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# BIM-Driven components library for Islamic Facilities (BIM-IF)

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**Abstract**

Islamic architectural history encompasses a substantial amount of information that needs to be categorized and digitally modeled so it can be utilized proficiently in the design phases of any project that seeks Islamic construction character. This paper centers on developing BIM-driven three-dimensional object library for Hejazi Islamic Architecture (HIAC) styles, construction methods, structural elements, and architectural components. The Ottoman style architecture has had profound effects on the Hijazi region for more than three hundred years. This influence remains largely uncategorized and digitally undocumented. Building Information Modelling (BIM) approach is used to develop parametric three-dimensional models of HIACs that are used in the structure and construction of Hijazi buildings. The HIACs are aggregated and classified according to their type and origin with respect to the chronological timeline of Islamic Architecture (IA). The creation of this BIM-Driven Components Library for Islamic Facilities (BIM-IF), thus allows for the use of HIACs in the design phases of projects that aim to incorporate IA styles. Each HIAC in the BIM-IA library contains architectural, structural and constructional data that is categorized using informatics tables appended with the digital models. In addition to the essential design data, the BIM-IF library provides designers with various historical information and details about numerous unique Ottoman styles.

**Keywords:** Building Information Modeling (BIM), Hijazi Islamic Architecture Character, BIM libraries, Ottoman style, Digital classification

## Background

Throughout history, Islamic Architecture (IA) has been regarded to possess distinctive characters that describe regional variations in both Islamic and non-Islamic countries. These peculiarities are observable in numerous buildings such as mosques, houses, and gardens which employ unique arches, tile designs, towers and interior spaces. Islamic Architecture (IA) is a receptacle of Islamic civilization, and it is significant that the interchange of these two facets is recognized when dealing with Islamic construction projects. 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 from and about the Islamic culture. (Ivy, 2001). Within the IA, Hijazi Islamic Architectural Character (HIAC) is a style that encompasses architectural features made popular by the Ottoman Empire over a period of 300 years beginning in the 16th century. As the Ottoman Empire's span of influence expanded across the Red Sea coastal region so did the replication of the HIAC in various coastal cities (Greenlaw 1995). The HIAC can be seen in the ornamentation of major city buildings such as mosques and on the homes of wealthy citizens scattered throughout these coastal cities. HIAC style ornamentation includes various doors, window types, woodwork designs, trimmings, and the creative use of internal and external spaces.

Grube (1973) defined IA as a set of architectural and spatial features, such as introspection, that are 'inherent in Islam as a cultural phenomenon. Hence, establishing 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 scarce. Examples of these research efforts comprise the work of Djibril et al. (2006)) who developed a region based indexing and classification system for Islamic star pattern images

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using rotational symmetry information. Their classification system is based on the number of folds by which an image is characterized and the image's fundamental region and class. Okamura et al. (2007)) 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 traditional architectural design and interdisciplinary studies. Further efforts are shown in the work conducted by Djibril and Haj Thami (2008)), who examined geometrical patterns in IA and developed an indexing and classification system using discrete symmetry groups. It is a general computational model for the extraction of symmetry features of Islamic Geometrical Patterns (IGP) images. IGPs are 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. Ma et al. (2016) discussed utilizing the BIM application in restoration and maintenance of wooden structures for architectural heritage in Taiwan. A more recent research effort on the topic is represented by work conducted by Baik et al, (2013), 2014, 2015). They used Terrestrial Laser Scanning and Architectural Photogrammetry to document a historical buildings in Old, Jeddah, Saudi Arabia. The data captured using these techniques was transformed into digital building information model (BIM).

The objective of this work is to develop a Building Information Models for Islamic Architecture (BIM-IA) library with the intent of using the library as a repository for Islamic Architecture components. The availability of BIM-IAS classified database to aid users in the comprehension of IA culture virtually results in "… 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" (Muir & O'Neill, 1994). BIM is a software platform that allows users to sort, organize and preserve designs in a single Building Information Model file which includes three-dimensional elements and embedded data. The BIM objects in the file can be edited and controlled according to a user's needs (Denis, 2015). BIM objects are digital, three-dimensional, measurable, and comprehensive in the sense that they meet the designer's intent, a building's performance needs and other functions, are accessible to the entire AEC, and reusable during all phases of the design process. Also, as defined in the original NBIMS document, "BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward." (National BIM Standard, 2016).

In BIM the professional user can draw the component and set it as a parametric model, then apply different values and use it in the project according to a design decision. Furthermore, the model can be used multiple times as a base model to create another version of it in outside the current project using the family system to apply it to other projects. As it appears as an example in the BIM-Driven Islamic Construction: Part 2 – Digital Libraries. (Almaimani and Nawari 2015a, 2015b; Nawari and Kuenstle, 2015). BIM opens to the architect and designer the opportunity to examine then analyze various solutions that can be through one of the different kinds of the parametric molding software as a part of the BIM technology. The iterative process leads the design team to a solution that fits the project requirements. The collaboration of the BIM software eases transferring between them which gives the designer the ability to provide more options to the other team members from other fields to collaborate efficiently on the project. Especially when it comes to the aspect of architectural and constructional documents synchronizing and matching which BIM technology has been applied.

BIM technology aids the architect by guiding the direction of the design and abbreviating the amount of time spent determining whether certain priorities of the project accomplished. Also, finding out the solutions whether that is for producing a project focusing on sustainability or interested in producing a traditional building style for a particular region. The obstacle in working on traditional styles is that the architect does not have access to an authenticated, organized, and classified BIM digital library for the architectural and structural elements. This BIM library transfers the possibility of making the appropriate decision which does not contradict with other majors. A BIM library guides architects and designers to use tools that make a project well-rounded and readily accessible through the database to owners, planners, realtors, appraisers, designers, engineers, estimators, specifies, safety, occupational health, environmentalists, contractors, subcontractors, fabricators, code officials, operators, and renovators. There are multiple design methods and approaches developed over time; BIM technology was one of the approaches developed in the last few decades to bring change to the way databases and tools which accelerate the design process and decision to produce a project are used. The existence of the equipped BIM-IA supports achieving the goals of the project from exploiting the architectural and structural data of the elements and the appended information to control and manage the schedules, fabrications, materials quantity, and other benefits to be valuable for the software user.

This BIM-Driven Components Library for Islamic Facilities (BIM-IF) categorizes architectural objects and then sorts them chronologically based on their appearance in the IA timeline. The parametric three dimensional architectural elements are accompanied by schema, data, models, shapes, and both structural and construction elements. This paper centres on developing library for the Ottoman Islamic Architecture styles of the Hijazi Region. By creating a digital classification of the Hijazi Islamic Architectural Characters (HIAC), this work will assist designers in better comprehending the HIACs once used in the Ottoman Empire. It also aims to provide a method by which future utilization and application of HIACs in contemporary buildings can be readily and efficiently engaged. The contribution of this research is pertaining and promoting the Architectural culture of the Hejazi Islamic Architecture Character (HIAC) through initiate digitalized architectural Islamic style library.

## Methods

### Classification System

Models in architecture have always played an important role throughout history. Ancient Egyptian used models in form of drawings and physical objects. Plans of the Tomb of Rameses IV and the drawing of the shrine from Ghorâb are good examples (Clark and Engelbach, 1990). Models also existed in ancient Greeks and Romans (Schattner,

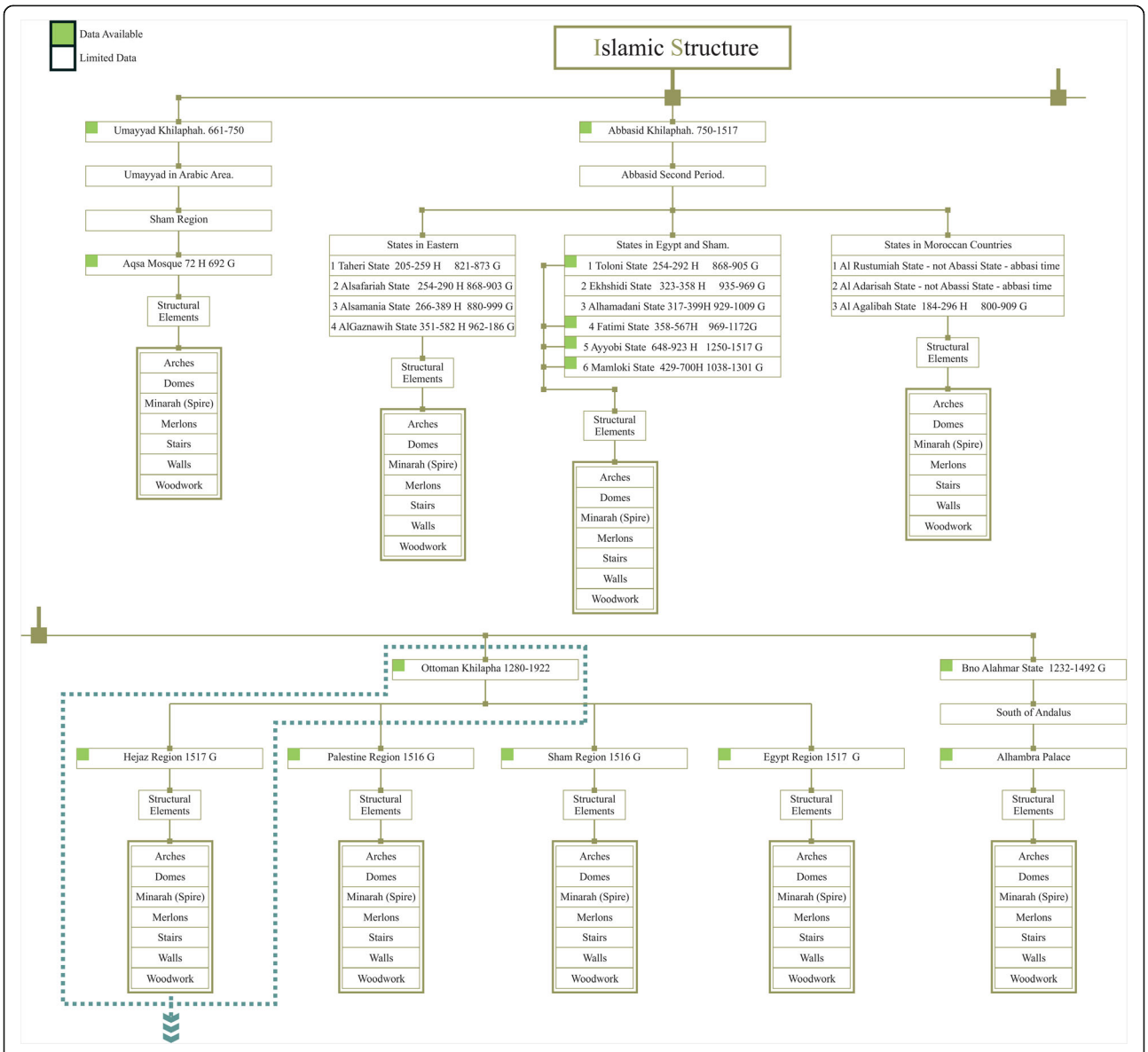


**Fig. 1** Classification chart concentrating on Hijazi Islamic Architecture Character (HIAC)

1990, Marconi, 2015). During the middle ages models were used increasingly for the design and construction of cathedrals (Kostof, 1977). These models were planned as an integral part of the design of building exteriors as well as in their interior decoration. The Roman architect Vitruvius (European Architecture Series) had traced the origination of architecture to the imitation or modelling of nature. Seeking shelter, humans learned lessons from swallows and bees built their habitations. Then, they started using natural materials to create forms that are based on shapes and proportion of nature. Certainly, Vitruvius affirmed that the figure of a man could be inscribed both in the circle and the square; the fundamental geometrical forms on which the design universe was ordered.

In the digital era, modelling has advanced significantly in the last decades. Particularly, building information modelling (BIM), which is fundamentally changing the role of computation in building design by creating a database of the building objects to be used for all aspects of the building from design to construction and beyond (Nawari, 2014). This research aims to develop BIM library for Hijazi Islamic Architecture.

There are numerous publications and other resources related to Hijazi Islamic Architectural Characters (HIAC) that are not aggregated and assorted in one single BIM digital library. This work seeks to enrich the HIAC architectural, structural, constructional elements by assorting and organizing the three-dimensional elements in hierarchical classification system.

The proposed methodology has been contrasted with the recent work 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 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) developed the general classification chart system of the BIM – Driven Islamic architecture library. This paper aims to demonstrate how the styles included in the BIM-IA classification system can be used to create a BIM library. 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. 1. 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 a category that then subdivides into subclasses of object types.

Figures 2 and 3 outline the hierarchical schema of the digital classification system used to organize the BIM-Driven Component Library Islamic Facility. 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).

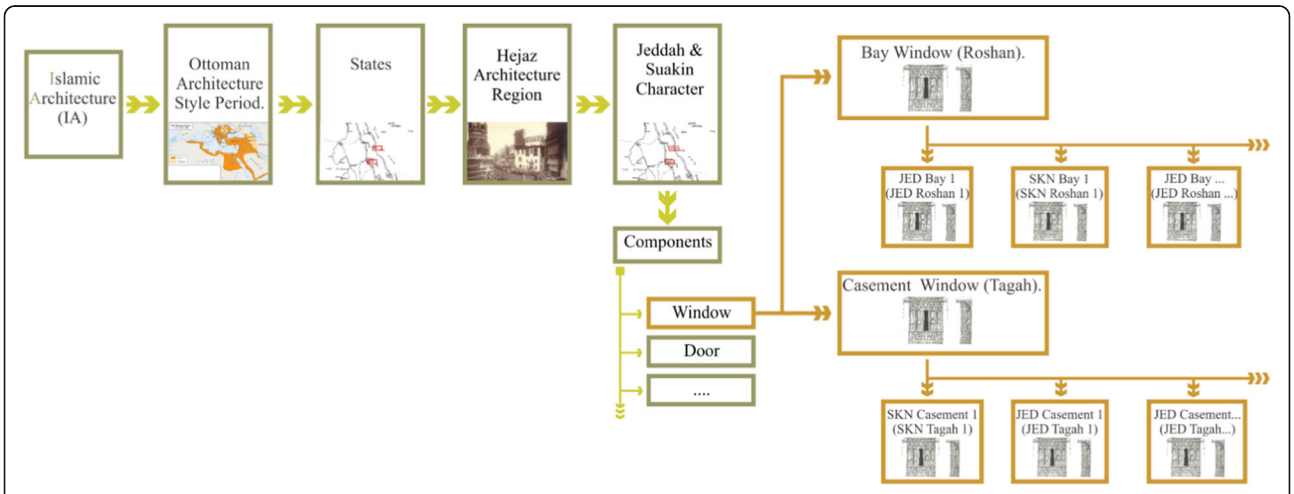


**Fig. 2** Hierarchal schema of the digital classification of HIAC

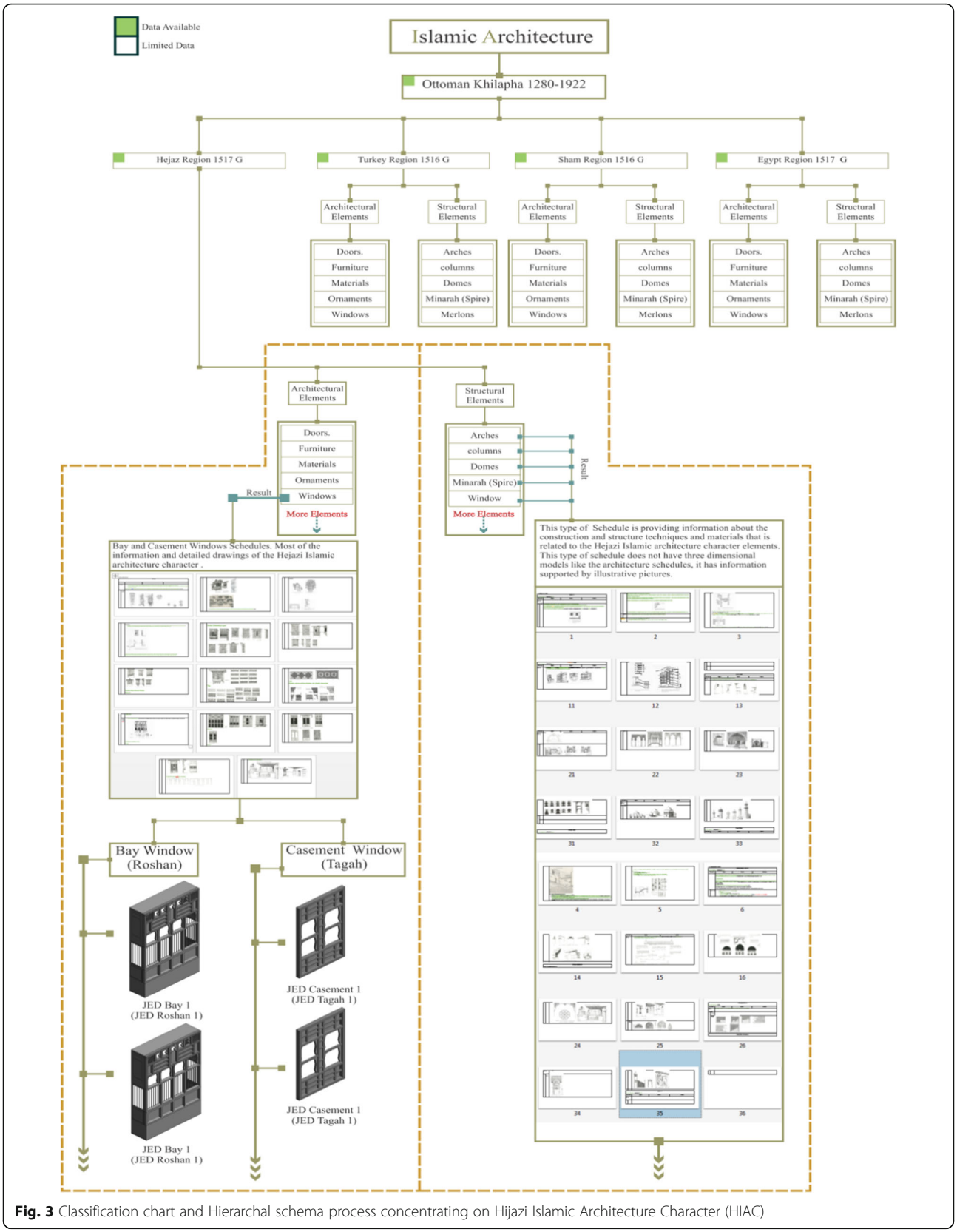


**Fig. 3** Classification chart and Hierarchal schema process concentrating on Hijazi Islamic Architecture Character (HIAC)

The hierarchal schema presented in Fig. 2 outlines the organization for the Ottoman time period and the Hijazi styles. For instance, if one seeks information about an HIAC window then that window's origin, style, period and building could be readily identified. Figure 2 is also a representation of the general logic of classification and how well each object in the BIM-IF is synchronized. For example, windows and other components are each assigned a unique identification number (ID) that describes the design origin of each object so that other similar styles can be easily cross referenced. Figure 3 illustrates how all of the data found in Figs. 1 and 2 are connected via a sequenced classification system that includes data on objects' origin, style, and relationship to other similar objects.

## Schema

The BIM-Driven Component Library Islamic Facility (BIM-IF) for HIAC encompasses details about various architectural objects such as window's details, design types and related information (see Fig. 4). The schematic workflow for a user begins with window details depicted in Fig. 1, and then proceeds to Figs. 2 and 3. As the user identifies and then selects a particular component, such as a window, details of that object are then displayed. About forty HIAC components have been collected and classified so far in the BIM-Driven Components Library for Islamic Facilities. Each object includes details that describe: object themes, element type, style history, character history, as well as additional architectural styles through the use of pictures and illustrations. All of these details are essential to designers who seek to employ the

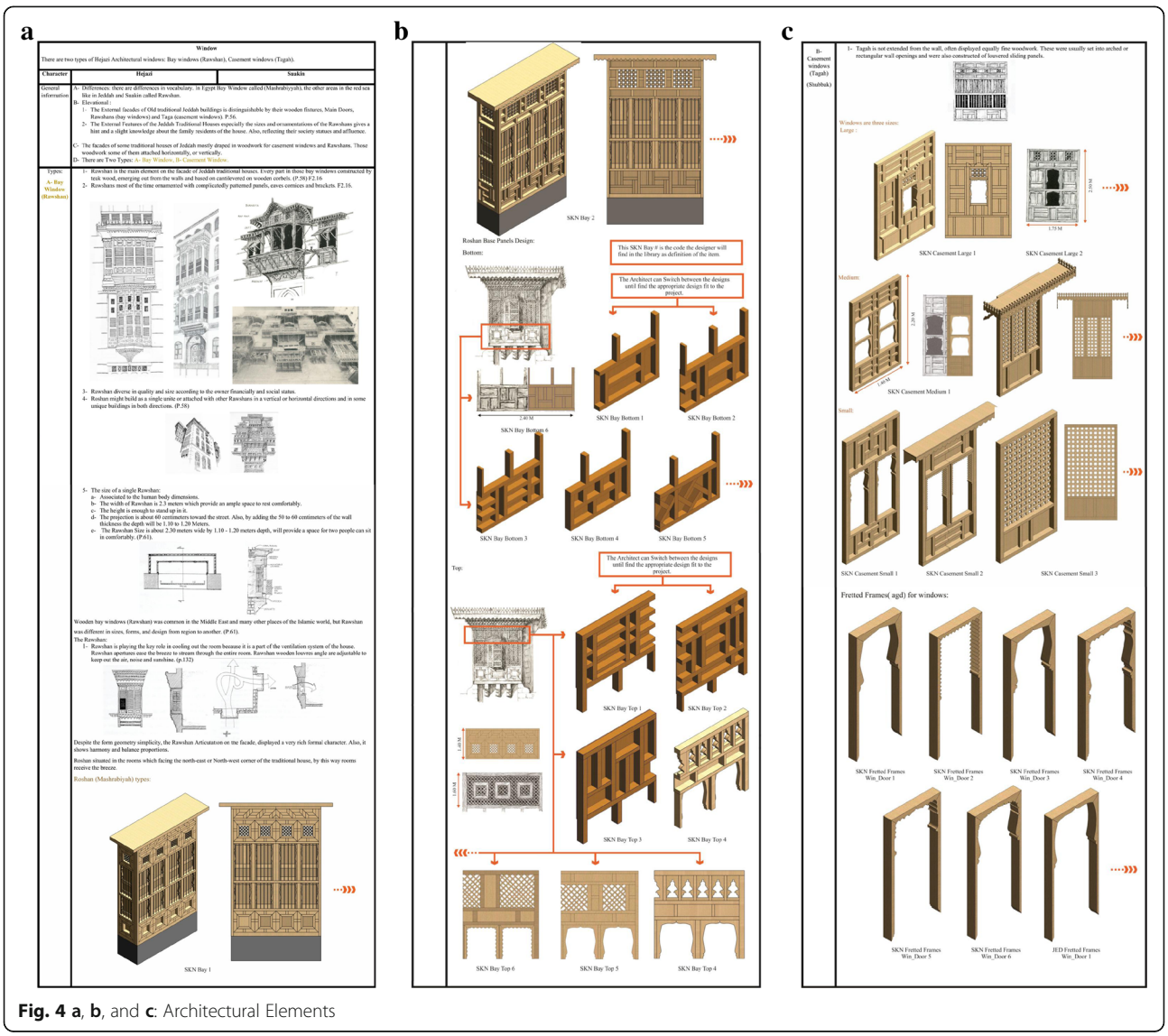


**Fig. 4** **a**, **b**, and **c**: Architectural Elements

HIAC into their buildings as well as to those who are interested in similar styles.

The data used to generate these charts are extracted from genuine Islamic Architectural references accredited and recommended primarily by Harvard and MIT universities through the Aga Khan Program for Islamic Architecture (Islamic architecture - Aga Khan Documentation Center, 2015). Other references include Art of Islam by Titus Burckhardt (2009), Historical Atlas of The Islamic World (Malise Ruthven and Azim Nanji (2004), and Atlas Tarikh Aleslam by Hussain Moans (1987). Additional sources of data include: The Coral Buildings of Suakin by Jean-Pierre

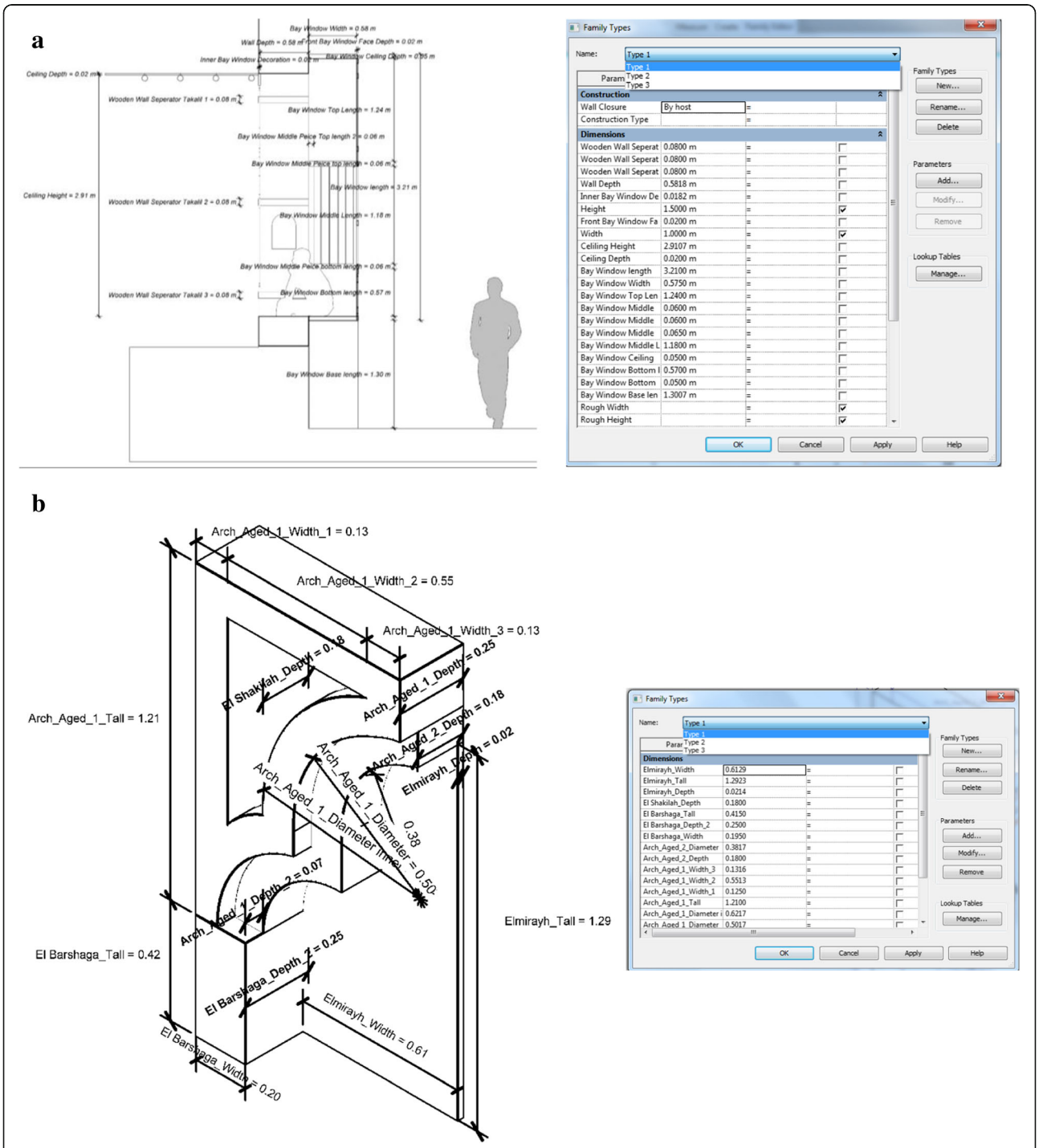


**Fig. 5** Examples of application of the BIM-Driven Component Library Islamic Facility (BIM-IF). Style: Ottoman; Character: Hijazi; Form: (**a**) Bay Window, (**b**) Arch: Agd Mawshah

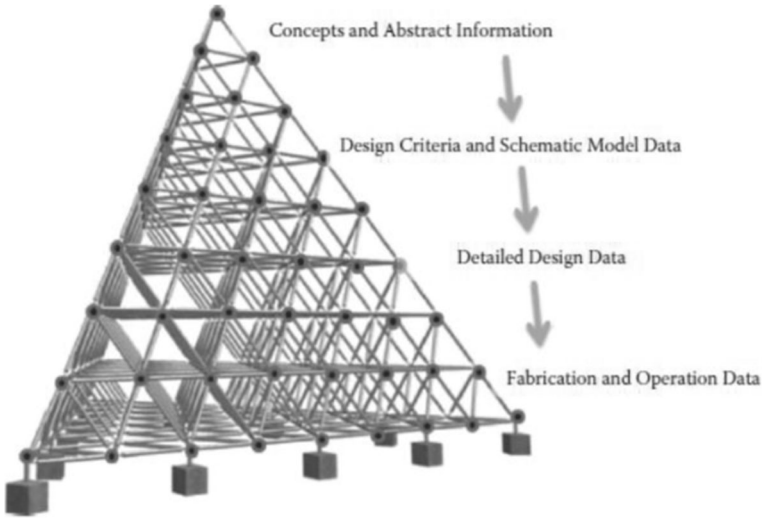


**Fig. 6** BIM Model Data Pyramid. (Nawari and Kuenstle, 2015)

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).

There are more than 300 BIM detailed parametrical elements. These elements Level of Development (LOD) are 200, 300, 350, and 400. Referring into Fig. 2 and 3 will explain the depth and extensive of the work provided in our research in compare with any other researches. Every one of the elements in Figs. 4 are LOD 400.

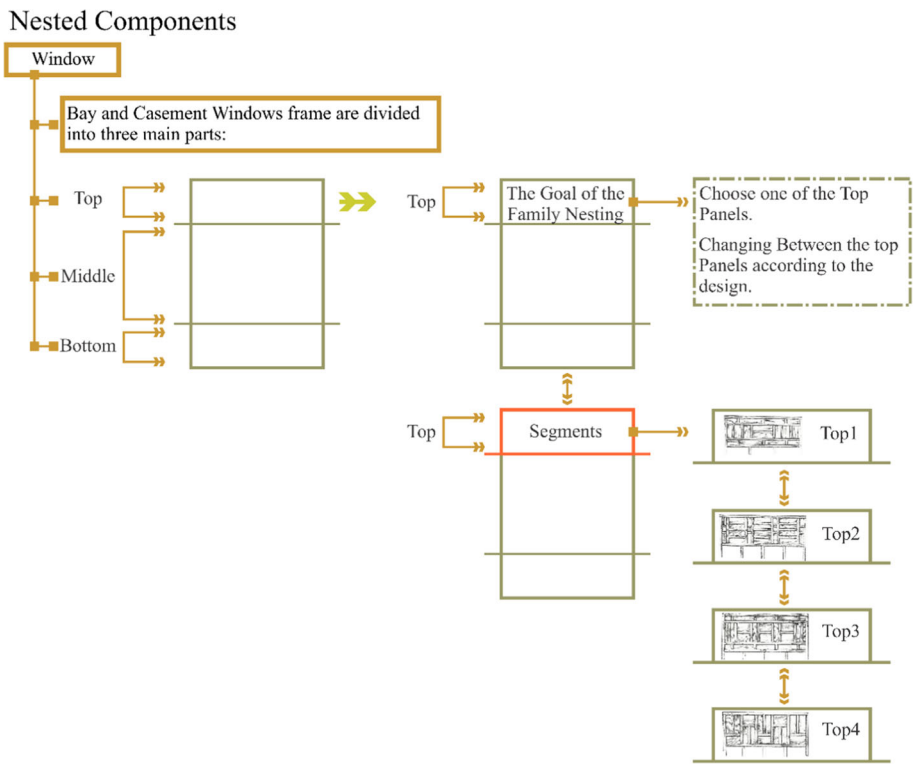


**Fig. 7** Hierarchal nested components of the Bay and Casement windows of HIAC components digital library

## BIM components

Each HIAC construction component is defined by its parametric three dimensional representation and its attached dataset as described in the previous sections. Figure 5 illustrate and example of how HIAC components can be utilized in projects. Each component geometric parameters such as width, length, and depth can be controlled to adjust to a specific conditions. These adjustments can made to either the whole component or only to a specific part of its subcomponents.

The information of the BIM model builds through the project phases; every time the project proceeds the info becomes more reliable and precise for use after every design phase is completed and every structure is prepared. As described in the book *BIM framework for Structural Design*, information in the BIM process expand in a pyramid form (Fig. 6) (Nawari and Kuenstle, 2015).

Building information data is appended to every object in the building; a report can then generated with each object estimated usage. This type of service is not available in the CAD system unless the user does it manually. All original data that exists in the BIM system can be utilized to produce many different operations, for example, the specifications and standards, schedules and documents of the

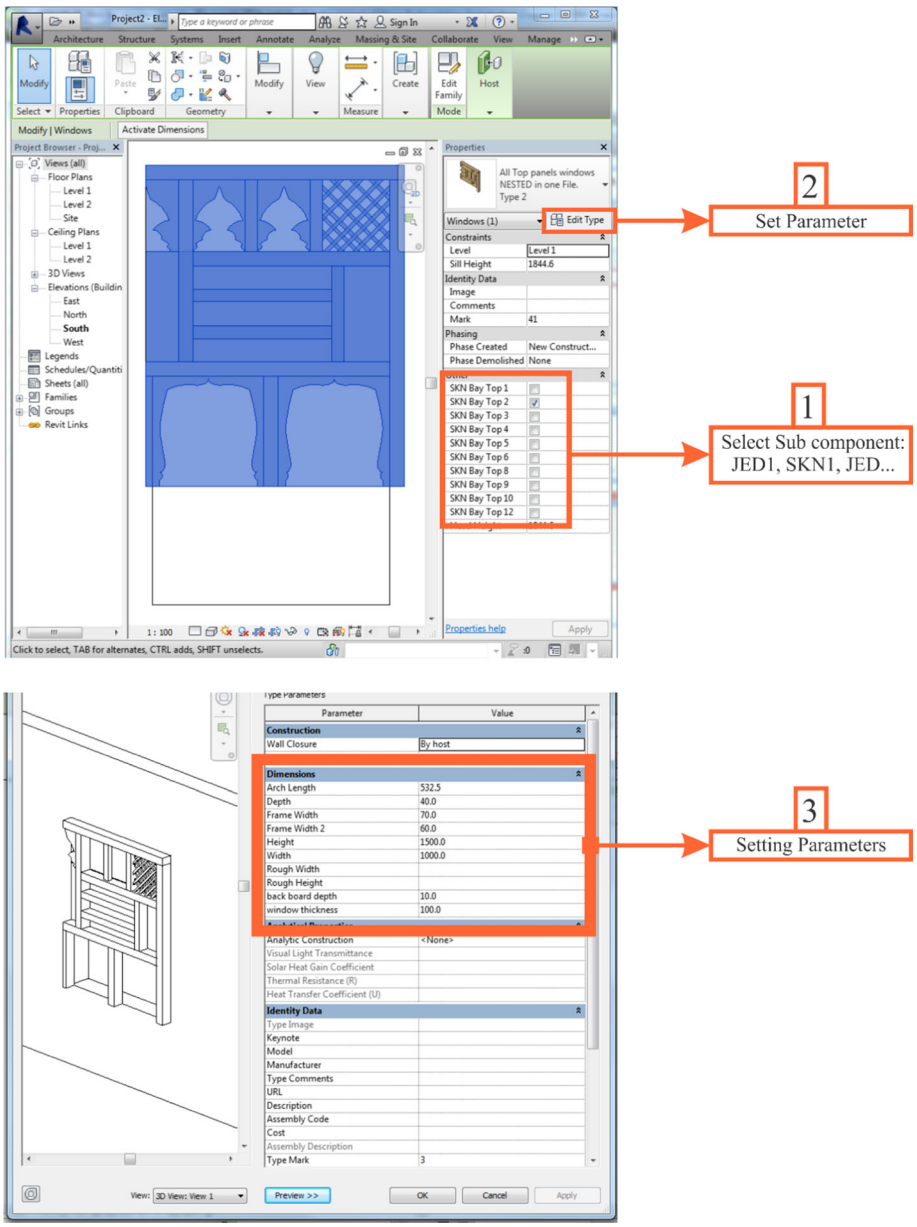


**Fig. 8** Nested components in modelling windows

materials, components, and any other object in the project. All this information increases the level of trust in the BIM technology. The benefits the designer gains from using BIM elements varies between the level of details compared with other object sources, the credibility of the sources, and decreased redundancy in the collected data.

## Nested components

The BIM-Driven Component Library Islamic Facility (BIM-IF) is based on hierarchal order and nesting of components. Figure 6 illustrates how the segments of a component are built using other components. For example, if designers intended to add a window to their building, they also have the options to select various subcomponents for a particular segment of the window (top, middle, and bottom) (Fig. 7). Figure 8 demonstrates how the various window's segments can be designed using a BIM authoring tool.

## Applications

To facility use and application of the developed BIM-Driven Components Library for Islamic style in any contemporary or historical facilities, a plug-in is created as an extension built for use with Autodesk Revit BIM platform. The BIM-IA plug-in is a catalogue of Islamic Architecture characters that can be accessed via the Add-In software ribbon found in Revit. It is developed using Microsoft's Visual Studio and each architectural style presented in the digital library includes a description (both of chronology and usage), as well as a three-dimensional model. The BIM-IA library aimed to provide a practical design source as well as a reference for various designers such as architects, engineers, interior designers, landscape architects, planners, and other related fields when designing a new facility or retrofitting historical structures. Hijazi Islamic Architecture Character (HIAC) is an example of the first completed set of components in the BIM-IA library.

## Conclusion

The architectural information coupled with digital parametric models of Islamic construction is critically important for designing contemporary project of Islamic styles. This work aims to develop BIM-driven library of Islamic Architecture styles for architects, engineers, and other related trades. The intent of this research is the classification and organization of Islamic construction styles using spatial and temporal categories to represent the styles of different Islamic cultures. The prototype used to demonstrate the BIM-IA library is the Hijazi Architecture Character of the Ottoman period. Hijazi architecture is categorized based on components type and each component is characterized with various geometric, materials, and historic information parameters that can be readily adapted. This informatics platform can be implemented in any projects seeking Islamic style

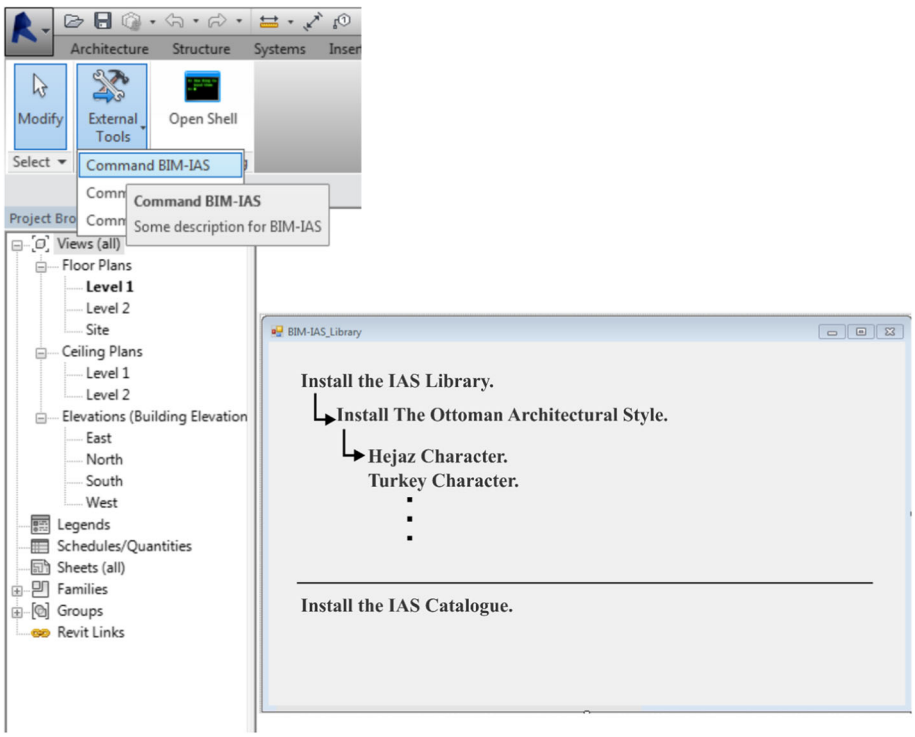


**Fig. 9** Plug-in for Autodesk Revit

while also serving as method by which Islamic architecture can be integrated into contemporary aesthetics.

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**Authors' contributions**
Both authors read and approved the final manuscript.

**Competing interests**
Building Information Modeling, Islamic Architecture.

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