3d MODELING of historic makkah

Strategies for Constructing Accurate CAD Models of Historic Buildings

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Abstract. In this paper, we outline the problem of historic preservation and the opportunities that rigorous CAD models provide to address it, describe the particular class of buildings in Makkah that we are concerned with, and discuss a modeling strategy that takes advantage of common elements, symmetry and repetition in the buildings' construction, and standard operations in current CAD programs. We briefly discuss tools for architectural heritage recording, construction of CAD models of historic buildings, and systematic analysis of built form. Finally, the paper shows how the method can streamline the construction of accurate CAD models.

1. Architectural Heritage Recording, from Traditional to Digital

Documenting historic buildings is important. It preserves information for future generations to learn from the past. A rich architectural heritage provides future architects and planners with design solutions to various problems. In addition, many cities gradually lose their rich artifacts and history, as historic buildings are destroyed to make room for new projects. Architecture results from interaction between different cultures throughout history reflecting the social values, economic situations, and behaviors of a particular time.

Traditional recording tools for historic buildings provide various formats to address different documentation needs. Measured drawings register accurate dimensions of the features and the spaces of buildings. Perspective drawings simulate what the human eye sees. Photography records scenes including general outlines, lighting quality, and the appearance of different materials. Sketching records a view or a detail in a suggestive artistic format. Videos record a live visit to a place that includes series of scenes and even

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sound of a place. Photogrammetry uses photography to accurately measure places that are difficult to reach. A physical model represents the three dimensional aspects of a building (Sanoff, 1991). Writing describes visual representations and unseen information such as building materials, owners and builders of buildings.

Computers provide easier and faster storing, retrieving, and sorting information capabilities than traditional tools. By constructing a 3D model of a building, we are making a digital database of the building. Furthermore, software has been developed to transform a database of measurements into CAD drawings (Nickerson, 1996). A digital database can be distributed widely over the World Wide Web for visualization, analysis, and discussion. Digital CAD Modeling can create visual geometric models that simulate the three dimensional form of a building or architectural detail (AlSayyad, et. al., 1996) or even help resolve ambiguities and inconsistencies in the raw data and drawing (Lewin & Gross, 1996). Once a digital model is constructed it can be used to generate elevations, sections, plans, and perspective views. It can also serve as a base for walkthroughs, flybys, and virtual reality tours. A CAD model includes recorded features of measured drawings, photographs, and videos as well as accurate dimensions of buildings. In addition, computer generated renderings can provide realistic representations of buildings. Furthermore, text can be linked with those CAD models, establishing a comprehensive database that merges visual and written information about a building. A digital format of photographs can provide new opportunities for image enhancement and manipulation (Mitchell, 1993). A computer model can also include the acoustic properties of spaces (Engeli, et. al., 1995).

2. Architectural Heritage in the City of Makkah

The city of Makkah, Saudi Arabia is an important cultural and religious center, hosting more than three million people each year to perform Hajj (Islamic pilgrimage). It has also witnessed rapid development in recent decades and many historic buildings from the middle ages through the 19th century have been destroyed to make room for modern development. We are working with the Hajj Research Center, Makkah to develop strategies for constructing accurate CAD models to record the remaining architectural heritage, and to reconstruct from existing documents the buildings and places that no longer exist (Figure 1).

Facades of traditional buildings in Makkah were affected by different factors, such as the available building materials, the building material imported through Hajj, Islamic rules about privacy and the sense of beauty, and social and economic factors (Hegazi, 1983). The two main categories of elements of these facades are the wood work (wooden windows), and the brick work (*Shabura*) (Angawi, 1988).

Figure1. A historic neighborhood that no longer exists.
Source: Hajj Research Center by Dr. Abdulmalik Haji Master

3. Elements and Rules of Facades

The woodwork of the historic buildings of Makkah consists of the wooden windows and the entrance doors. The wooden windows include the extended window (*Roshan*), and the flat window (*Shubak*). The wooden windows are important elements for the facade of Makkah buildings (Hariri, 1991).

The *Shubak* is a flat window covered by wood work. This type of window includes a wooden framework with different divisions. These divisions were either filled by wooden decorated patterns or louvers. The *Roshan* (extended wooden windows as shown in Figure 2) is similar to the *Shubak*, except that it is projected. It extends over the street from the main spaces of these buildings, providing more space and views up and down the street.

The *Roshan* and *Shubak* are similar in the way they are assembled. The upper and the lower parts were for decoration purposes and were constructed from a solid piece of wood covered with repeated geometric or botanical patterns. The middle part either includes a hollow wooden panel, or louvers made of small wooden pieces. These louvers can be rotated to control air flow, sunshine, and privacy. The middle parts move either vertically or horizontally. The *Roshan* increases the space of rooms by adding a projected portion.

Several rules affected the spatial arrangement of wooden treatments on facades (Figure 3). The *Roshans* were always at the first floor or above, never at the ground floor. For this reason the *Roshan* does not interfere with people walking on the street. This reflects the Islamic rule of the right of the way.

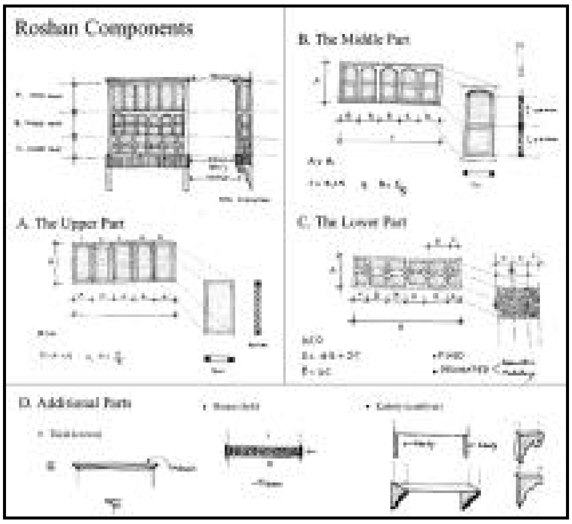

Figure 2. Roshan components and details

The process of constructing the wooden windows starts by building the main frames of these windows forming the outer edges and the inner subdivisions. This shapes rectangular openings that are later covered with various wooden treatments. Then the upper, the lower fixed parts, and the movable middle parts are assembled.

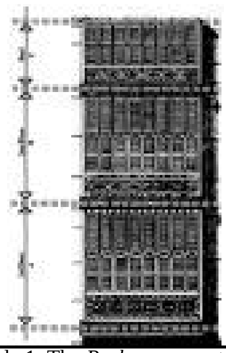	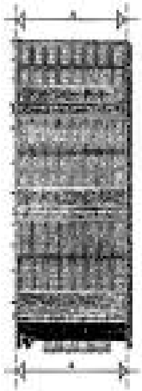	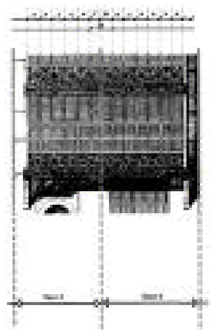
Rule 1: The *Roshan* may extend vertically to cover different floors, in this case the vertical dimension of each *Roshan* gets smaller as the *Roshan* goes up.	Rule 2: The horizontal dimension of the *Roshan* is fixed from the bottom to the top, even if there are many *Roshans* on top of each other.	Rule 3: The vertical subdivisions of the *Roshan* are equal, except where the *Roshan* covers horizontally different interior spaces.

Figure 3. Examples of the *Roshan* rules

4. Developing CAD Modeling Strategies

4.1. UNDERSTANDING THE CAD MODELING PROCESS

The process of constructing a digital model includes many stages. The first stage is understanding how to describe different objects by defining points, edges, or corners. A strategy is needed to manage the objects of the model with reference to the coordinate system.

Standard geometric objects can be constructed using primitives available in most modeling programs such as cubes, spheres, domes, and cylinders. Extrusion can transform two dimensional objects (lines, polygons, and splines) into three dimensional objects. Many transformation operations can be used to construct specific objects, or to modify shapes.

4.2. MATCHING CAD MODELING OPERATIONS TO DESIGN PRINCIPLES

Buildings are constructed from smaller elements that are combined to provide form and space. Orders control the relationships between these initial elements. Properties of form, organization of form and space, and proportion and scale are important design principles. Understanding ordering principles such as axis, symmetry, hierarchy, rhythm, and transformation guides analysis and modeling.

CAD modeling software provides a variety of commands that facilitate modeling repeated elements. Rather than repeating identical operations in a digital model, analyzing and defining repeated elements in buildings saves time and effort. Understanding the design elements and rules of the class can reduce the errors in the digital model. For example, the subdivisions of the *Roshan* are always equal, so during the modeling process the modeler must avoid making one of these divisions large or smaller (Figure 4).

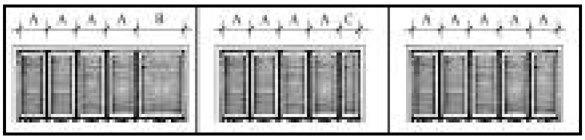

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Figure 4. Following the design rules reduces CAD modeling errors

4.3. MATCHING THE CONSTRUCTION PROCESS

Our modeling strategies derived from the construction methods of historic buildings. We divided this into four steps that can be followed as strategies. The theme is to establish the CAD model following the way the historic buildings in Makkah were constructed.

These steps were developed through architectural analysis, defining the elements and their rules; and the experimentation of two modelers in modeling the elements of the historic facades in Makkah. In our project we employed two students at the Master of Architecture, University of Colorado. Their first job was to experiment with various ways to model the architectural elements of these facades. Then from the analysis and their experimentation, we developed various modeling strategies.

4.4. STEPS FOR ANALYSIS AND MODELING

4.4.1. Decide the General Structure and Locations of Elements

Deciding the general structure layout (Figure 5) controls the locations of elements spatially and controls the outer frames of these elements. This guarantees that these elements after they are modeled will fit in their locations. The end result of this step should be 3D masses of the facades (building envelope) with holes in them for the different floors, minus the infill elements including *Roshans*, *Shubak*s, *Shaburas*, and entrance doors.

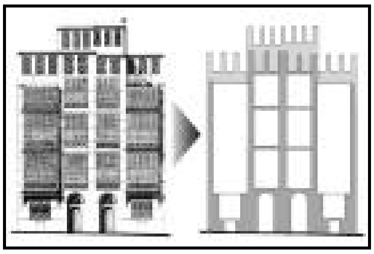

Figure 5. Step 1 for modeling: Constructing the 3D masses of the building

4.4.2 Analyzing and Classifying Elements

Analyzing the various architectural elements of the facades requires careful understanding of how these elements were constructed, and finding similarities between them. This step makes modeling similar objects faster and easier.

First, we classify the elements into major categories (Figure 6). This primary step suggests that similar elements require related modeling strategies. This step includes classifying the elements into the four main categories: *Roshan (R)*, *Shubak (S)*, *Shabura (B)*, and *Bab (D)*. Second, we classify the elements of same family. Third, bridging elements from different categories can facilitate easier or faster modeling. Defining these components and understanding variations saves time and make the modeling easier than modeling each element separately.

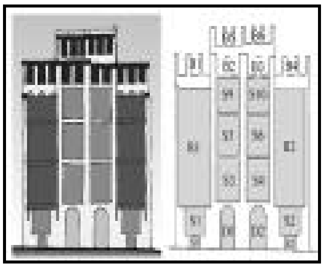

Figure 6. Step 2: Analyzing and classifying the elements

4.4.3 Modeling the Elements (Roshan, Shubak, Shabura, and Bab)

Each unique element requires a special modeling strategy, and similar elements may share a related modeling strategy. We show here a strategy of modeling the *Roshan* as an important architectural element (Figure 7).

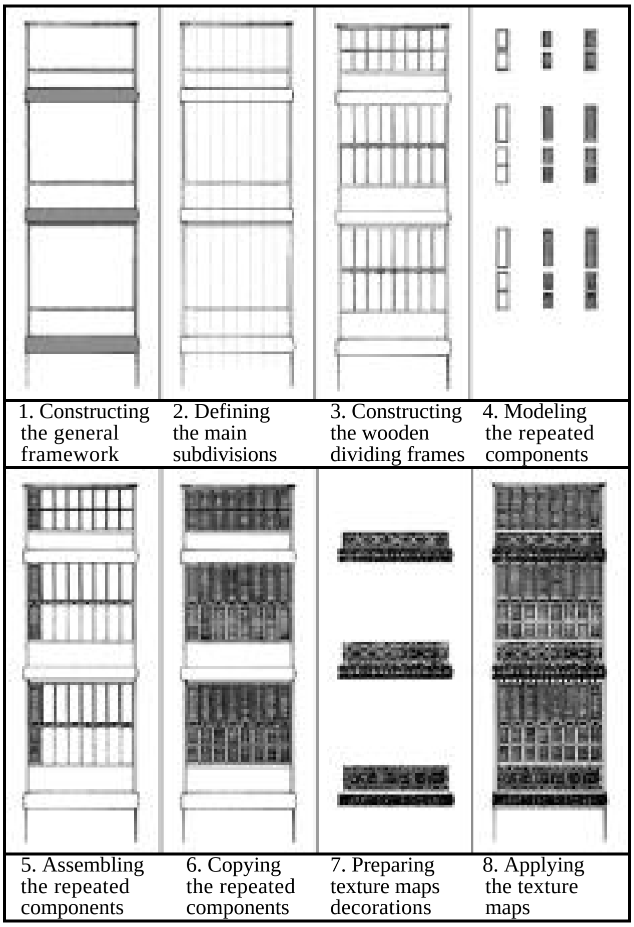

Figure 7. Step 3: Matching the construction process of the elements (*Roshan* Example)

The first step is to model the main wooden frame work. Next the subdivisions are modeled, including the three main parts of the wooden windows. After that, the modeler makes one 3D model of each repeated component. Finally, the modeler will use these basic components to assemble the whole window.

4.4.4 Assembling the Elements of the Structure in Sequence

This final step in the process ensures that every element of the facade is located correctly. This step is related to the first step. If the first step, constructing the main structure of the building with elements' openings, is done correctly then this step will be easy and fast.

It is important to determine the insertion point of each component (Figure 8). This allows controlling the placement of each element. The reference point should be described in the classification stage, in order to make this stage easier.

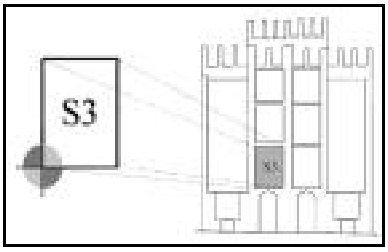

Figure 8. Step 4: Assembling the elements into their place

5. Example: Applying the Modeling Strategy of a *Roshan*:

The following case study shows using the strategies in modeling a *Roshan*. We choose the *Roshan* as an example, because it has been considered historically the most famous architectural element of the facades of the historic buildings in Makkah. The *Roshan* reflects many cultural, structural, and environmental factors that affected the construction process of this element.

In this example, (Figure 9) the block technique was the driving method to construct the whole model. "Block" objects allow adjusting parameters of different dimensions of an element (when inserting to location) to compose variations of the same element. This technique allowed the modeler to define the basic components of the *Roshan.* While following the steps of modeling, in each step the geometric models of these components were constructed. This includes drafting the two dimensional profiles then transferring them into 3D objects. These objects were controlled by the rules in order to ensure accuracy. Similar components at various locations were constructed once, then used many times.

The modeler analyzed the *Roshan* into its primitive components. These components were constructed into their 3D model format and saved as a block. Then, different components were assembled into their proper location, following the *Roshan* rules by adjusting dimensions from the existing block.

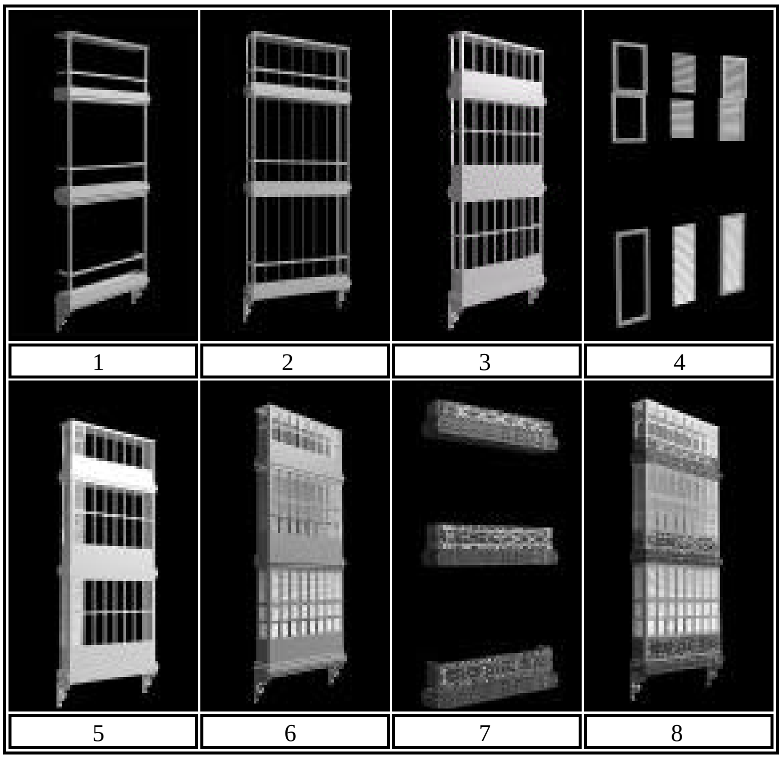

Figure 10. Example 2 (modeled by Fakhri Bukhari)

6. Discussion and Future Work

We have developed a strategy for CAD modeling historic buildings in the city of Makkah. This includes three important related issues: 1) Understanding CAD modeling principles and operations; 2) Understanding the design and construction process of the class of buildings that we are dealing with; 3) Developing modeling strategies through matching the design and construction process; then 4) Applying, testing, and modifying these strategies.

The accuracy in our modeling process has been achieved by two main approaches. First, matching the design and construction process, the model gets more precision through matching how different elements were constructed. Second, following the rules that controlled the design and the construction of these elements provides more accurate digital modeling of the details.

In future work we aim to apply similar techniques at a macro scale to record the urban form in the city of Makkah. An integration of geographic information systems (GIS) and computer aided design (CAD) would provide a richer urban documentation. In addition, we seek a better understanding of managing and integrating micro (architectural) and macro (urban) systems for heritage recording purposes. This includes developing new concepts, tools, and methods to streamline the digital recording process.

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This paper is abstracted from (Koshak, 97) Master of Architecture thesis, University of Colorado at Denver.

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