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Regenerating traditional houses facades of old Mosul city by Shape Grammar

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Abstract

The urban facades of the traditional dwellings in the old city of Mosul are part of a dense structure of the homogeneous urban fabric. These facades are characterized by a distinctive architectural style that gives a sense of place and local identity. Their design depends on the organization of architectural elements in syntactic characteristics, which are restricted by topological, geometrical, and dimensional relationships that responded to social, technical, and environmental requirements. Those restrictions made a special style in the local architecture that reveals the social and cultural influences of the residents. Shape Grammar is an effective system in analyzing the architecture structures because it combines both morphological and dimensional values In the analyzing.

Shape Grammar regulates the architectural elements and their relationships in specific rules to conserve these traditional facades and their values. In the conservation of built heritage, organizing these elements and defining their rules is essential. This paper seeks to derive the standard and parameters of shape grammar to regenerate the damaged traditional facades of Mosul Old City as a case study (especially after the great damage as a result of the last war in 2017), by determining the rules that restrict the relationships and the transformations in the structures of these elements in the virtual reconstruction of urban heritage according to principles of traditional architecture. The research analyzes and classifies the elements of the case study to obtain its shape grammar that enables the regenerating of these facades in the same architectural language and characteristics.

Keywords
Facade regeneration, Local architecture, Mosul Old City, Shape Grammar, Urban facades.

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1. Introduction

Most of the traditional houses in the Mosul old city – MOC date back to 1850, these units are characterized by a unique style as a result of climatic, religious, cultural, economic, and construction requirements (Al-Tayib, 2008). This traditional architectural style depends on its architectural language and elements (such as entrances, windows, and other) by syntactic rules in Topological systems to achieve unity and aesthetic as well as privacy and functional competence that distinguish it as a style with a distinct identity, which reflects the thought of society (Maan & Idrees, 2013). Traditional housing shares basic components include the courtyard, Iwan, rooms, corridors, and entrances. The idea of its planning depends on dividing the plan into functional parts that are linked to organizational relationships according to its function, the courtyard is the active part because it is the social space and the movement distributor in addition to its environmental function (Mustafa, Daizhizhong, & Hong, 2010). In general, these housing units share several characteristics, including:

- The housing units were organized in the urban fabric in a compact and organic composition (Dewachi & Ismaeel, 2010).
- Using the unity principle in the facades, which led to the coherence of the urban landscape by employing the repetition of the elements of the facade that include openings, entrances, details, and others, in addition to horizontal and vertical lines in a specific rhythm (Albotani & Alani 2010).
- Harmonious and specific relationships were used in urban facades to achieve climatic, social, and construction requirements and this is a unique feature for the vernacular architecture in Mosul, Which made it an integrated architecture at the exterior and interior scope in architectural and urban design (Albotani & Alani 2010)
- Gradient: By dividing the overall composition into harmonious parts to achieve the balance and the homogeneity in the mass, elements and details in the facades, this indicates the awareness in the design process (Albotani & Alani 2010)
- The traditional facades are distinguished by the variety of architectural treatments in addition to the variety of architectural elements, which gave the facade visually richness (Maan & Idrees, 2013).

Figure 1. *Top row scenes from the old Mosul before the destruction (Source: Researcher). The low row is destruction in some areas of old Mosul (Source: Profile Mosul, UN, 2016, p 46).*

Recently, MOC was severely damaged as a result of the military operations in 2016-2017, which led to the destruction of a large part of the urban fabric, amounting to 80%, and the damage ranged from destruction to partial damage for about 5,000 out of 15,000 housing units(Habitat, 2016) (Figure 1). Many Problems occurred to deal with the damaged parts of these buildings because of the absence of restrictions and rules that determine and restrict restoration operations led to deformation in the urban scene as a result of the intervention process by non-specialists, therefore, the importance of this study aims to determine the restrictions in the restoration as a Shape Grammar for these facades to preserving the urban facades, in addition to providing a database for the specialists in the reconstruction in MOC to preserve the local architectural language.

On the other hand, Shape Grammar was employed in many studies that dealt with language analysis of architectural productions due to its advantages to combining mathematical and morphological values in architecture, so Shape Grammar was used in several scopes of the built heritage as follows:

- Facades Scope: Traditional houses São Paulo(de Godoi & Celani, 2008) -Bali Traditional houses(-Di Angelo, Ferschin, & Paskaleva, 2013) - Traditional Greek Housing (Kitsakis, Tsiliakou, Labropoulos, & Dimopoulou, 2017) - The Brick patterns in Anatolia facades (Yavuz,2016).
- Plans Scope: Villa Palladio (G. Stiny & Mitchell, 1978) - Traditional Chinese houses (Chiou, 1997) - Traditional Turkish houses (Çağdaş, 1996), Traditional Damascene houses (Eilouti & Hamamieh Al Shaar, 2012) - Traditional Bosnia houses (Colakoglu, 2000) - Palladian villa, Malagueira houses, and Prairie housing (Benros, 2018) - Traditional Pol residences in Ahmedabad (Lambe-2019) - Traditional Suakin housing (AbdulRaheem , 2017) - Plans of Vernacular houses in Mazandaran (Yousefniapasha , 2019)
- Sections Scope: Traditional Taiwanese houses (Chiou & Krishnamurti, 1995) - Traditional Malay dwellings TMH in Malaysia (Said & Embi, 2008) .
- Masses Scope: Components of the Ottoman mosques (Şener & Görgül, 2008) , Components of heritage Churches (Tepavčević & Stojaković, 2013).

2. Shape Grammar

Shape Grammar is a production system that automatically generates 2D or 3D shapes based on a set of specific rules, invented by Stiny and Gips in 1972 as a production system that defines the rules of a set of designs. Its cognitive importance is embodied in the analysis of the architectural structures and its reproduction in the same language. Shape Grammar is similar to grammar rules, and it is used in architecture as a tool for classification, characterization, generation, and evaluation of the productions in terms of morphological, functional, and structural characteristics of the same architecture, in addition to being a tool for creating new designs(G. Stiny & Mitchell, 1978) . Shape Grammar does not seek to reproduce the architecture language in all its detail, but rather describes it in its essence, and aims of forming other designs in the same architectural language(de Godoi & Celani, 2008).

2.1. Shape Grammar structure

The basic elements of Shape Grammar include (G. Stiny, 1980) :

a) Shapes (S): represent a specific set of configurations, which represents an arrangement of lines in two or three dimensions.

b) Rules (R): A specific set of Rules in the form $\alpha \rightarrow \beta$, which consists of an alphabet of shapes and a set of spatial relationships between shapes.

c) Initial Shape (IS): The Shape to which the rule is applied.

d) Labels (L): Represent a group of signs that restrict the application of the rules, including:

- State Labels: Control the sequence of applying the rules, and the number of repeating the rule.

- Spatial Labels: Control where and how rules should apply by adding Labels to the shapes, and it owns its specific Position defined by a point.

2.2. Types of Shape Grammar

2.2.1. Standard Shape Grammar

This type consists of two parts separated by an arrow that points from left to right, the left side (LHS) represents the initial shape and its labels, and the right side (RHS) that defines the rule to generate the shapes, these rules deal with topological relationships that determine design characteristics regardless of the size of those parts (G. N. Stiny, 1985).

2.2.2. Parametric Shape Grammar

This type depends on parameters, which lead to the diversity of shapes that have the same topological characteristics that differ in dimensions. Specific length and angle parameters are used for expanding and diversifying secondary shapes groups. The parameter inside a rule is the key to generating many derivative shapes, and the number of times the rules are used depends on the complexity of the shape (Sayed, Ugail, Palmer, Purdy, & Reeve, 2016) .

3. Hypothesis, objectives, and methodology of the research

3.1. Research hypothesis

The traditional dwellings units in MOC were built cumulatively at different periods during 200 years, and the construction of these units was carried out by constructional, social, economic and cultural requirements which reflected as restrictions and rules in the construction which led to unify the urban scene and form modularity in the architectural language Local. These restrictions can be determined as a Shape Grammar to rebuild the old city in the same architectural language to preserve the city's identity.

3.2. Research objectives

Defining the local architectural language for traditional housing in Mosul TMHo by Shape Grammar to create a methodology that generates several alternatives s according to the local language.

1. Analyzing the structure of facades by determining the restrictions of elements in the traditional façades.

2. Formalizing the local architectural language and its principles to represent the style of dwelling units.

3. Establishing a knowledge and information base for future studies related to the adaptation and development of housing units in Mosul by contemporary requirements.

3.3. Research methodology

The study adopted the morphological, mathematical, and Topological analysis of the traditional facades to extract typical rules and restrictions by Shape Grammar as follows:

1. Data collection from documents, records and field documentation by the researcher.

2. Analyzing the information and data.

a) Determining the into functional, spatial, and morphological.

b) Classifying the architectural elements of the facades into nine main categories.

3. Analyzing the classified elements to derive the rules according to:

a) Morphological Analysis to determine the evolutionary series of genes for each element.

b) Topological Analysis to determine the rule that controls the placement of the element in the facade and its relationship with other elements.

c) Mathematical analysis to determine the parameters of dimensions, location, and proportions for each element.

4. Creating a database that includes the classified elements and their rules.

5. Applying: Evaluating the ability of Shape Grammar to generate designs belonging to the local architectural language by creating an algorithm (Flowchart) to determine the steps for applying derivative rules.

4. Applying the methodology

4.1. Data collection

Two types of data were collected for analysis:

1. Data of the architectural elements: About 4000 samples were selected for the architectural element to extract the evolutionary gene of the elements, and their components.

2. Data of the facades: About 250 facades were field documented by photography using a digital camera, with describing and recording the elements information to derivate Shape Grammar for topological analysis.

4.2. Classifying the architectural elements

The ability to perceive patterns is through categorizing elements with similar syntax into groups, and these elements represent the vocabulary for the architectural language (oxford, 2010). The elements will be categorized into major groups based on the concepts of mass, space, and surface, so the element has a measurable physical meaning (Norberg-Schulz & Schulz, 1966). Accordingly, the architectural elements in the case study are categorized into the following:

1. The Wall: The walls are the main element that is as a background for other architectural elements, and it is distinguished by different heights and proportions according to climatic and functional purposes.

2. Entrance: It is the most important element in the urban facades, and it is distinguished by unique structures and rich details, its shapes are varying from simple to complex according to the details and using various techniques in the construction.

3. Opening and Windows: The shape and Position of windows are related to the level of the interior space according to the various functions that include lighting and ventilation, in addition to using various techniques in construction.

4. Frieze and Cornice: A prominent element (strip) formed according to a specific geometry along the façade.

5. Skirting Marble - Madamic: An element covering the lower part of the exterior wall of the facades for covering the joint between the wall and the floor to protect the walls.

6. Arches: A structural element that is repeated on the facades of buildings, its main function is to carry the prominent parts of the floors, in addition to its aesthetic functionality.

7. Corners: This element is located in the buildings corner; its function is to connect the two facades of the building.

8. Corbels: It is an element that takes many forms and works as a structural element that supports the extension above, in addition to its aesthetic functionality.

9. Shanasheel: An extension (addition) on the top floor. It has aesthetic, climatic, and functional roles, working to handle the acute angle in spaces.

4.3. The analysis phases

4.3.1. Genotype analysis

The morphological characteristics can identify the architectural language to produce models that belong to the same language (Bonta, 1980). The structure of the architectural language is determined by two parts, the first is the Vocabulary of the language and the second is the set of Rules that determined the spatial relations (Koning & Eizenberg, 1981). In general, the (Vocabulary) visual shapes can be classified in terms of characteristics and topological relationships such as convergence, similarity and continuity, and the similarity is two types (Cha & Gero, 1998):

1. Phenotypic Similarity: It is based on the physical characteristics of the shape.

2. Structural Similarity (deep): It is based on the relational structure.

4.3.2. Analysis element as a structure

To analyze the structure of architectural elements, it must be divided into components with properties that distinguish them from others, then define the relationships between them, the fragmentation process must define the components, to a certain extent to form generic forms, by this way, the formal organization can be understood and perceived, and this component can also be divided into elements with secondary relationships to standardize the component and its relationships into higher-ranked components .

In this part of the study, the detailed components and components will be classified according to the evolution lines of the element. The beginning of the line represents the main components, and the more complicated element is forming by adding secondary components to it. The primary components are used to design new models belonging to the same group.

Then the elements are classified in a hierarchical way that begins from the simplest (which includes the primary components) to more complex (which includes the secondary components) to determine the evolutionary line of the gene for each element, and categorize them into patterns that share a basic characteristic, The analysis is carried out by fragmenting the element into main components (Figure 2).

After the analysis process, the genotype of each element will be determined sequentially: Entrances, Arches, Madamics, Friezes Opening and Windows, The Corners, Shanasheels, and Crobles (Figure 3).

4.3.3. Relational analysis

The architectural facade contains components (elements) that are organized in a specific system of a conceptual or physical nature, these elements are interconnected with each other by mutual relations, in addition to their relationship with the whole with other relationships, and these relations are subject to coordinated rules and foundations to achieve the principle designer (Abel, 2007).

The term Relation refers to the organization of the elements, and these relationships are either 3D (Tri-Dimensional), which depend on Masses and spaces, or are 2D (Bi-Dimensional), which determine the relationship in a plane to analyses of the facades (Abid Yahya Al-Hiali & Al-Tayib, 2006). In "Intention in Architecture", Schulz classified relationships into Topological Relation, and Euclidean Relation (Norberg-Schulz & Schulz, 1966):

a) Euclidean Relation: These relationships are based on concepts of quantitative engineering, and they organize the relationship between the elements in three ways, organizing according to a reference point, organizing according to the line, and organizing according to the coordinates system. These relationships analyze the principles of Centralization, Axiality and Coordinates (Norberg-Schulz & Schulz, 1966).

b) Topological Relation: This relationship is based on non-quantitative engineering concepts, and it is a type of mathematics that analyzing the Position of a thing according to other things,

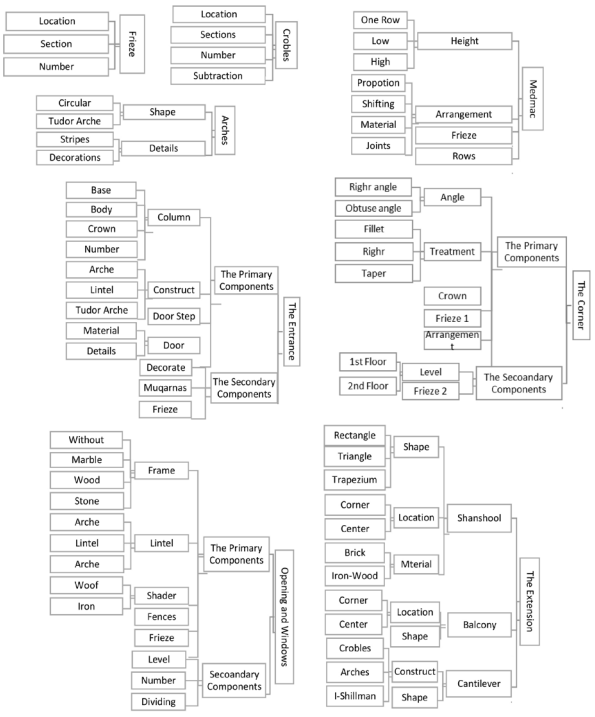


Figure 2. *The primary and secondary components of the architectural elements in the case study (Source: The Researcher).*

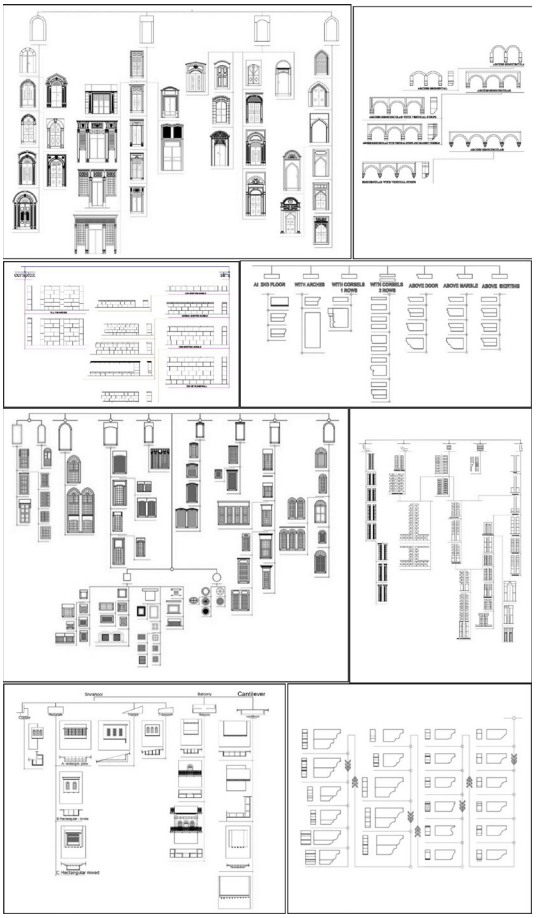


Figure 3. *The Genotype of the elements from left to right in sequence: Entrances, Arches, Madamic, Friezes Opening and Windows, The Corners, Shanasheels, and Crobles (Source: The Researcher).*

without dealing with size or distance. These relationships deal with spatial characteristics regardless of their type or geometric shape (Schulz, 1996, p. 141).

Thus, the analysis of the elements will take place on two levels, as follows:

1. Euclidean Relations: This type of relationship will be used to derive the rules for placement of architectural elements in the facade using the coordinate system in two levels, (H) Horizontal, and Vertical (V) by parameters for each element as follows:

A. Vertical Parameter V: This parameter determines the position of the element along the facade (on width W), in three basic Position:

- Corner Position: Determined by the VC parameter.
- Center Position: Determined by the VCe parameter.
- Mid Position: Set to the VM parameter.

B. horizontal parameter H: This parameter determines the horizontal element level on the facade (on the height H), in the following locations:

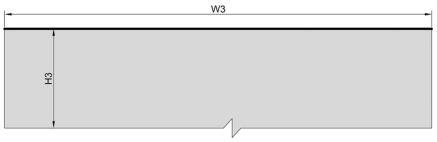
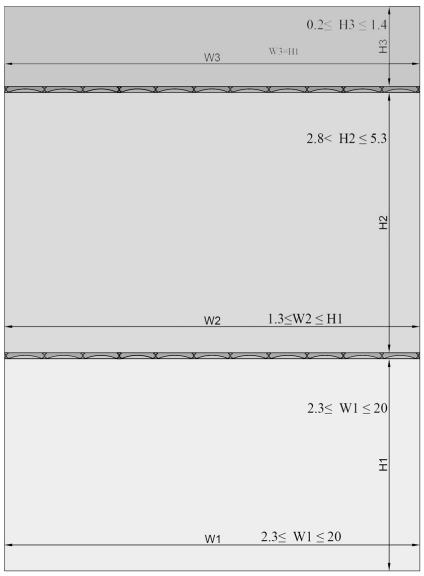
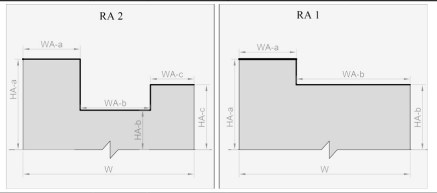
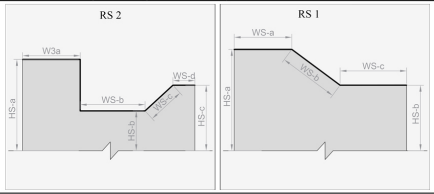
- Under the road level: It is determined by the parameter H-, it is specific for the entrances and the basement windows.
- With the road level: It is determined by the parameter H0, it specific is for the entrances and the basement windows.
- Above the road level: It is determined by the parameter H +for all elements that include a range of values to determine the level of the element in the floor level.

4.4. Deriving Shape Grammar

4.4.1. Euclidean Shape Grammar of the facade

The process of analyzing the facades was done mathematically in two phases, the first to determine the facade proportions of the ground, first floor, and the parapet, followed by defining the skyline for the building .then the parameters were defined, which included two types, the first determines the width of the facade represented by the parameter RW and the other determines the height of the floor that is rep-

Table 1. *The Euclidean Shape Grammar of the facade.*

Facade Proportions					Façade Sky Line				
S	Floor	Dim.	Rule	Value	S	Type	Dim.	Rule	
1	Ground Floor	Width	• R W1: 2.3 ≤ W1 ≤20	2.3-20	1	Straight	Width	• R W3: W3≡W1(W2)	
		Height	• R H1: 2.7 ≤ H1 ≤4.1	2.7-4.1			Height	• R H3: H3	
2	First Floor	Width	• R W2: 1.3 > W2 ≤ W1	1.3-H1					
		Height	• R H2: < 2.8 H2 ≤ 5.3	3.0-5.3					
3	Parapet	Width	• R W3: W3≡W1	H1	2	Right-Angled	RA1	Width	• WA1: WAa+ WAb
		Height	• R H3: 0.8 ≤ H3 ≤1.2	0.8-1.2				Height	• HA1: HAa< HAb
							RA2	Width	• WA1: WAa+ WAb
								Height	• HA1: HAa> HAb
									
					3	Sloped	RS1	Width	• WS1: WSa+ WSb+ WSc
								Height	• HS1: HSa< HSb
							RS2	Width	• WS2: WSa+ WSb+ WSc+ WSd
								Height	• HS2: HSa< HSb (<HSc)
									

resented by the parameter RH. Shape Grammar is formulated based on these parameters and their range of values (Table 1).

4.4.2. Euclidean Shape Grammar of the element placement

In this part of the study, the facades were analyzed mathematically and morphologically to determine the placement of each element in the facade (Table 2). Two types of parameters were used to determine the placement of the element, the first is the H parameter that determines the horizontal placement, and the second is the V parameter that determines the vertical placement. Each parameter symbolizes by a code to refer a specific element such as (Eh), which refers to the horizontal placement of the Entrance element.

4.4.3. Relational Shape Grammar (Topological analysis)

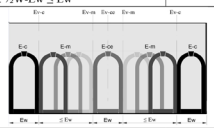
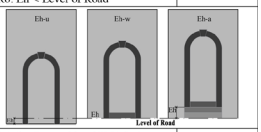
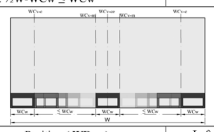
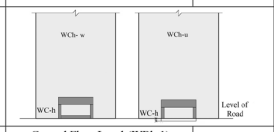
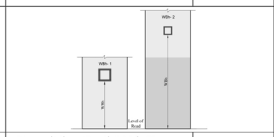
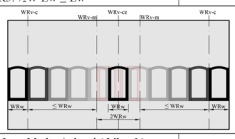
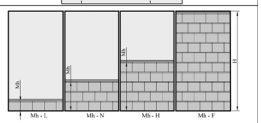
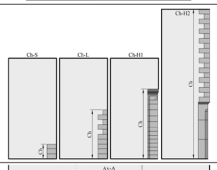
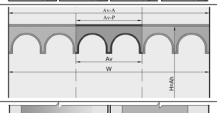
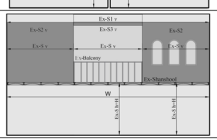
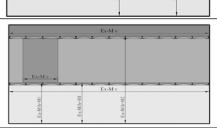
In the relational analysis, the priority of placement the elements in the facade was determined in sequence to formulate the grammar of its relationship to the other the element to prevent conflicts in applying of these grammars, So the priority of the elements was determined in sequence as follows, Entrance, Opining -Window, Extension, Madamic, Frieze, Corner, arches, and finally Corbels (Table 3).

4.5. Determine the priority of applying Shape Grammar

To apply the derived Shape Grammar, an algorithm will be determined to prioritize the applying of grammar to avoid the clash between grammars (Figure 4). These grammars are applied in thirteen stages, as follows:

- The First Phase: It begins with the initial shape by determining the facade proportions by its parameters.
- The Second Phase: Inserting the Entrance by applying its rules.
- The third phase: Inserting the Corners by applying its rules, if any.
- The Fourth Phase: Applying the rules of Madame, if any.
- The Fifth Phase: Inserting Windows and Openings according to its types, the cellar windows, the bath windows, and the room windows.

Table 2. *The Euclidean Shape Grammar for determining the placement of the architectural elements in the facade (Source: The Researchers).*

Element		Vertical Level	Value	Horizontal Level	Value
Entrance (E)		• Corner Position (Ev-c) R1: W ≤ 3* Ew	Left Right	• Under the road level (Eh-a) R4: Eh > Level of Road	0.15-1.0
		• Centre Position (Ev-ce) R2: ½W ≡ ½Ew	½ W	• With the road level (Eh-w) R5: Eh ≡ Level of Road	0.0
		• Mid Position (Ev-m) R3: ½W-Ew ≤ Ew	½W-Ew	• Above the road level (Eh-u) R6: Eh < Level of Road	0.15-0.4
					
W. Cellar (WC)	W. Cellar (WC)	• Corner Position (WCv-c) R7: W ≤ 3* WCw	Left Right	• Under the road level (WCh-u) R4: Eh > Level of Road	0.2-0.4
		• Centre Position (WCv-ce) R8: ½W ≡ ½ WCw	½ W	• With the road level (WCh- w) R5: Eh ≡ Level of Road	0.0
		• Mid Position (WCv-m) R9: ½W-WCw ≤ WCw	½W- WCw	---	--
					
W. Cellar (WC)	W Bath (WB)	• Corner Position (WBv-c) R12: W ≤ 3* WBw	Left Right	• Ground Floor Level (WBh-1) R15: 1.7 >WBh ≤ 3.2	1.7-3.2
		• Centre Position (WBv-ce) R13: ½W ≡ ½ WBw	½ W	• First Floor Level (WBh-2) R16: >4.3 WBh ≤ 10	4.3-10
		• Mid Position (WBv-m) R14: ½W- WBw≤ WBw	½W- WBw	---	
					
	W Room (WR)	• Corner Position (WRv-c) R1: W ≤ 3* Ew	Left Right	• Ground Floor Level (WRh-1) R21: 1.0 >WRh ≤2 .8	2.8-1.0
		• Centre Position (WRv-ce) R2: ½W ≡ ½Ew	½W	• First Floor Level (WRh- 2) R22: 4.3 >WRh ≤ 10	4.3-10
		• Mid Position (WBv-m) R3: ½W-Ew ≤ Ew	½W- WRw	---	---
					
Madamic (M)		• Low Madamic level (Mh – L) R23:1Row≤ Mh> 2 Rows	0.3-0.7		
		• Normal Madamic level (Mh- N) R24: Mh = 3 Rows	1.0		
		• High Madamic level (Mh- H) R25: 4Row ≤ Mh > 5Rows	1.3-1.6		
		• Complete Madamic level (Mh- N) R26: Mh = H	H		
Frieze (F)		• Frieze of Madamic (Fh – M) R27: Fh= Mh	H-0.3		
		• Frieze of Entrance (Fh – E) R28: Fh= Eh	Eh		
		• Frieze Down Extension (Fh- EX1) R29: Fh= Exh1	Exh1		
		• Frieze above Extension (Fh- EX2) R30: Fh= Exh2	Exh2		
		• Frieze of Parapet (Fh – P) R31: Fh= Ph	Ph		
Corner (C)		• Simple Corner (Ch-S) R32: 1 Unit ≤ Ch >2 Unit	0.3 0.6-		
		• Low Corner (Ch-L) R33: 3 Unit ≤ Ch >6 Unit	0.75 1.0-		
		• High Corner (Ch-H1) R34: 7 Unit ≤ Ch > H1	2.2 H1-		
		• Complete Corner (Ch-H2) R35: H1≤ Ch > H2	H1-H2		
Arches (A)		• Partial Arches (Av-P) R36: ½W ≡ ½ Av	½W		
		• Complete Arches (Av-A) R38: Av=W	W		
		• Ground Floor Level (Ah-F) R39: Ah=H	2..5-4.4		
Corbels (R)		• Arches (Rv) R40: Rv ≡Exv (Rectangle EX) R41: Rv<Exv (Triangle EX)	W- Exv		
		• Ground Floor Level (Rh) R42: Rh = Exh	2.4-5.7		
Extensions (Ex)	Shanshool	• Extensions (Ex-S v) R43: Ex-v=W (Along) R44: Ex-v<W (Side) R45: ½Ex-v≡½W (Central)	W <W ½W		
		• Ground Floor Level (Ex-S h) R46: Ex-h = H	2.7-5.1		
	Masses-Floor	• Partial Extensions (Ex-Mp v) R48: Ex-v<W	<W		
		• Along Extensions (Ex-Ma v) R49: Ex-v=W (Floor) R50: Ex-v=W (Parapet)	W		
		• Extensions Level (Ex-M h) R51: Ex-h= H	2.7-10.2		

- The Sixth Phase: Inserting the Frieze within the ground floor by applying its rules

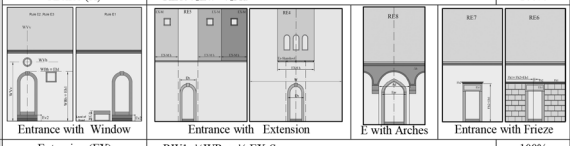
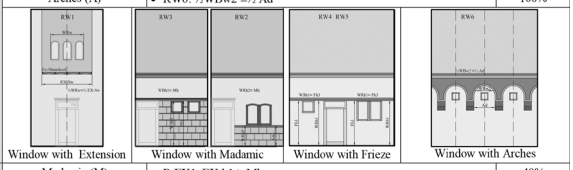
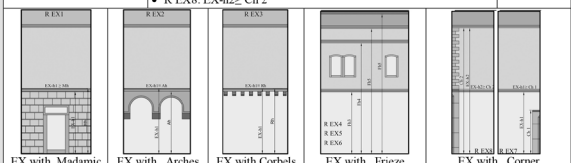
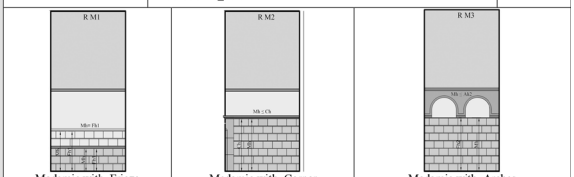
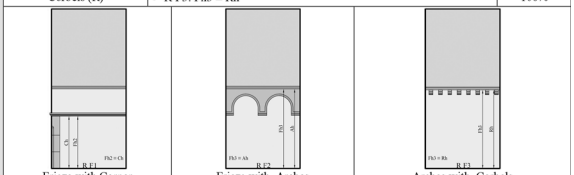
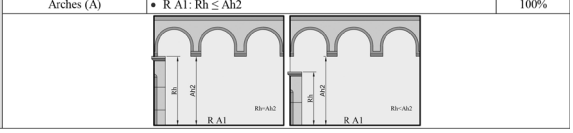
Either:

- The Seventh Stage A: Inserting the Extension (Parapet or first floor) by its parameters.

Or:

- The Seventh Phase B: Inserting Arches, if any.
- The Eighth Phase: Applying the rules of the Corbels, if any.
- The Ninth Phase: Determining the proportions of the first floor by the width and height parameters.
- The Tenth Phase: Inserting the extension, which includes Balconies, Shanshools, and Masses.
- The Eleventh Phase: Inserting the parapet.
- The Twelfth Phase: Determining the skyline of the facade by determining its type.
- The Thirteenth Phase: termination by erasing all labels and signs.

Table 3. *The Relational (Topological) Shape Grammar for the elements.*

Element			Rules	%
Entrance (E)	Window	Cellar Window	• RE2: if Eh1>Level of Road, then WCh≡ Level of Road	100%
		Bath Window	• RE2: if Eh2 > Level of Road, then WBh ≡ Eh1	80%
		Ventilation Window	• RE3a: = WVv= ½ WVv ≡ ½ Ev • RE3b: = WVh= Eh + (0.1-0.6)	100%
	Extension	Shanshool-Balcony	• RE4: if EX-S w< W, then EX-S h≡ Eh	100%
		Mass (Bath)	• RE5: EX-M h ≠ Eh	100%
	Frieze (F)		• RE6: Fh1≡ Fh2≡Eh1 • RE7: Fh2≡Eh1	100%
	Arches (A)		• RE8: ½Ew≡ ½Ad	100%
	 Entrance with Window; Entrance with Extension; E with Arches; Entrance with Frieze			
Window and openings (W)	Extension (EX)		• RW1: ½WRw≡½ EX-Sw	100%
	Madamic (M)		• RW2: WRh2≡ Mh • RW3: WBh1≡ Mh	50%
	Frieze (F)		• RW4: WRh1≡ Fh3 • RW5: WBh1≡ Fh3	85%
	Arches (A)		• RW6: ½WBw2 ≡½ Ad	100%
	 Window with Extension; Window with Madamic; Window with Frieze; Window with Arches			
Extension (EX)	Madamic (M)		• R EX1: EX-h1 ≥ Mh	40%
	Arches (A)		• R EX2: EX-h1≡ Ah	100%
	Corbels (R)		• R EX3: EX-h1≡ Rh	100%
	Frieze (F)		• R EX4: EX-h1 ≡ Fh3 • R EX5: EX-h1<Fh4 >EX-h2 • R EX6: EX-h2≡ Fh5	100%
	Corner (C)		• R EX7: EX-h1≥ Ch 1 • R EX8: EX-h2≥ Ch 2	100%
	 EX with Madamic; EX with Arches; EX with Corbels; EX with Frieze; EX with Corner			
Madamic (M)	Frieze (F)		• R M1: Mh≡ Fh1	100%
	Corner (C)		• R M2: Mh ≤ Ch	100%
	Arches (A)		• R M3: Mh ≤ Ah2	100%
	 Madamic with Frieze; Madamic with Corner; Madamic with Arches			
Frieze (F)	Corner (C)		• R F1: Fh2 ≡ Ch	100%
	Arches (A)		• R F2: Fh3 ≡ Ah	100%
	Corbels (R)		• R F3: Fh3 ≡ Rh	100%
	 Frieze with Corner; Frieze with Arches; Arches with Corbels			
Corner (C)	Arches (A)		• R A1: Rh ≤ Ah2	100%
	 R A1; R A1			

4.6. Applying Shape Grammar on the case study

Finally, to test the accuracy of the derived Shape Grammar, their rules were applied to generate a facade that belongs to the local architectural language of the ancient Mosul depending on the algorithmic scheme that determines the phases of applying these rules. The position and sequence of applying the rules in the facade were determined by State and Spatial Labels (Table 4).

5. Results

The study presented about 120 architectural elements distributed in eight groups which represent the vocabulary of the morphological formation of the architectural language including Entrances, Windows, Extensions (Shanshools, Balcony, and Cantilever), Crobles, Corners, Friezes, Madamic and Arches.

Also, 120 rules were derived which represent restrictions and rules of the facades, including three basic types, the first is the rules to determine the proportions of the facades and it contains 15 rules for the ground floor, the first and the parapet, and it has two basic parameters, the height, and the width parameter, the second is the rules of placement of the elements in the facades which contains 48 rules with 19 Parameter distributed on the eight-element, and the third is the relational rules to determine the relationship between the elements with 30 rules and 19 Parameter.

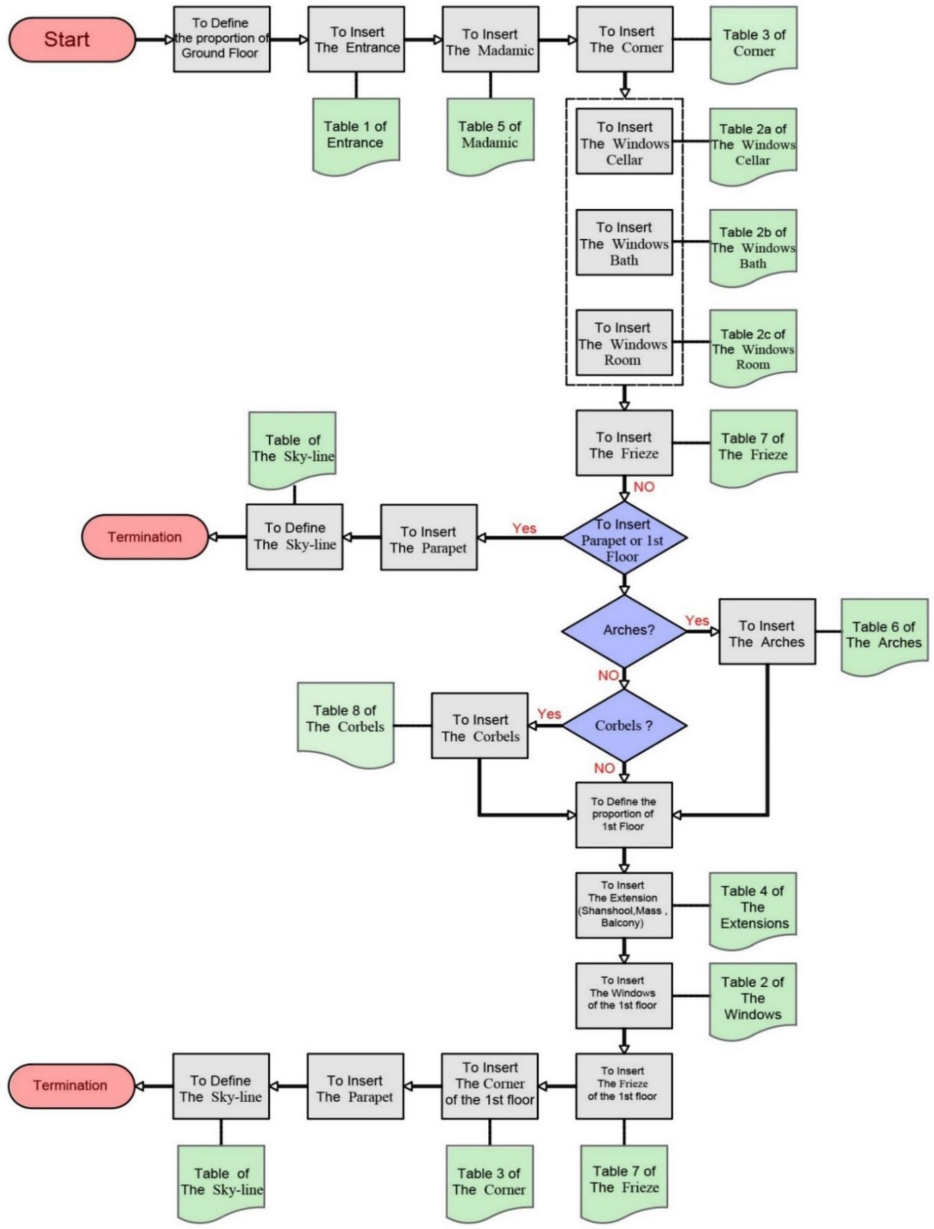


Figure 4. *Algorithm for applying the Shape Grammar of the facades in the case study (Source: Researcher).*

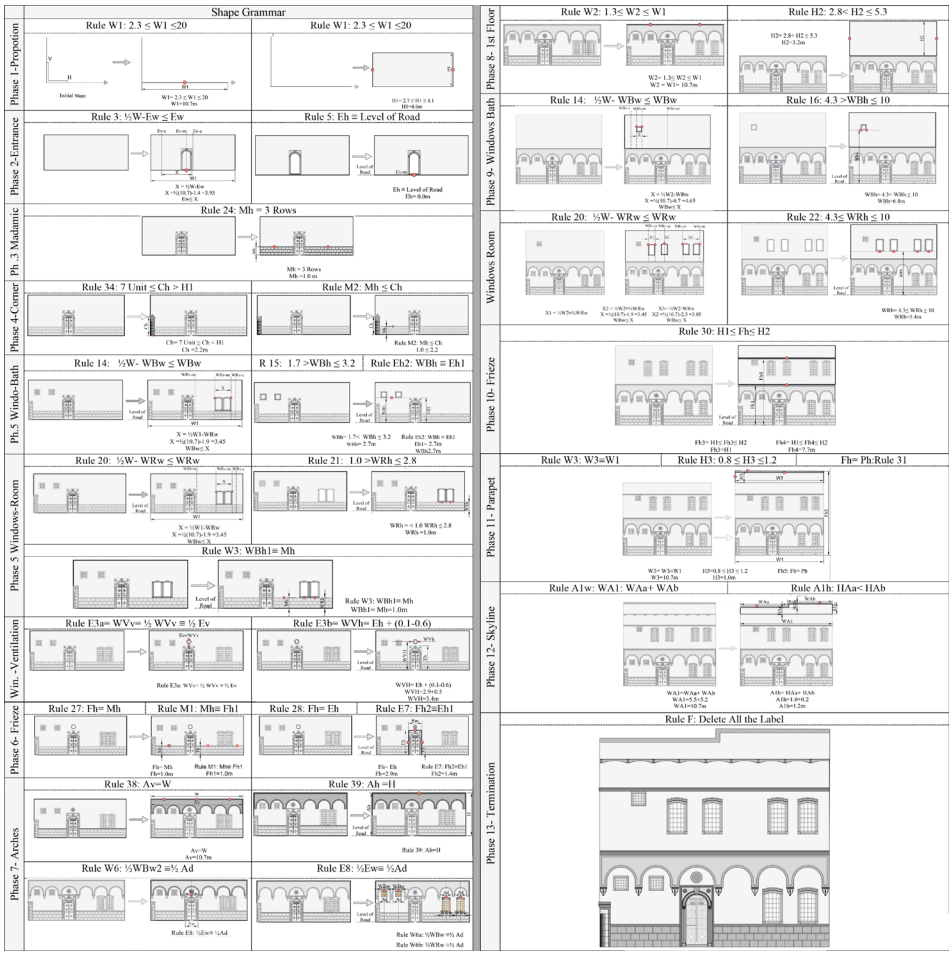
6. Discussing the results

The percentage of the element placements in the facade was calculated to verification of the mathematical and Euclidean relations of derived Shape Grammar of the architectural elements, then discuss this grammar and restrictions to determine the functional, constructional, and climatic requirements (Figure 5).

6.1. The proportions of the facade

- The width of the facade: The width of the facade ranges between (2.3-20) m, this great diversity in the width of the facades indicates the irregular planning of urban because of the organic planning in the city.
- The height of the facades: The variation of the height is related to the variation of width, so the skyline of the old Mosul is diverse and rich.
- The proportions of facade:
- For large façades, the proportion of the width of the façade to the height is (5:1-4:1), While the proportion of small facade range between (1:3-1:2).
- The facades characterized with a human scale, because the facades with a width less than (12) m have reached (91.4%), and the height did

Table 4. *Applying the Shape Grammar in the case study.*



not exceed (8) m by (91.5%), also the height to width ratio ranges (1: 3.22) of the small facade to (1: 0.912) as a maximum which indicates the human scale in these facades.

6.2. Entrance

- The percentage of the facade that included one entrance about (96.6%), while secondary entrances were added to other facades as a result of the modification the plan of the housing according to new functional purposes.
- The entrances that are located on the central axis of the façade is about 16%, which indicates an awareness of the principles of symmetry in the design, while the ratio of the corner entrances is 22.8% due to the boundaries of the land and the restrictions of functions. while the majority of the entrances are in mid-position between the corner and central axis.
- The horizontal position of the entrance: The entrance level is related to the level road of the alley, some of the entrances are below the road level due to the paving of the road that raises its level which led to removing some entrances due to non-functional efficiency which were replaced by new entrances.

6.3. Windows

It includes three types.

6.3.1. Ventilation windows

These windows are used in the bathrooms that are located often on the ground floor because it requires plumbing services that are difficult to provide on the upper floors.

- Vertical position: Most of these windows are located in the mid-position of the facade, then the corner position.
- The horizontal position: These windows are found in 58% of the facades and distributed in the ground floor by 48%, and the first floor by 14.2% (in the bathroom mass), so these windows are often on the ground floor close to the entrance or the cor-

ner by the internal configuration of the spaces to achieve privacy.

6.3.2. Cellar window

Its presence about (8.5%) out of the total housing in the Mid position, its height ranges between (0.4-1.6) m.

- Vertical location: Most of these windows are located on the mid-position of the facade, also located in the center with if these windows are along the facade.
- The horizontal position: The lower level of these windows is usually above the road level, but sometimes it is lower than it because of the paving works.

6.3.3. Room windows

The percentage of facades without any windows is (4.2%), most of the room Windows located on the first floor by (70%), while the ground floor contains this type of windows by (30%). This varied ratio between the two-floor attributed to privacy.

- The Vertical position: A small percentage of windows is located in the corner position due to the difficulty in employing these parts in the plan as rooms, most of these windows are located in the Mid position of the facade.
- The Horizontal position: The level of these windows on the ground floor is between (1-2.8) m, and the windows are enclosed for protection and privacy purposes, while the level of the windows of the first floor is between (4.3-10) m.

6.4. Madamic

It is found in (45.4%) of the facades, and its height ranges from simple Madamic with two rows of stone with a height of (0.3) m to the Madamic that completely covers the facade with a height of the floor.

6.5. The arches

Its presence is correlated with the extensions as a structural element, (2.1%) of the facades are contain the arches, its height is between (2.5-4.4) m.

6.6. Extensions

The facades that contain Extensions are about (65.2%) as follows:

- Shanshool: It is the most important element in the extensions of the facade. It extends over the façade by 40% or partially over the entrance by 60%.
- The Balcony: it is found on the facades overlooking a relatively wide alleyway, and it is located in the central position above the entrance.
- The Masses: mostly employed as a bathroom, and it is located in the corner position away from the entrance.

6.6.1. The structural elements

The structural system is related to the extensions as a structural and decorative determinant, this was reflected in the three types of extensions as follows:

- Crobles: their presence is related to small extension relatively by10%.
- Arches: these elements are employed to load the fully or partially floors and the Arches are located mainly above entrancesby10% of the total extension.
- Beams: This beam is locally called "Shilman", it is made of iron in I section, this Beams are the most used structural system by 83% in the balconies, Shanshool, floors, and other extensions.

6.7. The corner

They are found in the corner facades, their height ranges from the simple corner (0.3) m to the high corner that has the same height of the ground floor or the first floor.

6.8. The frieze

The Frieze is distributed on the ground floor by (54.2%), and on the first floor by (27.5%). The reason for the high presence of Frieze on the ground floor is for two reasons, the first is its association with the Madamic that is only on the ground floor, and the second is a confirmation of the horizontal rhythm of the facades.

6.9. Crobles

This element is located in some facades as a structural and decorative element and its height is the same as the height of the first-floor ranges between (2.4-5.7) m.

6.10. Facade boundaries

- The Skyline: There are several types of the skyline of the facades, some of which are related to the straightness of the alley, and the other is related to the functional characteristics as follows.
- The straight skyline: it is found in most dwellings at a rate of 65.8%.
- The skyline with a right angle: the change in the horizontal skyline is attributed to changing in the height due to the presence of prominent elements, or because of the sloping alley.
- The diagonal skyline: this type of skyline due to the stairs element and its ratio is about 7%.
- The Ground line: Most façades have a level close to straightness by 78%, and if the alley with a sloppiness, the ground of the alley is divided into steps, which is reflected on the facade.

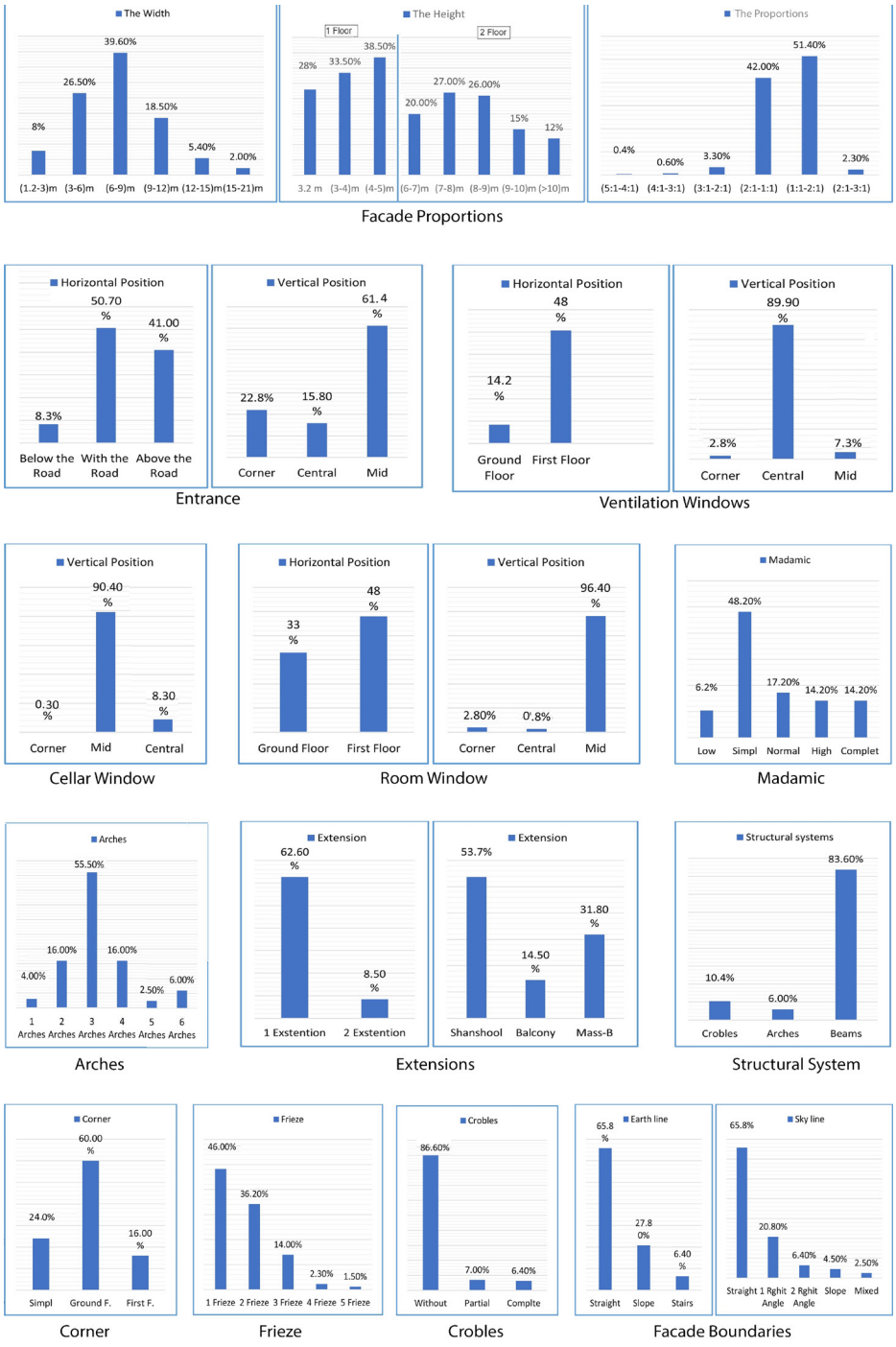


Figure 5. *The results of Mathematical and Euclidean Relations Analysis of the architectural elements (Source: Researcher).*

6.11. The relational (topological) analysis

In the relational (topological) analysis, some elements are related to each other (Table 5) for functional, structural, aesthetic, or climatic reasons as follows:

- The Entrance: The entrance is related to the basement windows with the lower horizontal level, it is correlated with the Bath windows with the upper horizontal level, and it is correlated to the ventilation windows with the same central axis of the entrance. The entrance is correlated with the extensions (shanshools and balconies) due to climatic and aesthetic requirements, while the extension mass (bathroom) does not locate on the entrance for technical purposes.
- The Openings and windows: The windows correlated with the Shanshool by locating it in the central position of Shanshool to achieve symmetry as an aesthetic purpose.
- The Extensions: The extensions are correlated with arches and corbels by determining the height as a structural purpose, and the Madamic and Frieze as a design purpose.
- The Madamic: It is always correlated with the presence of the Frieze above, and it is always the lowest level of arches, mostly with the level of corners.
- The Friezes are correlated with the corners, arches, and Crobles at the horizontal level, so that it is above these elements.
- The Corners are correlated to the arches by the horizontal level.

7. Conclusion

The current research sought to find out the deep structure that characterized the facades in the case study, it is clear from the results of the morphological, mathematical and Topological analysis of the facades which there is a hidden structure adopted to achieve the climatic, social and constructional requirements that reflected on the unification of the urban scene with uniform characteristics regardless of the difference of housing units in size and area as a result of the variation of the economic level of the residents and their requirements, which formed a unified architectural language for the city despite the different periods of the housing units that reach up to 200 years. Due to the advantages of Shape Grammar as an analytical, and generative system, in addition to its capabilities to deal with morphological and mathematical characteristics, It was used to analyze traditional facades and its architectural elements to determine the patterns and its structure to assign the vocabulary of the local architectural language, So the Standard and parametric Shape

Table 5. *The Results of the Topological analysis of the architectural elements.*

Croble	Arches	Corner	Friezes	Madamic	Extensions			Windows				Entrance	Elements	
					Bathroom	Balcony	Shanshool	Cellar	Bathroom	Ventilation	Room			
-	100%	-	41 %	18 %	%100	88 %	97%	55%	65%	100%	17.5%		Entrance	
-	100%	-	12.4%	72 %	-	-	100%	-	7.3 %	-		17.5%	Room	Windows
-	100%	-	-	47%	-	-	-	-	-		-	100%	Ventilation	
-	100%	-	36%	15%	100%	-	-	-		-	7.3 %	65%	Bathroom	
-	-	-	80 %	75%	-	-	-		-	-	-	55%	Cellar	
32%	-	67%	95%	-	-	-		-	-	-	100	97%	Shanshool	Extension
-	-	13%	12%	-	-		-	-	-	-	-	88 %	Balcony	
12%	-	30%	-	-		-	-	-	100%	-	-	%100	Bathroom	
23%	65%	88%	100%		-	-	-	75%	15 %	47%	72 %	18 %	Madamic	
78%	100%	85%		100%	-	12%	95%	80%	36%	-	12.4%	41 %	Friezes	
23%	73%		85%	88%	30%	13%	67%	-	-	-	-	-	Corner	
-		73%	100%	65%	-	-	-	-	100%	100%	100%	100%	Arches	
	-	23%	78%	23%	12%	-	32%	-	-	-	-	-	Croble	

Grammar were used to define the basic rules, with the potential for diversification in these rules using parameters.

The analysis process revealed deep structure used in the facades that can be defined as rules and restrictions and represented by three types, the first is a morphological structure which determined the genotype of each architectural elements and their evolution from primary components, the second is Euclidean rules that determine the placement of these elements in the facade, and the third is mathematical rules that represented by specific parameters to specify the possibilities of placing of these elements in specific values range. These rules and restrictions of the facade and its architectural elements indicate the impact of the construction technique, in addition to the social and climatic requirements that led to the creation of a stable structure in the architectural composition, which indicates the designer's awareness of the principles design such as repetition, rhythm, symmetry, and balance which united the urban facade with a distinct architectural language and constant. The importance of the study is to provide information, restrictions and rules for specialists in the field of conservation to rebuild the city, especially after the great damage as a result of recent military operations, which led to the destruction of large parts of the urban fabric, the study also presented the possibilities of employing the rules of form to generate interfaces that carry the same heritage values without copying them directly. The paper proposes several recommendations including:

- Adopting the same methodology in analyzing other traditional functional styles in old Mosul, such as religious buildings (mosques and churches), Service, and commercial buildings.
- Generating new (creative) architectural elements from the same basic and secondary architectural components using Shape Grammar.
- Remodeling the dilapidated parts of the heritage buildings using Shape Grammar by the procedural modeling methodology which uses the computerized Shape Grammar.
- Using Shape Grammar in analyzing the urban fabric of the Mosul city to derive rules and restrictions for the virtual reconstruction.
- Using the derived Shape Grammar in this study in digital reconstruction by converting these rules into digital formulas in the procedural modeling process.

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