

DORIC TEMPLE HBIM LIBRARY FOR CULTURAL HERITAGE MANAGEMENT

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ABSTRACT:

Heritage Building Information Modelling (HBIM) can be a valuable tool for the efficient management of cultural heritage. Adopting Building Information Modelling (BIM) for heritage architecture requires investing in training for modelling as-found elements, establishing standards for modelling, and developing accessible libraries of parametric assets. Parametric families of the Doric Order column and entablature were modelled in Autodesk Revit using standard measurements of the Doric Order, with parameters assigned to each element to remain adjustable and adapt to any as found project. These families were modelled with the ability to adjust all geometry to any point cloud with the intention of uploading the Revit files to an accessible online database, the Multimedia Inventory of Architectural Heritage (MIAH), developed by Carleton Immersive Media Studio (CIMS). The integration of these families into an online platform for any heritage professional to download and modify intends to ease the modelling process for future projects, as well as standardize the families used in future projects. To define the process of collecting data for as-found modelling, this paper outlines the documentation and data processing for two archaeological sites on the islands of Rhodes and Kos in Greece. To assist future HBIM library users in understanding the families, the process of converting point cloud to HBIM is demonstrated through the development of a parametric HBIM of the Temple of Hephaestus, located in Athens, Greece.

1. INTRODUCTION

The use of HBIM for the management of cultural heritage has significant potential with the introduction of accessible HBIM libraries. HBIM provides a more efficient methodology for the exchange of information by all stakeholders, to document the complexity of heritage architecture, including the tangible and intangible qualities. The preservation, rehabilitation, and conservation of cultural heritage at a global scale requires the development of accessible libraries of parametric objects to streamline and regulate the modelling process.

The development of HBIM requires the documentation of historic sites using laser scanning and digital photogrammetry. The process of acquiring survey data is outlined in Section 2 of the paper, which describes the geometric documentation and processing of 2 archaeological sites located in Rhodes and Kos, Greece. While the documented sites differ from the data that was provided for the development of the HBIM, the information explains what data is required in documentation projects, and how it is prepared to link to Revit for the development of a parametric HBIM.

In addition to the geometric documentation of historic sites, it is imperative to accumulate, study and manage information related to the heritage asset, to provide a thorough understanding of the project, as well as all the appropriate context to inform the future management of the site. For this reason, the Doric Order, as well as the case study, the Temple of Hephaestus, was studied to ensure the proper development of the HBIM based on the historic construction documentation.

To help understand the families and how they were created and function, section 3 outlines each architectural element, and how they were developed to parametric HBIM and adjusted to the Temple of Hephaestus point cloud. For the integration into the HBIM library, it was imperative for each element of the model to be parametric for the adjustment to future projects. Therefore, while each architectural form was developed based on the standard Doric Order measurements, each element contains the necessary parameters to be modified to the point cloud of any project.

The process of heritage modelling can be significantly improved through the development of HBIM libraries of parametric objects. While many BIM libraries exist, libraries of parametric objects available for heritage applications are very limited and remain primarily in the theoretical or development stages. Section 5 describes the importance of HBIM libraries, current efforts into their development, as well as the integration of the parametric HBIM of the Doric Temple into the HBIM library Multimedia Inventory of Architectural Heritage (MIAH), developed by Carleton Immersive Media Studio (CIMS).

2. CASE STUDIES: DOCUMENTATION AND DATA PROCESSING

2.1 Geometric Documentation

The following section outlines the data acquisition and processing for 2 archaeological sites, the Karageorgiou Burial Monument in Rhodes, Greece, and the Asklepios Sanctuary in Kos, Greece. While these sites differ from the site utilized to inform the development of the Doric Order HBIM, the

procedure for data acquisition and processing of the Temple of Hephaestus was the same. Therefore, the information presented will explain how the data was prepared for the HBIM development.

The project scope for the documentation of the Karageorgiou Burial Monument was to document the as-found conditions, before conducting a study to determine a plan for the restoration process. Square targets were introduced in strategic places throughout the site, to allow the software to register these known points during the processing stage for georeferencing. The Leica BLK 360 Laser Scanner was used to conduct 40 scans of the site, to ensure that all the required data was captured due to the destruction of the monument. The Leica TCR405 Total Station was used to measure horizontal and vertical angles, as well as distances to a point from the known point of the total station, through Electronic Distance Measurement (EDM). This process of measuring the horizontal angle, vertical angle, and distance to the point from the total station allows for the registration of the point cloud to the known coordinate system using targets. In addition, drone footage, as well as DSLR photos were taken to capture the monument.

For the documentation of the Asklepios Sanctuary, the project scope was to develop an orthophoto plan of the entire site from drone footage, provide data for the location of a future accessibility path, as well as the border around the site. A permanent network of 6 points targets were set up around the site so that each point is within view of at least 2 other points, creating triangles to allow the adjustment software to resolve any issues. Concrete was poured into holes filled with plastic tubes for the permanent setting of the bronze markers, which can be used to set the equipment for any future documentation processes to maintain known measurements. Their coordinates were determined after suitably adjusting geodetic measurements with the total station and referenced the network to the Greek National Reference system with minimum constraints. A Global Navigation Satellite System (GNSS) receiver was also used to take measurements around the border of the site. The Leica BLK 360 Laser Scanner was used to conduct 28 scans along the location where the accessibility path would be developed. Depending on the monument and required LOD, the required distance between the scans differs, but since this project was only for topography, scans were taken every 15-20 m throughout the path and every 6-7 m at the top and bottom where the required LOD was greater. The Cyclone Field application was used on a tablet to control the scanner and link each scan during the process, rather than linking each of the scans after the documentation process. Since scans within the archaeological site were not required, only the DJI Phantom 4 PRO drone was used to capture images for the orthophoto plan of the site. The flight path was conducted manually using the DJI application to control the drone, with timed photos every 3 seconds.

2.2 Data Processing

The processing for both the Karageorgiou Burial Monument and the Asklepios Sanctuary were conducted using Agisoft Metashape Professional and Geomagic Wrap. The images were aligned in Metashape, which finds the relative position of all images in 3D space by conjugating the points on each image and produces a sparse point cloud. The software recognizes the numbering on the ground control points and only 3 points are needed to scale and orient the points within the reference

system. Once the sparse cloud is generated, coordinates are added to the targets to give the object the correct position, scale and rotation. Then, the dense point cloud is generated in Metashape, the density of which is determined based on the individual project. Once the dense point cloud is created, the mesh is taken into Geomagic Wrap to clean up the noise and unnecessary points, which could also be done in Metashape, however, Geomagic Wrap is the preferred software, as it offers more tools. Once the mesh is cleaned up, it is converted into a surface and texture is applied to each triangle from the pixels of the image. The surface is brought back into Metashape to generate the orthophoto.

The Temple of Hephaestus point cloud was provided for the purpose of developing the HBIM, which was previously documented using the Leica ScanStation 2 terrestrial laser scanner with an inherent accuracy of 6mm. The following process was conducted to prepare the point cloud to be linked in Revit: Cyclone software was used to register the point cloud, while Geomagic Studio was used for the processing, including noise removal, hole filling, simplification and uniform distribution of the registered point cloud and the final production of the surface. The surface was converted to point cloud, which was exported as *.xyz file. The *.xyz file is an ASCII file, so it was renamed to a *.txt file then imported to Recap and saved as *.rcp file. The *.rcp file was linked into Revit for the modelling of the Doric Order temple.

3. CASE STUDY: DORIC ORDER HBIM

3.1 The Doric Order

Prior to the development of the HBIM, it was important to research the Doric Order elements and ratios to determine how to create the forms in Revit (Figure 1). It is also important to understand the order for future modelling use, to understand which elements to adjust. The Doric Order, the simplest of the architectural orders, is characterized by its plain capital and column with 20 flutes, which rests directly on the stylobate. The column has a height to base ratio of 6:1 and is wider at the base than the top to provide the optical illusion that the column is taller than it is (Kontoudaki and Georgopoulos, 2022). The capital of the Doric order consists of 3 parts: the necking, the transition of the shaft composed of the hypotrachelium, trachelium and annulets; the echinus, a circular block with a bulge at the top; and the abacus, a square block that supports the entablature. The hypotrachelium is the groove between the shaft and the trachelium, the trachelium is a fluted neck with a top larger than the base, and the annulets are a series of 3 rings, whose radii increase towards the echinus. The elements of the Doric Entablature include the architrave, frieze, and cornice.

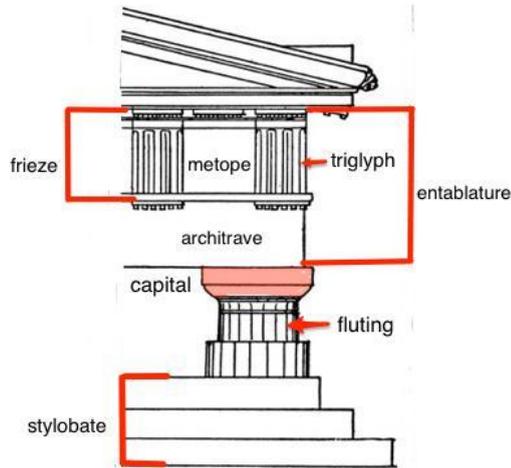


Figure 1. Doric Order Architectural Elements (Becker, n.d.)

The Temple of Hephaestus, the Doric temple which was used to inform the development of the HBIM, is located on top of the hill of Agoraios Kolonos, in the Western part of the Ancient Agora of Athens, Greece (Figure 2). The temple is 13.71 m North to South and 31.78 m East to West, with 6 columns on the East and West facades, and 13 columns on the North and South facades (Kontoudaki and Georgopoulos, 2022). It is one of the best preserved ancient Greek temples, with all the columns and pediments as well as the roof still intact, however, the friezes and decorative elements have deteriorated over the centuries (Kontoudaki and Georgopoulos, 2022). The temple was built in the peripteral style using entirely Pentelic marble, except for the limestone used for the lowest step of the crepidoma (Kontoudaki and Georgopoulos, 2022). The temple includes: a pronaos, the front vestibule; a cella, the inner chamber with a two-part colonnade forming a Π shape; and an opisthodomos, the rear porch (Kontoudaki and Georgopoulos, 2022).



Figure 2. The Temple of Hephaestus, located in the Ancient Agora of Athens (Image by authors)

3.2 Parametric HBIM Development

The parametric Doric Column (Figure 3) was developed using a variety of forms, each of which are adjustable within the family and project. In Revit, a family is a group of elements with similar properties that can be saved as a single file and reused in other projects. Families can represent various types of building components, such as doors, windows, furniture, etc. Each family consists of one or more types, which are variations of the

same basic element with different dimensions, parameters, and properties. Revit has two main types of families: system families and loadable families. System families are built-in families that are part of the software, such as walls, floors, and roofs. Loadable families are individually created and can be imported into a project from an external file or created from scratch within the project. Families in Revit allow for the customization of building components across projects.

The family uses a series of reference planes, which the geometry is aligned and locked to, to allow for the introduction of dimensions with assigned parameters that flex when the numerical value is changed. The shaft of the column is a series of swept blends to accommodate the entasis, the curvature of the column. Profiles for the top and bottom of each swept blend were loaded in separate profile families using calculations developed by Paul Aubin, the author of *Renaissance Revit: Creating Classical Architecture with Modern Software* (Aubin, 2013). The calculations assigned to the reference planes allowed the flutes of the column to flex when the radius of the column was increased, while remaining at a 60-degree angle (Figure 4). Therefore, the width of the column at each entasis break could be adjusted to any future project through the profile family. A height parameter was also included to ensure that the shaft of the column could be adjusted.

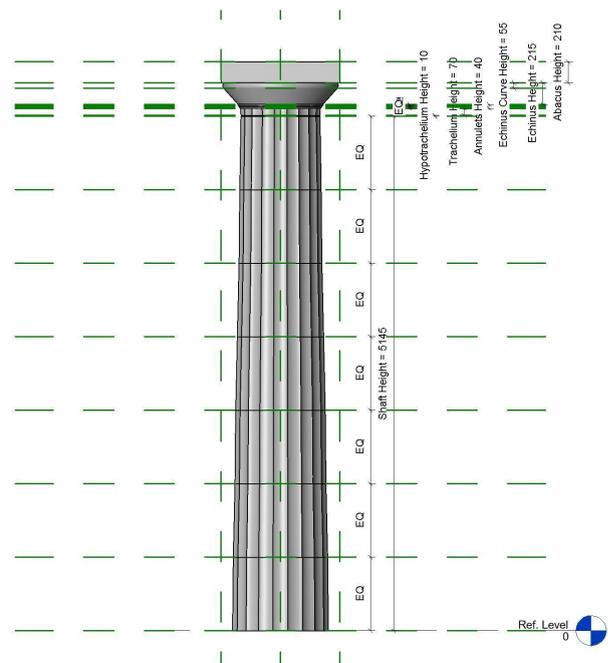


Figure 3. Parametric Doric Column family (Image by authors)

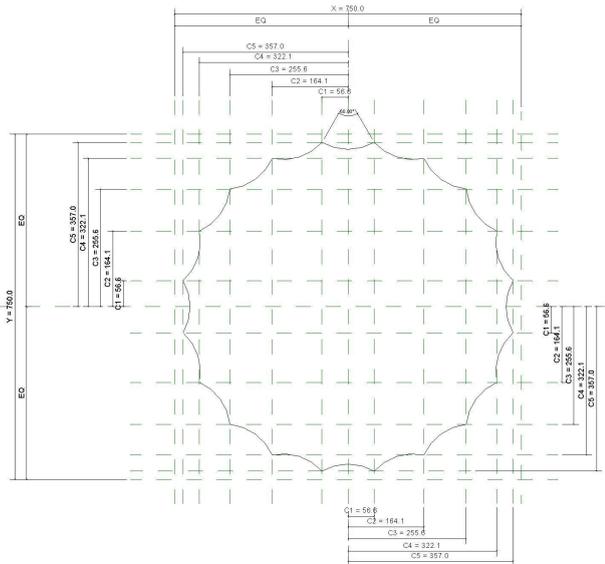


Figure 4. Parametric column profile created using calculations developed by Paul Aubin (Image by authors)

The capital of the column consists of a variety of forms best suited to the architectural element (Figure 5). The hypotrachelium is an extrusion with height and radius parameters, and the trachelium is a swept blend with a height parameter and radius parameters created with the same process as the shaft using parametric profiles. The annulets are sweeps with profiles aligned and locked to the reference planes, which have equal parameters to ensure each annulet flexes equally when the overall height parameter is adjusted. Each annulet has a separate radius parameter to account for the increasing radii. The echinus is a sweep with a radius parameter at the base, and a profile aligned and locked to the reference planes to control the distance from the abacus edge and angle, as well as flex with the height parameter.

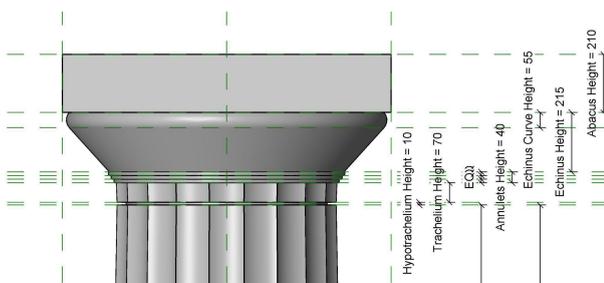


Figure 5. Parametric Doric Capital (Image by authors)

The entablature was developed as a separate family (Figure 6). The architrave, taenia regula and frieze are all extrusions aligned and locked to referenced planes with height, width and depth parameters. The horizontal geison is a sweep, with a profile aligned and locked to reference planes and a height, width and depth parameter. Reference lines were created and aligned and locked to reference planes to control the angle of the pediment, raking geison and raking sima. The pediment is an extrusion with height, width and depth parameters aligned to the reference lines. The raking geison and raking sima are currently extrusions but could be updated to sweeps to accommodate profiles. The triglyphs are a separate family with height, width and depth parameters and a profile aligned and locked to reference planes. To further develop the entablature, the guttae could be modelled, as well as the mutules. Various

LOD could be modelled to enhance the families for future use from the library.

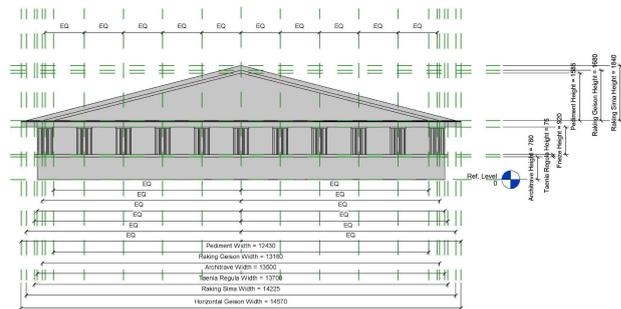


Figure 6. Parametric Doric Entablature (Image by authors)

As described above, the families created in Revit contain parameters so they can be adjusted to the Temple of Hephaestus point cloud, and the point cloud of any future project. This was imperative for the integration into the HBIM, because while the HBIM was created in reference to standard measurements of the architectural elements, in heritage architecture deviations exist for many reasons including construction discrepancies and deterioration over time.

The process for the adjustment of the parametric model in Revit to the Temple of Hephaestus point cloud begins by importing the point cloud data into the Revit model and using it as a reference to adjust the position and size of the parametric elements to match the as-built conditions of the Temple of Hephaestus. Figure 7 shows the Temple of Hephaestus point cloud imported into Revit. Figure 8 shows the parametric column and entablature families, combined into a model file to create the West facade of the Temple of Hephaestus prior to the adjustment of the cloud. Figure 9 shows the parametric column family adjusted to the Temple of Hephaestus point cloud. Figure 10 shows the families integrated into a model of the Temple of Hephaestus and adjusted to the point cloud.



Figure 7. Temple of Hephaestus point cloud (Image by authors)

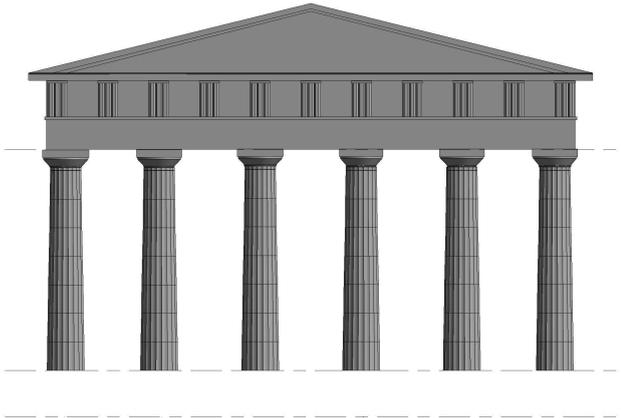


Figure 8. Parametric Doric Facade (Image by authors)



Figure 9. Parametric Doric Column adjusted to the Temple of Hephaestus point cloud (Image by authors)



Figure 10. HBIM adjusted to the Temple of Hephaestus point cloud (Image by authors)

Figure 11 shows the parameters of the original column family for download. Figures 12, 13, 14, 15, 16 and 17 show the adjusted parameters to the point cloud of each column of the Temple of Hephaestus point cloud. This shows what elements can be adjusted for the point clouds of any project when

downloaded from the MIAH HBIM library. Users could make adjustments to the families and add parameters as needed.

Abacus Depth (default)	1180.0
Abacus Height (default)	210.0
Abacus Width (default)	1180.0
Annulets Height (default)	40.0
Bottom Annulet Radius (default)	400.0
Echinus Curve Height (default)	55.0
Echinus Distance from Abacus Edge (default)	25.7
Echinus Height (default)	215.0
Hypotrachelium Height (default)	10.0
Hypotrachelium Radius (default)	360.0
Middle Annulet Radius (default)	410.0
Shaft Height (default)	5145.0
Sweep Base Radius (default)	570.0
Top Annulet Radius (default)	420.0
Trachelium Height (default)	70.0

Figure 11. Original Doric Column Family Parameters (Image by authors)

Abacus Depth	1185.0
Abacus Height	202.0
Abacus Width	1100.0
Annulets Height	40.0
Bottom Annulet Radius	400.0
Echinus Curve Height	50.0
Echinus Distance from Abacus ...	25.0
Echinus Height	212.0
Hypotrachelium Height	10.0
Hypotrachelium Radius	360.0
Middle Annulet Radius	410.0
Shaft Height	5145.0
Sweep Base Radius	570.0
Top Annulet Radius	420.0
Trachelium Height	70.0

Figure 12. Column 1 adjusted to the Temple of Hephaestus point cloud (Image by authors)

Abacus Depth	1160.0
Abacus Height	200.0
Abacus Width	1000.0
Annulets Height	40.0
Bottom Annulet Radius	380.0
Echinus Curve Height	50.0
Echinus Distance from Abacus ...	25.0
Echinus Height	225.0
Hypotrachelium Height	10.0
Hypotrachelium Radius	360.0
Middle Annulet Radius	390.0
Shaft Height	5145.0
Sweep Base Radius	540.0
Top Annulet Radius	400.0
Trachelium Height	70.0

Figure 13. Column 2 adjusted to the Temple of Hephaestus point cloud (Image by authors)

Abacus Depth	1170.0
Abacus Height	190.0
Abacus Width	970.0
Annulets Height	40.0
Bottom Annulet Radius	400.0
Echinus Curve Height	50.0
Echinus Distance from Abacus ...	25.0
Echinus Height	215.0
Hypotrachelium Height	10.0
Hypotrachelium Radius	360.0
Middle Annulet Radius	410.0
Shaft Height	5175.0
Sweep Base Radius	550.0
Top Annulet Radius	420.0
Trachelium Height	70.0

Figure 14. Column 3 adjusted to the Temple of Hephaestus point cloud (Image by authors)

Abacus Depth	1120.0
Abacus Height	195.0
Abacus Width	950.0
Annulets Height	40.0
Bottom Annulet Radius	370.0
Echinus Curve Height	50.0
Echinus Distance from Abacus ...	25.0
Echinus Height	235.0
Hypotrachelium Height	10.0
Hypotrachelium Radius	360.0
Middle Annulet Radius	380.0
Shaft Height	5155.0
Sweep Base Radius	525.0
Top Annulet Radius	390.0
Trachelium Height	70.0

Figure 15. Column 4 adjusted to the Temple of Hephaestus point cloud (Image by authors)

Abacus Depth	1150.0
Abacus Height	200.0
Abacus Width	1100.0
Annulets Height	40.0
Bottom Annulet Radius	360.0
Echinus Curve Height	30.0
Echinus Distance from Abacus ...	20.0
Echinus Height	225.0
Hypotrachelium Height	10.0
Hypotrachelium Radius	360.0
Middle Annulet Radius	370.0
Shaft Height	5155.0
Sweep Base Radius	520.0
Top Annulet Radius	380.0
Trachelium Height	70.0

Figure 16. Column 5 adjusted to the Temple of Hephaestus point cloud (Image by authors)

Abacus Depth	1160.0
Abacus Height	195.0
Abacus Width	1100.0
Annulets Height	40.0
Bottom Annulet Radius	400.0
Echinus Curve Height	40.0
Echinus Distance from Abacus ...	20.0
Echinus Height	235.0
Hypotrachelium Height	10.0
Hypotrachelium Radius	360.0
Middle Annulet Radius	410.0
Shaft Height	5155.0
Sweep Base Radius	550.0
Top Annulet Radius	420.0
Trachelium Height	70.0

Figure 17. Column 6 adjusted to the Temple of Hephaestus point cloud (Image by authors)

Adapting pre-created parametric families can benefit individuals with less time or resources to model from scratch by providing a starting point for the modelling process, saving time and effort. This approach of adapting standard families can also ensure greater accuracy and consistency across different projects, as the family is based on standardized measurements of the Doric order. Overall, downloading the parametric families from MIAH can improve accuracy and streamline the modelling process.

4. HBIM STANDARDS

4.1 Variables and Level of Development

Modelling as found elements introduces a variety of new variables not present in modelling for new construction, which makes HBIM libraries that much more important to improve the accessibility and standardization across the industry. Some of these variables include:

Condition of existing elements: Existing elements may have been damaged or deteriorated over time, which can require additional modelling modifications to accurately represent them in the model.

Inconsistencies in existing elements: Existing elements may not be consistent in size, shape, or placement, which can create challenges when trying to model them accurately.

Modelling tolerance: The accuracy of as-found conditions can vary widely, which is why it is imperative to rely on point cloud data for modelling existing conditions, rather than existing drawings. Setting a standard for modelling tolerance, such as modelling geometry within 25 mm of the as found data, is important to ensure that the model is consistent.

Overall, modelling as-found elements in Revit requires careful consideration of the existing conditions and variables that may not be present when modelling for new construction. It is essential to accurately represent the existing conditions to ensure proper integration with new construction and to minimize the risk of errors and inconsistencies.

The increased utilization of HBIM requires the development of standards to represent various levels of detail (LOD) in 3D models. The Level of Detail (LOD) system is used to describe the level of graphical detail in a building information model. It ranges from a basic placeholder model to a highly detailed one. The following is a breakdown of the LOD system, created by CIMS (Graham, Chow and Fai., 2018):

LOD 1 involves the graphical representation of elements with generic size and shape but without additional information, such as material or detailing. For example, a window may be outlined with proper dimensions but without specific details.

LOD 2 elements are graphically represented with primary materiality shown, but minimal representation of connections and secondary materials. In the case of a window, a basic frame detail would be included, distinguishing between wall, frame, and glazing materials, but without specifying actual materials used. This level of detail excludes additional detailing such as mullions, muntins, and headers.

LOD 3 involves elements represented with high precision, including the material palette and modelled connection pieces but without fasteners. For instance, a window may be depicted with materiality and detailed geometry around the opening,

frame, and major mullions, but may not include the ashlar and secondary mullions and muntins.

LOD 4 elements are depicted with all available information, including connections and the size of individual members, typically used in areas where extensive detail is required. An example of such an element would be a window containing all major and minor mullions, stained glass window detail, ashlar around the window, and materiality (Graham, Chow and Fai, 2018).

The choice of LOD for a specific element is determined by the available reference material and the purpose of the model. These levels of detail help to standardize the level of graphical detail and information contained within a Revit model, making it easier to communicate and collaborate across different teams and stages of a project (Graham, Chow and Fai., 2018). By defining these levels of detail, the CIMS provides a framework for creating models that are consistent, accurate, and useful for different purposes throughout the design and construction process. The column and entablature families were developed to LOD 200 to ensure that it can be adapted to any as found project for users who download the families. The base model can be updated for each use case to any level of detail depending on the requirements of the project, including increased detail in modelling and information integrated into Revit.

5. HBIM LIBRARIES FOR DATA SHARING

5.1 HBIM Libraries

The use of HBIM for the preservation of built heritage has significant potential, however, it faces many challenges that are not present in the context of new construction. Some of these challenges as discussed above include lack of standardization in data exchange. One way to improve standardization across the industry is the development of accessible HBIM libraries to make modelling more consistent. Currently, many digital libraries exist for the download of BIM objects, but the lack of libraries for HBIM elements is apparent. Developing libraries specific for HBIM requirements with parametric elements available for download would ease the burden of modelling every element of a project from scratch, especially for those with a limited knowledge of HBIM. Making parametric elements accessible would also ensure that similar projects establish similar standards, while remaining adjustable to each project.

MIAH, developed by CIMS (Figure 18), is an online database with downloadable content including model files (.rvt, .fbx, .ifc), families, drawings, and sources from four categories: assemblies, details, documents and tools (Carleton Immersive Media Studio, n.d.). The content available through MIAH was developed by academics, heritage professionals, archivists and industry leaders in software and computing, who contributed research of both tangible and intangible qualities of architectural heritage at a global scale (Carleton Immersive Media Studio, n.d.). This database for the dissemination of architectural heritage aligned with the goals of this project: to make the case study, the parametric Doric Order temple, accessible for download and adjustment to future projects. The MIAH database is accessible to anyone and can be found at: <http://www.cims-miah.com/#/home>.

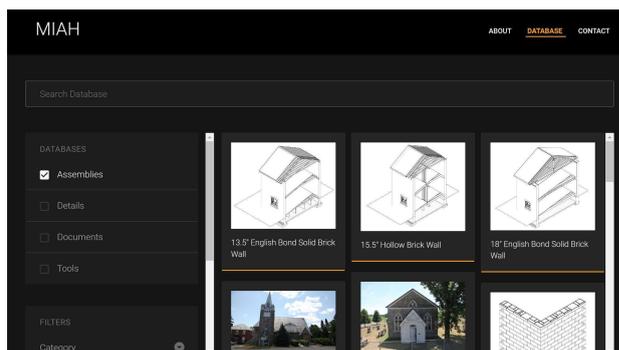


Figure 18. MIAH online database (CIMS, n.d.)

6. CONCLUSION

The methods and research outlined in this paper review the process for acquiring 3D data and modelling as found conditions to bridge the knowledge gap from BIM to HBIM. In addition, the review of standards for modelling as well as accessible HBIM libraries intends to inform and suggest a way forward for the efficient management of cultural heritage.

The review of the development of the parametric Doric Temple, based on research about the Doric Order as well as data acquired from the case study, the Temple of Hephaestus, provides context for future specialists who download the families from MIAH. Understanding how the families were built is essential for future users to modify the families to suit their project needs. The goal of providing accessible parametric families online is to ease the modelling burden and standardize families for future projects in Greece and beyond. Through adapting existing families to each project, time and money can be saved by avoiding modelling each as found project from scratch. Next steps that could be taken to develop the project include modelling the entire temple, modelling elements to various LOD in each family, and modelling mutules and guttae on the entablature. Additionally, next steps for the development of the families could be to research how to represent deterioration of the as found elements within the Revit families, which could be solved by professionals who access the families via the online database. For example, chunks of marble that are missing, entasis blocks that have shifted, or slight angles to columns could be represented within the families with future research and development.

The development of HBIM libraries can improve the modelling and project management process for researchers and professionals in heritage conservation. The development of HBIM libraries offers promising solutions for the future of architectural heritage conservation by facilitating interoperability and improving the modelling and project management process. The development of the parametric Doric temple families provides a valuable resource for future specialists who can modify families to suit their project needs. The aim of providing accessible parametric families on MIAH is to standardize families for future projects and ease the modelling burden for professionals in heritage conservation.

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