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Generating Digital Heritage Models for Conservation of Built Heritage: Theoretical Parametric Approach

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Abstract- It is well-known that, Heritage buildings are a valuable asset for people, that reveals their achievements over the years. The need to conserve built heritage become a very urgent aim to experts and community, they exploit any possible tool to achieve this aim. However, the concept of heritage conservation has completely changed due to the new technologies and inventions. These new technologies and inventions have given new chances to the conservation process of built heritage. This paper outlines a theoretical parametric approach for generating digital heritage models which will help in the restoration and reconstruction process, A library of parametric architectural models will be designed from architectural books and historic manuscripts to be embedded in a new plug-in for BIM software, this new plug-in will provide multiple solutions for restoring and reconstruct historical buildings and also will automate the modelling process by using parametric and procedural modeling techniques.

Keywords- *Built Heritage, Conservation, Parametric Approach, Digital Heritage Models, New Plug-In.*

I. INTRODUCTION

The importance of heritage conservation is in identifying, documenting, analyzing, and protecting heritage resources. Conservation of built heritage is an important tool in city development, as well as in supporting the tourism industry and producing financial return. It is also affording a sense of identity and permanency in a fast-changing world for coming generations [1].

Heritage buildings represent ancient history and the culture of nations. It creates the architectural heritage of the area. Heritage buildings retain historical values resulting from beautiful architectural details and their relationship to

important events in the heritage area. On the other hand, heritage buildings are at the risk of deterioration over time, which leads to inability to use them optimally, this enhances the importance to support and develop new techniques for heritage conservation.

The development of modelling techniques produces today accurate 3d data sets which used in several applications, for example architectural and scientific studies and virtual simulations for a better understanding of the historical sites. However, the modeling process still taking a lot of time whatever the used method because of the complex geometry of the architectural elements [2].

Conservation process deals with three main stages:

a) Documenting.
b) Analyzing.
c) Action (Figure 1).

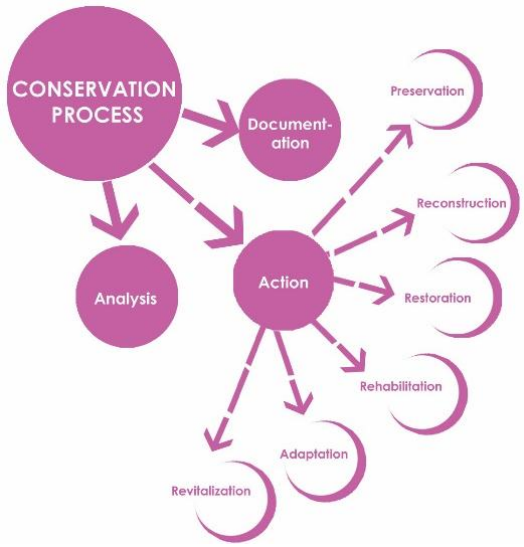

Figure 1. Stages of Conservation Process. Source: Researchers

The first stage is to record and document the historical buildings on the current situation, the second stage is to analysis the building in terms of the state of the building and its uses, as well as the architectural and structural elements of the building to reach recommendations that will implemented by the third stage, Then the third stage is to take one of these actions (preservation, restoration, reconstruction, adaptation, rehabilitation, revitalization) according to the recommendations of the previous stage.

This paper is focusing on finding solutions for the restoration and reconstruction processes, which facing problems while using the manual methods like the inaccuracy and the difficulty of imagining the missing parts of the historical buildings.

The paper uses a theoretical parametric approach to establish the concept of a new plug-in for BIM software, which aims to create a parametric library contains digital heritage models that will be designed from historical architectural data, the parametric library will be coded by using GDL the Geometric Description language that is an ArchiCAD BIM software embedded programming language. The presented approach uses a parametric technique which keeps a high level of accuracy and is also very effective compared with manual methods. The methodology of the paper combines between parametric modelling and procedural modelling techniques which based on architectural data.

In this paper the parametric approach for generating digital heritage models will be discussed, Section two contains a review of the documentation techniques, Section three includes a literature review about parametric modelling and the sources for design a parametric library, Section four describes in details the modeling steps to design the parametric library and then describes how to design a parametric façade using shape grammar rules. the workflow of the new plug-in will be described in section five. Finally, section six contains the conclusions.

II. CATEGORIES OF DOCUMENTING TECHNIQUES

Experts use different techniques in the process of recording heritage buildings based on several criteria. In the next section, the documentation techniques will be discussed to choose the appropriate ones that will take part in the implementation of the new plug-in [3]. Categorization is depending on the metric data and acquisition of points. In this regard, the following section present three categories of documentation techniques that will be studied: Image based, non-image based, and combinative methods (figure 2).

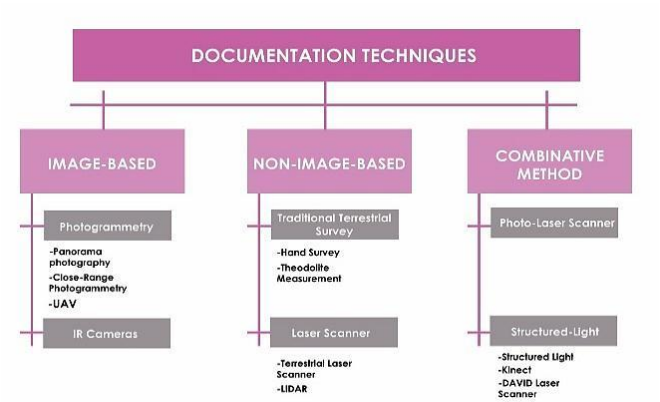

Figure 2. Categories of Documentation Techniques. Source: Researchers.

A. *Image-based Techniques*

Photography is a simple method for recording heritage buildings. Archiving and saving these data are important for future conservation needs. In this technique, images considered as the base for data collection of the targeted object and the coordinates can be reachable after the processing stage. Recently, photogrammetry and IR camera considered as the main examples of the image-based technique.

Photogrammetry is helping in understanding, analyzing, modeling objects based on their images. It's divided into three types:

- panorama photography which is a multi-image-based method.
- Close-range Photogrammetry which depends on taking at least two overlapped images, which assurance the triangulation process [3].
- UAV **"**Unmanned Aerial Vehicle" it is a method works without an on-board pilot [4]. This technique is composed of three elements, a light aerial vehicle like a small helicopter, a digital camera, and also GNSS/INS systems for detecting the position and navigating the system.
- IR Camera, IR is the part of the electromagnetic spectrum that we perceive as heat. objects radiate heat if their temperature above zero. In thermography or infrared light, an infrared imaging and measurement camera is used to observe and measure the emitted thermal energy from a target [3].

B. *Non-image-based Techniques*

These techniques are not depending on images, several coordinates points can be easily detected by using the range-based-tools, the main important examples of these techniques are traditional terrestrial survey and laser scanner.

Traditional terrestrial survey is divided into two methods, First, the hand survey method in which measurements are performed by using a simple tape or a laser distance measurer or plumb line [5], The measures are documented into a sketch which is drawn before the survey. Second, the Theodolite Measurement method which can be used in several missions such as topographic survey, determining coordinates, and providing the outline of the targeted object [6].

Laser Scanner also divided into two methods terrestrial laser scanner and LIDAR. Terrestrial laser scanner is a 3D scanning technique which can get data from the target object at a high speed and in a very short time [5]. The fundamental basic in the operation of this instrument is based on the two elements of distance and angle. While, LIDAR is a shortcut of Light detection and ranging system which was introduced for the first time by NASA in 1970. LIDAR scan an area in a slice pattern so that the integration of the scanned slices provides a point cloud model of the region. This data acquisition system functions based on measuring the distance with laser beam [3].

C. *Combinative Techniques*

The combinative techniques have the components and characteristics of both previous categories, which means that they take the advantages of them and try to overcome the shortage, these techniques combine between Photogrammetry base and surveying by transmitting beam to the surface, the next section describes the most important methods of these techniques.

Structured light technique depends on a single camera or a set of cameras which image the target and projection of a single pattern or a set of patterns onto targeted object [7] This coded pattern helps in correspond between image points and projected pattern points and perform the triangulation process [3]. "Kinect" technique is a game-oriented RGB-D camera, which is considered as general consumer-grade structured-light camera [8]. This structured-light-based sensor is composed of RGB and IR sensors with an IR pattern projector provides real-time color and depth data. DAVID laser scanner technique is a low-cost 3D method, which needs a computer, video camera, a background containing control points and a line laser source [3].

As a result of the aforementioned techniques, current studies have shifted towards merging the outputs of these techniques with new software platforms like BIM software to produce a 3d model for the documented object with accurate drawings and full information management.

III. PARAMETRIC MODELLING AND BIM

The basic parameters which define vector objects are shape and volume. They can be simply stated as coordinate points and their orientation as an angular value within a 3D space. The description of the materials and texture can be related to the numerical data, the parametric 3D models can be easily edited according to any changes of its parameters [9].

The parametric modelling was described by Shah and Mantyla as a system that solve object constraints by applying serial orders to model variables such as geometry, shape, surface texture or feature [10]. Architectural elements are characterized as genuine world objects through features, function and performance under different situations. In most architectural situations the parametric objects can be adapted which reduce their level of details [11].

Feature based CAD (computer aided design) can refer to geometry, specification of materials etc., also the function which describes the objects role (ex. window, door, wall etc.) and performance which shows how objects relate to each other [12]. It enables the user to make adjustments and variations to the parameters, the user also can combine between object features (such as openings in elements) and interaction between elements within a spatial environment [13]. In architectural modelling, this is now called Building Information Modelling (BIM) which considered as an architectural smart CAD tool instead of a drafting tool. We can define BIM as the assembling of parametric objects within a virtual environment, which representing the building components that can used to produce or form the whole building.

The parametric objects are not characterized independently, but as frameworks utilizing relations with other objects and their values within a BIM. The parameters which defined by users or others describe these objects, and this relate to position in a 3D environment relative to other shape objects. Objects can be visualized through viewing 2D and 3D features, plans, sections, elevations and 3D views. BIM can easily create all the drawings that user needs like cut sections, details and schedules, as well as 3D models and orthographic projections. BIM uses building semantics, the physical and conceptual elements, while old CAD mainly concentrate on drafting and modelling [14].

Parametric CAD is different from generic 3D CAD, as parameters are assigned to an object earlier to its utilize. For example, AutoCAD is a C++ written object-oriented program, AutoCAD rules are not parametric, they are existing as graphic objects and used to generate lines, arcs and dimensions that generate in turn architectural components, but these rules do not have intelligence [15]. The architectural CAD has been upgraded from 2D graphic representation to parametric modelling, then to nD modelling [16], after that to feature extraction and nowadays to Building Information Modelling.

The most leading platforms for BIM software are Autodesk Revit, GraphiSoft ArchiCAD and Bentley Architecture [17]. ArchiCAD, is an architectural design application, based on the BIM concept as a standalone application. In ArchiCAD the standard parametric construction elements are used in modelling objects. These elements are implanted in the software (such as walls, columns, beams, slabs, roofs etc.) or created as new objects using the implanted scripting language Geometric Descriptive Language GDL. The use of GDL enables the user to generate parametric BIM objects and to store it in inner libraries or data bases for future reuse or editing [16]. Autodesk Revit is also a BIM modelling platform, where the user constructs a mass model with a combination of solid and void forms, the surfaces of the mass can be turned into building elements like floors, walls and other architectural objects can be created inside the mass model. Bentley is different from Archi-CAD and Revit in that it is considered as a plug-in for the other Bentley platforms [14].

A. Sources for Design a Parametric library objects

Parametric objects design is depending on the architectural pattern books and the historical manuscripts. the renaissance architects have documented and introduced innovative rules for modelling the architectural elements, they also formulated a language of rules which govern the distribution and combination of parts.

Recently in the computing field the linguistics are used for semantics and that's for the procedural modelling of buildings and virtual environments. The detail behind the object's surface concerning its methods of construction and material makeup can be developed by using the historical data [18]. One of the sources that required for the parametric library is available in Vignola's manuscripts on classical proportions, this section presents an example of how these manuscripts can be translated to a set of (patterns, systems, values, parameters) which will be used later in the modelling phase.

The classical proportions consist of a series of modular relations, these relations are built on the diameter of the base of the column that represent a single module. In Vignola's manuscripts, he focused on the five orders and introduced an accurate method in order to set up the classical proportions. Instead of determining the height of the order based on the diameter of the column alone, he divided the order into a ratio of the pedestal, column and entablature. By using this method

for the larger elements, the complicated calculations to relate the whole building to the diameter of the base will be reduced. The sub relations between the column and details such as mouldings were invented by using 60 divisions of minutes, which consider the diameter of the column's base as a single module [19] [20].

In the books of the 18th century, Renaissance architects documented their rules on a wider scale (figure 3). In the 18th century Pain's described the geometry of the capitol and the modular arrangement of the base of the Doric column, he divided it into 60 units [21]. The systems of proportioning used in the pattern books had different explanations, which based on the knowledge of the writer or the level of detail given by the writer. In the 19th century, a much simpler approach was introduced for calculation of minute detail, it used fractions to replace 60 divisions.

In publications of the 20th century, Robert Chitham presented metric divisions for the most important elements, He used four scales A, B, C and D. Scale A characterizes the core elements (column, pedestal and entablature etc.) up and down from the base of the column, also additional division into tenths of the column diameter. Scale B shows the proportions of the main divisions and subdivisions of the order. Then, scale C present the proportions of the secondary subdivisions, and finally in scale D repeats these in accumulative figures [17].

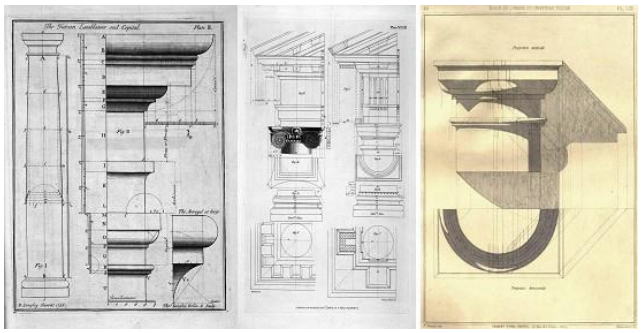

Figure 3. Examples of Pattern Books [17].

B. Using Geometric Descriptive Language in Building Parametric Elements

The programming language GDL is a language for creating parametric elements through ArchiCAD BIM software. It is similar to the Basic programming language, the parametric library objects can be created directly by using GDL language, it enables the user to use a large number of functions for generating 3D parametric objects using original shapes such as cones, spheres, ellipses and blocks or by crating shapes from 2D outlines.

All GDL objects are generated within a three-dimensional space, it is measured by the x, y, and z axes which is called the global origin (0, 0, 0) [17]. Both the global origin and local coordinate system can control of the orientation, scale and position of objects, and also marking positions of elements or shapes which can be moved in the x, y, z axis. The local coordinate system can be moved and provided a reference to the current point of an object with reference to the global origin. By using GDL the user can make graphical editing to the parameters and control various statements [21], He also can make complex operations and use mathematical functions in the process of generating parametric objects. GDL also provides the ability to write specific user interface scripts for objects and their parameters [22].

C. Building a Library of Parametric Architectural Elements

In this section the Doric column with some mouldings were chosen as an example for explaining the modelling procedures for building a library of historical elements. Simple basic primitives are used to represent the Doric column in (figure 4), these primitives are described by the geometry of each shape and determined by a value. The column is consisting of simple primitives which are Ellipse, Sphere, Bock, Cylinder and Cone, they followed by a numeric value or parameter that dictates their dimensions.

By using coordinate transformations, the primitives are collected on the Z-axis or moved instead in the x and y-axis. The base of the column is represented by a block, on the z-axis a cylinder and cone have been added to represent the column shaft, the combination of ellipses and cylinders represented the mouldings. These primitives are united into compound object, in this case they united in a Doric column, other transformations can rescale the following shapes or rotate the object around any of its axis [17].

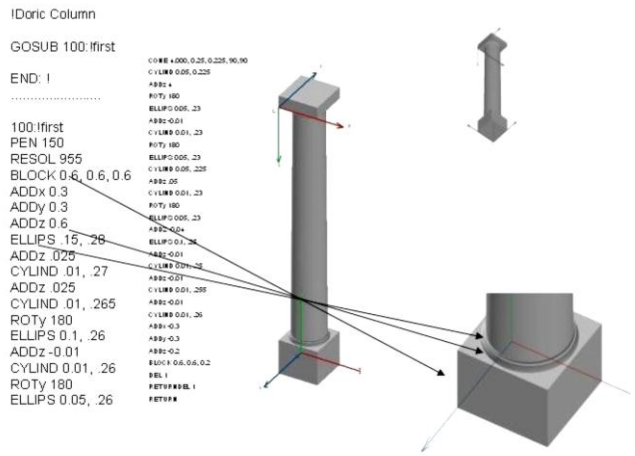

Figure 4. Modeling Simple Doric Column [17]

The procedures that required for complicated shapes and for transformations which are more abstract, may be not found in the use of simple primitives, Illustrated in (figure 5):

a) An astragal.

b) A base mould.

They considered as the mouldings that make up the Doric column, they were created by using two operations either

lathing or revolving to their profiles around their center point on the x and y axis 360 degrees. Decorated architraves are more complicated in the modelling process which required complex rules, the profile of these architraves can be achieved by using 2D prism shapes that gave depth or sent on linear paths [17]. The components are carried together by collecting on the Z-axis or instead moved on the x and y-axis. objects such as cornices, architraves, mouldings, columns are parametrically defined by joining primitive shapes that created by using GDL rules [17].

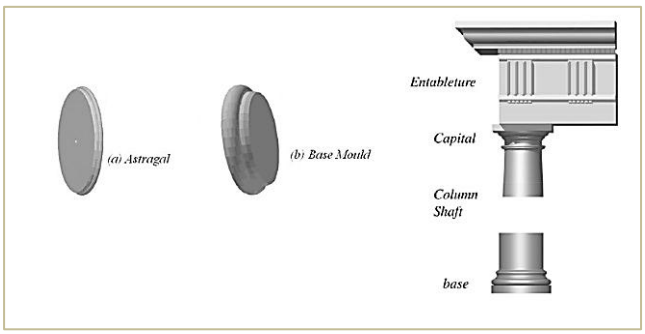

Figure 5. Details of Doric Column [17].

The Corinthian capitol which is one of the organic shapes requires more complex design, based on NURBS, Boolean and meshing operations. In (figure 6), C. Dore & M. Murphy used NURBS to build a 2D profile to form the Acanthus leaf, they also used meshing operation to use the irregular depth of the leaf. To model the bending leaves that surrounding the column, they used the Boolean operation, the upper bending of the leaf was constructed by using a shape command and introduced as a separate part of the leaf, it is not possible to bend an object in two directions.

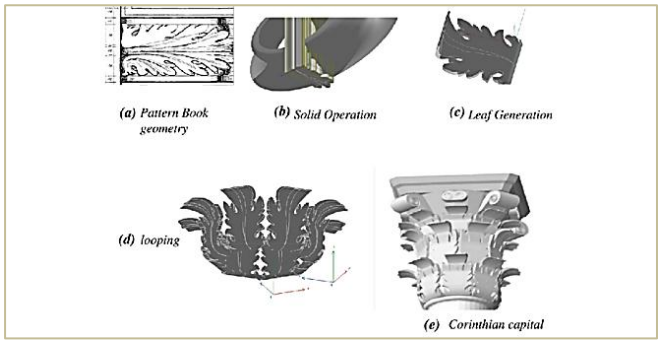

Figure 6. Corinthian Capitol [17].

Fixed numeric values with variable names can be replaced by using some parameters like geometry, texture and features which makes the object more flexible. These variables are accessible from the library part's settings dialog box while working on the project within the ArchiCAD software, these repetitive parts can be stored as existing library parts.

IV. ARCHITECTURAL RULES FOR GENERATING A PARAMETRIC FACADE

The parametric façade will be designed by using the same methodology of design the parametric library, the architectural knowledge will be used to assist with the digital reconstruction process. M. Murphy used the rules and proportions of the classical building facades which outlined in pattern books, He used the relationship between circles with the same radius to determine the proportioning of the facade by the geometry of window openings which is expressed in (figure 7).

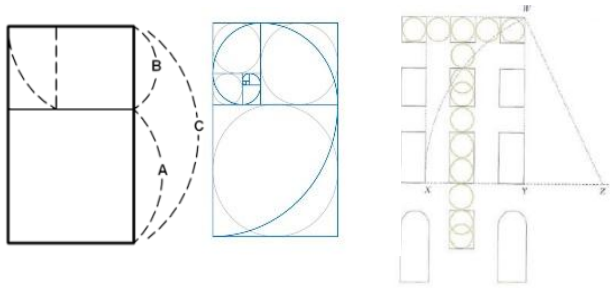

Figure 7. Proportions for facades and openings [22]

He used a single circle to determine the upper windows, and two intersected circles for the next row of windows and then he used two circles one on top of the other to determine the lower row of windows, the orientation of windows can be determined by the proportions that resulted from a parameter of window width or circle diameter. These proportions are obvious in most classical buildings, however modifications to buildings can obscure of remove some of the original façade proportions. These modifications can include enlarging or removal of brick walls, window and door openings and parapets. M. Murphy has tested the classical proportions on some surveyed facades (figure 8), then the most suitable proportions and parameters were implemented as seen in (figure 9) [22].

Figure 8. Testing classical proportions for some classical buildings [22].

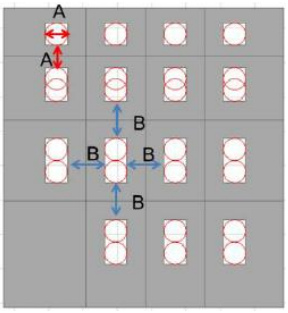

Figure 9. Proportions for Generating a Parametric Facade [22].

A. *Concept of Shape Grammar*

Shape grammar deals with the modelling process by using a set of basic shapes and replacement rules, these shapes can be replaced or transformed which make it an appropriate approach to architectural modelling. These principles enable the encoding of proportions and classical architectural rules which also use vocabularies or grammars for architectural elements, and rules to integrate these basic shapes [22].

Stiny et al. (1972) presented a set of standard rules for shape grammar which can be defined as {N, Σ, P, S} where N and Σ represent a finite set of nonterminal and terminal shapes (the vocabulary), P represents a set of production rules and S is the starting seed. Where terminal shapes are the basic elements and also points, lines, planes areas or solids. Markers or boxes are the nonterminal shapes which used to lead the terminal shapes during generation process and to control the range and orientation of shapes.

When the rules applied, the production process starts and the nonterminal shapes are replaced by terminal shapes. When no more rules can be applied and all nonterminal shapes have been removed in this case the production process ended. Production rules are applied in the form A→B where A and B are shapes. The two shapes replaced by each other when the rule is applied [23].

B. *Parametric Façade by Shape Grammar*

The concept of parametric shape grammar was presented by Stiny at 1977, it contains shape rules that defined in terms of parametrized shapes which is different from standard shape grammar, Stiny (1977) defined parametric shape grammar as {S, L, R, I, T}, S is a finite set of shapes, while L is a finite set of labelled points, a finite set of shape rules is R, I is an initial shape and T is a set of transformations. The nonterminal shapes replaced by labelled points or parameters that are combined with shapes which makes the difference between the two grammars.

In this section M. Murphy (2013) used shape grammar rules to generate the parametric façade, he used the elements {S, L, R, I, T} of the parametric shape grammar to apply it. The initial shape {I} is made up of a labelled solid shape (figure 10). This shape contains four labelled points as parameters that control both size and shape of the object. He added a parameter to define the thickness of the shape which converts the 2D shape to a 3D solid shape. The basic elements that setting up the vocabulary of shapes {S} can be seen in (figure 11) [24].

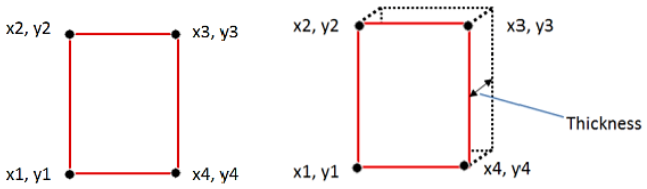

Figure 10. Initial Shape (I) for shape grammar [22].

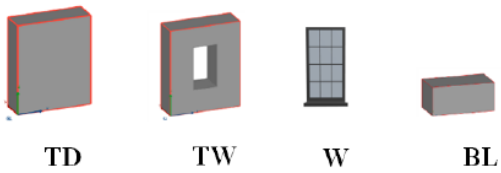

Figure 11. Vocabulary of Basic Shape (S) for shape grammar [22].

The first shape TD represent a solid panel wall that can have a door opening and linked with a library objects relating to doors, pediments and columns. The second shape is TW which represent a wall that contains a window opening, W and Pl are represent window and simple block which used to create geometry for a solid wall.

The following (table 1) shows the used rules {R}, the initial shapes located on the left-hand side and the resulted shapes after applying the rules are on the right-hand side, these rules have been applied with an assignment of real values to parameters and transformations, it is also built on the concept of CGA shape grammar [25].

Rule 1: to replace the initial shape {I} with the window shape *TW* which has new parameters to define the coordinates of the opening, Rule 2: to repeat the shape on the x-axis and to control the number of repetitions and distance by using parameters, Rule 3: same as rule 2 but on the y-axis, Rule 4**:** to split the shape on the x-axis into separate or smaller parts, the parameters control the number and positions of splits, Rule 5: same as rule 4 but shapes splits in the y-axis, Rule 6: to split the shape in the x-axis to two parts and remove one of them, Rule 7: same as rule 6 but on the y-axis, Rule 8: to repeat with conditions, Rule 9: to replace a window tile *TW* with a door tile *TD*, finally Rule 10: to select a window *W* from the library and add it to a window tile *TW*.

The facade structure is mainly created by using rule 8 which repeats the wall tile TW in the x and y directions based on architectural rules and parameters. This method is different than the principles of CGA shape grammar in which splitting the facade into smaller tiles. In Murphy's method the façade divided to a number of columns based on the architectural proportions of the building, the input shape will be repeated in each column in the y direction for the specified parameters.

Parameters for the number of floors and columns control in the number of repeated tiles which will be placed in each column and floor [22]. In the repetition process the coordinates of the shape TW should be changed to allow for different dimensions of tile depends on the classical proportions, the coordinates for the wall tile calculated automatically after applying the classic proportions. these proportions have been determined by user that defined the parameters of window dimensions and distance between floors. After determining and calculating the proportions, the coordinates of tiles and windows are stored in four arrays, when applying the rule 8 on the shape TW, the coordinates for each repetition are acquired from these four arrays, which is resulted in a facade with window openings classically proportioned.

TABLE I. SHAPE RULES (R) FOR SHAPE GRAMMAR [22]

Rule	LHS		RHS	Description
Rule 1		→		Shape Replacement
Rule 2		→		Repeat x
Rule 3		→		Repeat y
Rule 4		→		Split x
Rule 5		→		Split y
Rule 6		→		Split x & Remove
Rule 7		→		Split y & Remove
Rule 8		→		Conditional Repeat x, y
Rule 9		→		Shape Replacement
Rule 10		→		Shape Replacement

V. A NEW PLUG-IN FOR BIM SOFTWARE

This paper introduces a concept of a new plug-in for ArchiCAD BIM software that generates digital heritage models, the aim of the new plug-in is to help architects in the restoration and reconstruction process, this is by presenting 3D model proposals for the missing or demolished parts of the historical buildings, these proposals are imported from a built in parametric library for digital heritage models.

The parametric library is representing the data base of the plug-in, that contains 3D models for Heritage Architectural elements and also 3D models for famous and important historical buildings, the modeling process of historical architectural elements is based on the parametric modeling method which adopted by Murphy and described in (section 3.3), the plug-in also allows to generate a full historical facade by using shape grammar rules which will be embedded in the scripting process of the plug-in by GDL scripting language, these rules are based on the shape rules which developed by Murphy that have been described in (section 4.2). The plug-in will work on the 3D models of historical buildings which will be exported from one of the documentation techniques that mentioned in (section 2).

To create a 3D model of the historical building which need to be restored or reconstructed the user has to follow four main steps (figure 12).

First step: the user has to choose from several options and provide values that will be assigned to the parameters. Second step: the user has to insert a 3d modeling file of the documented historical building. Third step: the plug-in gives the user some alternatives of 3d models to choose from. Fourth step: adjust the chosen alternative with the documented building.

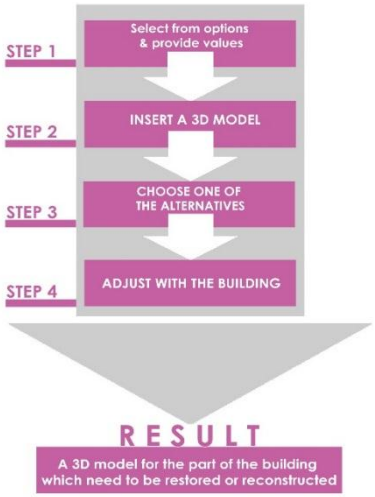

Figure 12. The steps of implementation the new plug-in. Source: Researchers

VI. CONCLUSIONS

This paper presented theoretical principles for a new plug-in for ArchiCAD BIM software that guarantee accurate and efficient solutions for the restoration and reconstruction process. The methodology of the paper uses historical architectural pattern books and manuscripts to generate a library of parametric elements, it also uses a shape grammar rules to create a parametric façade based on architectural proportions.

User can control the parametric or graphical editing over the façade and the models, he also can use the full benefits of

BIM software which include automated construction or conservation documents and the ability to add and link additional information to the model. This approach integrates procedural modelling techniques with parametric modelling techniques by merging detailed parametric objects with shape grammars. The workflow of the new plug-in can be summarized in the following flow chart in (figure 13). It is worth mentioning that the new plug-in presented in this paper is a hypothetical layout till now, it has not been applied yet.

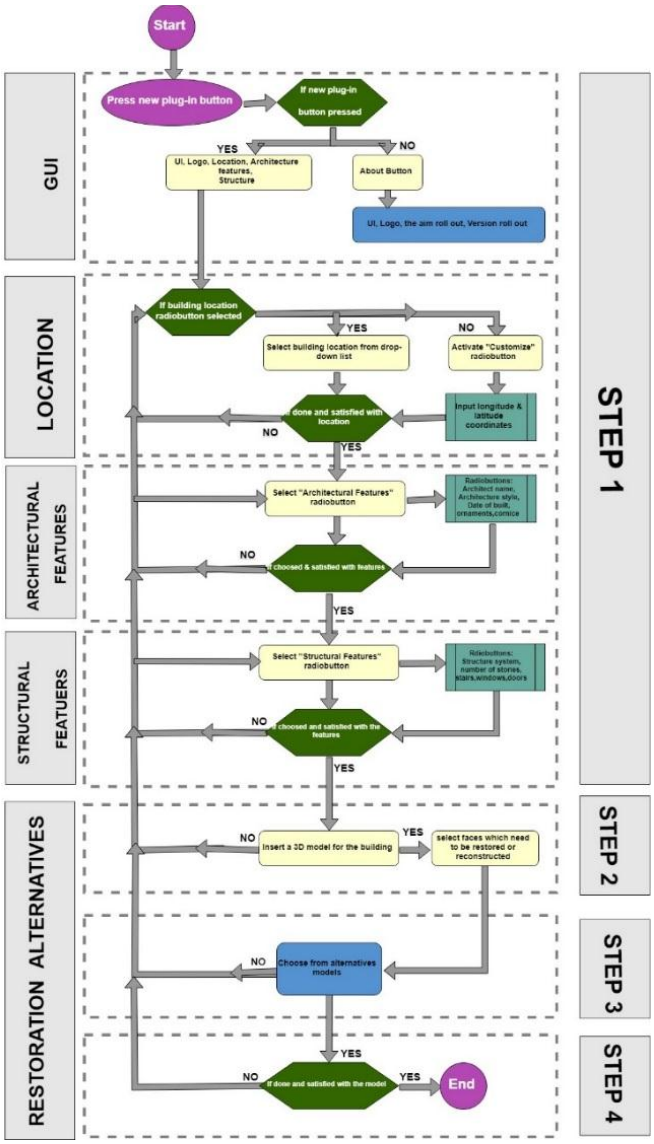

Figure 13. Flowchart summarized the workflow of the new plug-in. Source: Researchers

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