www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

BIM-DRIVEN LIBRARY FOR HISTORIC ISLAMIC STRUCTURES

SUBMITTED: 2017
REVISED: June 2017
PUBLISHED: November 2017 at http://www.itcon.org/2017/14
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ABSTRACT: *The use of building information modeling (BIM) is an essential step for the integration of architectural, structural, and constructional information in any project. BIM tools assist designers to complete their projects in a cohesive, efficient and fluid manner. The digitally classified and assorted informatics data of the Islamic Structure Style Library (IAS) serves to assist designers through the design phases of a project by allowing appropriate three-dimensional elements to be configured and adapted in various forms. This paper centers on the method by which parametric three-dimensional models and structure informatics data of the Hejazi Islamic Architecture Character (HIAC) library are built. This information is initially derived from the Ottoman Islamic Architecture style library and is intended to support the design phases of historical or contemporary projects. The purpose is to combine the HIAC library and the process of BIM to build parametric BIM structural and architectural objects. These objects are further characterized by the inclusion of architectural and structural HIAC designs and illustrations in their completed forms. The HIAC BIM library provides designers a variety of architectural and structural components, accompanied with parametric models and data, to choose from via a software application, which is categorized based on style and chronology. The BIM library of Islamic historic structures endeavors to facilitate the use of the HIAC BIM structural elements to assure the optimum accuracy in design and data through the digital application library. The HIAC library is the first step towards creating a comprehensive BIM library for Islamic historical structures to assist in preserving and maintaining many Islamic facilities around the world.*

KEYWORDS*: Building Information Modeling (BIM), Hijazi Islamic Structures, BIM Historical Library, Ottoman style*

REFERENCE: *Ayad Almaimani, Nawari. O. Nawari (2017). BIM-Driven Library for Historic Islamic Structures. Journal of Information Technology in Construction (ITcon), Vol. 22, pg. 266-286, http://www.itcon.org/2017/14*

1 INTRODUCTION

Architectural drawings and working drawing documents are continuously being moved towards digital representations. In order to facilitate the use of architectural illustrations in these digital schematics, there is a need to establish and facilitate the availability and accessibility of parametric BIM components to designers. It is for this reason that the BIM-driven Islamic Architecture Style were created so as to document and relate these three-dimensional components and encourage their use in design projects using contemporary and accurate methods.

Grube (1987) defined IA as a set of architectural and spatial features, such as introspection, that are inherent in Islam as a cultural phenomenon. Hence, establishing a digital library of IA will assist in enabling a better understanding of IA while also providing a resourceful library for practical applications in the IA design domain. Currently, data and research efforts in digital Islamic Architecture is uncommon. Examples of these research efforts

comprise the work of Okamura et al. (2007) who have likewise established semantic digital resources of Islamic historical buildings focusing on Islamic architecture in Isfahan, Iran. Their research work revealed that a topic maps-based semantic model applied to collaborative metadata management paradigms can be easily exploited as a tool to enhance the traditional architectural design and interdisciplinary studies. There are a limited number of research efforts in the digital classification of Islamic Architecture. One of these examples includes the work of Djibril et.al (2006) who developed a region based indexing and classification system for Islamic star pattern images using rotational symmetry information. Their classification is based on the number of folds in which an image characterized by its fundamental region and class. Further efforts are shown in work conducted by Djibril et al. (2008), who examined geometrical patterns in IA and developed an indexing and classification system using discrete symmetry groups. Djibril et al. (2008) used a general computational model for the extraction of symmetry features of Islamic Geometrical Patterns (IGP) images. IGPs were then classified into three pattern-based categories. The first pattern-category describes the patterns generated by translation along one direction. The second pattern contains translational symmetry in two independent directions. The third, which is called rosettes, describes patterns that begin at a central point and grow radially outward. A more recent research effort on the topic is represented by work conducted by Baik et al., (2013, 2014, 2015) which used Terrestrial Laser Scanning and Architectural Photogrammetry to document some historical buildings in old, Jeddah, Saudi Arabia. The data captured using these techniques was transformed into digital building information models (BIM). Furthermore, MA et al., (2015), conducted research focusing on Taiwan wooden traditional buildings conservation and presented the BIM technology as an effective solution for documenting, managing, and preparing full engineering drawings and relevant information.

In other recent research conducted by MA et al. (2016), they explored some common issues that occur during the restoration and maintenance of wooden structures that represent the architectural heritage of Taiwan. These problems vary between recording the information of geometric and non-geometric objects, controlling the phases of construction, and the occurrence of structural damage during disassembling. They demonstrated a method by which BIM was used to bridge the gap in communication between designers and builders by developing a software plug-in to guide the restoration process.

There are a few companies endeavor to prepare libraries containing commercial company products as three-dimensional objects in a BIM format. Most of these objects are based on commercial items available in the market. Hence, the designers can utilize them in their design so the owner can purchase them from the commercial company. ARCAT is one of companies that offers this service to architecture firms and other engineering companies alike General Electric.

Nawari and Kuenstle (2015) designated in their book, Building Information Modeling Framework for Structural Design, how BIM Software applications is different from CAD system, such as, the methods of thinking and innovative. Also, BIM is an auspicious evolution in the AEC industry. Furthermore, BIM provides numerous amenities demanded to model the buildings and facilitate the integration between the design phase and construction process (Alves de Souza et al.,2009; Eastman et al., 2008).

The process of developing a BIM-driven library of Islamic architectural components begins by first categorizing relevant architectural components based on a particular style era and then classifying them as either architectural or structural elements. HIAC which is derived from the Ottoman Islamic Architecture style has components that are organized according to the classification system of the IAS. Architectural components, for instance, occur as doors, construction material, and windows while structural components occur as arches, domes, and minarets.

Adding these components to the BIM parametric system of IAS of the HIAC can help contribute to the revitalization of the use of these elements in contemporary designs. Furthermore, the BIM library will aid the designer by ensuring that no time is wasted searching through different architectural and structural resources like books and websites just to identify certain parts, shapes, and types that form a component or whether that particular component actually represents the architectural era the architect wants to exhibit in their design. The creation of a BIM-driven library of Islamic Architectural components will reduce the time required to develop a design and will result in a cost-effective solution to preparing architectural, structural, and construction documents. In addition, the BIM HIAC components library will assist in preserving and rehabilitation of many historic Islamic structures.

There are several publications and resources providing information regarding the Hijazi Islamic Architectural Characters (HIAC). These sources depict structural and architectural components and parts, but they are largely disjointed. There exists a need to aggregate this data into a comprehensive digital application. This paper seeks to encourage the use of the Islamic architecture components by providing this information in a detailed and coherent parametric three-dimensional object library. Furthermore, this library provides instructions and information that ought to encourage their accurate implementation in projects and the revitalization of these objects using contemporary design methods.

2 STATEMENT OF THE PROBLEM

Due to the lack of information and details about Islamic historic structures and the continuous degradation and demolition of many Islamic buildings owing to war or economic needs, the development of a digital library for historicl Islamic structures is becoming an essential factor for preserving and maintaining these historic structures (Hillenbrand , 1994; Ivy, 2001). The lack of information and details of the Islamic Structure Library demands to innovate BIM components to assist designers and planners to develop designs that meet historical, cultural and regional requirements in a cohesive, efficient and fluid manner. Thus, this research paper centers on advancing digital modeling by proposing HIAC BIM structural components library to achieve optimum design. The applicability of the suggested BIM library has been demonstrated in a design project in collaboration with Martin Gold & Associates Architecture Office in Gainesville, Florida. Results show that the time used to develop the conceptual and detailed design has been reduced to almost one third in addition to the enhanced aesthetic quality of the design and client satisfaction

3 OBJECTIVES

This research work focuses on developing a parametric three-dimensional library for Islamic historical structures by proposing HIAC BIM structural components library to address the lack of digital design data, as a key element in preserving and advancing Islamic structures. Furthermore, this paper aims to use recent research results as templates to build more developed structures of the BIM-IA library and classification system. The classification of three-dimensional HIAC components is restricted to styles that have originated from the Hijaz region as indicated by the blue color outline in FIG. 3a and 3b.

3.1 Methodology

The study approach is based on developing a new taxonomy and hieratical classification system for the development of BIM digital IAS component library. The methods of classification used in the BIM-IA library are delineated in figures 3a and 3b. The first part is the historical period in which the style can be found, in this case is the Ottoman Khilaphia period. The second classification type uses building names as categories then subdivide them into subclasses of object types. The proposed methodology has been contrasted with the current workflow with similar focus. The distinct feature of the proposed library includes: The classification applied in the BIM-Driven Islamic Architecture sorts the root and sources of the architectural and structural data based on their availability. The filtered data is then distributed according to the architectural and structural information while being sorted by chronological style which has not been available in any previous literature or applications. Furthermore, the approach of categorization followed utilizes various BIM components making it more comprehensive than other systems cited in the literature. This is particularly the case for applications that call for a variety of parametric components. The BIM IAS library is proposed to reduce time and resources when dealing with designing projects that addresses cultural and historic identity.

4 TAXONOMY

The term “Taxonomy” stems from Greek. In Greek, “taxis” means order and organization. Thus, taxonomy refers to the study of the principles of technical classification. It is based on the utilization of taxonomic units to classify and arrange otherwise random objects in a hierarchical structure. For example, a shear wall is a subtype of walls, so a shear wall is a wall, but not every wall is a shear wall.

The classification and organization of the historic Islamic Structure (IS) play a major role in advancing the usability of this knowledge system to achieve many purposes such as preserving, maintaining or developing new building topologies. Additionally, this taxonomy is designed to improve data management of IS to support better query functionality, and various investigations such as structural analyses, energy simulation, and ventilation studies.

5 CLASSIFICATION

In the digital era, modeling has advanced significantly in the last few decades. Particularly, building information modeling (BIM), which has fundamentally changed the role of computation in building design by creating a database of building objects for use in all aspects of the building from design to construction and beyond (Nawari et. al 2014). This research aims to develop a BIM library for the Hijazi Islamic Structure.

According to Nancy Um (2012) at Binghamton University, a specialist in Islamic Art and Architectural History, when talking about the Red Sea Style (RSS), which Hijazi Islamic Architecture Character is part of, she observed that “This marker has never been contested or challenged, but at the same time, it has never been explored in any thoroughgoing or critical manner”. Arms (1997) stated that Architects are in need of organized architectural application libraries. The first aim of the study is to classify and organize Islamic historical structural elements in efficient manner to enable digital accessibly. This research work contributes to the current body of knowledge related to the general architecture of Red Sea Port Cities. Furthermore, the study is a part of an extension which may lead to an increase in the interest of IAS’s style as a contemporary architectural topology. Islamic Architecture is a huge source to be taught as, His Highness Aga Khan, mentioned in one of his interviews, that the people from outside the Islamic world felt that there was a lot to be learned about Islamic culture (Architectural Record Magazine, 2001). However, the focus on Ottoman Architecture styles from that era has not been a priority, “Thus Ottoman monuments were rarely cataloged, studied, and preserved in their own right, and were at best neglected” (WATENPAUGH, 2007). The availability of a BIM-IAS classified database will aid users in the comprehension and application of IA. Muir & O'Neill (1994) indicated that increasing numbers of architects have acknowledged the fact that digital three-dimensional modeling can help better understanding of data and are moving beyond static 2D representation. One of the reasons that this research is being conducted on BIM-driven Islamic Architecture and HIAC is the strong connections that lead to the wider understanding of the Red Sea Architecture Style. The architectural culture of the port cities of the Red Sea area have suffered from many issues and as a topic of study and analysis vary between the limited access to sources or the lack of various textual and visual primary sources due to building destruction, wars or modernization of existing architecture (Um, 2012).

Previous works that explored the classification schemes includes the work of Okamura et al. (2007) and Ma et al. (2016). Okamura et al. (2007) prepared and applied semantics and digital resources of Islamic historical buildings to the Isfahan Islamic architecture database (IIAD). The approach supported the “Who, What, Where, When, How and Why” (5WIH) model for the purpose of research and education. Figure 1 shows two viewpoints of multifaceted classification. Faceted 1 and 2 classify the resources as a digital image and as a mosque.

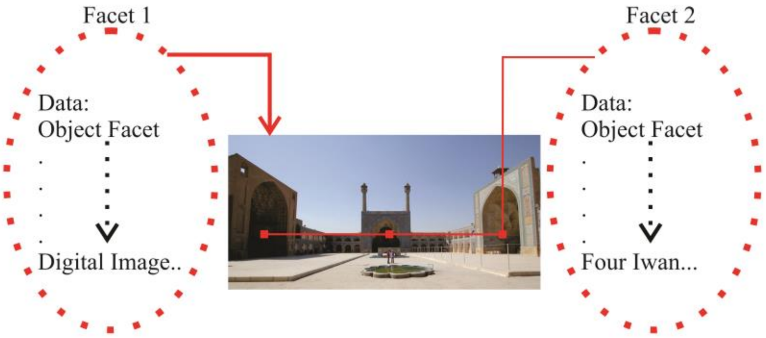
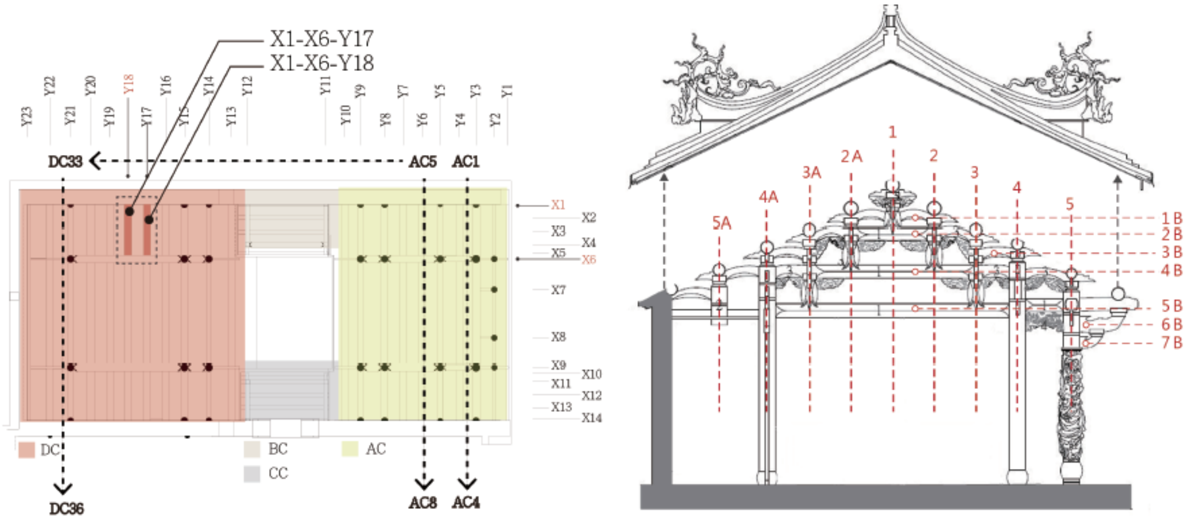


FIG. 1. Efforts to classify Isfahan Islamic Architectural elements (modified from Okamura et al., 2007).

Ma et al. (2016) discussed utilizing the BIM application in restoration and maintenance of wooden structures for architectural heritage in Taiwan. Their work focused on recording the information and managing the various phases of construction and structural damage that occurred during the dismantling process. Their classification schema can be seen in figure 2, which depicts two-dimensional sections of Huchi Temple located in Ma Tou, Taiwan. Every component is labeled with a code according to its position in the grid as it appears in the plan and section. For instance, the purlin, which is a horizontal beam along the length of a roof, has an X and Y axis code according to the spatial order, such as, X1-X6-Y17 and X1-X6-Y18 as it appears in Figure 2. The same approach is applied to the columns and the other components.



(i) Section 1 (ii) Section 2

FIG. 2. Sections of the Huchi Tem illustrating the classification and coding system (Ma et al. 2016).

The classification applied in the BIM-Driven Islamic Architecture sorts the root and sources of the architectural and structural data based on their availability. The filtered data is then distributed according to the architectural and structural information while being sorted by chronological style which has not been available in any previous literature or applications. Furthermore, the approach of categorizing followed utilizes various BIM components making it more comprehensive than other systems cited in the literature. This is especially true for applications that call for a variety of parametric components.

Almaimani & Nawari (2015a, 2015b) founded and established a general classification chart system for the BIM – Driven Islamic architecture library. Moreover, a few months later, Almaimani & Nawari (2016) developed another detailed version of the general classification chart system of the BIM – Driven Islamic architecture library. This paper aims to use these recent research results as templates to build more developed structures of the BIM-IA classification system. The classification of three-dimensional HIAC components is restricted to styles that have originated from the Hijaz region as indicated by the blue color outline in FIG. 3. In this figure, the methods of classification used in the BIM-IA library are delineated. The first is the historical period in which the style can be found, which in this example is the Ottoman Khilaphia period. The second classification type uses building names as categories then subdivide them into subclasses of object types.

FIG. 4 outline the hierarchical schema of the digital classification system used to organize the BIM-IAS library. The data used to generate these figures is extracted from various Islamic Architectural references collected by the Aga Khan Program for Islamic Architecture (Islamic architecture - Aga Khan Documentation Center, 2015). Additional sources of data include: The Coral Buildings of Suakin by Jean-Pierre Greenlaw (1995), The Traditional House of Jeddah: A Study of The Interaction Between Climate, Form and Living Patterns by Sameer Al-Lyaly (1990), Suakin: On Reviving an Ancient Red Sea Port City by Abdel Rahim Salim (1997), and The Development of Housing in Jeddah: Changes in Built Form The Traditional to The Modern by Thamer Alharbi (1989).

The hierarchal diagram displayed in FIG. 4 outlines the sequential order from which the Ottoman architecture style period branches down into the Hijazi region and its own component library. For example, if a designer desires information about one of the HIAC BIM components like the Structural Minaret, the user can find that the BIM three-dimensional components of HIAC are categorized using two criteria. First, the location and style can be used, which displays various choices for specific period. This can be further explored by using sub-categories of building types that used the component. The second criteria, as demonstrated by FIG. 4 can be explained as follows:

1- The library starts with the Islamic Architecture style
2- The geographical location of the style can then be selected
3- The relevant BIM component library is then displayed and divided into two main parts. The first part provides a complete parametric three-dimensional component accompanied with information about that component. The second part has all the three-dimensional parametric parts utilized to form and build up a complete component that can be manipulated by the designer.
4- The example, given in FIG. 4, depicts minarets of the Jeddah and Suakin Character and include components that are assigned a unique identification name and number (ID) which are used to describe the origin of each object so that other similar styles can be easily cross-referenced.

Capturing the entirety of Islamic Architecture Culture from the beginning until the end of the Ottoman Empire at 1929. The BIM components of Islamic Architecture have never been created in any previous work.

The method of validating is asking one of the companies that is well-known in designing projects in the Islamic world to validate how the application perform by comparing the same project completed in traditional design method with the same project utilize the plug-in. The validation of the plug-in will be tested more after preparing a questioner depending on the existence of the plug-in and validated through specific companies.

6 SCHEMA

When a BIM-IAS user chooses an HIAC component like the minaret for example, there are detailed charts and graphs appended in the IAS application comprised of information about the minarets of the Hejaz province. The chart embedded in the library preview the minarets details. The user selects the appropriate elements, such as a complete minaret, or one of its parts in order for the necessary data to be displayed. More than 180 total HIAC components have been modeled, illustrated, assembled and categorized in the BIM-IAS digital library. Each one of these three-dimensional components comprise details that identify: component themes, element types, style history, character history, as well as additional architectural styles using pictures and illustrations. The inclusion of this organized and categorized information in various schedules and charts allows the user to determine whether the parametric component is structural or architectural and allows the user to modify the component for design reasons. The relevant historical and geographical data for each component can also easily be identified using the BIM-IAS library.

7 FRAMEWORK FOR BIM COMPONENTS

Islamic architecture styles in this research have included two types of data. The first is data on the styles. The second is the reciprocal three-dimensional geometries. This amount of massive data consists of fourteenth centuries of the Islamic Architecture elements, which are scattered throughout a variety of sources and only vaguely exist as BIM elements. This data has not been classified in a digital library but it the goal of this research to begin the work of classifying these components, and creating digital parametric models for each of them. This will allow every single part forming the element to be modified from the BIM model directly without returning to the family file to edit it. The limited understanding of the nature of the Islamic Architecture Styles (IAS) by many designers evokes to form these diverse architectural, structural, and constructional elements of IAS in a BIM library.

One of the most significant Islamic structural components is the Minaret of the Ottoman Islamic Architecture Style in the Hejazi Character. In order for the Minaret to be customizable in a digital representation, the Minaret should have parametric capabilities. The step of creating a parametric library comes after drawing the shape based on primary sources from which the shape is extracted. The Hejazi minaret is formed from different architectural and structural elements. Technically, every one of these elements are created in separate file accompanied and combined with it is an own parametric library. Although, it can be downloaded to any file and combined with other elements to form a new minaret type and design. There is another method, used in creating the BIM IAS library, which includes a minaret file that is accompanied with a specific parametric library as demonstrated in FIG. 6 below.

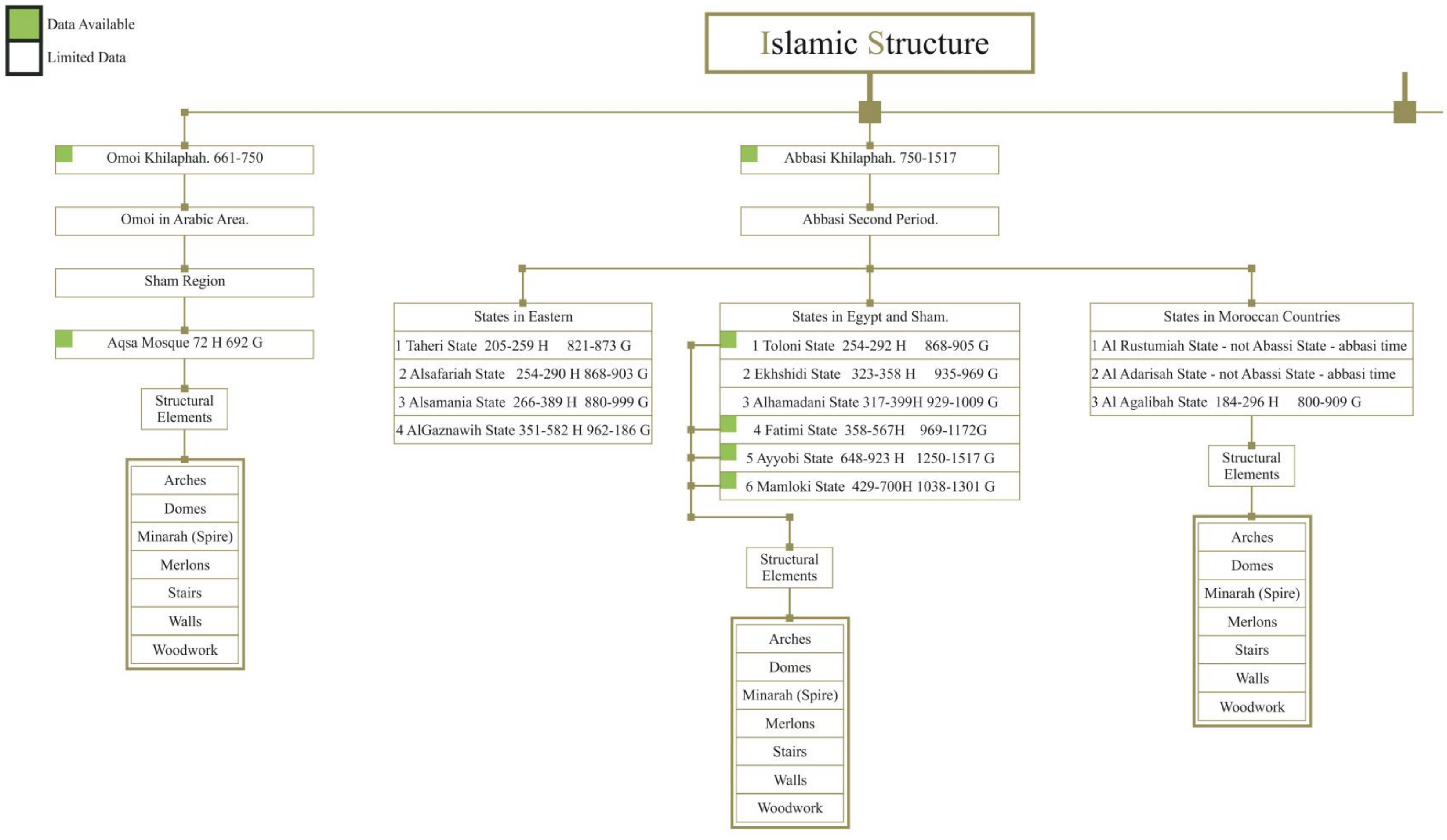


FIG. 3a. Classification system showing Hijazi Islamic Architecture Character (HIAC) (continued).

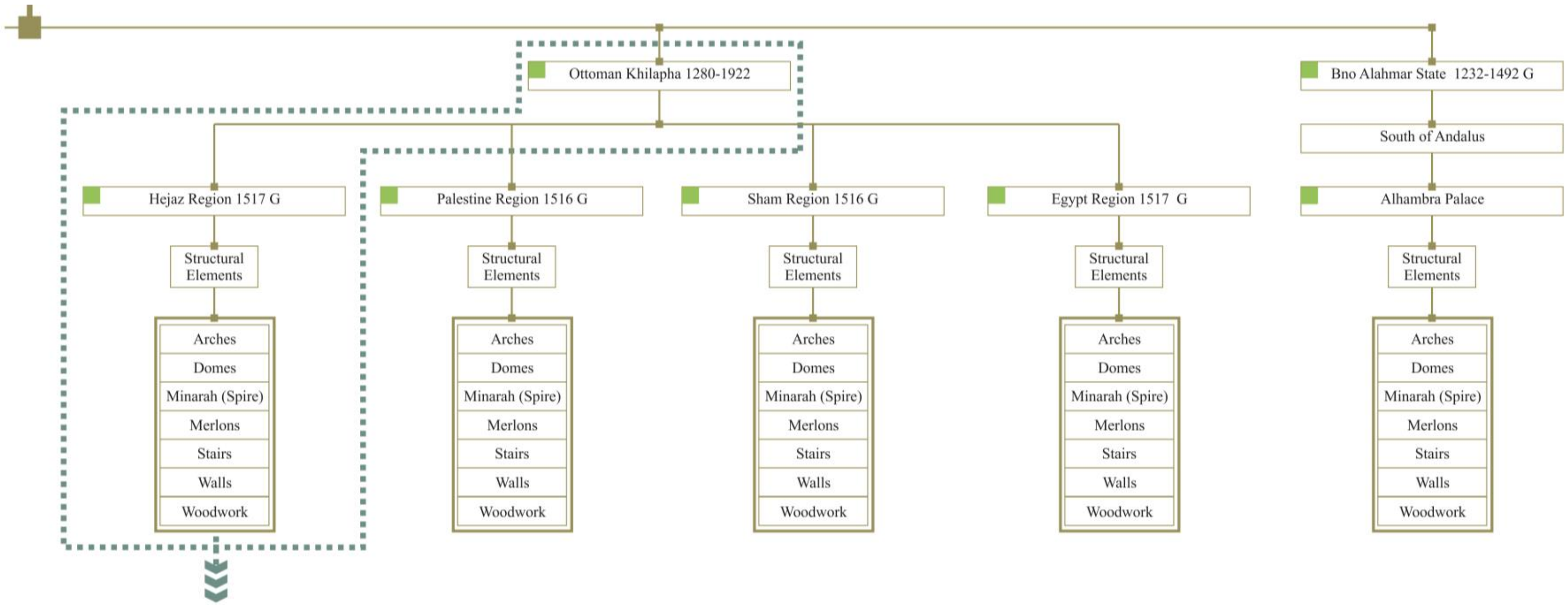


FIG. 3b. Classification system showing Hijazi Islamic Architecture Character (HIAC).

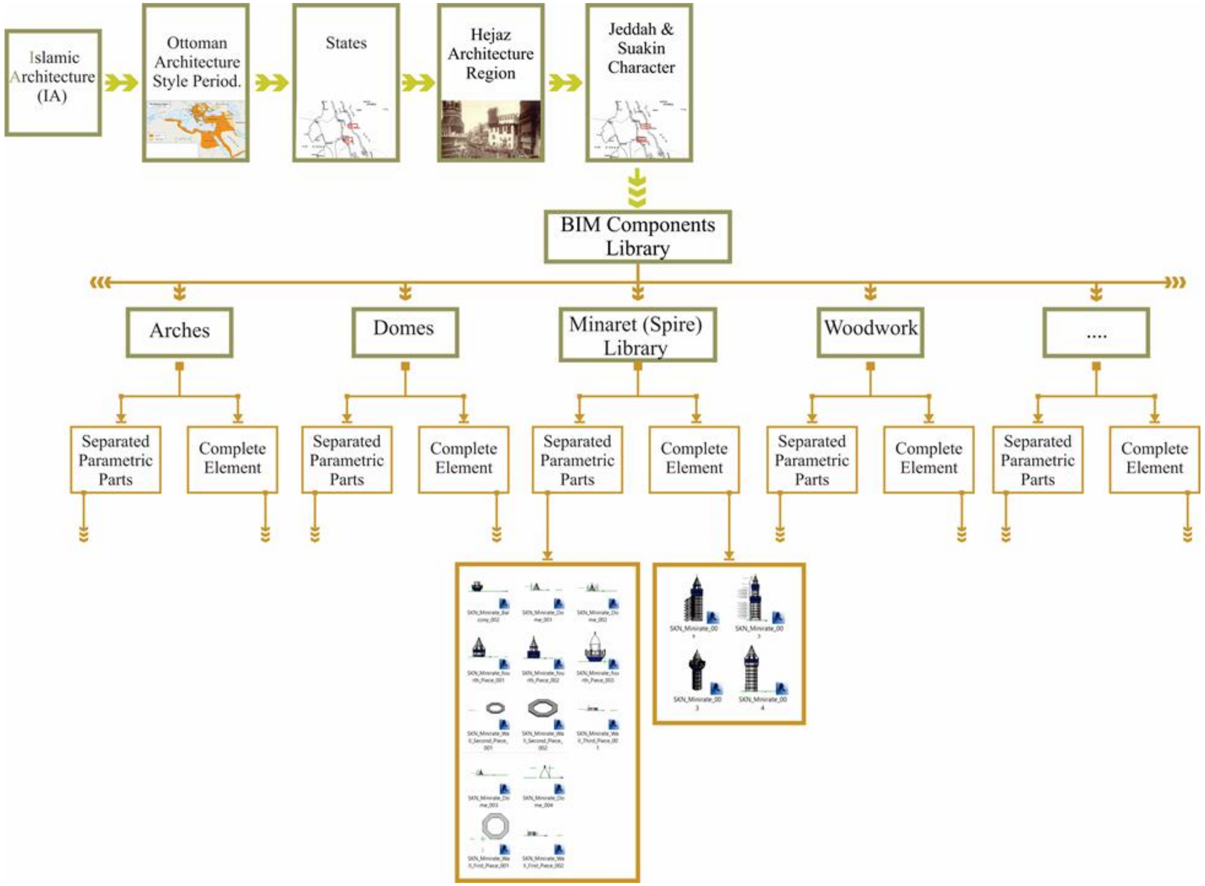


FIG. 4. Hierarchal schema of the digital classification of HIAC.

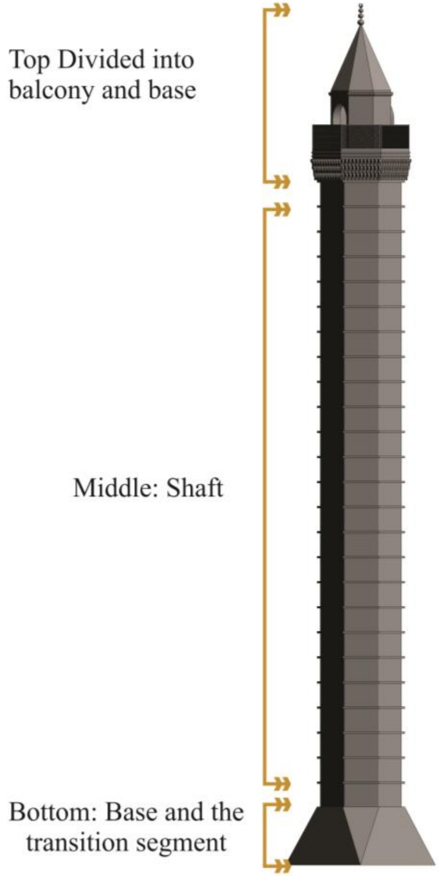


FIG. 5. The HIAC minaret.

The process of combining the minaret parts and elements must be clarified and explained by providing an example of one of the minarets as displayed in FIG. 7. First, one of the features of the minaret must be known so that every subsequent element can be arranged serially. This gives the user the opportunity to choose from similar parts in the same category position allowing for continuity when using an element. This approach is referred to as stage one. In the next step, called stage two, the designer can build the final model by duplicating and pairing parts of an element. Moreover, because the BIM elements are accompanied with a built-in parametric library, there are multiple ways to use these elements and parts in the design process. According to the architect redesign, one of the elements of category number one is the part needed to be used in the minaret illustration. FIG. 8 illustrates that once the element is downloaded in the project file, the user has three ways to duplicate the element with a new name to make the required changes for the design purposes (stage two).

Minaret is one of the architectural characteristic monument that exists in the mosques and considered one of the main element per references and definitions related Islamic architecture (BLOOM, 1926). The shape of the minaret is very unique because of its high length as it looks a tall slender tower attached to the mosque or next to it, and includes balconies where the Muezzin (the person who calls for prayer) stands. Minaret consists of three parts. Bottom: the base and transition segment, Middle: the shaft, Top: gallery or balcony. FIG. 6 and **7** illustrate the definitions and clarifications of elements and sub-assembly of minaret structure.

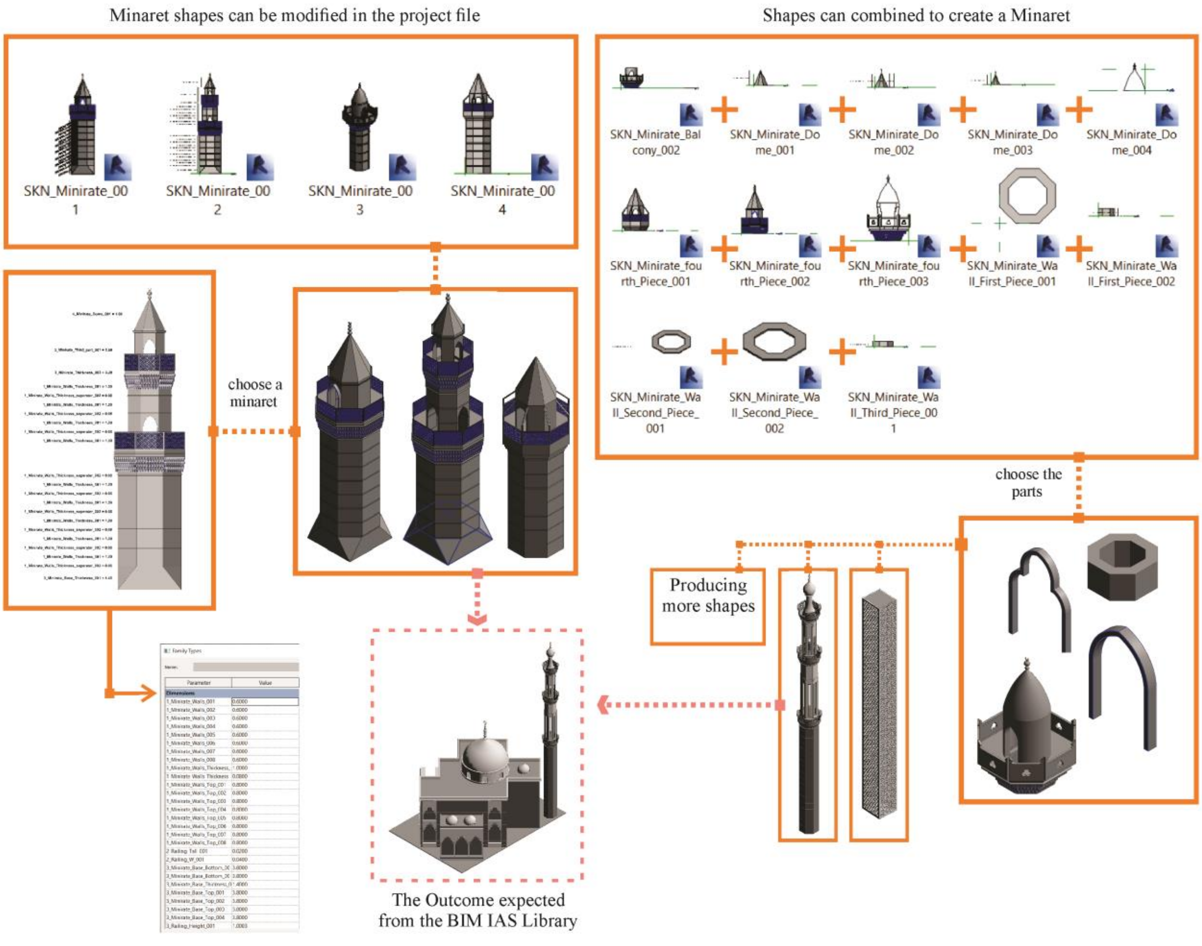


FIG. 6. The complete component and separated parts of HIAC minaret.

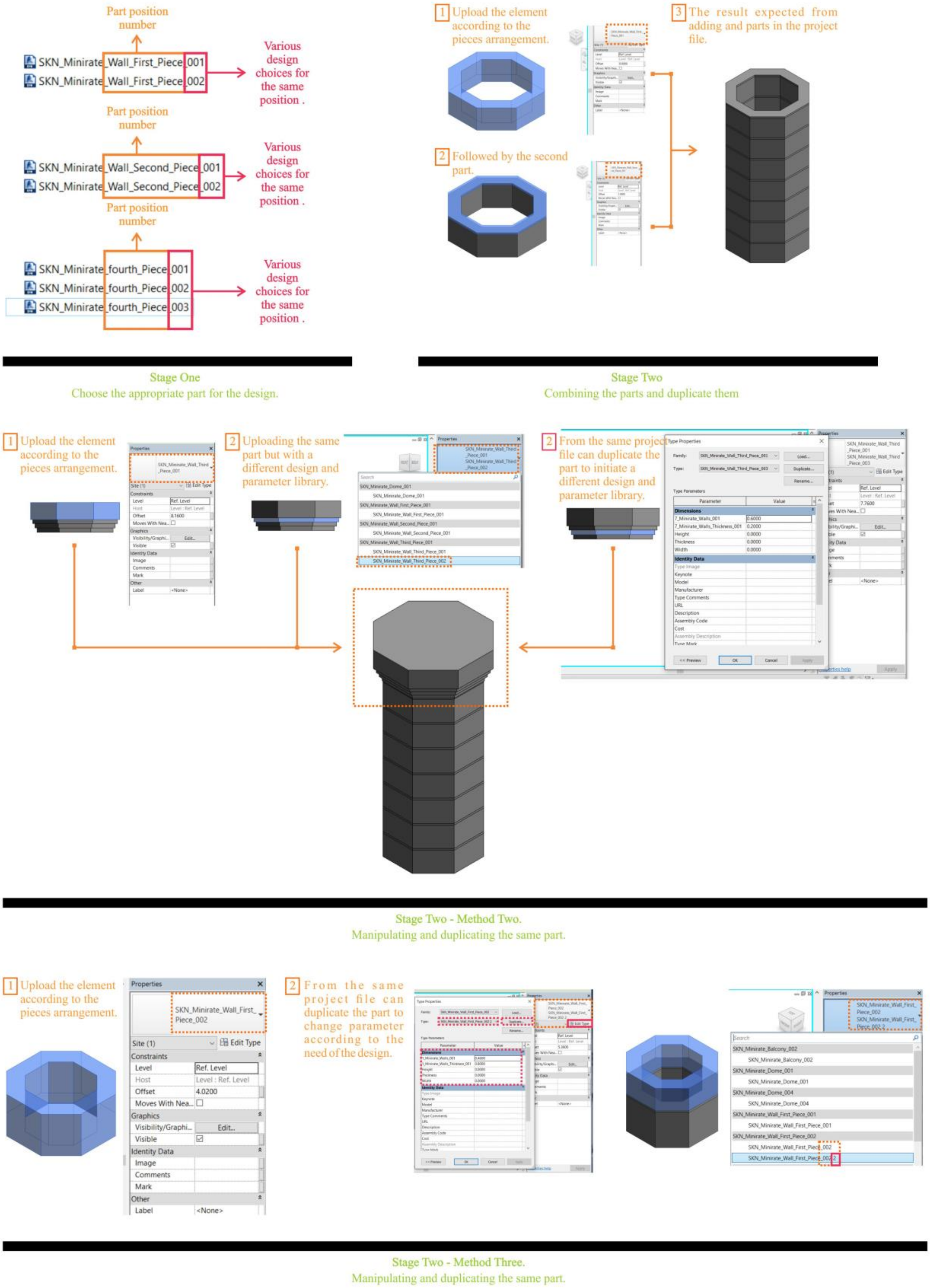


FIG. 7. Phases of combining the minaret parts and elements.

The BIM-Driven Components Library of Islamic Structure is centered on the hierarchal order and nesting of components. Figure 8 and 9 demonstrate how the segments of a component are assembled and then combined with other components. For instance, if the designer decided to exchange a part of the Minaret's design with an alternative design, then the designer has the ability to choose from a variety of other subcomponents for specific segments of the Minaret. For instance, the top of the minaret consists of the top segment but also contains a base and balcony segment which make up the middle segment, and bottom segments. Each of these can be exchanged using an alternative style. Figure 9 demonstrates how the top segment of the Minaret which displays similar family style balcony segments can be utilized to make changes to the balcony segment by using the BIM authoring tool. Furthermore, Figure 8 serves as a proof of concept of the favorable outcome achieved when using the HIAC library to modify IAS components.

Preparing every one of these parts and elements in a nested fashion required a group of procedures and steps to ensure the highest accuracy and efficiency in controlling the created library parameters of each shape. The drawing and illustration techniques used to avoid the development of non-scaling technical issues on the end-user side of the application were as follows:

1- Model every single element, which can be combined to form the minaret element in a separated file containing the main parametric library.
2- Examine the parametric dimensions and references to make certain they are responsive to changes and can be manipulated independently.
3- Plan the components in such manner that other parts need to be nested with other parts to add new parameters to serve the new created model.

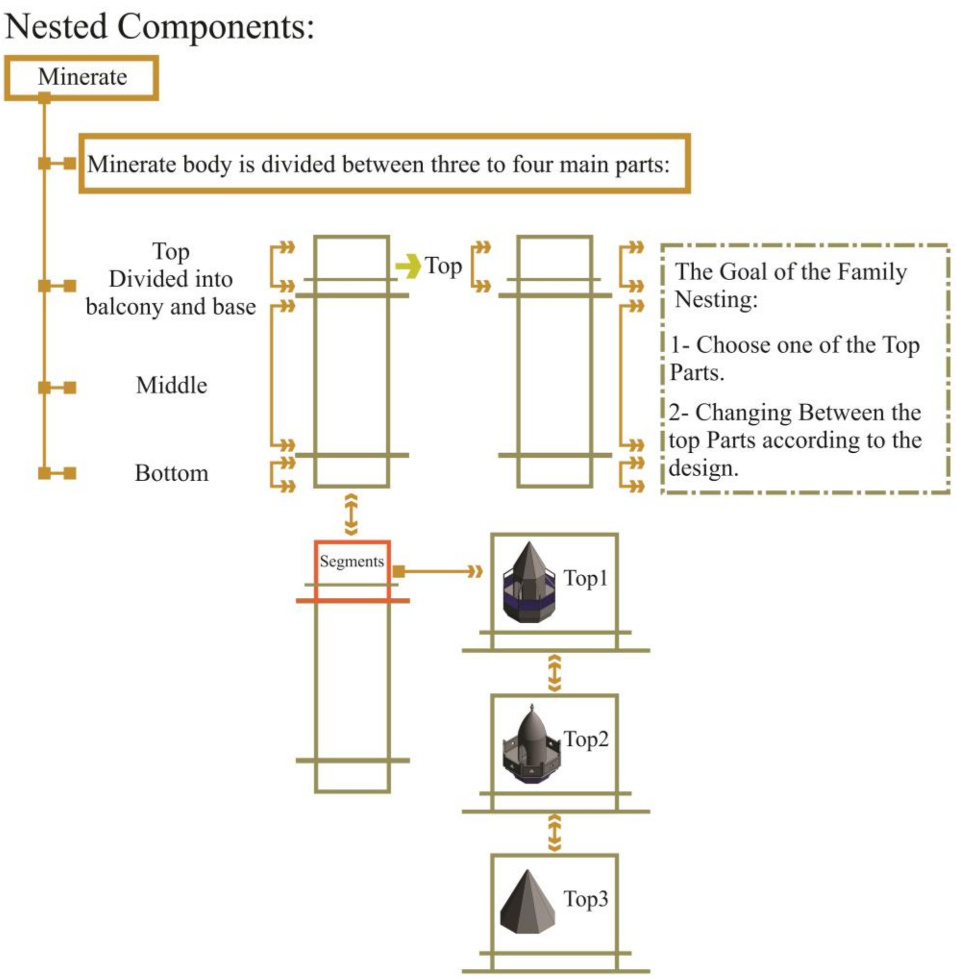


FIG. 8. Hierarchal nested components of the Minaret of HIAC components digital library.

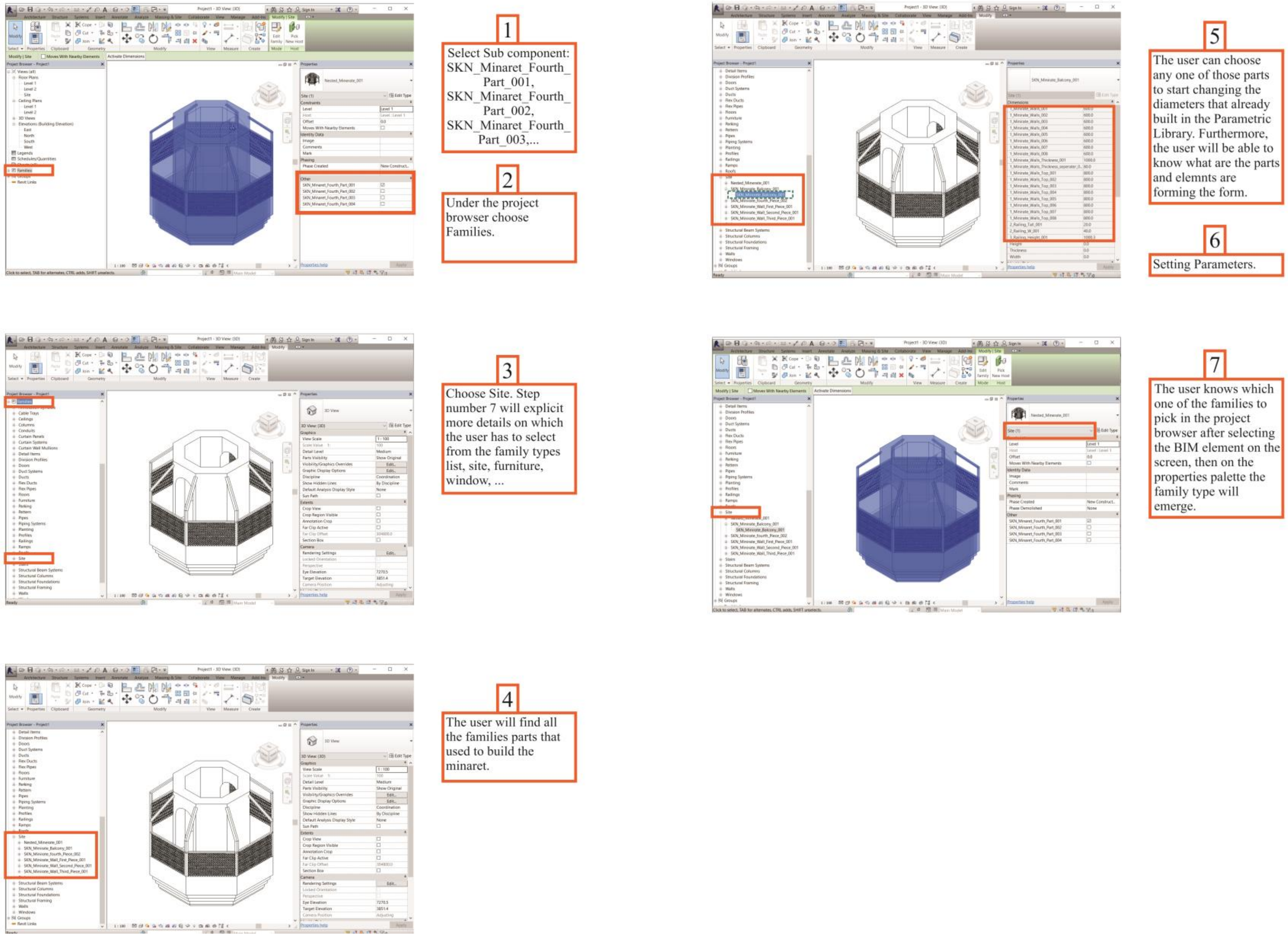


FIG. 9. Nested components in modeling windows.

The necessity of accurately drawing individual parts of the Hejazi Islamic architecture minaret necessitated the creation of reference objects which can be used in a parametric system. Figure 10 displays the method by which reference objects were drawn: starting from down to up select the dimension type button to create a dimension line, choose the purple line of the shape then choose the reference line, this allows the shape to be enlarged in the opposite direction of the reference line. By drawing multiple reference lines, the accuracy of the three-dimensional component is ensured, which will in turn ease the use, utilization, and employment of the HIAC or other IAS products by designers. Knowing that every part of the minaret can be manipulated as independent pieces to form new minaret designs is a great flexibility benefit to architects and engineers.

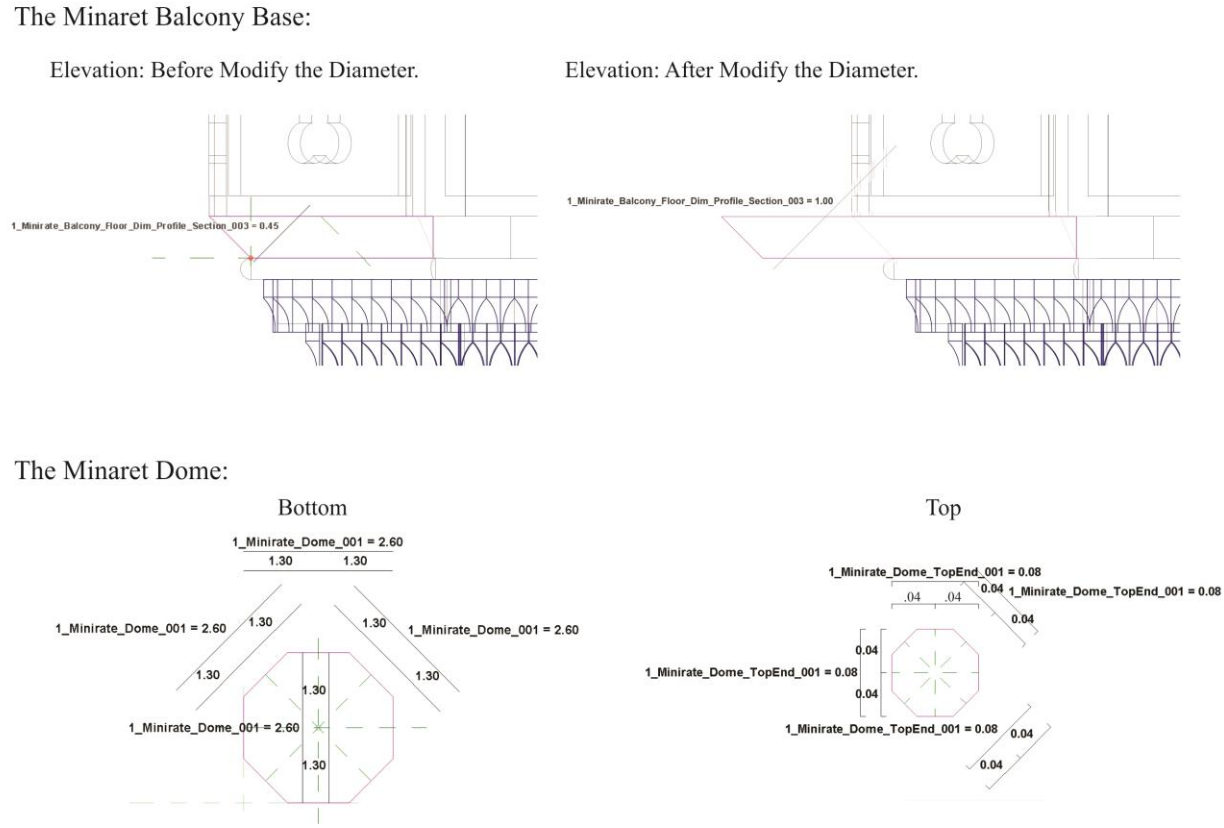


FIG. 10. One of the minarets of HIAC accuracy example.

8 STRUCTURE OF NESTED COMPONENTS

For Islamic historic structures, BIM elements need to satisfy three conditions to be utilized efficiently in building design. The first condition is that individual parts must be built based on authentic and accurate resources. The second requirement is that Islamic structural components must be parametric and adaptable to allow for aggregation with other parts and elements to form a subcomponent which can be used directly into the design process. The third condition requires that subcomponents be built using a nested element strategy. The expected outcome of the development of HIAC BIM Library is to enrich the design environment guidelines and standards for historical retrofitting or contemporary building design.

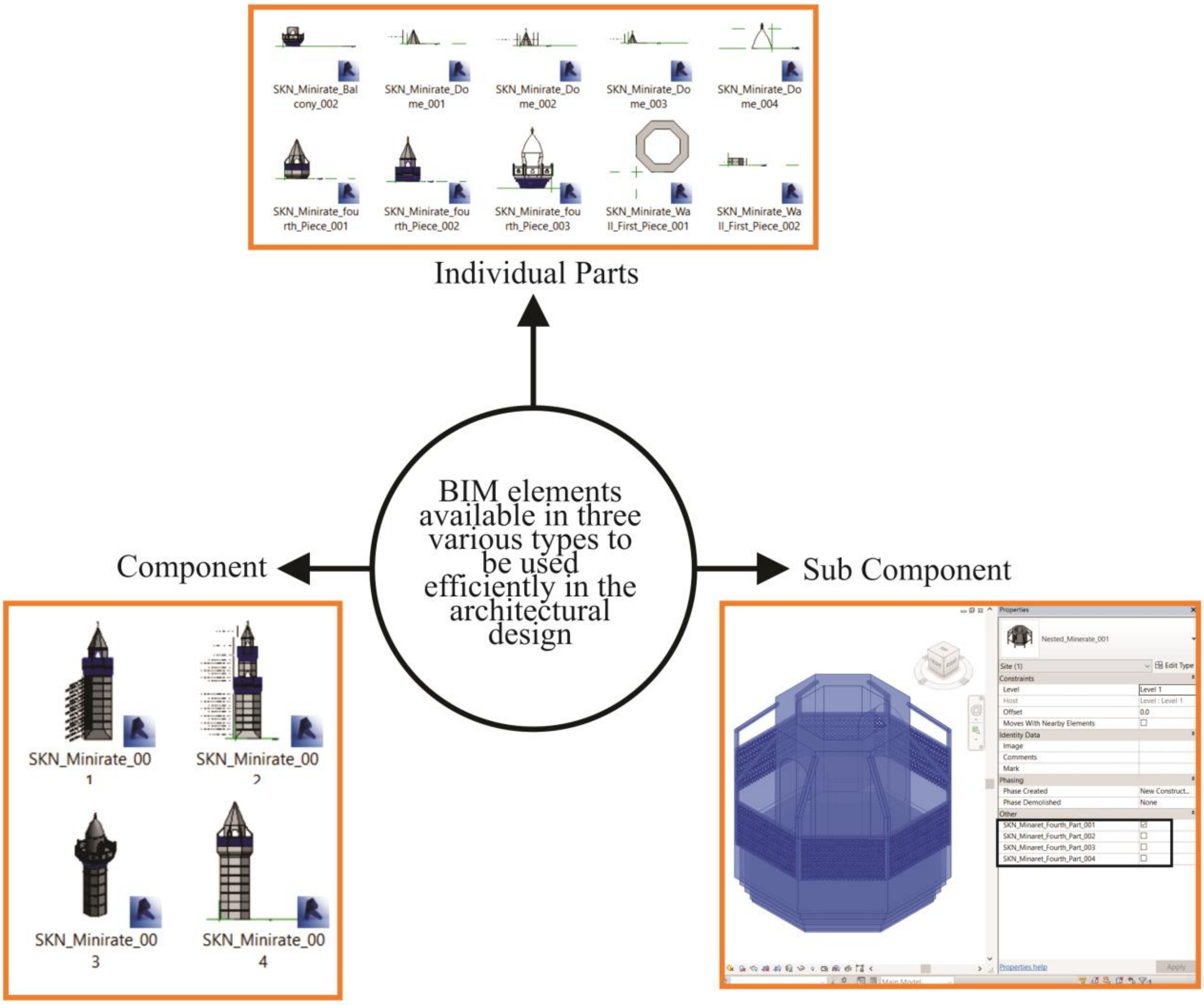


FIG. 11. BIM components in the digital library.

9 PLUG-IN APPLICATION

9.1 Plug-in:

The preliminary design of the application plug-in is depicted in Figure 12. It represents the vision of creating a complete BIM IAS application. The details of this vision have been shown in Figure 13. The current iteration of the plug-in includes explanations and guidelines on the sequence of choosing IAS components and represents how the IAS system functions. Per the first step, there is an introduction to every single Islamic Architecture Style. This is intended to help users to have enough understanding of a particular style so that the user can decide whether or not to incorporate the style into the design project. This also allows the user to determine which component or subcomponent ought to be utilized.

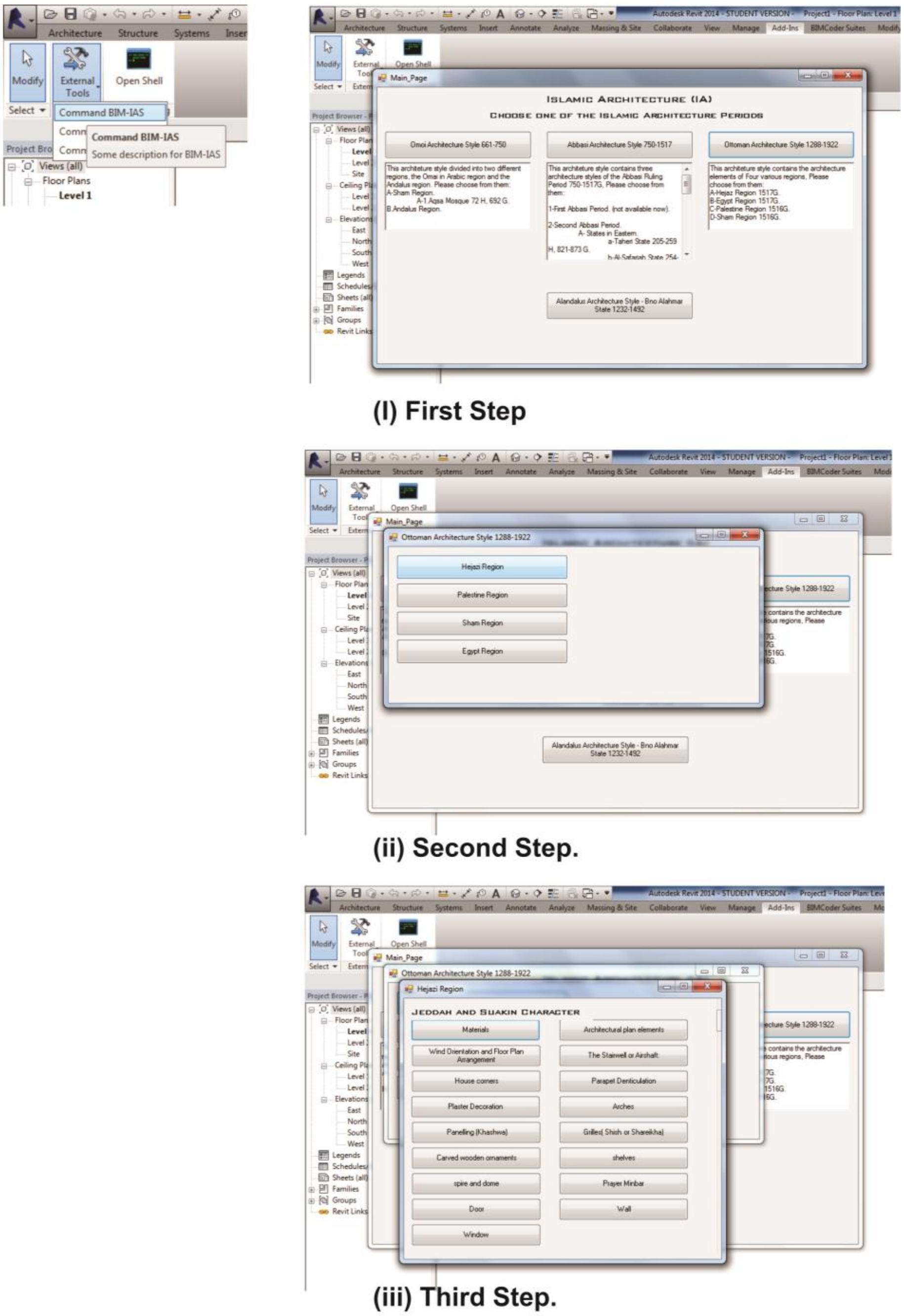


FIG. 13: Developed Plug-in for Autodesk Revit.

9.2 Example:

The application of the HAIC component library has been demonstrated in a conceptual structural design of the Islamic Center of Gainesville (ICG) (see Figure 14). The location of the site is at 1010 W University Ave, Gainesville, FL 32601. The block size is 21m x 75m. In this example, the focus is on the structural components of the Minaret which are defined as a historic structural element. The preliminary design procedure using the HAIC components library is illustrated in the following steps (refer to figure 14 and 15):

A. Locating the project site and the structural plan. Determine the location of the minaret in the structural plan (figure 14_A).
B. Choosing the appropriate Islamic Architecture Style for the project. In this case, it is the HIAC.
C. Start combining the elements and parts to form the minaret.

D. The alternative approach of combining elements is to use the preconfigured sub-models.

E. In this stage, a suitable form will be used by combining the parametrical models.

F. The designer decides which of the minarets are going to be used:

1. Alternative design one.
2. Alternative deign two.

Figure 15 shows detailed steps for designing the minarets. The plan in image 1G in figure 15 was largely determined by reading the data appended with the components and the HIAC era. The developed library guides the designer towards the appropriate direction of Muslims' Qibla (the orientation towards the Kaaba (the holy building at Makkah), to which Muslims turn at prayer). Furthermore, it assists in describing the features of the major Islamic structure characters for the HIAC Mosque that are needed for the worshipers. Illustrations 1H and 2H in figure 15 represent the design alternatives derived as a result of utilizing the HIAC BIM library. Diagram 1H of figure 15 delineates the traditional model of the Islamic architecture and the components used to design the mosque employed without any major change in their parametrical features. This design option represents traditional Islamic structural design style. The design in figure 2H reveals the capability of the components of the HIAC library to express more contemporary design approach. The design delineated in 2H can be derived from stages D, then E of figure 14 to gain a design based on the spirit of the Islamic character but reflect contemporary design style.

The benefits of this approach include that the same model can be utilized to perform various simulations and analyses such as structural, energy and caustic among others. When a designer decides to apply an idea, the BIM-IAS's library guides the designer through various details about Islamic historic structural components enabling the selection of the appropriate objects for the specific project, thus improving efficiency and accuracy. In contrast to the above-proposed approach, if designers decided to use the traditional BIM workflow, many issues would arise. These include, for instance, getting authentic data about the minaret styles, domes, arches as related to the project. Next, the designer must draft these elements in traditional CAD files manually. Thus, design changes and alternatives are time and resource intensive while also may result in errors and emissions. Moreover, the CAD file cannot be shared for collaboration with other designers to perform further analysis and simulations. The table below summarizes the comparison between the two design approaches.

Table 1. Comparison Between Two Design Approaches

Traditional	**BIM IAS approach**
1- Searching and hiring various specialists in the architecture style in the region. Also, looking for collaborators in the particular region is not an easy task. and the architectural firms to collaborate with them to supply the office in the United States with the necessary data to start the work	1- Designers do not need to hire or search for any data because all design and details data about the historic IA structures data are available in the proposed BIM IAS library.
2- The designers often do not have the time, and resources, to collect data related to historic IA structures.	2- BIM IAS library has the assorted database, diverse knowledge resources, the architecture and structural elements classified according to the style.
3- The design firm needs to look for examples and case studies to investigate the project before starting the design.	3- There are a number of examples and case studies with details about how other designers through the history employed the IA in their project.
4- Quality of the outcomes can be challenging due to the difficulties of early input from key participants and coordination.	4- The quality of outcomes is considerably enhanced due to the availability of the library at the early stages of the design that assist all participants to get involved in making input to the design decisions.

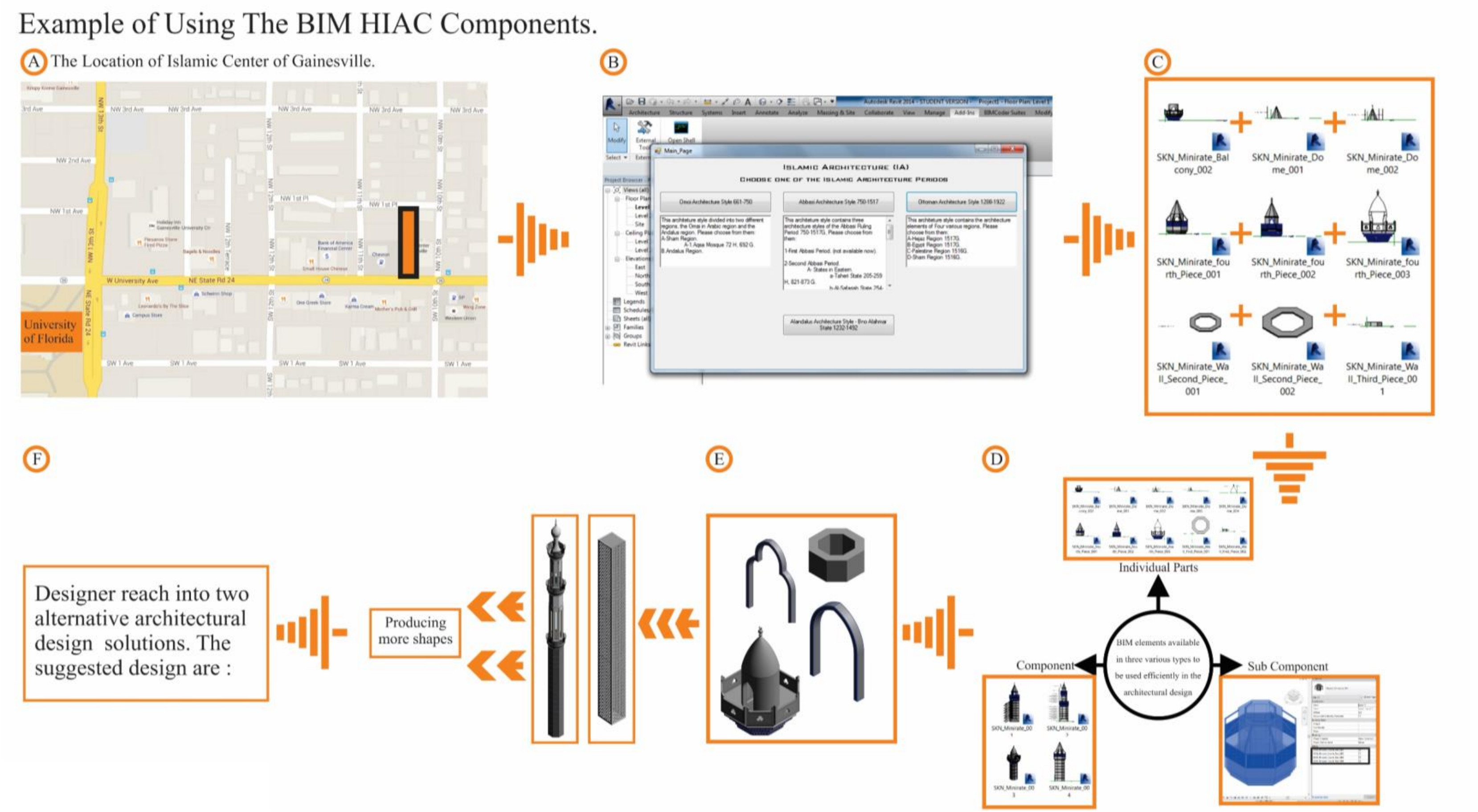


FIG. 14. Preliminary Design of the ICG Minaret.

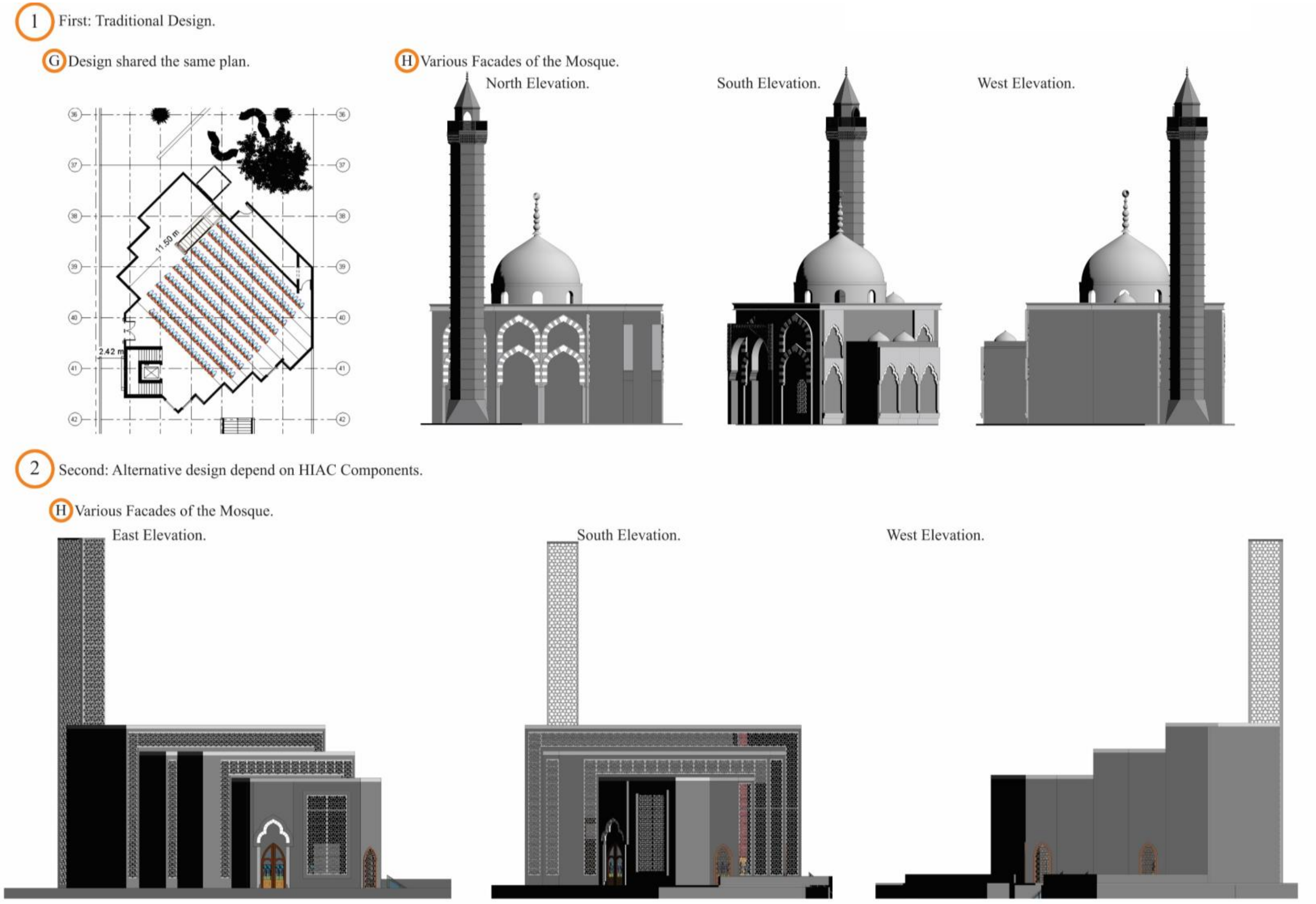


FIG. 15. Preliminary Design of the ICG Minaret.

10 CONCLUSION

The parametrically assorted informatics data of the Islamic historic structural components serves to assist and guide designers through the various phases of a restoration project of historic nature or new contemporary design project. The lack of information and details advancing the digital modeling of IAS BIM components to support the architects and engineers to develop optimum designs. The objective is to combine the HIAC library with the process of BIM to build parametric BIM architectural structure objects which are organized into the hierarchical schema. This library supports the designer's ability to select styles and components that suit a project with the capacity of modifying the three-dimensional components as needed by the project. The development of an IAS plug-in library that can be utilized by architects and engineers seeks to aid designers with an array of options of systematically categorized architectural structure components that are supplemented with parametric models and data and to ensure optimal usage during the design phases of a project. The applicability of the suggested BIM library has been demonstrated in a design project in collaboration with a local design Office in Gainesville, Florida. The outcomes of the application of the proposed library signify the indicated benefits of the developed library such as saving time and resources, assisting in preserving, maintaining, and retrofitting historic Islamic structures. The BIM library of Islamic architectural structure elements endeavors to enable the use of the historic Islamic structural style while maintaining optimum accuracy and efficiency in designing new facilities or retrofitting existing structures.

ACKNOWLEDGEMENT

Authors would like to thank King Abdul-Aziz University, College of Environmental Design, Architecture Department, for sponsoring Mr. Ayad Almaimani in his pursuit of Ph.D. research at the University of Florida.

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