that it is possible to develop a user-friendly application with design and inclusion of pertinent queries.

2.2 The Doric Order

The Doric order is one of the main architectural orders of the Ancient Greek temples, characterized by its austerity and form simplicity. It originates from the 8th century BC mainly from the area of Argos and Corinth, where it flourished during the geometric period. It is easily identified by its plain capitals and lack of ornamented base for the columns. Usually, the columns have a height to base diameter ratio of 6:1. The column shafts are wider at the bottom and become narrower upwards, i.e., the column radius decreased with height. This caused an optical illusion as it made the building appear taller than it really is (Zambas, 1998). The columns are the support of the temple, they are conical in shape and are decorated with flutes, usually 20, which run the full height of the column. The number of flutes is always multiple of four, in order that with sunlight three or two flutes are shaded in succession, while the rest are fully illuminated or shaded. Between the fully illuminated and the shaded part of the column is always mediated by two or

three shaded flutes, which change rapidly. In this way an exceptional spectacle is created and emphasizes the sense of the three dimensions of the column. The alternation of light and shadow and the rapid direction movement of these zones during the day transfuses a noticeable dynamic to the building.

The Doric capital is usually sculptured in a single stone along with its upper part column. It consists of the abacus, the echinus, the straps and the hypotrachelium (Figure 2). The abacus is placed between a horizontal beam and the vertical column to easily receive the loads and prevents crushing of the pillar head. Corresponding is the role of the echinus, which transfers the loads with an elegant elasticity. The straps provide an extra resistance. At the top of each column, there are three horizontal grooves known as the hypotrachelium. Doric temples are clearly identified by their sectioned, non-continuous frieze, with its alternating arrangement of scored triglyphs and sculpted metopes (Konstantinidis, 1970).

The triglyphs are three elongated and vertical carvings on the marble. Their shape reminds of the wooden beams that were formerly used in the construction of the temples. For that reason, just below each one, are imitations of nails that once held the wooden beams, called "drops". The metopes were located between the triglyphs and were either mere pieces of marble or carried written or relief representations. In ancient times, the triglyphs were painted blue while the metopes red (wikipedia.org).
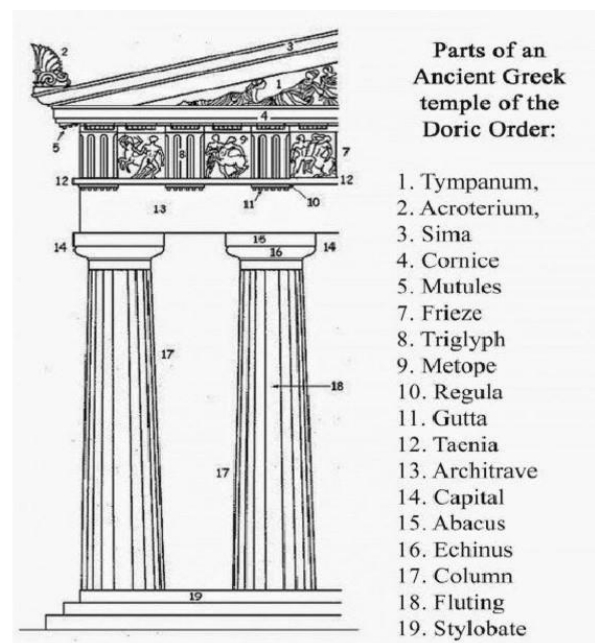

Figure 2. The parts of an Ancient Greek temple of the Doric order. (source: https://gr.pinterest.com/pin/466826317618574442/)

3. DATA PROCESSING AND HBIM APPROACH

3.1 Semantics and parametric modelling

Even though BIM is a process mainly developed for new constructions (Eastman et al., 2008), whose information is shared among actors using digital models, the scientific bibliography evidence that it can be extremely useful if applied to existing cultural heritage constructions as well, irrespective

of the age of the investigated context. HBIM models rely on a fundamental characteristic, which is represented by their parameters of their architectural identity and conscious of their mutual semantic interactions (Dore et al., 2012). This way, an HBIM model is an ideal database where elements, from the whole building to the smallest detail, can be related to heterogeneous data, keeping track of their relationships and roles in the global construction. A point cloud model, on the contrary, cannot be proficiently used to carry out such models, even if its geometrical precision is relevant in order to author an accurate digital model. In other words, an HBIM model needs to be interactively prepared from a point cloud, creating a parallel geometric abstraction where the metric accuracy of single object can be extrapolated if needed by the cloud itself, which continue to incorporate the database even after the digital retracing with parametric components. A parametric model, in fact, is a representation that binds the architecture of its components to numerical variables, which can be modified according to semantic relationships (Gerber, 2007), mathematical formulas (Aubin, 2013), e.g., knowing an ideal proportion, it can be attributed to the parameters in form of equations or polynomials (Aubin, 2013, Oxman et al., 2015). Beginning from ratios that emerged from the bibliography of Zambas (1998) and Konstantinidis (1970), parametric modelling was set up resulting in a coherent grammar able to describe the architectural details and their general composition system in a parametric approach that was supported by the software Autodesk Revit 2021. Revit's parametric engine, unlike a generic CAD software, manages the construction of a three-dimensional model (Figure 3) by verticalizing the result to the architectural scale: it is not possible to use this modelling environment as an electronic drafting tool, since its ultimate goal is the virtual construction of a digital prototype of the investigated building.
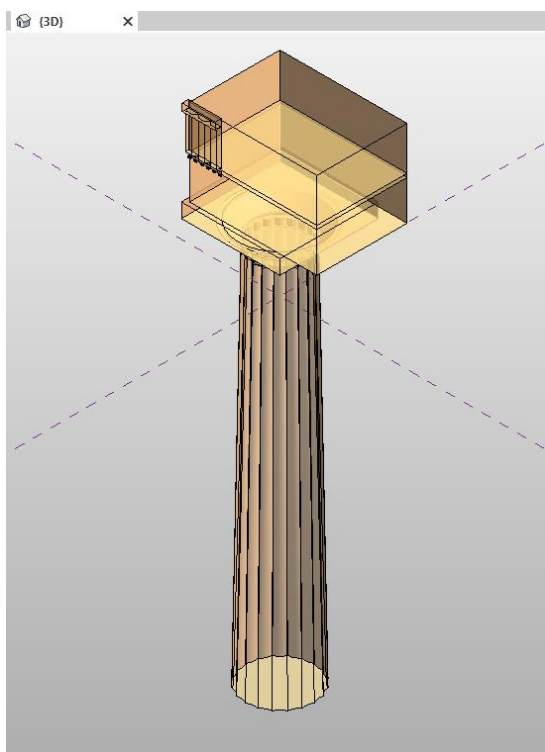

Figure 3. The three-dimensional model of Doric column.
(source: Kontoudaki, 2021.)

3.2 Programming in Dynamo

All the above observations were translated into dimensions of a standard column with visual programming, Dynamo, which is a visual programming add-in for Autodesk Revit. Dynamo provides open-source graphical programming, which enables custom computational design and automation processes for the building information modelling (BIM) process. Dynamo is more than a modelling interface. Using Dynamo, enhances BIM capabilities in Revit. Dynamo and Revit together can be utilized to model and analyse complex geometries, automate repetitive processes, minimize human error, and export data to Excel files and other file-types. Dynamo can make the design process more efficient, with an intuitive interface and many pre-made scripting libraries available as well.
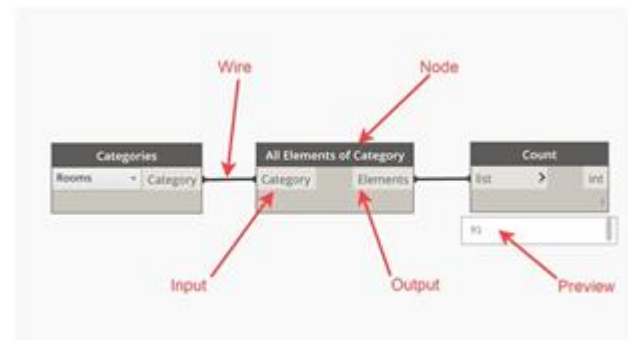

Figure 4. The interface of Dynamo. (source:
https://dynamonodes.com/category/workflows/)

For the creation of the library of the architectural members of the Doric order, the architectural members that would be constructed were initially selected. They are the following: column, notch, hypotrachelium, straps, echinus, abacus, architrave, regula, frieze and triglyph (Figure 2). Within Dynamo, each node performs a specific task. Nodes have inputs and outputs. The outputs from a node are connected to inputs to another using "wires" as shown in Figure 4. Hence, nodes are linked for identifying relationships and the execution hierarchy in order to define algorithms.

3.2.1 Formation of Doric order architectural elements

The most interesting part of the visual programming in Dynamo is the formation of the column and the flutes, which are analysed below. The Doric column is a conical surface, showing a reduction towards the top part, which is equal to M = (D-d)/D, where D = the large diameter of the lower base and d = the small diameter of the upper base. In the given construction D = 1.68m and d = 1.36m, with result M = 1: 5. In the archaic times, the ratio of the lower diameter to the height of the column was approximately 1: 6, therefore the height was set at 10.08m. Then, the side surface of the column does not appear even but is decorated by ornamental flutes. In the Doric style these flutes are usually twenty, as mentioned above and the cross section of the flute, according to Vitruvius, is a circle which for the lower base of the column should be designed as follows: 20 points are initially recorded on the perimeter of a circle with radius 0.68m and step 18°, these points were the starting and the ending of the 20 arcs. Then the distance d between the starting and the ending of each arc was calculated (d = 0,212m), to define the radius of each flute which has a circular and not elliptical cross section. Since d = 0.212m, the required radius is 0.68-0.212 / 2 = 0.57m.

Hence, for the center of the arc, points were recorded on the perimeter of one circle with a radius of 0.57m and a step of 9°. The above command is described in the workflow as it is shown in Figure 5 and the result within Revit is presented in Figure 6. Respectively for the lower base of the column the same procedure was applied with circles of radius 0.84m and 0.71m. The result of the column shaft design is shown in Figure 7.
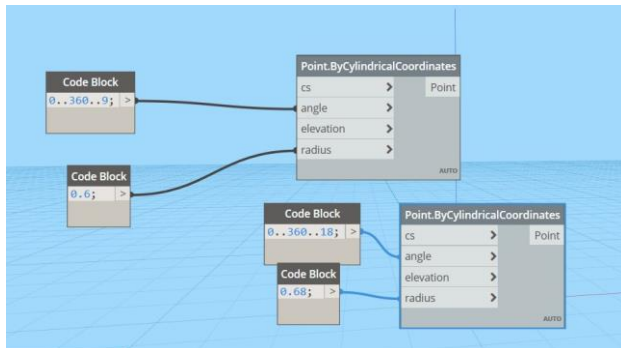

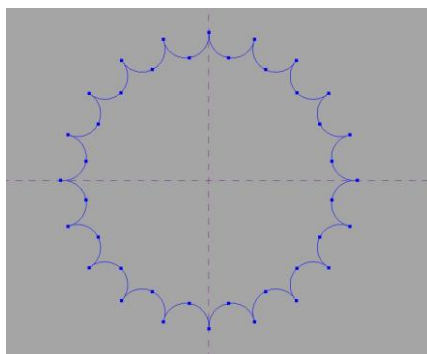**Figure 5.** Dynamo workflow. (source: Kontoudaki, 2021)

Figure 6. The result of workflow in Figure 5 at interface of Revit (source: Presentation of Kontoudaki's thesis.)
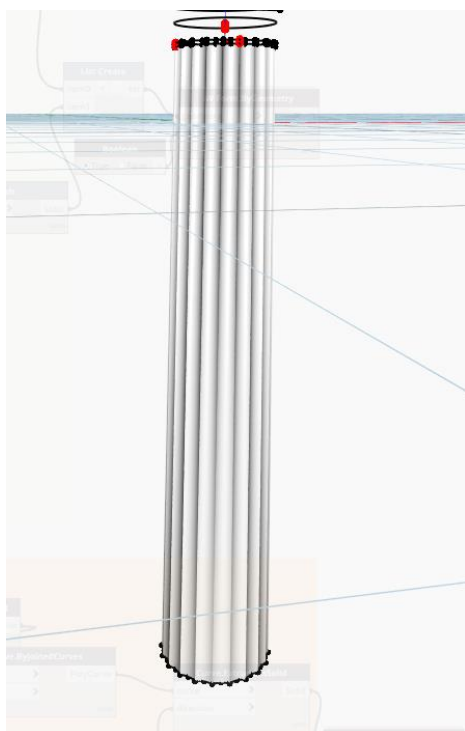

Figure 7. Representation of column shaft in Dynamo. (source: Kontoudaki, 2021)

3.3 Parameterized Column and Point cloud

All the above architectural elements are predefined and unchanged items users are not allowed to change their dimensions. It is therefore necessary to create a pertinent "family" in Revit so that the column can be customized to any dimensions specified by the user. The parameterization is dependent on the measurement of the dimensions that are desirable to change.

A family in Revit is a group of elements with a common set of properties, called parameters. So, a family was created, which includes the column, the notch, the hypotrachelium, the straps, the echinus, the abacus, the architrave, the regula, the frieze and the triglyph. The dimensions of all these elements are related to ratios to the height of the column and the length of the architrave. These two dimensions are the independent variables, that the user should insert to construct the model.

A point cloud of a Doric column was available from the geometric documentation of the temple of Hephaestus in the Ancient Athens Agora (Figure 8). The temple of Hephaestus is one of the best preserved ancient Greek temples and a great example of the architecture of the classical times.

Figure 8. The temple of Hephaestus in the Ancient Athens Agora (image by authors).

It is also known as Thisseion and it is a Doric order temple located at the northwest side of the ancient Agora of Athens, in a district which contained many foundries and metalwork shops. It is a peripteral temple, with columns entirely surrounding the central enclosed cella. Pentelic marble was used for the construction, with the exception of the lowest step of the crepidoma which is made of limestone. The building has a pronaos, a cella and an opisthodomos. Unlike the Parthenon, the temple still has all its columns and pediments intact, and most of its original roof. However, its friezes and other decorations have inevitably been damaged or worn out over the centuries (Georgopoulos et al, 2008).

The original point cloud was the result of a previous documentation project conducted by the Laboratory of Photogrammetry (http://digiphotolab.survey.ntua.gr/) using the *Leica ScanStation 2* terrestrial laser scanner with an inherent accuracy of 6mm. The point cloud of the specific part was used as example, to verify the correctness of the parametrized family in Revit. The real point cloud data were inserted into Revit and the dimensions of the modelled column were suitably modified to best fit the point cloud. For that purpose, the real dimensions of the given column, were measured and recorded from the cloud in Revit, for them to be transferred to the developed family types as may be seen in Figure 9.
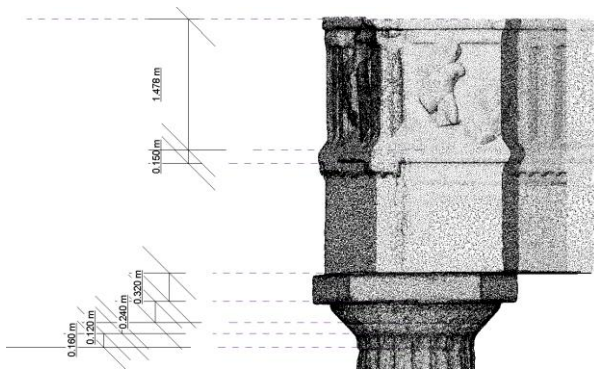
Figure 9. Measuring the column dimensions from the point cloud. (source: Kontoudaki, 2021)

4. EVALUATION

4.1 Adjustment of point cloud to parametrized column

The inserted point cloud was adjusted to the parametrized column based on just two lengths: The height of the column (8.564m) and the length of the architrave (3.008m). Following that, all other architectural elements were adjusted accordingly (Figure 10). In general, without detailed comparison of the dimensions of the standard model and the point cloud, the two columns seem to be almost identical.
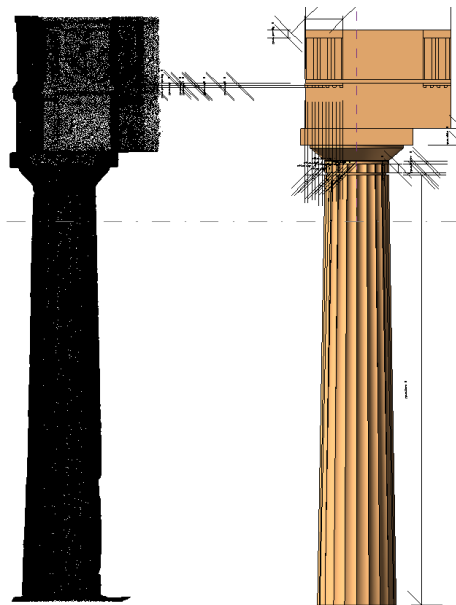

Figure 10. Adjusted dimensions of the parameterized column (right) based on the point cloud (left). (source: Kontoudaki, 2021)

For evaluating the parametrization and the whole procedure, almost all lengths and sizes were recorded and compared to the original ones, i.e., to the ones of the standard column. In Figure 11 all these differences are presented in a comparison chart. Each line of the chart represents one architectural element and the blue and red parts of the line show the comparison of the two measurements, that of the standard model column in reality (blue) and the respective one after the parametrization adjustment (red). Ideally all percentages should be at 50%.

As it is shown, not all pairs of measurements coincide, as they ideally should. These differences may be attributed to several

reasons. Firstly, the scan data include an inherent scan error of the order of 5-6 mm, not considering the eventual noise of the scanning process due to the material, the scan angle and the post processing actions. Secondly, the dimensions of the model column are by no means fixed and they were determined by the thorough study of related works, hence they constitute a mean of all those studies. Thirdly, the era of construction and the skills of the various craftsmen of antiquity, which improved with the years, might also be accounted for these deviations. Finally, the natural weather tear of the material should also be considered. It may be seen in Figure 10, that the larger differences are observed in elements which have a small physical size, i.e., the regula and the trunnel. The general impression is that the various sizes are almost equal within a 10% margin, i.e., 50% ± 5%.

It has been shown that the complex problem of inserting complicated heritage surfaces to a BIM environment is possible under certain conditions. A library of architectural elements covering a lot of historic buildings and spanning over many centuries of human architectural activity would be an important requirement. For this purpose, specifications should be compiled along with pertinent guidelines. For that, a recognized international body should undertake the lead, like e.g., ICOMOS (www.icomos.org) or CIPA-HeritageDocumentation (www.cipaheritagedocumentation.org). In this way, HBIM technology will be even a more decisive factor in documenting and preserving cultural heritage.
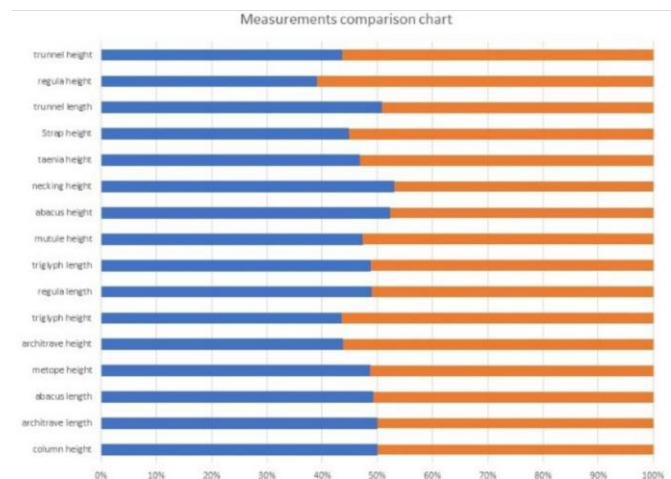

Figure 11. Comparison chart of dimensions between standard column and point cloud (source: Kontoudaki, 2021)

5. CONCLUSIONS

The experimentation carried out in this research shows that the use of HBIM in the cultural heritage field is a good solution and has significant potential for coordinated and efficient management and preservation. Nevertheless, a widespread application of HBIM system to cultural heritage buildings requires a large investment in terms of costs, training and processing times. In particular, it is necessary to invest in technological development and scientific research to provide accurate and verifiable data, optimise and speed up surveying and modelling processes, overcome interoperability problems and create user-friendly systems.

With HBIM related software, parametric elements can be created for the family of each element. Having all the information of the structure associated with different periods,

this allows to compare and analyse the evolution of the structural health of the construction. Moreover, in a next study could be considered the introduction of corrosion data into the parameterized column, in order to be able to do better maintenance management and taking the most reliable actions of maintenance and intervention.

Furthermore, in the final standard column, there is possibility for its later use by specialists, in order to integrate it with additional architectural members such as: cornice, raking cornice, gable, acroterion etc. Additionally, the material could be defined as parameter, as well as to add colors to the architectural elements to make it representation of the data in their original state. All of the above could be used for the digital representation of temples, in order to be preserved unharmed over time.

These ideas offer new opportunities in the field of cultural heritage management; however, the effectiveness of the methodology is obviously strongly related on cost and time consideration and must be carefully evaluated in relation to the HBIM purpose.

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