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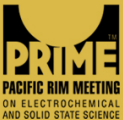
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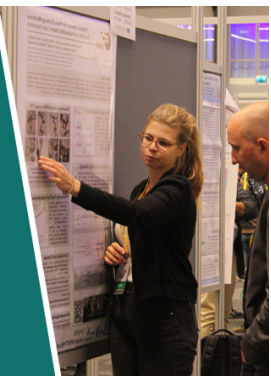
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Scan-to-Building Information Modelling vs. HBIM in Parametric Heritage Building Documentation

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Abstract. This paper introduces some studies developed regarding the Greco-Roman Museum at Alexandria, in Egypt. The heritage building was built by Dietriche and Steinon and had 11 halls were completed in 1895 and opened by Khedive Abbas Helmy II. The museum embodies many elements of the Italian Renaissance, including the columns, the entablature, and the pediment, as well as a staircase of white marble in the front façade, follows the Doric order. The museum was surveyed using terrestrial laser scanning to produce a model with high detail level translated into a Heritage Building Information Modelling (HBIM) prototype. The Scan-to-Building Information Modelling (BIM) approach was obtained with a generation of semantics and components proper of Dietriche and Steinon's architectural grammar, first of all defining the object, then geometry, and then their parameterization. This method of modelling the Museum's main facade, used to better understand the architectural composition of the volumes, producing particular hypothesis on its form according to the architectural patterns books, to understand the restrictions of the method and the perception of a research that goes from a digital survey to the HBIM model.

Keywords: Digital survey, Point clouds, Renaissance Order, Parametric, HBIM, Scan to BIM.

1. Introduction

There is a great need for the development of digital documentation using advanced technologies that are useful in collecting information with less time, effort, and cost, focusing on how this information can be converted to formal and organized documents and the ability to share them effectively.

The Following researches investigated different workflows and methods in order to fill the gap between the existing building and the digital model creation.

1.1. Digital modelling of heritage buildings

Modelling of the existing building with the new methodology of digital survey led to a better understanding of cultural heritage especially in terms of expected output [2]. Nowadays, using a point cloud model generated by a laser scanner and following the workflow of managing and processing this model output can be used to generate two-dimensional technical drawings such as sections recognized in special software of reverse engineering (i.e. MeshLab, Geomagic Design, etc.). This model can also



be cut into CAD environments using planes or boxes and extract point sections useful to draw technical graphic representations. In the same approach, a textured mesh with orthographic image processed with high detail and resolution often obtained after good processes of mesh repair and decimation. The conventional workflow changes when a BIM model is generated from a heritage building that is produced in the form of a polygonal model controlled by parameters. Heritage Building Information Modelling (HBIM) is a solution to the process of documenting buildings and thus preserving the heritage and can become an effective technique for preserving the architecture and cultural heritage. The objectives of the project or the goals of the researchers affect the possibilities that must be provided in this technique in terms of the accuracy of the method [3], the ability to analyse, time consumption and the communication level between the parties of the project. It should be considered that there are different workflows in applying HBIM. For example, the surveying work should be done by a sensitive scientist with interpretative and measurement skills, and the ability to use the technique. There are many skills needed to complete the process correctly. For example, it depends on the feedback resulting from experiences and which may lead to a change in the model and each step in this process is monitored deeply.

2. Historic and Scientific Background

2.1. *The Greco-Roman Museum: a case study*

The Graeco-Roman Museum was chosen as a case study, one of the most important archaeological buildings in the city of Alexandria. This museum was built in 1892 in a five-room apartment inside a small house on Rosetta Street, now known as Horriya Street. The museum was transferred to a larger building near Gamal Abdel Nasser Street, where a larger number of archaeological artefacts are being displayed [4]. Because of the discovery of more monuments and required to display in the museum necessitated the need to increase areas by extending and redeveloping the museum. This development required the comprehensive documentation of the old museum before embarking on work, which consumed a lot of time, effort and cost. Therefore, HBIM technique was needed to facilitate documentation. The museum has a beautiful neoclassical facade of six columns and pediment bears the large Greek inscription 'ΜΟΥΣΕΙΟΝ'. The museum contains 27 halls to display marble statues, mummies, carpets, coins and other antiquities offering a view of Greco-Roman civilization in contact with ancient Egypt. It also contains a patio that will be used as a space for temporary exhibitions. The building entrance was designed taking a Doric style, with columns, Pediment and Entablature. These elements are obviously visible in the western façade of the museum, which the main entrance exists. There are also some elements such as doors, stairs and ceiling that define the entrance.

As a result of the archaeological activity and the increase in discoveries, the need for renovating the museum by increasing the number of halls to display what was discovered from the relics was required. Therefore, the Municipality of Alexandria increased the number of halls until it reached 25 halls now. The study was dealt with part of the museum, which includes the western façade as part of a larger project, the redevelopment of the museum. This project includes the development of an integrated BIM model for the entire site to inform future decisions related to the maintenance, addition, management of the museum, proposals for reuse and adaptation, for repairs, presentation and exhibition material. The BIM model will be a central source of information and a platform for interdisciplinary collaboration for use in different types of study, analysis, documents and proposals.

In the field of surveying the historical architecture, there is continuous progress in applying the terrestrial laser scanning technology. This developed methodology allows the generation of a detailed 3D model of the captured elements in the form of point cloud, which utilized for inspection and metric inquiry. More precisely, the output of this type of survey is represented by a set of points that form the shell of the object which can be measured accurately [5]. There are a number of differences between this survey techniques and the traditional survey that can be found in creating high detail 3D reproduction, in the precision of the measurements, in the time consuming of capturing data, and in the adaptability and flexibility to different projects states and needs. This developed technique of using

terrestrial laser scanning has many applications, useful for heritage documentation, conservation management and intervention decision making. 3D point cloud production can help in recognizing the deteriorated elements, distinguishing the original areas from restored ones, classifying historical layers and materials.

BIM has been known to integrate a lot of data into a single model through the use of many specialized programs that have led to the production of a large database. Therefore, this database has contributed in significantly developing of research and has been continuously developed so far. Currently, this research is being developed through the possibility of integrating the point cloud into some of the available BIM softwares, thus allowing comparison between the techniques used in documenting the heritage buildings that are discussed in the research. This includes comparison between the standardized object and the captured cloud [6]. One challenge is defining the 3D point cloud as possible to be BIM objects and create an integrated library of historic elements to be stored within a specific database for new HBIM model [1]. However, creating all these elements based on standards, pattern books, and original sources may take a lot of time, especially as these elements are presented in very complex forms with many parameters to be constrained precisely.

2.2. Extended surveys and architectural representation

2.3. “All classical architecture of the Greco-Roman tradition is composed, or written, in one language of forms. These elements of classical architecture include specific Mouldings and assemblages of moulding called an Order. And Order is an accepted way of assembling a column (supporting element) with an entablature (spanning element) while imparting a certain character. In short, an Order orders a design. Orders are never applied after the building is designed, as they are generative” [7]. There are several source materials that can be used for reference when determining the proportions and forms, such as “The Classical Orders of Architecture” book by Robert Chitham [8]. In this book Chitham details how to construct many traditional forms including the five architectural orders (Tuscan, Doric, Ionic, Corinthian and Composite) as well as many common mouldings, balustrades and other forms (Figure 1). The book was first published on cusp of the computer age and therefore focused on traditional techniques to construct the orders using hand drafting methods. Other sources provided detailed drawings of each order with dimensions for each component of the order that was useful in the parametric modelling work (Figure 2). Also, existing building drawings and other documents (Figure 3) were useful for modelling process. As an original document this plan has been examined as a parameter to check differences between the original design intent and present building [9].

2.4. Historical buildings knowledge: the HBIM process

Maurice Murphy, Eugene McGovern and Sara Pavia, have defined Historic Building Information Modelling (HBIM) in 2009, as “the procedure of remote data capture using laser scanning and the subsequent processing required in order to identify a methodology for creating full engineering drawings (orthographic and 3D models) from laser scan and image survey data for historic structures” [10]. A comparison between accurate surveys data (with a point cloud files output) and a created library of architectural components (represented in a parametric family into the Revit environment) was adopted as a methodology. By locating the parametric family in the related portion of the point cloud, it can then differentiate between the two models and the simplification of the complex shapes and creating the final model in a lighter three-dimensional representation. In previous years, the use of BIM was studied in the management of existing buildings, but without considering the approach of generating the data of them. Currently, a new methodology developed and defined as Scan-to-BIM that depends on the generation of point cloud model that are converted into “in-place” mass objects, which are modelled separately without storing them in libraries.

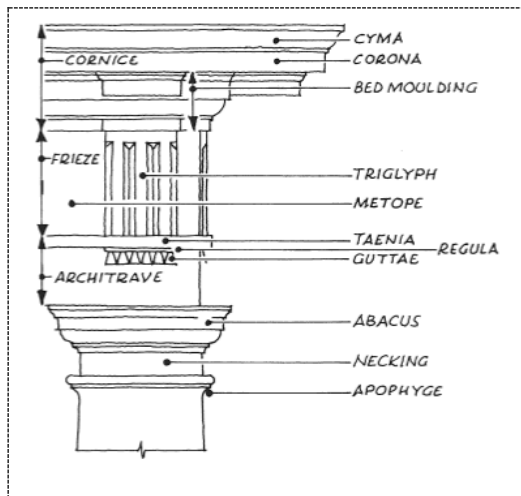


Figure 1. Doric order. Source: The Classical Orders of Architecture by Robert Chitham.

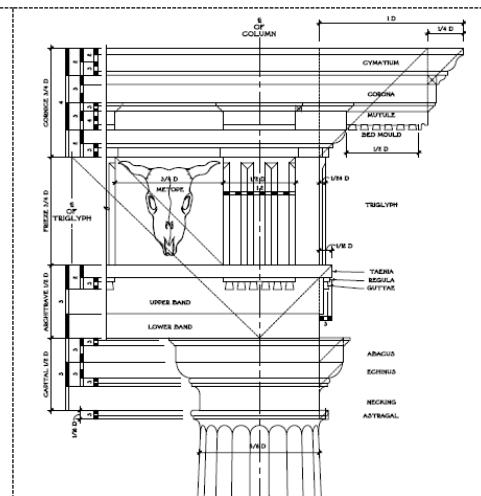


Figure 2. Doric order with Dimensions. Source: Institute of Classical Architecture and Art. <https://www.classicist.org/>.

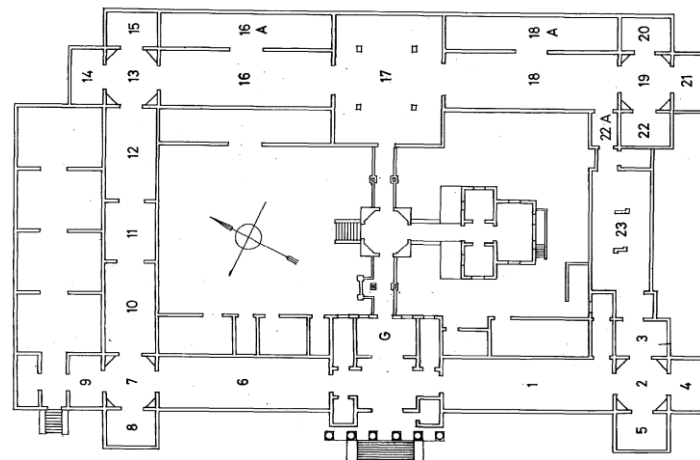


Figure 3. Doric order. Source: The Classical Orders of Architecture by Robert Chitham.

This building data can be shared with the different parties of the project in the form of a 3D model [11]. The aim of both approaches is the creation of a standard 3D model that can be integrated and shared with a specific data format such as IFC or other standard data-schemes. The approach followed in this research work was partly derived from Scan-to-BIM, while most of the components investigated on the Graeco-Roman Museum were reproduced in the digital domain in form of geometric libraries, not authored as general components but as parametric and dedicated elements instead, in order to better fit the actual geometry. The HBIM methodology adopted, this way, combined the starting point cloud accuracy retracing with a production of libraries directly connected to the Doric order grammar.

This research aims to generate a complete perceptible data that comes from the TLS survey of a heritage building, examines using different survey and measurement technique, the evidence of the ultimate Level of Accuracy, forms a point cloud to be integrated with a BIM environment. The parametric components of classical forms are not fully presented in the commercial platform libraries

and missing the parametric 3D of the existing condition of the building to be consulted for any intervention required: from documenting the building itself to the comparison with similar heritage building architectural style, study of the building deterioration and pathologies to a renovation project [1]. The research seeks to explore the possibility to reverse the construction process by converting the real building into a digital model that represents a particular case study taking into account the accuracy of the model compared to the actual building. The research adapted the following methodology to achieve the mentioned aims through the practical and analytical work.

3. Data Acquisition

3.1. Planning the survey: preliminary approach to a wide and complex data collection

The Museum main facade were surveyed using Terrestrial Laser Scanning (TLS) technique that granted a reliable metric model, providing architectural details and textures by adding image capturing, in order to document materials, damages and preservation. A preliminary plan was prepared to allow a successful survey campaign, taking into account geometries of the pediment, columns, entablature, which are the defining elements of the building and to work on it from a scientific perspective: the campaign was prepared for the terrestrial laser scanning (Figure 4).

Some proportional systems or even the choice of a typological element such as the pediment, column, or the entablature in fact, can be properly evaluated in the light of an accurate survey model. Documentary sources to investigate the geometry of the column have been investigated both in the literature. The survey was performed, this way, also to investigate more and more geometric and constructive criteria chosen by the architect. For the best success of the laser scanning of pediment, column, and the entablature an accurate targeting project was drawn. The morphology of the entablature contains elements of increasing difficulty for the laser scanning restitution: the Triglyph and the Mutule along the entablature containing in-depth details, which are repeated with constant distances, featured a white and uniform background, difficult to be isolated by software. Furthermore, the clouds sometimes blockaded the sun light during the scanning process of the entablature causing darkened and whitened areas in the final point cloud model. Therefore, removing these scans from the file was required to correct the model (Figure 5).

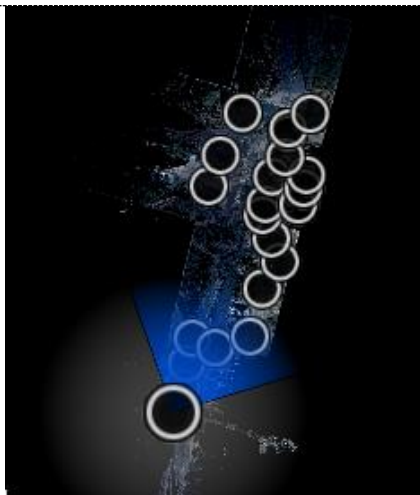


Figure 4. The main survey plan, indicating the positions of all the 22 acquired scans around the Museum facade.

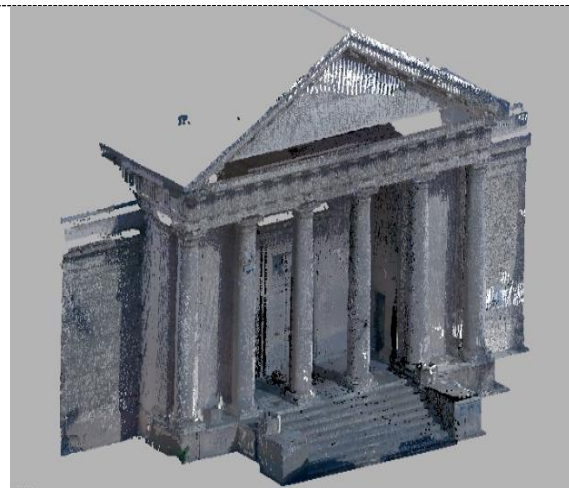


Figure 5. The presence of some defects in the model due to the sunlight alteration.

3.2. Terrestrial laser scanning BLK360 (Leica) of the Museum

TLS techniques were applied, registering almost 22 scans outdoor the monument: a general referenced point cloud related to the Museum was authored taking advantage of Autodesk ReCap and Geomagic Design software, processing colour raw files collected by a Leica BLK 360. The BLK360 (Figure 6) is the last low-cost 3D scanner commercialised by Leica. The company put a lot of effort in creating a compact product with a captivating design and user-friendly interface. The BLK 360 is selected for some advantages including the connection through Wi-Fi, and with Autodesk Recap Pro software to transfer the surveyed data automatically. In addition, this device doesn't require high skills or an expert user, and all work is completed through a tablet. The weight and size of the device make manoeuvring easier in the surveying work of cultural heritage [12]. The following (Table 1) reported the specifications of the BLK 360.



Figure 6. Leica BLK 360. Source: leica-geosystems.com

Table 1. A simple table. Place the caption above the table. Here the caption is wider than the table so we extend it slightly outside the width of the table. Justify the text. Leave 6 pt of space between the caption and the top of the table.

Operational range	0.6-60 m
Ranging error	± 4 mm
Vertical/horizontal FoV (Field of View)	300/360 °
Embedded camera Resolution	3×15 Mpx + Thermal Cam
Acquisition speed	up to 360.000 pt/s
Weight	1 Kg
Size	165×100×100 mm

4. Data Processing and HBIM Approach

4.1. Getting the point cloud output

The pediment, columns and the entablature existing in the Graeco-Roman Museum main façade were modelled following a working workflow consisting in four stages during which they were surveyed with high definition techniques (data collection stage), the survey results were processed and registered in overall point clouds (data processing stage), then the architectural elements were recognized and classified into categories after segmentation and mesh creation (semantic abstraction stage) and finally they were imported into a BIM software and converted to a parametric families to be managed (BIM modelling stage). After the first two stages of the process, the point cloud model is a finite model of precision, which may cause deformation of the model and the presence of some distortions that must be repaired during the process. Furthermore, the model is a single block without distinguishing between the different architectural elements that must be classified before the conversion to the BIM components. Since a predefined architectural grammar composed by patterns books, an HBIM approach as meant by its original definition [13] was partially pursued. Instead of superimposing digital libraries of components to the point clouds, the digital parametric objects were inferred retracing geometries over the survey references.

4.2. Semantics and parametric modelling

The main façade has many complex details that were analysed and classified, following Scan-to-BIM approach, taking the advantage of the generated and segmented point clouds. Even though BIM is a process mainly pledged to new constructions [14], whose information among actors is shared using digital models, the scientific literature proved it can be extremely useful on existing cultural heritage as well, regardless of the age of the investigated context. HBIM models depend on the standard geometries, which parameters are controlling the architectural scale, proportions, identity, and their semantic interactions [15]. Thus, the HBIM model incorporates a lot of heterogeneous data for all the architectural elements that can be ideal database for any conservation project. The point cloud digital model, even its precision and accuracy, cannot be used in quantity take-offs, simulate the building or extract the architectural drawings necessary for documentation without being introduced into the BIM environment [16]. Also, the HBIM model requires the prepared point cloud model for retracing accurately and creating the desired documentation drawings for the building and its details with the advantage of the flexibility using parameters. A parametric model, in fact, is a representation that binds the architecture of its components to numerical variables [17] that can be modified based on semantic relationships [7] (columns are always connected to the entablature supporting it, even if these change their initial shape), mathematical formulas [6] (in order to achieve the geometrical standards in the pattern books and the ideal proportions, by construction equations or polynomials considering the parameters as variables) or variable constraints (defining the relation between elements under certain conditions, following explicit mathematics that exclude possible alternatives). Starting by importing the survey data into a BIM software such as Autodesk Revit 2018, a parametric modelling was arranged in a grammatical way to describe the architectural patterns and their details. (Figure 7).

Revit's parametric engine, unlike generic CAD software, manages the construction of a three-dimensional model by verticalising the result to the architectural scale: it is not possible to use this modelling environment as an electronic drafting tool, since its main goal is the virtual construction of the investigated building's digital prototype.

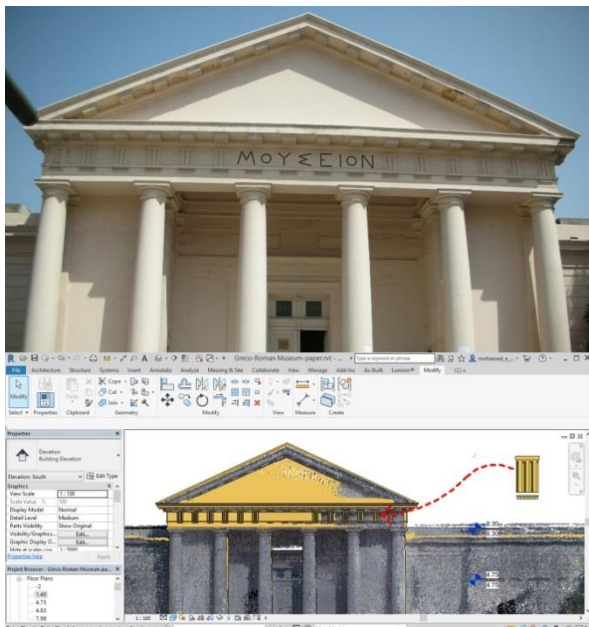


Figure 7. Historic entablature and columns, generated by point cloud retracing (Scan-to-BIM approach), and in the complete model, compared to the point cloud (HBIM approach)

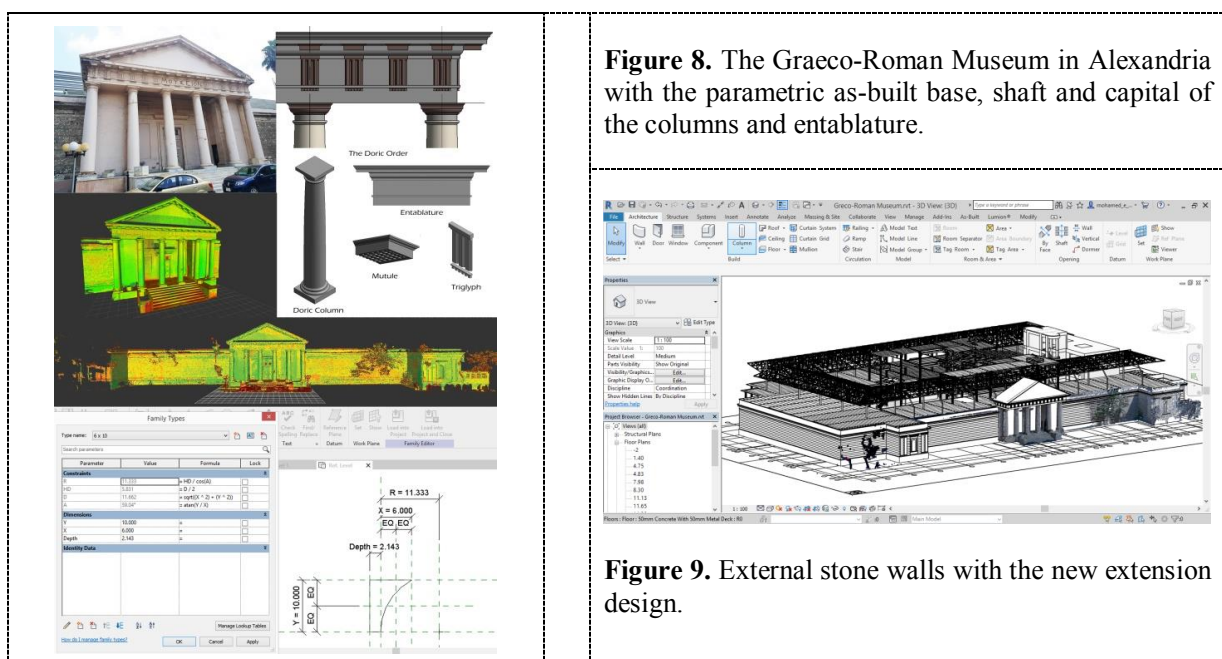
5. Results

5.1. From the HBIM model to the knowledge of the Museum

The major drawbacks of the HBIM approach is the high time consumption required for modelling in a correct way and in identifying the parameters and equations for constraining the model in order to change morphologies to fit the real building situation. The automation of this process is still under test and research in order to reduce the problem of time consumption. The high skill level is required also and the knowledge about the specifications of the graphic engine is essential. Lower number of parameters do not bring advantages in terms of architectural reference values, while a system of overabundant or poorly distributed constraints does not allow the parameters to explicate correct geometries. In general, constraints and parameters were prepared at first for the main elements like the entablature, while subdivisions and details (such as Triglyphs or Mutules) were added to the former, without introducing other dedicated variable parameters. In this way, by making grammar choices from global parameters, the proportional relationships were highlighted with the association only of numerical rules and geometries implied by the point clouds. Considering the model as a collector of data related to the Museum, the point cloud is still available: the parametric representation can be really considered as a contemplation, which serves as an interpretation of building components as well as a geometric code for extended data contents.

5.2. Digital reconstruction

The architectural composition of the Museum is the result of the semantics proper of every single component assembled. The final HBIM model of the exterior façade incorporates the functions of a digital model with the ability of historic data enhancement (photos provide the data about the materials and manifestations of deterioration were, for example, linked to walls and columns), to gather information on the original building techniques and modifications occurred over the years in materials and structures, and to perform simulations and analysis. The building's columns in the front façade, for instance, was not built according to the original elevation drawing and changed during the lifetime of the monument. The model generated could be likely used as a knowledge framework to simulate the architect's intent, with different base, shaft and capital of the columns and the entablature instead of the actual ones (Figure 8). Furthermore, the model was experimentally already used to better understand the relation between the external stone walls with the new extension design (Figure 9).



The exterior boundary and all the significant construction details needed to be coordinated with the new design and with minimum clashes between elements. Even if it would have been much more significant a complete analysis considering both exterior and interior walls, this first attempt proves the versatility and the updating possibilities of the digital reconstruction.

6. Conclusion

This study presented a methodology for developing a semantic-aware high-quality 3D model capable of connecting geometric-historical study with descriptive thematic databases. A centralized HBIM will thus serve as an extensive data set of information in the field of conservation, especially for the documentation work. The use of laser scanning can help to record the heritage building in a very high level of detail. Using accurate parametric objects can enhance the HBIM process to be automated.

A HBIM parametric model is conceived to improve information quality and quantity as the knowledge on the existing building grows; when this approach is applied to an existing monument, just like Graeco-Roman Museum in Alexandria, data collection becomes a complete digital repository aimed at the knowledge of the architectural heritage. This paper proved that the methodology and its tools have certainly to be improved in terms of accuracy, reliability and automation; the theme of model accuracy is still open and the expected precision of a BIM model perhaps a case by case theme still in progress. But among winning aspects the BIM modelling gives the possibility to implement data set making them accessible to following studies and implementation. The approach based on a mixed Scan-to-BIM and a HBIM comparison with digital libraries of elements modelled in-place can be successful in gathering data even on wide and complex monuments. In addition, this framework has been applied by the researcher as a practitioner in the rehabilitation project in order to reduce the time consumption, cost, and the effort exerted in the documentation work. Future perspectives on this work are focused on the survey and the modelling of the whole building, since a HBIM repository has to be referred to the complete investigated context, in order to better understand how it was built and how many issues are solved. This research shows many of the advantages and boundaries connected with the HBIM approach in documenting heritage buildings, considering a development in the methods and techniques in further researches to achieve the automation of the process in less time consumption aimed at managing the cultural heritage conservation.

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