SCIRES-IT
SCIentific RESearch and Information Technology
Ricerca Scientifica e Tecnologie dell'Informazione
Vol 2, Issue 2 (2012), 41-62
e-ISSN 2239-4303, DOI 10.2423/i22394303v2n2p41

BIM-BASED MODELING AND DATA ENRICHMENT OF CLASSICAL ARCHITECTURAL BUILDINGS

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Abstract

In this paper we presented a BIM-based approach for the documentation of Architectural Heritage. Knowledge of classical architecture is first extracted from the treatises for parametric modeling in object level. Then we established a profile library based on semantic studies to sweep out different objects. Variants grow out from the parametric models by editing or regrouping parameters based on grammars. Multiple data including material, structure and real-life state are enriched with respect to different research motivations. The BIM models are expected to ease the modeling process and provide comprehensive data shared among different platforms for further simulations.

Keywords

BIM, Knowledge system, Semantic structure, Doric orders, Palladio

Introduction

Andrea Palladio's *The Four Books of Architecture* (Venezia, 1570; New York, 1965) is his influential architectural testament, in which he set up his formulae for the orders, for room sizes, for stairs and for the design of details. Using a concise and clear language, and an effective communication of complex information through the co-ordination of plates and texts, the *Four Books* represents the most effective illustrated architectural publication up to that time and one of the best descriptions of the design and construction of architecture from ancient to the introduction of digital systems. *Four Books of Architecture* is structured in such a way as to form a sort of architects' manual, organized as a knowledge system. We remark that an architectural knowledge system is able to describe a series of structured objects using a specific architectural lexicon. In the first part of *Four Books*, basic principles of architecture, the words that architects use, the architectural orders and their declinations, the preferred proportions, the choice of materials and their usage, are illustrated. Palladio then proceeds with a catalogue of his principal works for private clients, palaces and country villas, followed by public buildings. The text is structured in such a way that the characters of each building could be reconstructed in every part, using an arrangement given by a plant and an elevation (e.g. for the villas depicted in book II), 'buildable' through construction systems, details and proportions published in the book I.

In the end Palladio explains the compositional and constructive system of architecture as a knowledge parameterized system, and classical design method - i.e. that of Architectural Heritage - exactly in the way we understand it today: a system that requires the industrialization of the process, sharing more figures, an order of magnitude from the entire object to its detail, finally a system that summarizes different design and construction procedures.

An excellent solution to fit Palladian, and more in general classical design and construction method (Tzonis A., Lefaivre L., 1986) is the use of 3D digital semantic models organized as cognitive systems with geo-object items in a 3D Information System. Models are an excellent means of understanding architecture, describable as a collection of structural objects, and identified through a precise architectural vocabulary. Once the model has been divided and hierarchically organized, each part of the artifact could be connected to a series of information designed to facilitate the recovery process in a context based on semantics; this improves the discovery of 3D objects and related information in a global system; in addition, it allows to treat any shape not only as a whole, but also in terms of its major elements, attributes and relationships.

The availability of 3D semantic models organized as cognitive systems allows having a semantic approach to the classical problem of building design, management and understanding. The basic idea is to use the concept of 3D database as effective tool and is based on the fact that as large, ordered database of spatial information, a 3D model can be added to and altered over time. In this perspective, modeling does not follows exclusively a logic belonging to geometric criteria, rather this is a prerequisite upstream of a methodology based on architectural element as the basic unit and its construction methods as organizational tool, exactly as it is in classical architecture.

A powerful structured development of the naive concept of semantic 3D modeling is the Building information modeling (BIM). BIM is a building design and documentation methodology characterized by the creation and use of coordinated, internally consistent computable information about a building project in design and construction. Using the words of one of the BIM fathers: “Modern BIM design tools go further. They define objects parametrically. That is, the objects are defined as parameters and relations to other objects, so that if a related object changes, this one will also. Parametric objects automatically re-build themselves according to the rules embedded in them. The rules may be simple, requiring a window to be wholly within a wall, and moving the window with the wall, or complex defining size ranges, and detailing, such as the physical connection between a steel beam and column." (Eastman C., 2009)

From these characterizations we will detect that classical building composition and construction and parametric BIM are closely linked and BIM will be an excellent technique to build knowledge-based architectural system.

The transition from CAD to BIM (Building Information Modeling) in AEC (Architecture, Engineering and Construction) industry is already underway (Eastman C., Teicholz P., Sacks R., Liston K., 2007), while the documentation and management of architectural heritage has barely benefited from this technological renovation (Gaiani M., 1999). The applications of BIM in new projects remind us that BIM is not only a powerful modeling tool, but also provides inherent semantic data pertaining to structural, material and operational information（Ibid., 2007). Therefore BIM is expected to be a central database supporting comprehensive data input for life-cycle management, and where multiple data are collected, stored and retrieved for various motivations.

In recent years, as the field of architectural heritage has taken great advantages from the improvement of data capturing technologies (Remondino F., 2011), the need to establish centralized repositories creating further simulations is on the schedule (Koller D., Frischer B., Humphreys G., 2009). The application of BIM is opening considerable possibilities. Researchers took advantage of different features of BIM for various purposes. Modeling parametric components (Chevrier, C., Perrin J.P., 2009) with BIM tools is an effective approach which eases the time consuming modeling process in traditional CAD. Based on architectural pattern books, parametric objects are scripted using Geometric Descriptive Language (GDL) in ArchiCAD, and then mapped onto points cloud to automatically produce engineering drawings. Some authors (Attar R., Prabhu V., Glueck M., Khan A., 2010; Fai S., Graham K., Duckworth T., Wood N., Attar R., 2011) explored the potential of BIM in life-cycle management and simulation such as energy saving and fire evacuation. Besides explicit semantic description, BIM also facilitates the theoretical and historical study via historical documents enrichment (Pauwels P., Verstaeten R., De Meyer R., Van Campenhout J., 2008).

Among these current approaches, several common problems are to be addressed. The first one is the integration of BIM platforms and data capturing technologies for existing buildings. Integrated approach taking advantages both of them is to be explored. The second one involves the platforms of BIM and relevant techniques. ArchiCAD (Murphy M., McGoverna E., Pavia S., 2011) and Revit (Pauwels P., Verstaeten R., De Meyer R., Van Campenhout J., 2008) have been employed in the researches of architectural heritage currently, and there will be much work dedicating to the appropriated platforms and techniques. Standard of data exchange in BIM as well as BIM and other platforms is the last concern. Existing since early CAD, interoperability became more complicated with the advent of BIM, for not only geometry, but also its constraints and intelligence are to be exchanged. Information Foundation Class (IFC) is expected to be a promising format among BIM platforms in object level. Extensible Markup Language (XML) is used to send and store information over web. Some of the exchange formats are XML-based, such as City Geography Markup Language (CityGML) and Green Building XML (gbXML), which provide data exchange to GIS and energy analysis respectively.

In the following parts of the paper, analogy of treatises and BIM is first built in the light of knowledge system. The third part provides two case studies. The first one draws reference from parallel of orders in treatises about Doric order. It illustrates how the parametric 2D profiles generate the 3D form via sweep operation and Boolean operation. The second case extends the scope to the façade of Palazzo Barbaran da Porto. The rules developed from Doric orders also apply to other components. In the fourth part, variants of formal composition evolved from the parametric objects and their combinations. Multiple data enrichment to the geometric model is discussed in the fifth part. Conclusions and futures works are presented in the last part.

Treatises and BIM as knowledge system

Analogy between BIM and architectural treatises could be built if we regard both of them as knowledge systems. In the light of data collection, users of BIM confront similar problems as authors of treatises. Just as Palladio and other architects or theorists built their written works partly on the precedents and partly on their own observations of antique ruins, people modeling a historical building or a piece of component have to determine the origins of data with respect to different motivations. In recent years, thanks to the improvement of data capturing technologies, image-based modeling (Remondino F., El-Hakim, 2006), range-based modeling (Blais F., 2004) or multiple techniques (El-Hakim, S., Beraldin, J.A., 2002) can capture data with high geometric accuracy, but knowledge from treatises is still a neglected reference in modeling and documentation of architectural heritage (chart 1):

1. Digital camera and laser scanner record only the surface of the object. Construction details behind the surface can be detected from historical data (Murphy M., McGoverna E., Pavia S., 2011).
2. The data collected from the survey should be extracted into different levels to ease the further retrieval from the data repository (Manferdini A.M., Remondino F., Baldissini S., Gaiani M., Benedetti, B., 2008). Thus, the semantic classification and hierarchical organization according to architectural drawing conventions related to the different historic periods is necessary (De Luca L., Véron P., Florenzano M., 2005).
3. The treatises are by no means only collections of ancient surveys, but also consist of composition rules of classical architecture as well its application. The algorithms developed from the shape grammar can lead to automatic variants generation (Stiny G., Mitchell W. J., 1978; Sass L., 2007).

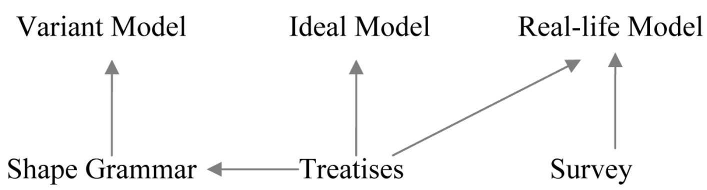


Chart 1: Central role of treatises in producing different models

Among the knowledge-system structured treatises, Palladio's *Four Books of Architecture* is a typical example (Baldissini S., Beltramini G., Gaiani M., 2008). It set up the grammar of geometric composition from single components to building types, and demonstrated great flexibility via the exhibition of Palladio's works. In the first book, Palladio described the modular composition of the orders and other architectural components, basic principles of architecture and the selection of material. The drawings of Palladio's own design for palaces, villas, public buildings and bridges were exhibited in the second and third book. The last book consisted of the surveys of surviving Roman ruins which he had studied most closely. Palladio provided the majority of images with measurements which are mathematically based on modules. Therefore, it is feasible to employ the plans, elevations and details in the book to build accurate 3D models of Palladio's architecture. *Four Books of Architecture* present two important properties for computer applications: they show the Palladian buildings theoretical foundation as complete system, and they demonstrate a rigid formalism that well fits computer features and techniques (Wittkover R., 1962). For these reasons many methods and techniques based on Palladian grammars, mainly generative techniques such as Palladian villa production with 3D printer (Sass L., 2007) and generative algorithm applied to Villa Rotonda (Park H.J., 2007), were developed during the last 30 years.

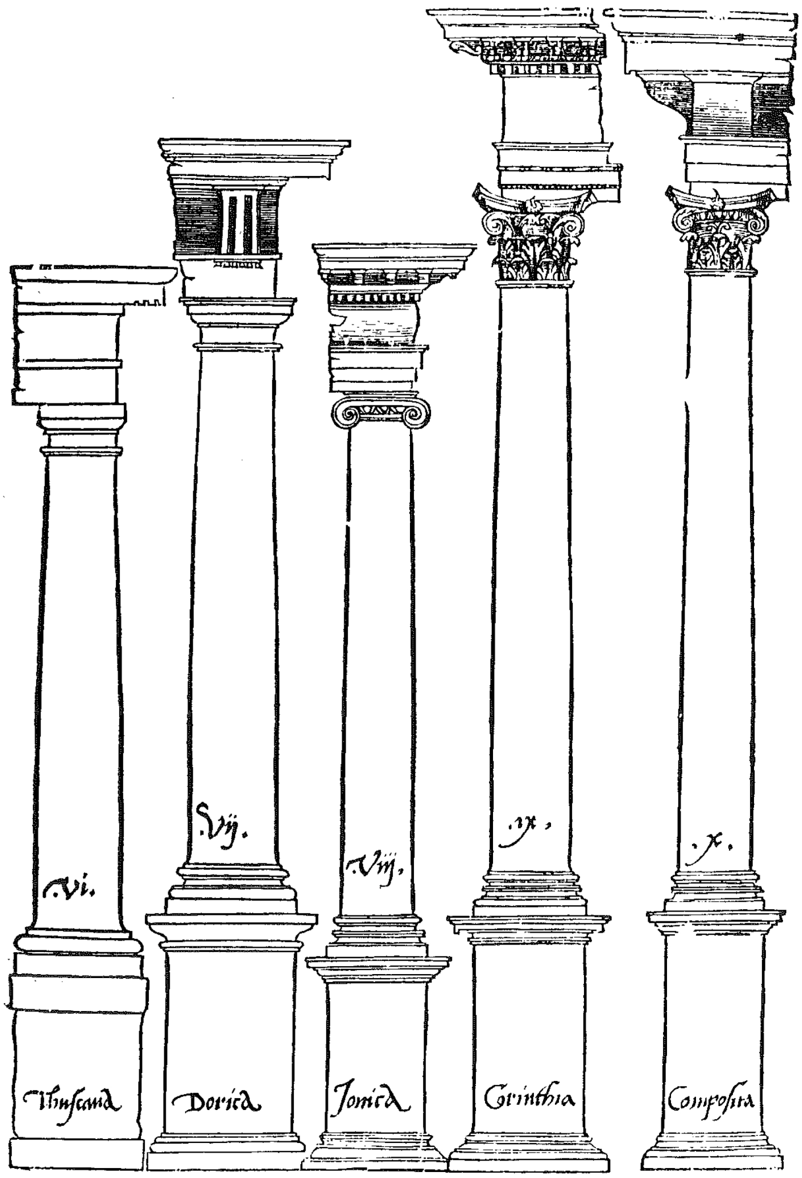


Fig. 1: Parallel of five orders after Serlio. S., (1619).
Tutte l'opere d'architettura et prospettiva di Sebastiano Serlio Bolognese. Venezia.

Case Study 1: Modeling of Doric orders based on treatises

We present a BIM-based modeling approach with the case of Doric orders based on the treatises of Palladio, Scamozzi and Vignola. Architectural treatises provide large amount of historical data including dimensions and shapes. BIM-based modeling extracts knowledge from these data and draws reference from the way data is collected and represented, as in the case of parallel of orders. It was from Serlio's notable plate (figure 1) that the parallel of orders grew out and evolved into canons that reached its climax in 18th century French architectural discourse. Doric order is one of the most common icons in the treatises, probably for it articulates the same rules of modular composition as the other orders, while the geometry is much less complicated than Ionic and Corinthian- the other two Greek orders.

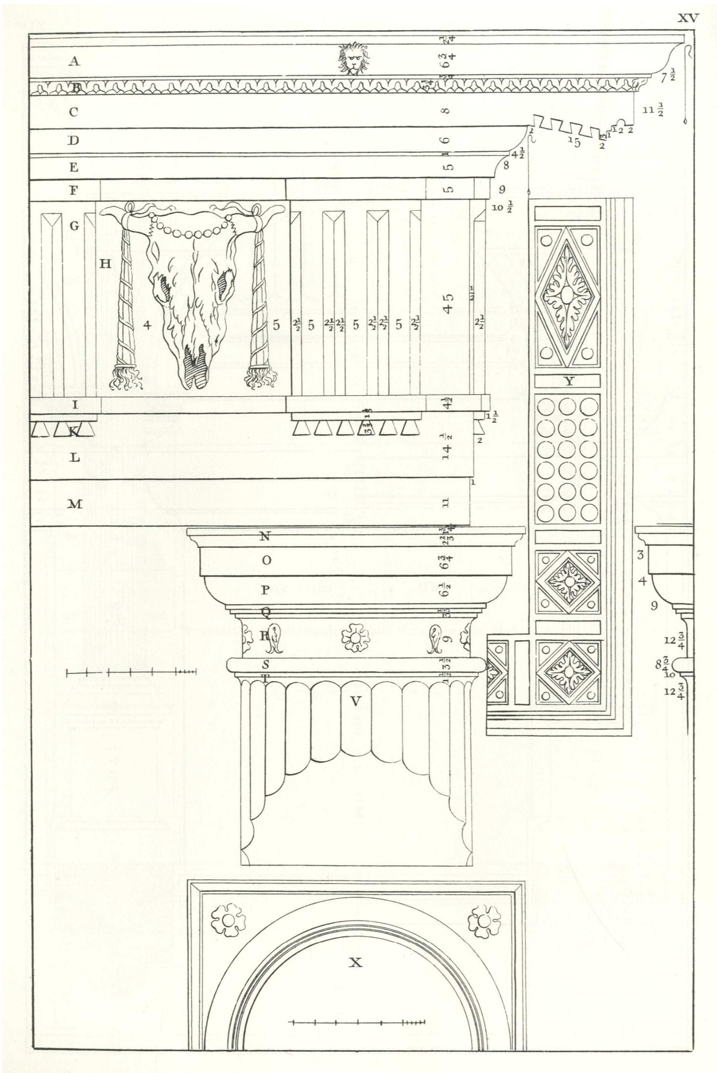


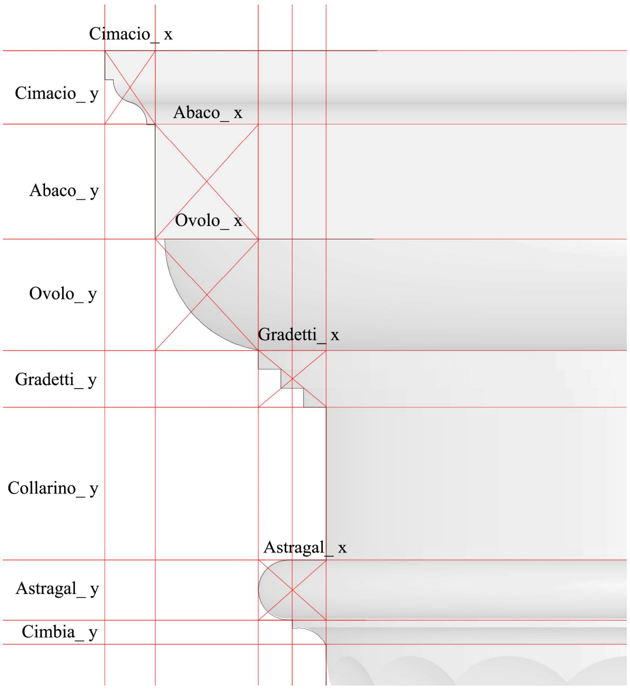
Fig. 2: Doric order after Palladio A., (1965). The Four Books of Architecture. Dover Publications, New York

Palladio set up the semantic structure and modular composition rules of his Doric order (figure 2). Supporting the entablature, the order was composed by capital and shaft. The height of capital equaled a module which was the shaft's bottom radius; the height of shaft was 7.5 or 8 modules. The capital was divided into Cimacio, Abaco, Ovolo, Gradetti and Collarino, each of which was measured by minute (1 module= 30 minutes). In Scamozzi's and Vignola's version of Doric order, they added bases under the shaft whose heights also equaled a module. Besides this obvious difference, the three Doric orders had similar semantic organization with tiny deviations in dimensions.

Current BIM platforms are capable of object-based parametric modeling (Eastman C., Teicholz P., Sacks R., Liston K., 2007). Instead of drawing concretes shapes, users first define the category (window, door, column, etc) of the objects, and then establish the parametric frameworks. Objects of different categories vary in semantic meanings and inherent behaviors. A rail and a column could have the same form, but the structural data, logic relations with the other components and semantic meaning in the whole building are different. The parametric geometry allows accurate and flexible generation of various dimensions and automatic adaptation to other components. These attributes are closely analogous to classical architecture's proportional semantic structure.

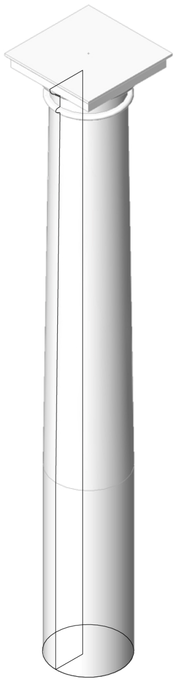
Extracting the semantic organization and modular dimensions from treatises of Palladio, Scamozzi and Vignola, we modeled the parametric Doric orders in Revit Architecture 2012. The workflow consists of 1) creating a set of reference planes among which distances are labeled with parameters in the name of semantic nodes' xy coordinates; 2) setting up the parameters' constraints by formulas (chart 2); 3) creating geometry of the semantic nodes and aligning them to the corresponding reference planes (figure 3); 4) loading the profile to the column family and sweeping it along the bottom edge of the order (figure 4). 5) creating another profile and loading it into the column family to generate the fluted order via Boolean operation (figure 5).

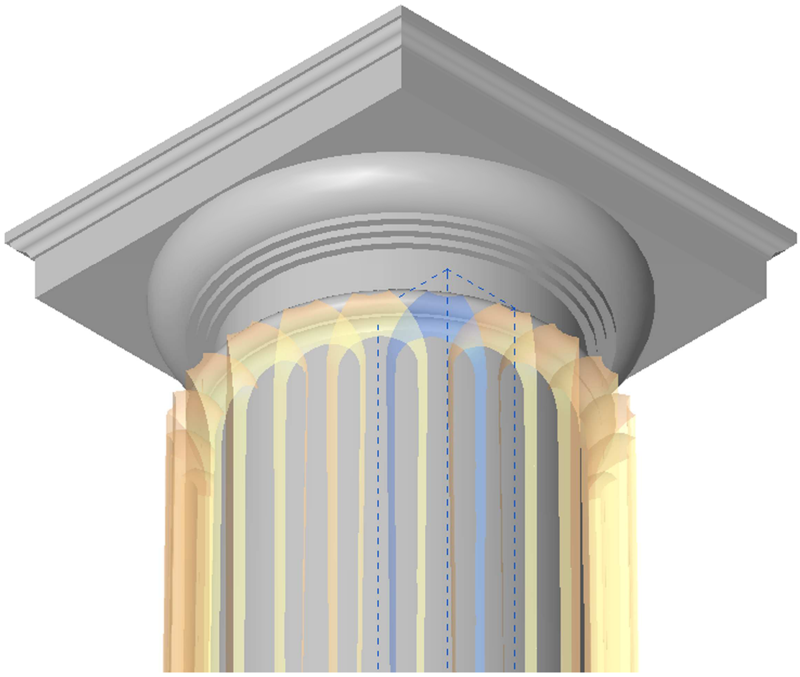
When the modeling process finishes and is proved to be well-performed, we are able to generate a set of types in a wide range of dimensions by assigning new values to the "module" parameter. The ideal models strictly based on treatises enable automatic generation of knowledge-based components and serves as central platforms to which data captured from surveys could be linked. The parallel of Doric orders in BIM platform provides a set of views (figure 6, figure 7) similar to the parallel of orders in the treatises, and also creates schedules of the data in a parallel way (chart 3).



Parameter	Value	Formula
Module	600	Minute*30
Minute	20	
Cimacio_ x	70	Minute*7/2
Cimacio_ y	88.33	Minute*53/12
Abaco_ x	120	Minute*6
Abaco_ y	135	Minute*27/4
Ovolo_ x	120	Minute*6
Ovolo_ y	130	Minute*13/2
Gradetti_ x	250	Minute*25/2
Gradetti_ y	66.67	Minute*10/3
Collarino_ y	180	Minute*9
Astragal_ x	80	Minute*4
Astragal_ y	70	Minute*7/2
Cimbia_ y	30	Minute*3/2

Left figure 3: Drawing profile labeled by parameters in Revit Architecture
Right chart 2: Parameters defined by formulas of Palladio's Doric order





Left figure 4: Loading profile into sweep operation to generate Doric order
Right figure 5: Editing profile of flute and Boolean operation

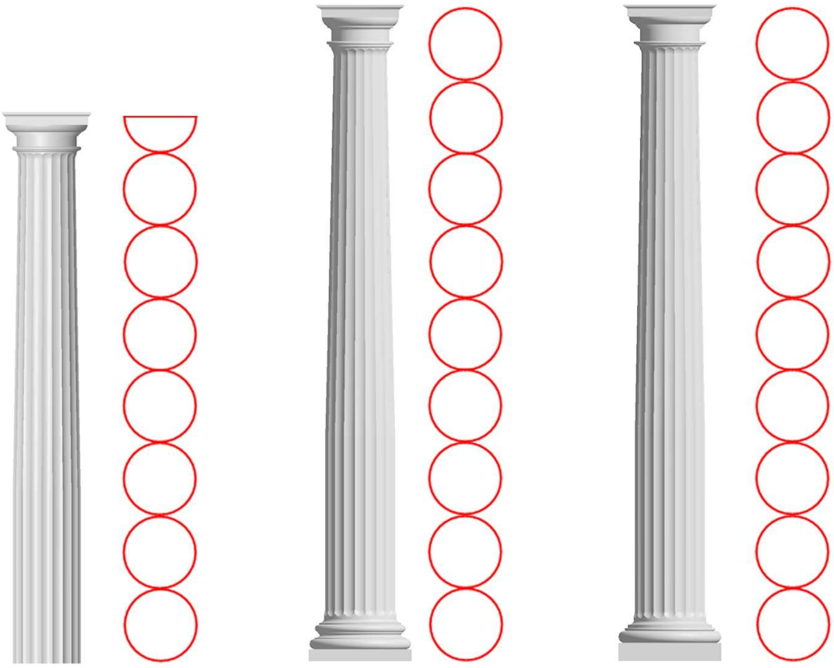


Fig. 6: Parallels of Doric orders modeled in Revit Architecture after Palladio, Scamozzi and Vignola (from left to right)

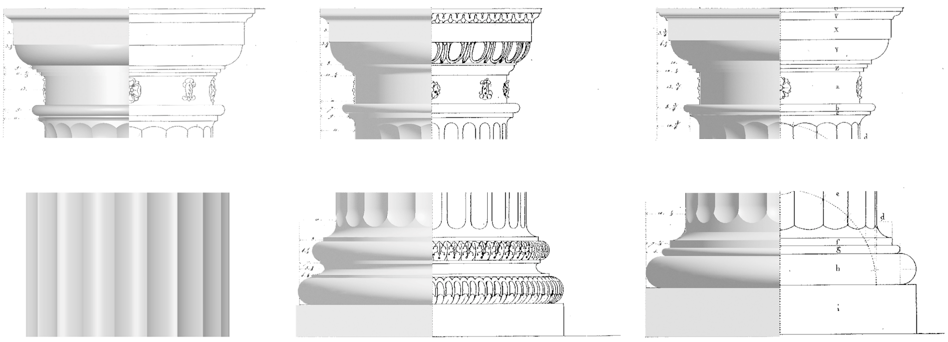


Fig. 7: Parallel of Doric orders' detail modeled in Revit and from treatises of (from left to right) Palladio, Scamozzi and Vignola (Rattner D., 1998. Parallel of the classical orders of architecture, Acanthus, New York)

Family	Radius	Capital				
		Cimacio	Abaco	Ovolo	Gradetti	Collarino
Palladio	600	88.33	135	130	66.67	180
Scamozzi	600	90	120	140	70	180
Vignola	600	75	125	125	75	200

Chart 3: Data of capital dimensions of Palladio, Scamozzi and Vignola retrieved from Revit models (unit:mm)

The advantage of using profiles in modeling is that it is a reusable family file which could be edited and loaded into other families. The Doric order modeled according to Palladio's treatise could become Vignola's or Scamozzi's easily and elegantly by profile substitution in the option list. In addition, a 3D form is translated into 2D shape via the sweep operation. Common transformation operations of geometry such as extrusion, revolve, blend and even loft can all be regarded as variations of sweep with specific constraints or conditions. For example, a cylinder can be modeled either by revolving around its central axis or sweeping along the edge of its bottom or top surface. A cone can be constructed by sweeping a diminishing circle along a straight line. Most classical architecture elements can be modeled by sweep operation. It is not a coincidence but closely analogous to the craftsman's technique of using a template to make a profile on a block of stone and then cut off the extra parts (Mitchell W.J., 1994).

Case study 2: Palazzo Barbaran da Porto

Palazzo Barbaran da Porto was designed in 1569 by Palladio and built between 1570 and 1575. It is the only great city palace that Palladio succeeded in fully executing during his life. Commissioned by Montano Barbarano, a Vicentine nobleman, Palladio was asked to coordinate the new design and the existing houses belonging to the family of the client. Palladio contributed a set of masterful proposals with a central atrium and symmetric façade with 7 bays. Following the completion of the drawing, Barbarano acquired an adjacent house in the west, which eventually resulted in a façade with 9 bays.

We applied our profile-based modeling approach to other components in this case study. Most elements' geometry in Palladio's works (column, gable, cornice, frieze and baluster, etc.) can be modeled by sweeping the profiles, which he employed similar semantic nodes with different combinations. Besides nodes in rectangular form, the types of curve nodes are much limited that the same node (ovolo) exists in both the window's cornice and capital of Doric order (figure 8). The rules also apply to the language of classical architecture, which barely invented new semantic nodes, but built new forms on the foundation of regroup and combinations (Mitchell W.J., 1994).

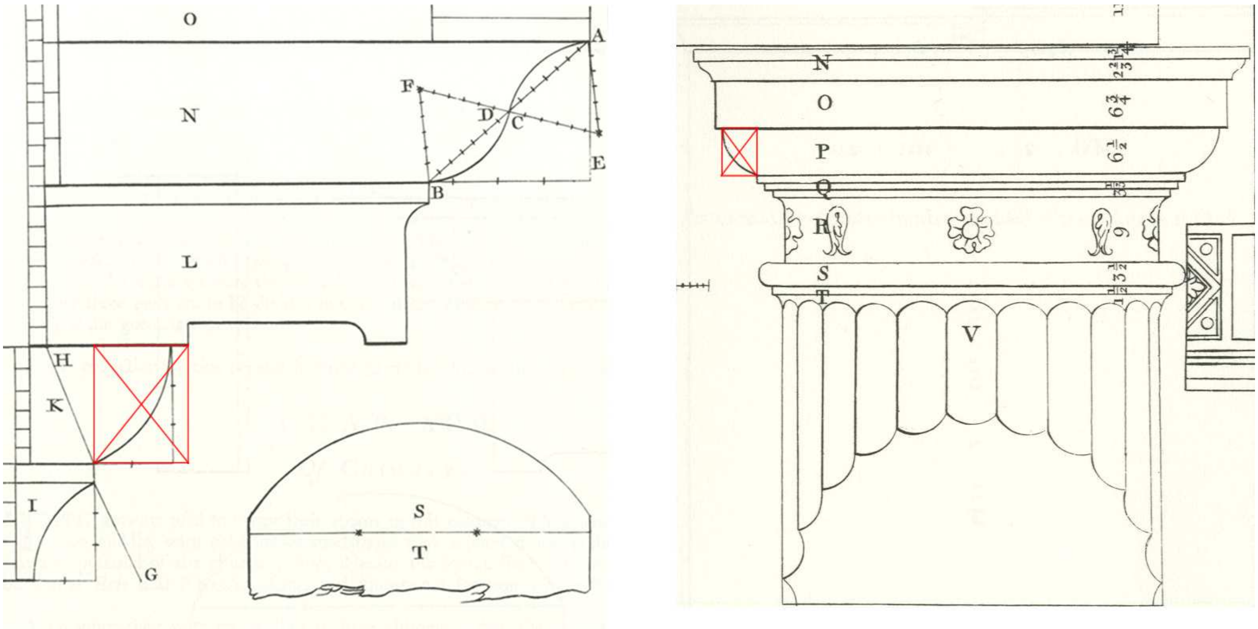


Fig. 8: The same semantic node (Ovolo) existed in both cornice of window and Doric order after Palladio A., (1965). The Four Books of Architecture. Dover Publications, New York

Taking advantage of BIM modeling approach, we can establish a library of profiles cataloged semantically. Just as profiles after Palladio, Scamozzi, Vignola or the others exist in the catalog of Doric order, catalogs of cornice, gable, baluster consist of a set of profiles extracted from treatises or measured via survey (figure 9). New forms could be produced by modifying parameters of profiles or substituting profiles. If we take into account of the paths along which profiles are swept, the possibilities of formal compositions are multiplied. In Palazzo Barbaran da Porto, for example, the triangular cornice and curve cornice above the windows on the façade in noble floor share the same profile but different path, and the cornices of noble floor and 3rd floor have different profiles but the same path (chart 4; figure 10).

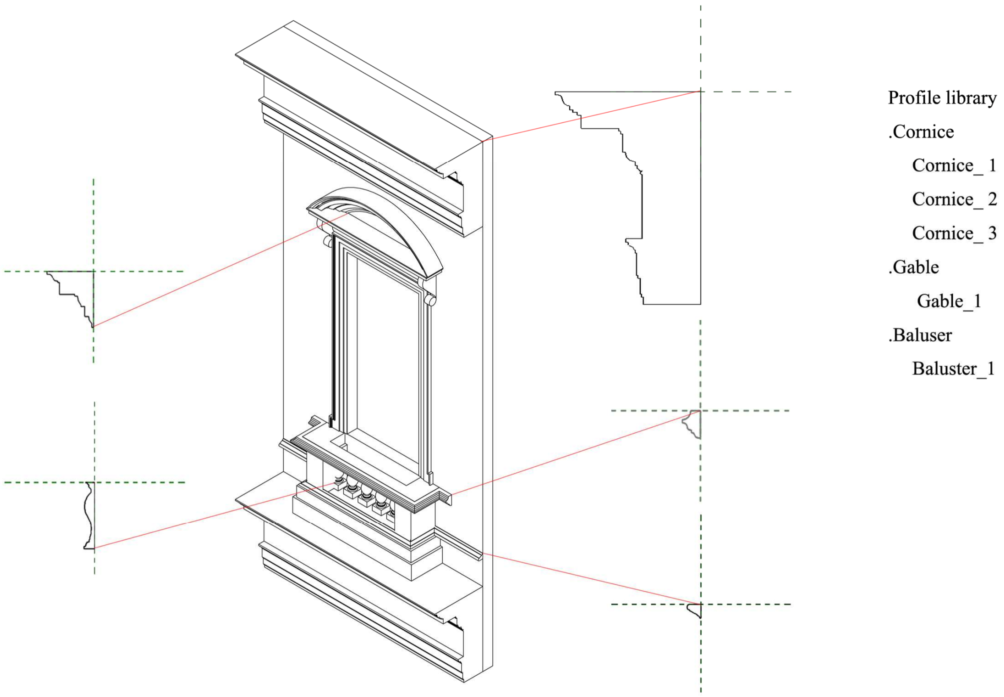


Fig. 9: A unit of facade of Palazzo Barbaran da Porto and its profile library

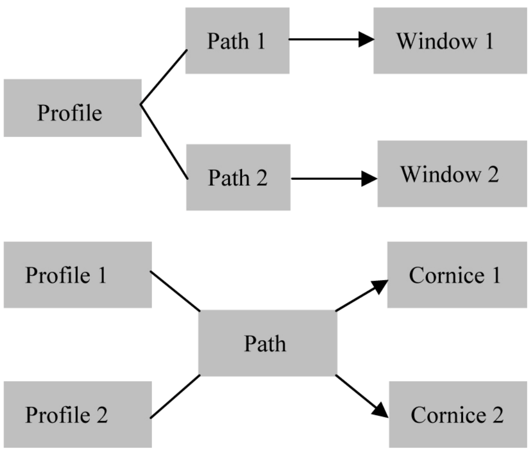


Fig. 10: Two groups of components sharing the same path and profile in Palazzo Barbaran da Porto
Chart 4: Integration of path and profile in components generation

Bottom-Up process

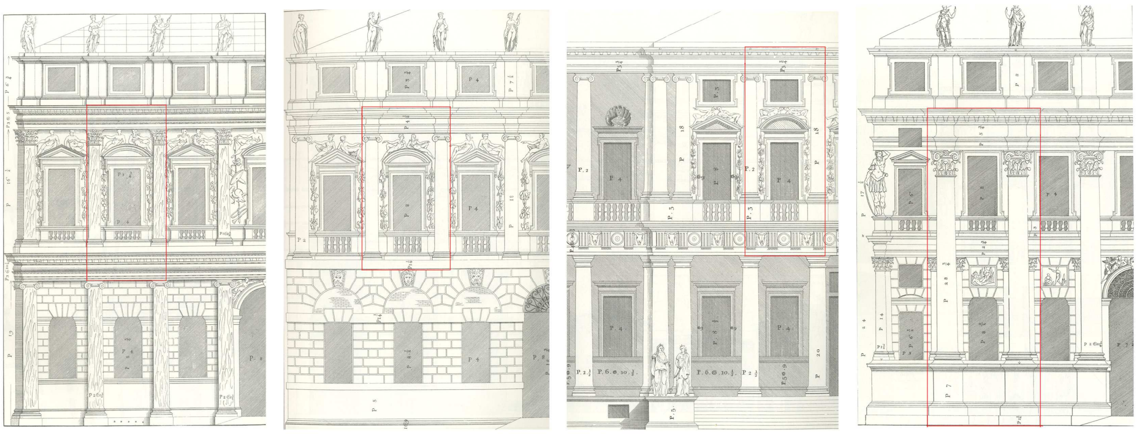


Fig. 11: Illustrations of palazzo's façade after Palladio A., (1965). The Four Books of Architecture. Dover Publications, New York. Red lines represent the basic unit of repetition on façade. From left to right: Palazzo Barbaran , Palazzo Porto, Palazzo Chiericati, Palazzo Valmarana

Up to now, we have illustrated the modeling process from parametric semantic nodes to the whole profiles, and from Doric order to the other components. New geometry in a certain category could be generated via profile edition strictly based on grammar. Now we extend our scope to a set of components that are semantically organized. A basic unit that composes the façade of Palladio's Palazzo (figure 11) is usually articulated with four rules:

1) a pair of pilasters whose capital could be either Ionic or Corinthian, shaft cube or cylinder, height dominating one floor or two floors (chart 5);
2) a window with top molding's cornice either triangular or curve. (If the pilasters dominate two floors in rule one, then a rectangular window is added either above or below the window on the noble plan);
3) a balcony with cornice and an array of balusters;
4) two segments of entablatures on the bottom and top of the façade unit.

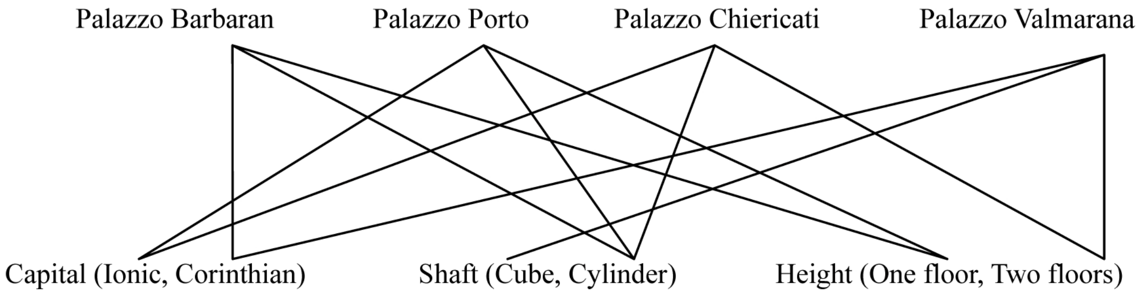


Chart 5: Options of rule 1 applied to Palazzo Barbaran, Palazzo Porto, Palazzo Chiericati and Palazzo Valmarana

In this case, we set only variables in the first and the second rules, while keep the constants in the third and fourth rule. The second rule is articulated with a “If, then” sentence. The result of first rule determines whether the part after “then” will be executed. The application of the first rule and the second rule lead to the generation of façade’s unit as shown in figure 12.

If we keep in mind that the options listed in each of the four rules are in essence parameters of dimensions, visibility and substitution that we illustrated in the two case studies, we realize the Bottom-Top process from semantic nodes to the whole façade. As Revit Architecture enables interactive data transfer between the main model and database, users can create database (Microsoft Access, Microsoft Excel, or ODBC database) via DB link and modify the values of parameters. Modified values in the database would cause update of data when importing to the model. As metadata of model are cataloged semantically with optional parameters in the database, it provides user with interfaces to make modification of dimensional parameters (values with number) and Boolean (values: yes or no) parameters. In this way, the Bottom-Top process could be realized via data modification in Excel or Access.

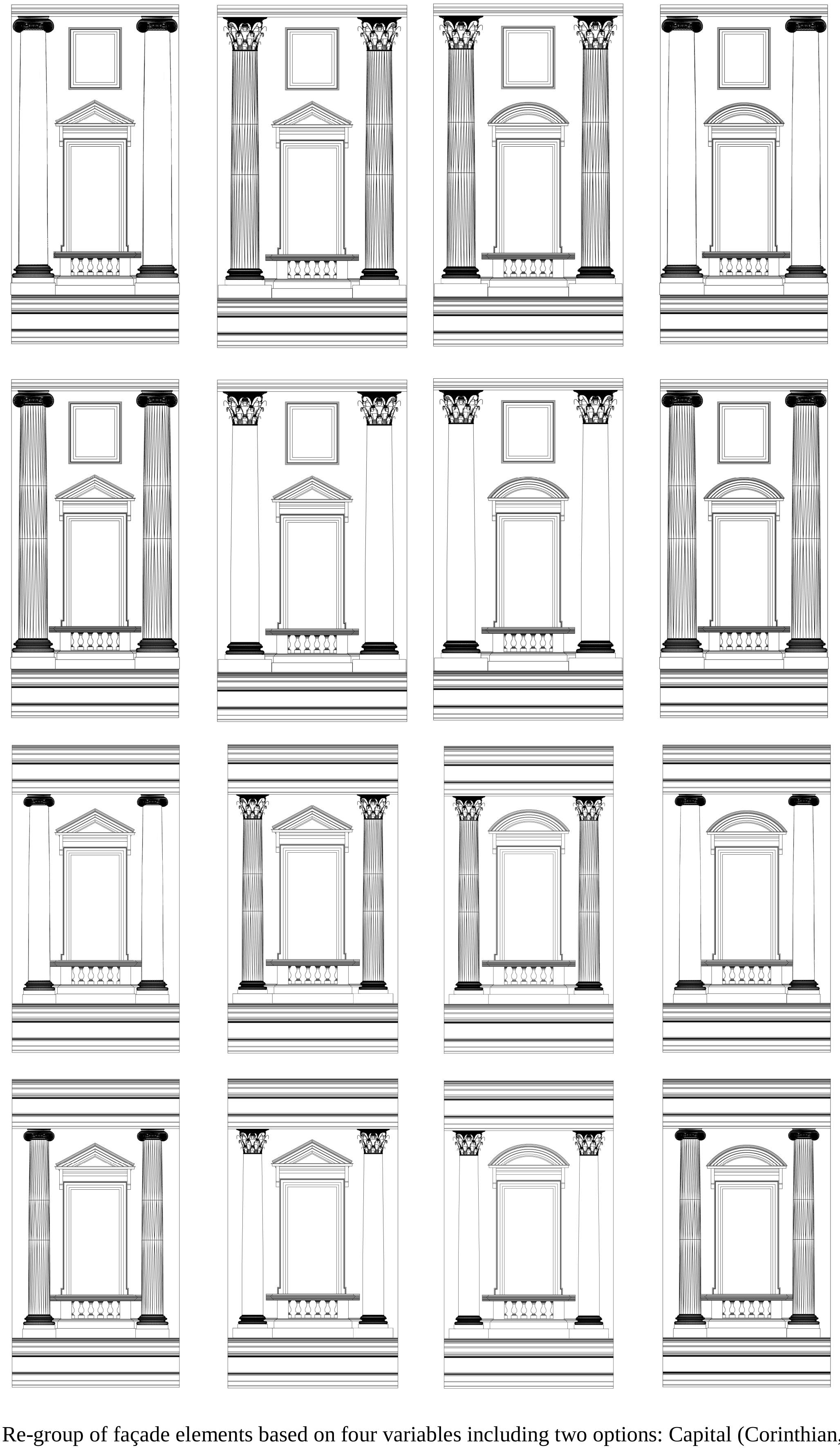


Fig. 12: Re-group of façade elements based on four variables including two options: Capital (Corinthian, Ionic), Shaft (Cube, Cylinder), Height (One floor, two floors) and Window cornice (Triangular, Circle)

Data enrichment and interoperability

The parametric models established geometric frameworks, to which multiple data in a wide range of domains such as structure, material and real life state could be assigned. Parameters are the central attributes of BIM platforms. They could be shared in the level of category, family and type, or not shared as instance attributes. Category represents the semantic domain of objects; family refers to models with unique parametric frameworks in the category; a family consists of a set of types with different dimensions; and instance means a concrete piece of object with unique ID in a project (chart 6).

Category	Column
Family	Ionic_ Palladio
Type	Ionic_ Palladio_ Radius 364mm_Palazzo Barbaran da Porto
Instance	Ionic_ Palladio_ Radius 364mm_ Palazzo Barbaran da Porto _ NO.001

Chart 6: Semantic organization and instances in Revit Architecture

Material attributes are shared as parameters of category. When the value of material parameter is selected, parameters linked with the default material integrate with the geometric parameters to calculate the parameters such as volumes, areas and cost as well as physical and thermal data for further energy analysis. In real construction, a piece of order may have more than one material, which lead to different ways of construction. BIM model could simulate this construction method via material set, geometric operation and nested family. It also produces various modes and views of drawings including details. In the family level, the parameters not only include geometric dimensions. We can assign visibility parameters with the value “yes/no” to the fluted void. As a result, when the value is “yes”, the Doric order is fluted, and vice versa. In the same way we could produce a set of variants evolved from the original type and save them as different types.

It is in the type level and instance level that data captured from surveys could be added to calibrate the ideal models. A piece of Doric order from Palladio’s villa may not be perfectly matched with the description in his treatise in the light of ratio among different semantic nodes. In this case, formulas among the semantic nodes are replaced by precise numbers. A set of order in the corridor of a building is supposed to be of the same type, but each of them has unique data in the instance level. Besides the difference of existing period and coordinates represented by (x, y, z), these columns have different geometric surface as the result of construction deviations and historical damage. When high geometric accuracy is required, photogrammetry and laser scanner could be employed to generate precise mesh surfaces linking with the BIM model. Existing period is another feature applied to instances. In palazzo Barbaran da Porto, for example, the building witnessed several construction phases. We could assign this parameter to the orders on the façade and other components. The time line feature presents a morphology evolution of architectural heritage to the public, and fosters a sustainable frame to which properties with temporal dimensions can be attached.

A considerable functional extension of BIM performs not in BIM models, but via interoperability with other applications and platforms. The simulation tools are the most common applications of BIM extensions in new projects and various workflows exist, such as energy performance, crowd simulation, environment analysis and fire evacuation, while the application of BIM extension for architectural heritage is a new area of research. Interoperability has traditionally relied on file-based exchange formats limited to geometry, while BIM repositories are distinguished by providing object-based management capabilities, representing attributes, properties and behaviors of geometry (Eastman C., Teicholz P., Sacks R., Liston K., 2007).

IFC is supposed to be a promising standard for BIM. It not only transfers geometry among different platforms, but also possesses the intelligence of objects such as geometric relations and additional data. Revit DB link facilitates to export model to Microsoft Access shown as database, and then generates XML file (Extensible Markup Language) (figure 13), which stores the metadata of Doric orders and shares over the web. Revit Globe Link acquires the site information needed in Revit modeling from Google Earth, and publishes Revit model into Google Earth via KML and KMZ files. Both semantic and visual attributes remain in Google Earth as they are set in Revit Architecture. Revit also supports Green Building XML (gbXML) format, which leads to energy analysis in Ecotect and other simulation tools. A set of plug-ins transfer model data between Revit and Rhino, grasshopper and its plug-ins (Mirtschin J., 2011). It takes advantage of Rhino's Nurbs approach and grasshopper's associative mode, eases the modeling process of complicated geometry.

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   <Pilaster>No</Pilaster>
   <Material>Marble</Material>
   <Material_xFF1A_Volume>9.92㎡</Material_xFF1A_Volume>
   <Material_xFF1A_Area>49.35㎥</Material_xFF1A_Area>
   <TopOffset>4000</TopOffset>
   <BaseOffset>-300</BaseOffset>
   <TopLevel>1363</TopLevel>
   <BaseLevel>1363</BaseLevel>
   <ExcitechX>2033</ExcitechX>
   <ExcitechY>1916</ExcitechY>
   <ExcitechZ>-300</ExcitechZ>
</Columns>
```


Fig. 13: XML file of an instance of Doric order modeled according to Palladio’s treatises

Conclusions and future works

In this paper, we explored the workflow of BIM-based modeling and data enrichment for the documentation and management of architectural heritage. In the case study of Parallel of Doric orders, parametric frameworks were formed via a set of operations of geometry and Boolean. Based on treatises of Palladio, Scamozzi and Vignola, it is supposed to be the central database, from which geometric variations grow out. The methods developed in the Doric orders also apply to other objects as shown in the case study of Palazzo Barbaran da Porto. BIM’s semantic structure enables multiple data enrichment and filter according to various analysis need. Also, multiple data is enriched in different levels of category, family, type and instance out of different motivations. It gave access to potential simulation by sharing data among various platforms. Therefore, the centralized BIM model serves as a sustainable dataset comprising comprehensive information, and provides access to life-cycle management and potential simulations of various disciplines. In the future, a number of works will be developed:

- Exploration of automatic generation of complicated architectural geometry in BIM.
- Integration of knowledge extracted from the treatises and real life data captured from image-based survey and range-based survey, as well as its interoperability among various platforms.
- Customize the application of BIM in heritage management via Revit API. Revit API enables users to add external command and external application by scripting in Microsoft Visual Studio.
- Establishment of web-based data repository interactive with GIS.

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