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ROLE OF GEOMETRICAL ART IN THE MORPHOLOGICAL DEVELOPMENT OF MUGHAL TOMBS

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ABSTRACT

Art and architecture are said to be interconnected from a long time. Mughal time period has been said to have the maximum art and art influence in its era. The architecture of that time is termed to be marvellous and spectacular. Art is considered something that is unique and a form of self-expression. The aim of this paper is to investigate the geometry used in morphological development of Mughal monuments and in their transitions. Live case study is done to explore the different elements, their geometry, artworks, and materials in Mughal monuments (Humayun's Tomb and Itimad-Ud-Daulah tomb). The geometrical transitions in different elements of the tomb buildings studied and their interrelationship is then found. Findings shows that these transformations contributed in the development of overall morphological definition of Mughal tomb structures. It can be seen that Mughal era art and architecture made use of geometry in their morphological development. Also, different materials and art forms were used in different architectural elements of tomb buildings.

Keywords: Mughal Architecture, Mughal Art, Geometrical Art, Morphological Development, Mughal Tombs

1. INTRODUCTION

Throughout time since the ancient ages to the modern history and then by now, the correlation between art and architecture is deemed to be as an inseparable symbiotic relationship Dawoud & Elgizawy (2018). In contrast to architecture, art might not be useful in the conventional sense; for example, in meeting social needs, providing shelter from the rain, or creating a space for open-heart surgery; but it might be useful in that it offers specific resources for introspection, critical thinking, and social change Rendell (2006). Al-Farabi said that the bases of architecture lie

within the mathematical sciences and the beginning of architecture is the knowledge of hiyal, variously translated as skill, art or cunning when concerned with the manipulation of geometric forms. According to Oleg Grabber, no embellishment, fixed or movable, which plays a part, even a temporary one, in any architectural ensemble can be excluded from the term 'Art' if this ensemble is to be seriously considered.

Collaboration between art and architecture is seen as crucial. The integration of the arts with architecture should not be approached as adding separate elements to the building but rather making architecture open to other arts from the early stages of conception. The collaboration should aim for an equilibrium of forces, resulting in a total integration of the arts, rather than simply a plastic equilibrium.

Through the review of Islamic literature, it is observed that Geometrical Patterns, Calligraphy and Arabesques (floral designs) were the major form of arts which also prevailed in the Mughal Architectural practices having references and traces from Persian Architecture, Art & Culture. Here, Bonner (2017) refers Hillenbrand (1994a) that in Islamic ornamental traditions, three primary design idioms were used from the beginning of this ornamental tradition: calligraphy, geometry, and stylized florals. Art in Islam is not considered separate from religious or everyday life but is rather integrated into various aspects of Muslim societies.

Review of Literature shows that geometry is not mere used as physical entity for the development of patterns and Art works but rather it also developed a metaphysical relation for Mughal Architecture. Influence of geometry can be seen in the design, construction, and ornamentation of Mughal buildings. In Following ways, Geometry can be seen in morphological development in Mughal Architectural Practices:

1) Structural Stability

Geometry provided a foundation for structural stability in Mughal Architecture. Mughal buildings often feature dome structures, arches, and vaults, which rely on geometric principles to distribute weight and ensure stability. The use of geometric calculations and mathematical proportions helped architects to design structures that could withstand the forces of nature and stand the test of time.

2) Symmetry and Balance

Mughal architecture is known for its emphasis on symmetry and balance. Geometric principles allowed architects to achieve perfect symmetrical compositions. The use of geometric shapes and patterns, such as squares, circles, and polygons, helped create balanced and harmonious architectural forms.

3) Ornamentation and Decoration

Geometry played a significant role in the ornamentation and decoration of Mughal architecture. Geometric patterns, such as stars, interlacing lines, and intricate geometric tessellations, were employed to adorn surfaces, including walls, ceilings, and floors. These patterns were meticulously designed using geometric constructions and mathematical calculations to ensure visual harmony and coherence.

4) Proportions and Scaling

Mughal architects used geometric principles to determine the proportions and scaling of architectural elements. By applying mathematical ratios, architects could create visually pleasing compositions that were in proportion to human scale. This consideration of proportion helped create spaces that were aesthetically pleasing and provided a sense of balance and harmony to the occupants.

5) Visual Illusions and Perception

Geometry was used in Mughal architecture to create visual illusions and enhance the perception of spaces. Techniques such as the use of geometric patterns, repetitive motifs, and arabesque designs created a sense of depth, movement, and rhythm. The manipulation of geometry allowed architects to play with light, shadow, and perspective, adding a dynamic and captivating element to the architecture.

6) Integration of Art and Architecture

Geometry served as a unifying element that connected art and architecture in different architectural styles & periods. The use of geometric patterns and motifs in architectural ornamentation created a seamless integration with other art forms such as calligraphy, ceramics, and mosaics. Geometry provided a common language through which different art forms could be harmoniously combined, resulting in the rich artistic traditions seen in Mughal architecture.

Literature informed that the Mughal Empire in the Indian subcontinent blended Islamic and Indian artistic traditions, resulting in the creation of unique geometric patterns. Geometric designs were combined with floral motifs and calligraphy. In this context, Reki & Selçuk (2018) elaborated that the floor designs incorporate 6 and 8 point geometrical motifs in Humayun's Tomb, Delhi, which are elegantly sculpted and carved in the balcony railings and window grills (also known as screens or jali). Further, in addition to the same, a few geometric designs with 10 and 12 points also makes use of the same materials and patterns in Red Fort, Agra (1564–80 CE). Friday mosque in Fatehpur-Sikri (1571–96 CE) is very good example which shows that Mughal architects started to employ more 10-point geometric designs near the end of the 16th century Embi & Abdullahi (2012). Few researchers like Krusche et al. (2010), Ali & Hassan (2019), Ali (2016), Lowry (1987), Khazaee (2015) discussed the aspects related to the morphological development of Mughal buildings. Elaborating on the morphological development of Mughal Tombs, the use of the octagonal form, first observed at Humayun's tomb, softens the abrupt change from a cube to a spherical dome, easing the eye's movement from the pointed arch Iwan to the circular dome reaching into the heavens Krusche et al. (2010).

Overall, the use of geometry in the built form development (Morphology) in Mughal architecture demonstrates the integration of mathematics, aesthetics, and spirituality. It creates architectural structures that are not only visually captivating but also imbued with symbolic and cultural meaning. The application of geometric principles in Mughal architecture contributed to the distinctive and awe-inspiring architectural heritage that continues to inspire and captivate people to this day. In summary, geometrical interventions in Mughal art are defining characteristics which permeate various art forms. The precise execution of geometric patterns and designs reflects the intellectual rigor, craftsmanship, and spiritual depth within Mughal artistic traditions.

2. MATERIAL AND METHODS

Since the nature of this research is Historical and interpretative, therefore methodology adopted for this research are: Historical Interpretative and Case Study approach Groat & Wang (2013) and Yin (2018). To achieve the desired objectives of the research, this research was carried in two phases:

Phase I conceived to review the available literature and elaborating on Geometrical art and its intervention in the morphological development of Mughal Tomb structures. Also thereby identifying the criteria and indicators to observe the geometrical art in Mughal Architectural practices.

Phase II explores the geometry in the morphological development of Mughal tombs. Research proceeds to analyse the identified case studies from Mughal tomb structures on the identified criteria and indicators from the phase-I. This section will adopt both qualitative and quantitative data collection/analyses framework. First the desired primary data (qualitative) was collected from the live case studies and then got evaluated to work out the findings and inferences quantitatively. Therefore, geometry as an art studied in the morphological development of Mughal monuments and a quantitative analysis of the different Architectural elements like dome, Façade, arches etc and materials used in Mughal monuments is developed.

For Evidence and data collection, triangulation approach in the case study is used Groat & Wang (2013) and which enabled the researcher to verify the facts from different sources and perspectives that helped further to make the concrete observation and generalizations about the phenomenon or research aspects. Multiple sources of evidences adopted for this research are: Documentation, direct observations, archival records, and audiovisuals Yin (2018).

3. LITERATURE STUDY (PHASE I)

Geometry in Morphological Study: Identifying Indicators of study

A literature review was conducted of earlier researches focusing on morphological aspects of Mughal buildings. This review includes several research papers and articles from different online platforms like Google Scholar, Scopus, Academia, Research Gate etc.

Description of included studies and criteria of studies:

Table 1

Table 1 Literature Review on Geometry, Built Forms and Material Used

Reference	Methodology	Case Study	Material	Geometry & planning	Built/unbuilt forms
Lowry (1987)	Geometrical & spatial analysis, Visual analysis	Humanyun's tomb	Red Sand Stone & White Marble, Rubble core masonry	Spatial analysis, Study of Charbagh & Use of six pointed stars	Built form analysis, Architectural Elements Screens (Jali)
Klingelhofer (1987)	Geometrical & spatial analysis, Visual analysis	Red fort Agra, Jahangiri Mahal	Stone Stucco & Tile work	Rectangular cross axial ratio 5:4, Modular System, Generative approach, Axial Planning, Rigid spatial Iconography	Symmetrical Interdependence, Sequential Relationship, Spatial Experience
Krusche et al. (2010)	Comparative Proportional analysis: axis symmetry and rhythm	Humayun's Tomb, Akbar's Tomb, Itmad's Tomb, Taj Mahal	Red sand stone & White marble, Glazed tiles	Symmetrical & axial Planning for both built & unbuilt spaces, Variation in simple geometry, 9-fold plan, Use of double square and 1:2 ratio in overall composition	Comparative proportions study, Proportion & Geometry, Volumetric representation of sphere/dome, Use of perfect proportions
Afzal & Koch (n.d.)	Visual Analysis of Plan & Section	Humayun's Tomb	Red sand stone & White marble	Radially symmetrical planning, square volume appears to be octagonal space relationship, Concept of Chahar bagh	Comparative study of form: with previously built tomb structures, Architectural elements, Persian style double dome
Ali & Hassan (2019)	Case studies used as direct observation, Survey also conducted as primary resource	1. Quwwat-ul-Islam Mosque 2. Alai Darwaza 3. GhiyasuddinTughlaq's Tomb 4. Bara Gumbad Mosque	Dome Construction material: Red Sandstone, White Marble, Black marble & sand stone for	Ghiyasuddin Tughlaq's Tomb raised on an octagonal drum, Humayun's Tomb: Central Octagonal Chamber covered with double shell dome: Transition from octagon to circle, also a reference for Taj	Early domes built in Corbelled Technology Early True dome was a shallow dome with a finial at its top. • Structural Analysis of Domes

		5. Humayun's Tomb 6. Taj Mahal 7. Jami Masjid Delhi 8. Safdar Jang Tomb	calligraphy and relief work	Mahal & other structures. Bulbous domes resting on high drum.	• Morphological Analysis • Comparative analysis of geometry of domes
Khazaee (2015)	Qualitative study involving triangulation Analysis of results	• Goharshad mosque • Mosque of Mir Chakhmaq • Mosque of Torbat Jam • Shah Mosque • Fatehpur Sikri Jami mosque • Taj Mahal mosque • Delhi Jami mosque	-	Morphological study includes Ivan, Dome, Domed chamber, Arches and their sub elements like spandrel, band, plinth, minaret etc	Geometrical analysis of built unbuilt on identified established patterns format
Haidry & Chaudhary (2018)	Descriptive research from secondary resources	-	-	Method: Planning Stage Division phase, Order & Structure, pattern formation (proportions of √2 √3 √5), Common formations are: 4-fold 5-fold 6-fold	-
Mishra (2019)	Descriptive research based on secondary sources	General examples	Red sandstone & White marble	-	-
Mahina et al (2018)	Descriptive research, Visual analysis of Geometrical patterns used in jail/screen development	The Jalis of The Naulakha Pavilion in The Lahore Fort	Naulakha Pavilion: White Marble Stone, Inlay, Glasswork on roof	-	Basic pattern of Naulakha pavilion Jali is Hexagon, Use of 8-pointed star pattern and 8-fold rosettes
Azmat & Hadi (2018)	Descriptive research, Visual Analysis	Taj Mahal, Tomb of Itmad ud-daula, Qutub minar	Red sandstone, white marble and polychromic tiles	-	Use of 6-point, 8-point, 10-point, 8 fold rosette, 10 fold rosette
Lotankar, & Daketi (2016)	Visual Analysis of Case studies, Comparative Analysis of Jali patterns	Fatepur Sikri, havelis of Shekhavati region, Hawa Mahal jaipur	Jali: Stone marble, Sandstone, Door/Window: Timber, Stain glass	-	Shading devices, Jali Patterns
Chishti et al. (2017)	Descriptive research based on secondary sources	Shalimar garden Lahore	Use Marble & sand stone to build pavilion or baradaries brick pavements	Chahar Bagh Concept, Fourfold gardens with axial path intersecting at the center following the concept of order & Symmetry, Garden plan are geometrical, Lower & upper terraces were square while middle one was narrow & rectangular	Influence of Persian Style, Distinguishing features are two stepped chahar bagh with three terraces
Wescoat (1994)	Empirical research on Lahore Tombs, Inductive analysis about	Tomb Gardens of Lahore: Includes tomb of emperor, wife, women, wazirs & amirs, and saints	-	Square Geometry of Tomb Gardens, walkways elevated one metre or more, and axial water canals dividing the area into quadrants, Tomb	Relationship of Tomb & Garden Dynastic representation through size rank & status.

	dynastic representation			Geometry is square or octagonal	
Ullah et al. (2020)	Descriptive research based on research papers, online articles, books and library archives	Mughal gardens of Lahore	Bricks laid with lime-mortar, red sandstone, different types of marble and wood	Mughal Gardens follow the concept of Chahar Bagh, Gardens were formal rectilinear enclosures, Allusions to cosmologic dynastic and territorial themes	Pavilions and plantings. Laid around Tombs or attached to palaces. Canals fountains tanks & Pavilions were introduced by mughals
Latip et al. (2016)	Descriptive research Morphology Analysis	Aram Bagh, Anup Talao, Turkish Sutana bagh, Jahangir quadrangle, Shalimar bagh, Kashmir, Anguri bagh, Shalimar Bagh, Lahore, Shish Mahal Lahore	-	Chahar Bagh: Rectangular geometry was employed to gardens which were cross-axially separated into four sections by water canals or pathways. (concept of heaven gardens).	Four types: Attached to palaces, Funerary Gardens gardens for royal residences, Pleasure gardens. Horizontal and vertical morphology of water flow and supply to built spaces and gardens.
Ali (2011)	Study is descriptive based on literature and qoranic revelations	-	-	Chahar Bagh: Two axis intersecting at right angle & dividing in four quadrants each quarter further divided into four quadrants Geometry is based on division & subdivision	Strong relationship between built environment & nature, Mughal gardens improves the microclimate.
Sparavigna (2015)	Satellite image study to investigate orientation of Mughal gardens Visual Analysis	-	-	Chahar bagh (except humayun's tomb) are oriented to the cardinal directions and directions of sunrise & sunset e.g. Taj Mahal, Akbars tomb, Chahar bagh etc. In case of Taj Mahal have six main directions	

Source Author

Review of above-mentioned research document conducted on the aspects: material used, geometry & Planning and built/unbuilt forms (identified through preliminary review of research documents) with different case studies to identify different keywords used under each aspect. These key words are further collected and arranged in categories of similar orientation Saquib (2020) as follows:

Table 2

Table 2 Indicators Identification

Keywords/Phrases	Spatial analysis	Charbagh	Axial Planning	Order & Structure	Corbelled Technology
	Built form analysis, Structural Analysis, Morphological Analysis, Built form analysis	six pointed stars, Four-fold gardens, 6-point, 8-point, 10-point, 8-fold rosette, 10 fold rosette, 4-fold 5-fold 6-fold, 9-fold plan, six pointed stars	cross axial ratio	proportions of $\sqrt{2}$ $\sqrt{3}$ $\sqrt{5}$, 1:2 ratio	Red Sand Stone & White Marble, Black marble
	Screens (Jali), Jali Patterns, Ivan, Dome, Domed chamber, Arches	Rectangular, square, Square Geometry, Hexagon, rectilinear, octagon to circle, octagonal	cardinal directions	proportions study, Proportion & Geometry, perfect proportions	Rubble core masonry, Glasswork on roof
	built	Chahar Bagh	Axis	Transition	Stone Stucco
	Tomb Gardens	right angle	cross-axial		Tile work, Glazed tiles
	Morphological study	four quadrants	axial		Stone Inlay,

Geometrical analysis	Geometry, Geometrical	symmetrical planning	Sequential Relationship	polychromic tiles
octagonal drum, Octagonal Chamber	Tomb Geometry, geometry of domes	Symmetrical Interdependence		brick pavements, lime-mortar
double shell dome, Bulbous domes	order & Symmetry, Symmetrical & axial Planning			
shallow dome	Spatial analysis			
space relationship				
Architecture & Elements	**Geometry & Pattern**	**Axial study**	**Ratio & Proportions**	**Materials & techniques**

Identified Indicators of study (Category of Similar Orientation)

Source Author

Arrangement and alignment of keywords/phrases under different identified categories results into the development of study indicators. Further, this table highlights the different categories/indicators discussed and analysed by the researchers and shows that major studies conducted under these categories prominently. Out of the identified indicators, large number of keywords are from the categories: Architecture & elements and Geometry & Pattern which shows that development of 'Architecture & elements' is more related with Geometry and Patterns in context of use of geometry in morphological development during Mughal Architecture.

Five indicators: 1. Architecture elements, 2. Geometry & patterns, 3. Axial study, 4. Ratio & Proportions and 5. Materials & techniques are taken as inferences out of the literature review and considered further for the study of phase-II. Major evidences under these indicators were collected through direct observations and audiovisuals by conducting live case studies of two Mughal Tomb structure of importance: Humayun's Tomb & Itmad-ud-Daula's Tomb.

4. EXPLORING GEOMETRY IN MORPHOLOGICAL DEVELOPMENT OF MUGHAL TOMBS: (PHASE II)

4.1. DEFINING INDICATORS

4.1.1. ARCHITECTURE ELEMENTS

These include the fundamental components of a structure or design, such as domes, arches, and columns, which are characteristic of Mughal architecture. The use of geometry in these elements helps create a harmonious and visually appealing design.

4.1.2. GEOMETRY AND PATTERN

Geometry and patterns are essential aspects of Mughal architecture, as they contribute to the visual appeal and structural integrity of the designs. The use of repetitive geometric elements, such as star patterns, rosettes, tessellations or fractal patterns etc, can be seen in the decoration of mosques, monuments, and other architectural elements Majewski (2021).

4.1.3. AXIAL STUDY

Axial study in Mughal architecture involves analysing the spatial organization and circulation patterns of a building or space. This can include studying the arrangement of axes, sight lines, and circulation paths to understand how people move through and experience a space Krusche et al. (2010).

4.1.4. RATIO & PROPORTIONS

Ratio and proportions are crucial in Mughal architecture, as they help create aesthetically pleasing and structurally sound designs. The use of mathematical relationships between different elements of a design contributes to the visual harmony and balance of the architecture Krusche et al. (2010).

4.1.5. MATERIAL & TECHNIQUES

In Mughal architecture, materials and techniques are closely related to the use of geometry and morphological development. The primary materials used in Mughal architecture, such as stone, brick, and wood, are shaped and constructed using geometric principles to create intricate and visually appealing designs.

4.2. CASE STUDIES SELECTION

Case studies identified for this study are: Humayun's Tomb, Delhi (1560-1570 CE) and Itmad-ud-Daula's Tomb, Agra (1622-1628 CE). Rationale behind the selection of these two buildings as case studies: as Humayun's tomb structure is considered as one of the first Mughal tomb structure in India which act as the source of references for many following tomb and other Mughal structures. The reference of dome geometry of Humayun's tomb is further reflected in the Taj Mahal, Agra. Similarly, Itmad-ud-Daula's tomb built during Jahangir period is considered as one of the best remarkable examples for the use of art forms like geometrical patterns, arabesques and calligraphy and this structure acted as the source of art forms references in Taj mahal, Agra. Importance of these two structures can also be understood in following manner:

4.2.1. HUMAYUN'S TOMB (1560-1570 CE)

Humayun's Tomb located on the flat plain near the bank of river Yamuna and surrounded by a series of other Sultanate and Mughal monuments Lowry (1987). This monument is fine example of Mughal architecture made up in red sandstone and white marble, resting on massive plinth made up of fifty-six cells containing grave stones. This plinth is of 6.5 m high, square in shape measuring one side 99 m and measuring the height of the monument is 42.5 m above the ground level. Though the plan of the monument is square but because of the chamfering edges it appears to irregular octagon. As Figure 2 shows, the plan of the tomb structure is nine-fold plan, comprising of four octagonal chambers connected through the four recessed passage ways. The outer facades of the monument are simple and flat surfaces punctured by arched recesses arranged around the central chamber. This tomb structure has two floors (Figure 1): the first floor is composed of a central domed chamber with main gravestone and small chambers around it connected through narrow corridors. The ground floor is made up of series of hall and passageways arranged around the central domed chamber.

This massive tomb structure is set in the center of garden the garden known as chahar bagh. A series of cross axially arranged canals and pathways divided it four quadrant and giving the definition of 'Chahar Bagh' Lowry (1987). The major aspects of Humayun's tomb designing are: its scale & proportions, Use of Geometry in built form development, cross axially symmetrical plan, Chahar bagh concept, use of combination of red sand stone and white marble executed in core rubble finish.

4.2.2. ITMAD-UD-DAULA'S TOMB (1622-1628 CE)

This marvellous white marble tomb known as Itmad-ud-Daula's tomb was built by Noor Jahan although both Nur Jahan's mother, Asmat Begum, who died in 1621, also buried there along her father. It took six years to be completed. This tomb structure follows 9-fold pattern in plan as shown in Figure 4 and placed in the center of the garden (based on chahar bagh concept) like Humayun's tomb, Delhi. This mausoleum structure is situated on the Yamuna River bank and comparatively small on scale. It is a two storeyed marble structure which also famous for its art work and decoration. This mausoleum is a very rich example of Mughal art where all forms of Mughal art (geometric patterns, arabesques and calligraphy) are displayed and also executed in pietra dura (inlay) technique.

The white marble tomb is exquisitely carved and heavily inlaid with semi-precious stones. It is situated on a modest pedestal that is roughly 7 meters on each side Asher (1992). The nine bays that make up the inside are conceptually reminiscent to Humayun's tomb layout and in contrast to the octagonal radial plan of Humayun's tomb, eight rooms; two on each side; hug the center vaulted chamber in this arrangement. The central truncated pyramidal vault is flanked by chattri-topped turrets at each corner of the second floor. Both the inside of the second floor and the white marble façade of the tomb are heavily inlaid with semi-precious stones Asher (1992).

Figure 1

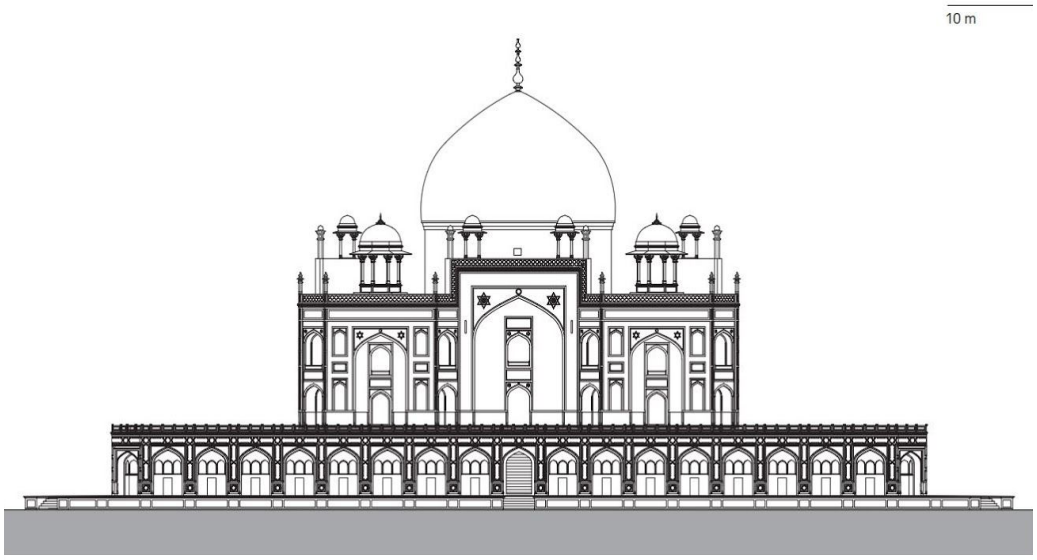


Figure 1 Elevation (Humayun's Tomb)
Source Hidden Architecture, Farhat Afzal

Figure 2

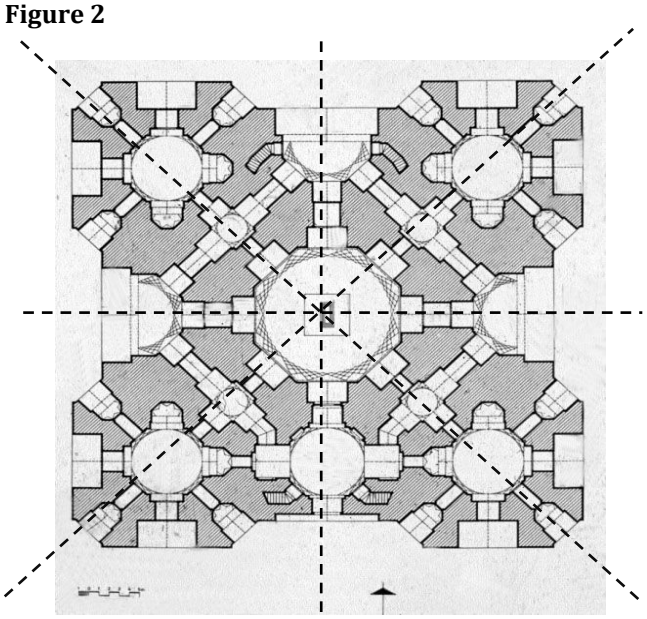


Figure 2 Plan (Humayun's Tomb)
Source Hidden Architecture, Farhat Afzal

Figure 3

Figure 3 South Face View, (Humayun's Tomb)
Source Author

Figure 4

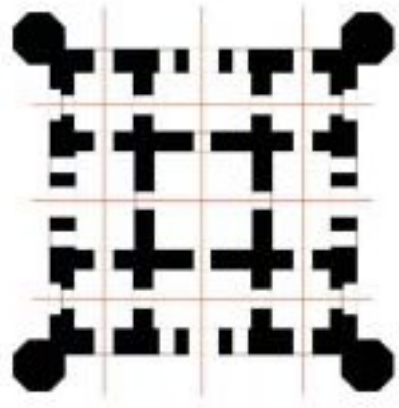


Figure 4 Nine-Fold Plan of Itimad-ud-Daula Tomb
Source Stefanovic (2012)

Figure 5

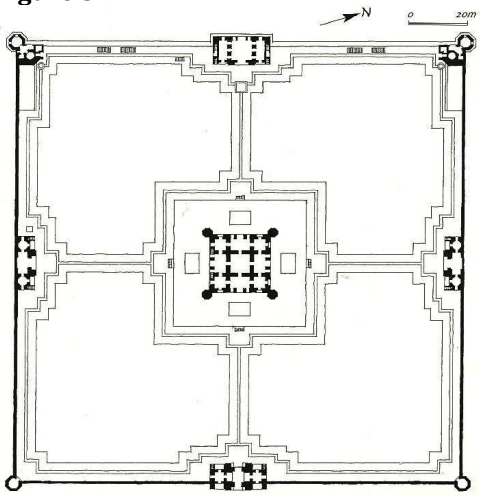


Figure 5 Site Plan of Itmad-ud-Daula Tomb
Source Stefanovic (2012)

Figure 6

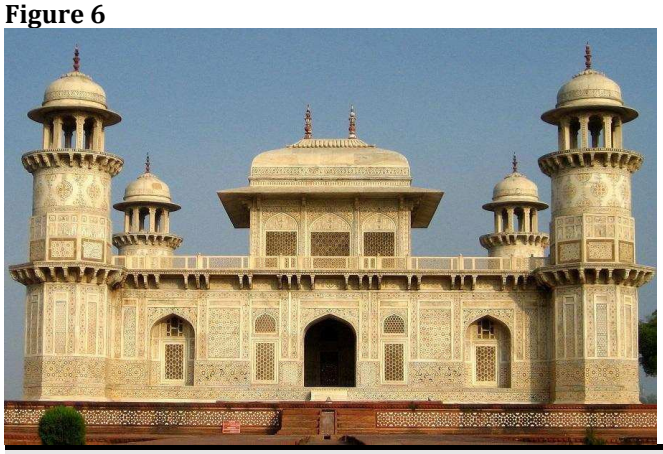


Figure 6 Itmad-ud-Daula Tomb
Source Author

4.3. DATA COLLECTION AND ANALYSIS

4.3.1. HUMAYUN'S TOMB

Figure 7

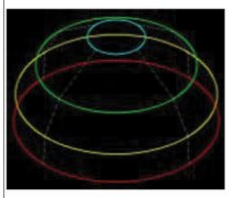
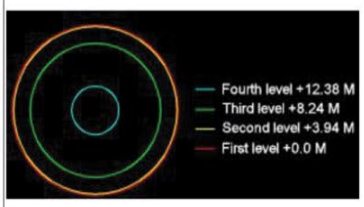
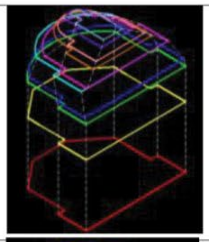
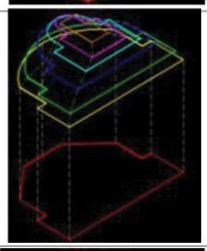
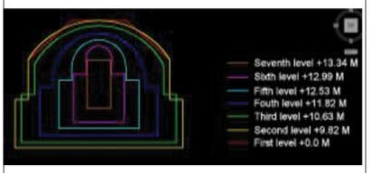
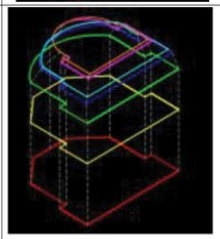
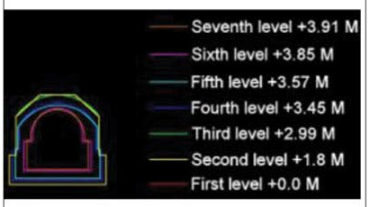
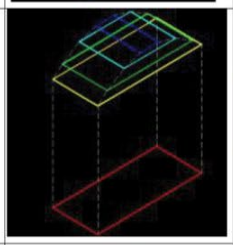
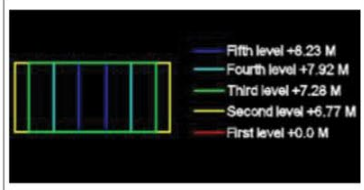
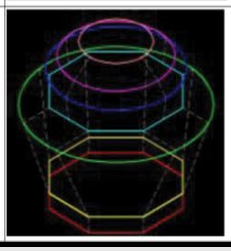
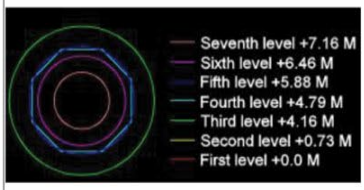
Humayun's Tomb											
Geometry											
Heirarchy		Number of elements	Images	Geometry in plan	Orthographic projection	Top view	Number of transitions as per keystones	Number of axis used	Number of shapes used	Basic Shape of development	Findings
Element											
	Dome (Outer Shell)	1		Octagon base/circular drum-Circle			4	Cross axial-4	1	Circle	The plan of this is circle that is a basic shape circle. The end of transition is a basic shape only. The transitions happens at regular intervals with 4 being the maximum transition
	Arches (South face)	1		Octagan			10	1	2	Rectangle + Octangon Rectangle + Arch	The plan of this is rectangle + octagon that is derived from the basic shape of square and circle. The transitions happened rapidly after second level with 10 being the maximum transition
	Arches (West face)	2		Octagan			7	1	2	Rectangle + Octangon Rectangle + Arch	The plan of this is rectangle + octagon that is derived from the basic shape of square and circle. The transitions happened rapidly after second level with 7 being the maximum transition
	Arches (Small Arches/ niche)			Octagan			7	1	2	Rectangle + Octangan Rectangle + Arch	The plan of this is rectangle + octagon that is derived from the basic shape of square and circle. The transitions happened rapidly after second level with 7 being the maximum transition
	Arches	4		Square			5	1	1	Rectangle	The plan of this is rectangle that is derived from the basic shape of square. The transitions happened rapidly after second level with 5 being the maximum transition
	Chattris			Octagan			7	6	2	Octagon Circle	The plan of this is octagon that is derived from the basic shape of square. It ends on a basic shape only The transitions happened rapidly after second level with 7 being the maximum transition

Figure 7 Geometry in the Morphological Development: Humayun's Tomb
Source Author

Figure 8

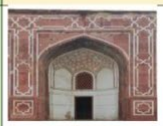
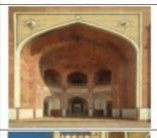
Humayun's Tomb Arabesque/Calligraphy/Carving/Geometrical Patterns													Findings
		Pattern identification								Materials			
Element	Number		Types of patterns identified	Relief work/Inlay work	Percentage of each pattern as per surface area	Shapes	Derivatives	Type of repitition in the module	Solid/void ratio	Artwork/plain façade ratio	Number of materials used	Types of materials used	Percenatge of materials used	
Façade	1		8 fold geometric pattern	Inlay	18.70%	Square	8 flod star Rectangle	Linear and perpendicular	1.45:1	0.23:1	2	Red sand stone White marble	Red sandstone - 76.47% White marble - 23.53%	Red sanstone and white marble are the dominant materials that are used. The artwork present is very less on the surface. There are derivative shapes derived from basic shape
Façade	2		6 fold geometrical pattern	Inlay	1.02%	Traingle	6 fold star	Linear	0.81:1	-	3	Red sand stone Black marble White marble	Red sand stone - 67.91% Black marble - 5.23% White marble - 26.6%	Red sanstone and white marble are the dominant materials that are used. The artwork present is very less on the surface. There are derivative shapes derived from basic shape
Façade	3		6 fold geometrical pattern Rectangle	Inlay	0.4% 10.3%	Traingle Rectangle	6 fold star Rectangle	Linear	01:01.2	0.07:1	4	Red sand stone Black marble Laterite White marble	Red sand stone - 30.92% Black marble - 7.05% Laterite - 5.45% White marble - 56.58%	Red sanstone and white marble are the dominant materials that are used. The artwork present is very less on the surface. There are derivative shapes derived from basic shape
Façade	4		6 fold geometrical pattern Rectangles Floral pattern	Inlay	0.25% 5.0% 5.47%	Triangle Rectangle Circle	6 fold star Rectangles Floral pattern	Linear	1.52:1	0.17:1	4	Red sand stone Black marble Laterite White marble	Red sand stone - 52.90% Black marble - 3.22% Laterite - 5.56% White marble - 38.31%	Red sanstone and white marble are the dominant materials that are used. The artwork present is very less on the surface. There are derivative shapes derived from basic shape

Figure 8 Geometry in Facade Patterns Development: Humayun's Tomb
Source Author

4.3.2. ITMAD-UD-DAULA TOMB

Figure 9

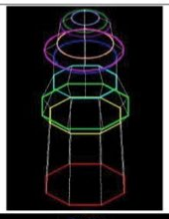
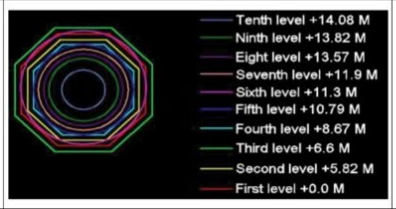
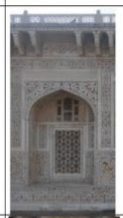
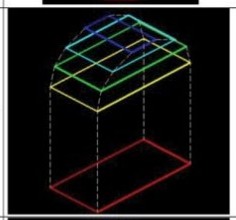
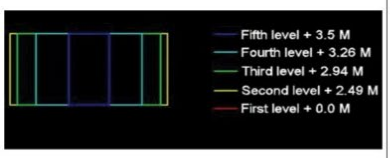
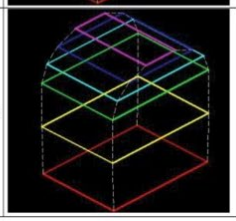
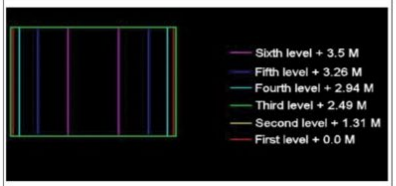
Itimad ud dualah Geometry											Findings
Heirarchy		Number of elements	Images	Geometry in plan	Orthographic projection	Top view	Number of transitions as per keystones	Number of axis used	Number of shapes used	Primary shape/s	
Element											
	Minarets	1		Octagan			10	6	2	Octagan Circle	The plan of this is octagon that is derived from the basic shape circle. Hence we can see that the end of transition is a basic shape only. The transitions happened rapidly after second level with 10 being the maximum transition
Element	Arches	1		Rectangle			5	1	1	Rectangle	The plan of this is rectangle that is derived from the basic shape square. The end of transition is a derived shape only The transitions happened rapidly after second level with 5 being the maximum transition
Element	Arches	2		Rectangle			6	1	1	Rectangle	The plan of this is rectangle that is derived from the basic shape square. The end of transition is a derived shape only The transitions happened rapidly after second level with 6 being the maximum transition

Figure 9 Geometry in Morphological Development: Itmad-ud-Daula Tomb
Source Author

Figure 10

Itimad ud dualah											
Arabesque/Calligraphy/Carving/Geometrical Patterns											
Element	Number	Pattern identification								Materials	Findings
		Images	Relief /Inlay	Percentage of each pattern as per surface area	Shapes	Derivatives	Type of repitition	Solid/void ratio	Artwork/plain façade ratio	Image	
Façade	1		Inlay	Geometric patterns -25.01% Arabesque - 42.03% Calligrapghy - 3.7%	Square	Rectangle	Linear	Open - 1.85:1 Niche 1 - 1.01:1 Niche 2 - 8.87:1	2.86:1		Inlay work is done on the facade with arabesque being in maximum use. Calligraphy is used the least as it is just present as the versus in top. The façade consist of basic definition of shapes i.e. square. The solid percentage is more than the the void. The artwork surface is much higher than the plain surface
Façade	2		Inlay	Geometric patterns -29.40% Arabesque - 37.8% Calligrapghy - 1.18%	Square	Rectange	Linear	Niche 1 - 3.87:1 Niche 2 - 2.04:1	2.45:1		Inlay work is done on the facade with arabesque being in maximum use. Calligraphy is used the least as it is just present as the versus in top. The façade consist of basic definition of shapes i.e. square. The solid percentage is more than the the void. The artwork surface is much higher than the plain surface

Figure 10 Geometry in Facade Patterns Development: Itmad-ud-Daula Tomb

5. DISCUSSION AND FINDINGS

Figure 7 elaborates on the geometry used for the morphological development of the Humayun's tomb. This analysis focuses on morphological aspects of the dome (outer shell), arches (South & west), arch niches and chatris which decipher the geometrical shape transformations occurred at different intervals in the respective architectural elements like dome, arch and chatri etc. As study of central dome (outer shell) shows that it started with octagonal plan and further transformed to circle with four axes. Similarly for arched entrance gateway, shape of plan has been recorded at different levels as mentioned in the table to observe the various transformations and to identify the maximum level of geometrical shapes used. As result, it started with the combination of rectangle and octagon till 6 level and transformed to arch from 7 level with one central axis. The rest of the two elements (Chatri & Arch niches) are studies in the same way and do have the transformation resemblances with central dome and arche entrance way. Figure 8 identifies the use of geometry in façade pattern development. Here like Figure 7, same faces of Humayun's tomb have been evaluated for the geometrical pattern study. Façade 1 in this table at ground floor deciphers the use of 8-fold pattern derived from square and executed in inlay technique (inlaying marble in red sand stone) which was a unique kind of pattern development technique example at that time in Mughal architecture. Further linear repletion format was followed for the pattern development. Analysis also identifies the solid-void ration i.e. 1.45:1 and artwork/plain façade ration i.e. 0.23:1 in case façade 1. Similarly other façade 2, 3 and 4 has been evaluated for the geometrical intervention in facades pattern development.

To study Itmad-ud-Daula tomb (Figure 9 and Figure 10), Architectural elements: Minaret, Arch niche and Arch entrance way were studies for analysing the role of geometry in the morphological development. Minaret of the tomb shows the 10 level of transition starting with octagon as basic shape and transforming to circle from 5 level with six axes used. Further arch niches on the façade, starting with rectangle as basic shape and converging to a line on top with 5 level of transition. Similarly, entrance Arch way started with rectangle as basic shape and converged to

a line at top. The same pattern has been repeated on both sides of each façade as structure is symmetrical on its axes. Further evaluating the geometry on façade development, as images of Figure 10 shows, the surface area occupied by the geometric patterns, arabesques and calligraphy on façade 1 (wall surface) is 25%, 42% & 3.7% respectively. Similarly, façade 2 (minaret wall surface) shows the area occupied 29.4% (Geometrical patterns), 37.8% (arabesques) and 1.18% (calligraphy). Furter elaborating on artwork vs plain surface ratio, on façade 1 it is 2.86:1 and on façade 2 it is 2.45:1 which shows heavy influence on art intervention on both the surfaces. Looking on to the morphological geometry on the façades, it shows the use of squares and rectangles which defines the basic outline of the facades in which further art work like geometrical patterns, arabesques and calligraphy inscribed in inlay technique. This study also deciphers the solid vs void ratio for both facades in case of openings and niches. Abdullahi & Embi (2013)

Findings from both the case studies shows that both tomb structures are cross axial in nature and are symmetrical to their axes. In earlier study, humayun's tomb, it is executed in red sand stone and at some places inlay work in sand stone with marble has been observed whereas in later case tomb structure made with marble. Both the structures served as reference for the world-famous monument or tomb Taj Mahal. Morphological references of the taj were taken from Humayun's tomb whereas art work references were taken from Itmad-ud-Daula Tomb. Ali & Hassan (2017)

6. CONCLUSION

Geometry is the fundamental unit and division used in architectural design and transformation. Transitions and element design may both benefit from the usage of geometry. The use of various geometrical shapes, their combinations and transformations, height/depth of their transitions, and the number of transitions occurred in an element, can all be learnt from Mughal architectural practices, which were regarded as the pinnacle of architectural design. Al-Mosawi (2016)

This study can aid future investigations into the function of various forms, the seamless transition and transformation of these shapes from one to another. Additionally, it can aid in the progression of learning about those ideal proportions and the application of geometry. In earlier researches, the measurement of artistic intervention in building was less prominent. This study will allow a general examination of Mughal structures with a comparable backdrop, this quantification can support in the design of features of similar contexts. Future researches may also be: the purpose of diverse forms, as well as the smooth transition and transformation of these shapes from one to another, may find their references in this study. This study can also help to advance the application of geometry and the study of those ideal proportions. Findings of this study direct the strong relation of geometrical art with the morphological development of Mughal structures and tomb buildings in particular. The measurement of creative construction intervention was less significant in earlier study. This quantification may support the creation of features for analogous situations by enabling a broad analysis of Mughal structures against a comparable background.

CONFLICT OF INTERESTS

None.

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