The Use of *Muqarnas* in the Transitional Zone of Domes in Egyptian Islamic Architecture: From the Fatimid to the End of the Mamluk Era

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The local brick dome technique had already existed when *muqarnas* started to appear as a feature in the transitional zone of domes in Egyptian architecture. Based on a detailed analysis of the transitional zone of domes in Egypt dating from the Fatimid to the end of the Mamluk era, 126 examples of *muqarnas* can be classified into four types according to their forms and geometrical features when projected onto a horizontal plane from above. These four types can be sub-divided into fourteen sub-types. Based on a morphological classification, six stylistic periods are identified as follows: The first period is from the 1050s to the 1230s, when the vernacular technique of the brick dome might have evolved into the *muqarnas* with a trefoil arch. The second period is from the 1240s to the 1310s, when a geometric change occurred based on the local tradition of *muqarnas* using multi-foil arches. The third period is from the 1320s to the 1360s, when the influence of stone *muqarnas* from Syria became evident. The fourth period is from the 1370s to the 1400s, when the local development of *muqarnas* based on corbeling and the multi-foil arch was preferred. The fifth period is from the 1410s to the 1450s, when the trend of the fourth period was promoted and innovations were made. The sixth and final period is from the 1460s to the 1510s, when the complete form based on the local tradition appeared. Through this analysis of the use of *muqarnas* in the transitional zone, it is clear that foreign influences were at some points important to their development. However, adopting, compromising and subliming these influences with local tradition or aesthetics constituted the major way in which the style and use of *muqarnas* in domes evolved in Egypt from the eleventh to early sixteenth century.

Keywords: *muqarnas*, Egypt, vaulting, corbeling, transitional-zone

I. Introduction

Muqarnas is a corbeling technique, also known as stalactite or honeycomb vaulting, that was developed and refined in Islamic architecture. The etymology of *muqarnas* is not clear and several explanations have been put forward (see for example, Tabbaa 1985, 61; Bloom 1988, 27; Behrens-Abouseif 1993, 501; Necipoğlu and al-Asad 1995, 349–350). Generally speaking, the *muqarnas* shape was formed when the requirement to bend a structural arch was incorporated into the lamination of the decorative facet (Fukami 1998, 267–271). The corbel decoration existed before Islam, for example in the cornice of ancient Egyptian and Greek architecture from the pre-Christian era. However, from the existing examples, the “bending” of structural arches first appeared in Islamic architecture in the tenth century, as evidenced in the Samanid tomb in Bukhara and the Jurjir mosque in Isfahan. In the former this technique was applied at a squinch while in

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the latter it appeared at both ends of a semi-dome. In both cases, there are curved facets lined by a half arch bending at right angles. Following the appearance of these examples, many curved facets were arranged horizontally and vertically to form *muqarnas*, and were introduced in various places from Andalucía to Central Asia. *Muqarnas* then evolved and developed predominantly in Islamic architecture and became the technique that symbolized “Islamic-ness” just as the Arabic language in which the Qurʾān was written became synonymous with Islam.

On the other hand, *muqarnas* also developed into local types based on the architectural tradition of each area. Egypt can be regarded as a prominent area with respect to the development of *muqarnas* (Fukami 1998). From the eleventh century onward *muqarnas* can be seen in Egypt in the cornices of minarets, niches of façades and transitional zone of domes (Bloom 1988). Subsequently, the most common way of using *muqarnas* in Egypt became in the transitional zone of domes and in the semi-dome at entrances to mosques and tombs. This article focuses on *muqarnas* applied in the transitional zone of domes from the mid-eleventh century to the early sixteenth century, with the purpose of describing the evolution in their shapes.

II. Prior Studies

Following K. A. C. Creswell’s seminal work in the 1950s on Muslim architecture in Egypt (Creswell 1952; 1959), there were many further studies on Cairene architecture. As regards the domes that were constructed before the end of the Mamluk era, many studies discuss their outer appearance (see for example, Kessler 1976; Ciprani 2005; Behrens-Abouseif 2007, 80–84; Wahby and Montasser 2012), but rarely their inner vaulting.

Creswell concluded that the trefoil squinch arch of the mid-eleventh century seen in Aswān tombs was local in its technique and that its development had no relation with the Persian dome technique (Creswell 1952, 251–253). In his work, he described the detail of the transitional zone of the domes in Egypt, but his research was limited to a comparison with examples in other areas and covered only those constructed until the 1330s (Creswell 1952; 1959). Some years later, Laila ʿAlī Ibrāhīm analyzed the transitional zone not only in terms of its outer appearance, but also its inner vaulting, and she expanded Creswell’s work to encompass the Mamluk era (Ibrāhīm 1975). Yet, her description of the inner transitional zone was still not comprehensive and there was a lack of continuity between the Fatimid period and thereafter. Moreover, she looked at the transformation in style only from a vertical perspective and regarded any exception as a special example. However, these exceptions should be discussed in the context of the development of *muqarnas*, and also, the structural methods, the materials of construction, and the influence of examples from other areas must be considered. Hence it is necessary to reconsider the whole history of *muqarnas* in the transitional zone of domes in Egypt through detailed morphological analyses that pay attention to these aspects.

In previous studies such as those mentioned above, the terms squinch and pendentive were used although they are the terms coined by historians of Western architecture to explain the transitional zones and the modeling methods employed to construct a spherical dome on arches above a square room (Jones 1972; Mainstone 1973). However, as the complexity of vaulting developed, the whole transitional zone came to support the dome instead of just the modeled arches. So it is

actually quite difficult to explain this development using only these particular architectural terms such as squinch and pendentive. In addition, in previous studies, an understanding of the original significance of *muqarnas*, that is corbeling, was lacking. It is important to examine the structural methods employed and the techniques of construction carefully in order to clarify the development of the transitional zone in Egypt.

III. Typology of Examples

As mentioned, this article focuses only on the transitional zone of domes, and for this purpose 126 examples¹ of *muqarnas* were collected from a review of previous studies and a field survey and then indexed in chronological order² together with their morphological characteristics (Table 1). As a result of this process, it was possible to group the examples into four types according to their formation. The classification indexes for these types were as follows: 1) the formation of *muqarnas* facets from the base (lowest part) to the top (under the dome or drum) of the transitional zone; 2) the geometrical feature of *muqarnas* when projected onto a horizontal plane from above; 3) the shape of the encircling four walls of the room.

By modeling the corbeling of half arches, *muqarnas* can be shown as an assemblage of curved facets and flat facets. There are four types of curved facet (Fig. 1) and two types of flat facet (Fernandez-Puertas 1993; Fukami 1998, 12–13; Hoeven and Veen 2010, 6–7). The former are petal, fan, semi-tunnel and double-arch while the latter are horizontal and vertical.

Fig. 1: The Four Types of Curved Facet

¹ First, examples of the *muqarnas* transitional zone in domes that were constructed up to and including the Mamluk era were collected from previous studies. Second, existing domes that were constructed up to and including the Mamluk era (Comité 1951; Warner 2005) were examined by the author, and for these examples, photos were obtained from the Ministry of Antiquities of Egypt and a field survey was done. However, it was not possible to enter four of these domes, so those four were excluded from the analysis. The domes in question are Qubbat al-Wazīr (fourteenth century, No. 84), the tomb of Rajab al-Shīrāzī (1379, No. 476), the mosque of Bardbak (Umm al-Ghulām, 1460, No. 25, the dome no longer exists but a transitional zone does), and the tomb of Timurbāy al-Ḥusaynī (sixteenth century, No. 161, the dome no longer exists but a transitional zone does). The monument numbers used in this article are those in Comité 1951 unless indicated.

² To determine the construction date of each *muqarnas* is difficult where the building does not have a construction date and where some reconstruction work has been done later. Therefore, this article adopts the dates proposed in previous studies (mainly the studies by Comité 1951; Creswell 1952 and 1959; Meinecke 1992, vol. 1; Warner 2005; Behrens-Abouseif 2007) (see Table 1).

Table 1: List of *Muqarnas* Examples in Egypt

Monument numbers in previous studies			Monument	Date ⁽¹⁾	Material	Type	Wall arch	Diagonal arch	Layers	Number of petal facets in each layer ⁽²⁾													Drum shape ⁽³⁾
Comité 1951	Behrens-Meiske 1992	Aboûseif 2007								1	2	3	4	5	6	7	8	9	10	11	12	13	
199			Tomb at Aswān	ca. 1050 C	stucco	I a	3-foil	3-foil	2	3	2									8			
511			Bāb Zuwayla	1092 W	stone	I b	none	arch	2	3	1									8			
			Tomb of Shaykh Yūnus	1094 C	stucco	I a	3-foil	3-foil	2	3	2												
			Abū al-Sayfayn (Coptic chapel)	1094–1121 C	stucco	I a	3-foil	3-foil	2	3	2												
			Abū al-Sayfayn (Coptic chapel)	1094–1121 C	stucco	I b	arch	shoulder arch	1	3													
333			Tomb of Sayyida 'Atika	1120–25 C	stucco	I a	3-foil	3-foil	2	3	2												
333			Tomb of Muḥammad al-Ja'farī	1120–25 C	stucco	I a	3-foil	3-foil	2	3	2												
			Tomb at Qūs	1120–30 C	stucco	I a	3-foil	3-foil	2	3	2									16			
479			Tomb opposite Khānqāh Sulṭān Baybars al-Jashnākīr	ca. 1133 C	brick	I a	3-foil	3-foil	2	3	2									8			
273			Mashhad Sayyida Ruqayya	1133 C	stucco	I a	3-foil	3-foil	2	3	2												
285			Mashhad Yahyā al-Shabīb	ca. 1150 C	stucco	I a	3-foil	3-foil	2	3	2												
276		6	Tomb of Abbasid caliphs	1242/43, 1260–77 BA	stucco	II a	3-foil	3-foil	2	3	1/6												
38			1 Tomb of al-Sūlṭh Najm al-Dīn Ayyūb	1250 BA	stucco	II b	5-foil	3-foil	3	3	3	20								C			
169	0/1		2 Tomb of Shajar al-Durr	1250 BA	stucco	II a	3-foil	3-foil	2	3	1/6									16			
274	7/18		7 Tomb of Fātima Khātūn (Umm al-Sūlṭh)	1283/84 BA	stucco	I b	arch	arch	4	0	1	2	1da							16			
146	7/22		Zawīyat al-Abbār (Khānqāh al-Bunduqḍāriyya)	1284/85 W	stucco	II a	3-foil	3-foil	2	3	1/6									24			
146	7/22		Zawīyat al-Abbār (Khānqāh al-Bunduqḍāriyya)	1284/85 W	stucco	II c	5-foil	5-foil	3	5	5	24								16			
296	9C/315		Qubbat al-Ṣawābī	ca. 1285/86 C	stucco	II a	3-foil	3-foil	2	3	1/6									16			
275	7/58		9 Tomb of Sulṭān al-Ashraf Khalīl	1288 BA	stucco	II c	5-foil	5-foil	3	5	5	24								24			
590	8/1		Tomb of Ḥusām al-Dīn Turunṭāy	1290 W	stucco	II c	5-foil	5-foil	3	5	5	24								24			
245	8/12		10 Ribāṭ Aḥmad b. Sulaymān	1291 BA	stucco	II e	3-foil	3-foil	3	3	4	8da											
44	10/10		13 Tomb of Sulṭān al-Nāṣir Muḥammad	1295–1303 BA	stucco	II c	5-foil	5-foil	3	5	5	24											
220	11/2		Dome in front of mihrāb at mosque of Ibn Ṭūlūn	1296 M	wood	II a	3-foil	3-foil	2	3	16/4*									24			
220	11/2		Fountain of mosque of Ibn Ṭūlūn	1296 M	stucco	II c	5-foil	5-foil	3	5	5	24								20			
172	11/11		12 Tomb of Zayn al-Dīn Yūsuf	1298–1325 BA	stucco	II b	5-foil	3-foil	3	3	3	20								24			
31	9B/11		Tomb of Qarāṣunqur	1300/01 W	stucco	II c	5-foil	5-foil	3	5	5	24								20			
221	9B/40		14 Tomb of Salār	1303/04 BA	stucco	II b	5-foil	3-foil	3	3	3	20								24			
221	9B/40		14 Tomb of Sanjār al-Jawālī	1303/04 BA	stucco	II c	5-foil	5-foil	3	5	5	24								20			
292	9C/145		Tomb of 'Alī Badr al-Dīn al-Qarāṭī	1300–10 C	stucco	II c	5-foil	5-foil	3	5	5	24								24			
32	9B/65		15 Khānqāh Sulṭān Baybars al-Jashnākīr	1307–10 BA	stucco	II d	7-foil	5-foil	4	5	5	5	24							16			
270	9C/52		Tomb of Saḍī al-Dīn Jawhar	1315 W	stucco	II a	3-foil	3-foil	2	3	1/6									24			
263	9C/59		Tomb of Ḥasan Sūḍaḡa (madrasa of Sunqur Saḍī)	1315–21 BA	stucco	II c	5-foil	5-foil	3	5	5	24											

- (1) The sources for the construction dates are C: Creswell 1952 and 1959, M: Meinecke 1992, W: Warner 2005, and BA: Behrens-Abouseif 2007.
- (2) Numbers indicate the number of petal facets in a layer in a corner of a room except: "0" in the first layer indicates one fan facet (no petal facet); a number followed by "da" denotes double-arch facets; a number followed by an asterisk ("*") denotes multipartite petal facets which form the upper layers of star-shaped units. A number followed by a "V" denotes teardrop motifs or stalactites (see types III-a to III-c of Fig. 4). The shaded numbers indicate the total number of facets in the top layer(s) encircling the drum. A *muqarnas* in which the number of petal facets increases with each layer is indicated by a bold frame; a *muqarnas* that forms a step-like shape in a dotted frame; a multi-foil arch is in *italics*.
- (3) Drum shape is indicated by either the number of sides of the polygon or the letter "C" (circular drum). When the top foil of a multi-foil arch on the wall is located in the drum zone, the number or "C" is in *italics*.

Monument numbers in previous studies			Monument	Date ⁽¹⁾	Material	Type	Wall arch	Diagonal arch	Layers	Number of petal facets in each layer ⁽²⁾													Dome shape (3)
Comité	Ménckle	Rehens-Avancif								1	2	3	4	5	6	7	8	9	10	11	12	13	
261	9C/142	115	9C/176	20B	Qubbat al-Muzaffar 'Alam al-Din Sanjar	stone	III a	none	5	0	1	2	6,5+2*	26+8*									12
262	9C/176	115	9C/176	20B	Tomb at mosque of Ahmad al-Mihmandar	stucco	II a	3-foil	2	3	1/6												16
300	9C/166a-	300	9C/391		Turbat al-Sitt (Qubbat 'Abd Allah al-Manifi)	stucco	IV b	7-foil	4	0	1	2	1/6										16
26	9C/259	128	9C/249		Tomb at mosque of Mughuliy al-Jamali	stucco	II a	3-foil	2		1/6												16
234	9C/250	234	9C/250		Qubbat al-Qinari	stucco	II b	5-foil	3	3	3	20											20
215	9C/251	215	9C/251		Tomb of Abi al-Yusufayn	stucco	II b	5-foil	3	3	3	20											20
130	9C/240	130	9C/240	21	Qubbat Awlad al-Asyid	stucco	II b	5-foil	3	3	3	20											20
92	9C/328	92	9C/328		Tomb at mosque of Iman al-Hajib	stucco	II b	5-foil	3	3	3	20											20
312	9C/321	312	9C/321		Tomb of Tashimur (Humus Akhdar)	stucco	II a	3-foil	2	3	1/6												20
10	9C/323	10	9C/323		Tomb of Ibn Ghurab	stucco	II a	3-foil	2	3	8/6												8
143	9C/324	143	9C/324	19	Tomb of Ahmad al-Qasid	stucco	II e	3-foil	2	3	8/6												8
291	9C/339	291	9C/339		Dome in front of <i>mihrab</i> at mosque of Sulān al-Nasir Muhammad	wood	III a	none	6	0	1	2	4+1*	40+8*	48								
120	9C/373	120	9C/373		Tomb of Qasim	stucco	II e	5-foil	3	5	7	8/6											
299	9C/412	299	9C/412		Dome in front of <i>mihrab</i> at mosque of Atunbugha al-Mardani	wood	III a	none	6	0	1	2	2+1*	32									
280	9C/393	280	9C/393		Tomb of 'Abd Allah al-Dakruri	stone	I b	arch	4	7	6	2+1*	1										
112	16/26	112	16/26	23	Tomb of 'Abd Allah al-Dakruri	stone	III a	none	4	3	8	6+3*	56										
86	16/18	86	16/18		Tomb at mosque of Aslam al-Siladhar	stucco	II b	5-foil	3	3	3	20											20
22	18/12	22	18/12		Tomb at mosque of Qaraqutlu al-Hasani	stone	III a	none	5	0	1	4	7	32+12*									
123	18/3	123	18/3		Tomb at mosque of Aydmur al-Bahlawan (Baydar)	stone	III a	none	3	0	24	20+8*+4V											10
221	19A/1	221	19A/1	24	Tomb of al-Ashraf Kutub at Aqsunur mosque	stone	III a	arch	2	0	12												12
81	19A/15	81	19A/15		Tomb of Bashrak at mosque of Sular and Sujar Jawli	stone	II a	3-foil	2	3	12+4*												16
288	19A/18	288	19A/18		Tomb of Khawand Tughay (Umm Anuk)	stucco	II b	5-foil	3	3	3	20											20
288	19A/18	288	19A/18		Tomb of Tatar al-Hijaziyya	stone	III a	none	5	2	4+1*	9	48										C
147	19A/22	147	19A/22	28	South dome of Sulaniyya	stone	III b	none	5	0	2	3	5	7									12
50		50		25	Tomb at mosque of Shaykh al-Umar	stucco	II a	3-foil	2	3	1/6												16
50		50			Qir'a of Muhibb al-Din al-Muwaqqi'	stucco	II f	5-foil	4	3	7	9	32										8
218	19B/4	218	19B/4	26	Tomb of Muhibb al-Din al-Muwaqqi'	wood	III a	none	4	0	1	2	24										
218	19B/4	218	19B/4		Tomb of Sharghamish	stucco	II f	9-foil	5	3	7	7	6	32									
36	19B/48	36	19B/48	26	Dome in front of <i>mihrab</i> at mosque of Sharghamish	wood	III a	none	7	0	1	2	2+1*	4	24+8*	32							
133	19B/13	133	19B/13	27	Tomb of Tatar al-Hijaziyya	stone	II b	5-foil	3	3	3	20											C
133	19B/13	133	19B/13	27	Tomb at Sulān Hasan mosque	wood	III a	none	8	0	3	10	8+1*	8	18	64	40+24*						C
80	22/6	80	22/6		Vaulting at entrance hall of Sulān Hasan mosque	stone	III a	none	11	0	1	2	3	4	5	6	64+3V	96+32V	96	32+32*			
					Tomb of Khawand Tughay (Qubbat al-Amira Tulbiyya)	stucco	II e	3-foil	3	3	4	8/6											

Monument numbers in previous studies	Monument	Date ⁽¹⁾	Material	Type	Wall arch	Diagonal arch	Layers	Number of petal facets in each layer ⁽²⁾													Dum shape ⁽³⁾
								1	2	3	4	5	6	7	8	9	10	11	12	13	
310	22/60	Tomb of Ibrahim al-Ansari	stone	III c	15-foil	none	7	0	1	2	3	5+IV	4+1*	6							32
131	22/78	Tomb of Ujjay Yusuifi	stone	III c	13-foil	none	6	0	1	2	5	5	6								32
157	24A/1	Tomb of Anas (Yunus al-Dawadiri)	stucco	III e	3-foil	none	3	3	4	8/10											8+C
139	25A/5	Tomb of Yunus al-Dawadiri	stone	III a	none	none	6	0	1	2	7	28+4*									8
250	25A/9	Tomb at mosque of Aytamish al-Bajasi	stone	II a	3-foil	3-foil	2	3	12+4*												16
187	25A/19	Vaulting at entrance hall at mosque of Sulṭān Barṣbiy	stone	III b	none	none	6	0	1	2	5	4+1*	13								16
187	25A/19	Tomb of Sulṭān Barṣbiy at mosque of Sulṭān Barṣbiy	wood	III b	none	none	7	0	1	1	2	4+IV	4+1*	6							C
118	25B/16	Tomb at mosque of Ināl al-Aṭbakī	stone	III c	13-foil	none	7	0	1	2	5	4+1*	6	32							32
117	25B/34	Tomb at mosque of Mahmūd al-Kurdi	stone	III c	13-foil	none	6	0	1	2	5	4+1*	6	7							24
89	26A/24	Qubbāt Gural (Sidi Karkur)	stucco	II a	3-foil	3-foil	2	3	16												C
35	26B/15	Tomb of Jamāl al-Dīn al-Uṣṭādār	stucco	II e	7-foil	7-foil	4	1	11	13	16da										16
149	26A/1	Dome in front of <i>mihrāb</i> at <i>khānaqāh</i> of Sulṭān Faraj b. Barṣbiy	stucco	II a	3-foil	3-foil	2	3	16												48
149	26A/1	North dome at <i>khānaqāh</i> of Sulṭān Faraj b. Barṣbiy	stone	III d	none	none	9	0	1	3	4	5	6	8	8						48
149	26A/1	South dome at <i>khānaqāh</i> of Sulṭān Faraj b. Barṣbiy	stone	III d	none	none	9	0	1	3	4	5	6	8	8						48
102	26B/45	Tomb at mosque of al-'Aynī	wood	III a	none	none	6	0	1	2	28+4*	32	24+8*								24
151	29/7	Tomb at mosque of Qanḫay al-Muḥammadi	stone	IV a	15-foil	none	7	0	1	2	3	4	5	6							40
190	29/15	Tomb at mosque of al-Sulṭān al-Mu'ayyad	stone	IV a	21 foil	none	10	0	1	2	3	4	5	6	7	8	9				28
410	29/31	Ḥammām al-Sulṭān Mu'ayyad	stucco	III a	none	none	9	0	1	4	5	10+IV	9	12	80+32V	48+32*					32
175	33/10	Tomb at mosque of Sulṭān al-Ashraf Barṣbiy	stone	III a	none	none	6	0	1	2	5	6	32								18
192	33/31	Zawiya al-Fayrūz	stone	III a	none	none	5	0	3	2+1*	6	36									24
119	33/41	Tomb at mosque of Jamḥak al-Ashrafī	stone	IV a	13-foil	none	6	0	1	2	3	4	5								36
122	33/45	Tomb of Jamḥak al-Ashrafī	stone	III a	none	none	5	0	3	2+1*	6	36									C
121	33/19/33/62	Tomb at the north of mosque of al-Ashraf Barṣbiy	stone	III a	none	none	6	0	2	5	4+1*	6	36								48
121	33/19/33/62	Tomb at mosque of al-Ashraf Barṣbiy	stone	III d	none	none	9	0	1	2	3	4	5	6	7	8					16
106	33/97	Tomb of Khadīja Umm al-Ashraf	stucco	II a	3-foil	3-foil	2	3	16												16
209	35/11	Tomb at mosque of Taghrī Bardī	stone	II a	3-foil	3-foil	2	3	16												24
97	35/13	Tomb at madrasa of Jawḥariyya (at al-Azhar mosque)	stone	III a	none	none	4	0	1	4	24										C
88	33/108	Qubbāt Kiz al-'Asal (Naṣr Allāh)	stone	III c	15-foil	none	7	0	1	2	2+2*	5	6	7							16
344	35/48	Dome in front of <i>mihrāb</i> at mosque of Qāḍī Yahya Zayn al-Dīn	wood	II e	5-foil	5-foil	3	7	7	16da											16
90	35/33	Qubbāt al-Zunm (Ardumur)	stone	III a	none	none	9	0	1	2	4+1*	8	5+2*	12	40+8*						C
110	35/31	Qubbāt Saḥ Banāi	stone	III a	none	none	6	0	1	2	3	6	32								C
204	35/75	Dome in front of <i>mihrāb</i> at mosque of Qāḍī Yahya Zayn al-Dīn	wood	II e	5-foil	5-foil	3	7	7	16da											36
124	37/11	Qubbāt Barṣbiy al-Bajasi	stone	III a	none	none	5	0	3	2+1*	6	32									C
158	37/9	Tomb at mosque of Sulṭān Ināl	stone	IV a	17-foil	none	8	0	1	2	3	4	5	6	7						

Monument numbers in previous studies		Monument	Date ⁽¹⁾	Material	Type	Wall arch	Diagonal arch	Layers	Number of petal facets in each layer ⁽²⁾													Drum shape ⁽³⁾
Comité 1951	Ménecke 1992								1	2	3	4	5	6	7	8	9	10	11	12	13	
601	37/29	Tomb of 'Umar b. al-Farid	1460/61 M	stone	IV b	11-foil	none	6	0	1	2	3	4	24								
3	39/22	Tomb of Abū al-Ghaznawī al-Fā'izī	1462 W	stucco	II e	5-foil and 3-foil	none	2	4	3+0.5da	14											
105	39/36	Tomb of Sūḍān al-Qasrawī	1468 W	stucco	III a	none	none	7	0	1	2	5+IV	6+1*	64+16V	112+32V							
99	42/21	Tomb of Sūḍān Qayrbay	1472-74 BA	stone	IV b	19-foil	none	10	0	1	2	3	4	5	7	8	40					
100	42/55	Tomb of al-Jalshānī	1474 M	stone	III c	9-foil	none	5	0	2	5	4	24									C
168	42/53	Tomb of 'Abd Allāh Manāfī	1474 M	stone	III b	none	none	4	0	1	2	4+1*										C
281	42/127	Tomb of Inām al-Shāfiʿī	1480 M	wood	II e	5-foil	5-foil	3	5	7	16da											C
114	42/116	Tomb at mosque of Qīmās al-Ishaqī (Abū Huraybā)	1479-82 BA	stone	IV a	13-foil	none	6	0	1	2	3	4	4								C
216	42/33	Tomb at mosque of Tīmāz al-Aḥmadī	1482 M	stone	IV b	11-foil	none	6	0	1	2	3	4	24								C
340	42/159	Tomb at mosque of Abū al-'Ilā	1485/86 M	?	II f	7-foil	7-foil	5	0	3	7	7	28+4*									C
303	42/211	Tomb of Ya'qūb Shāh al-Mihmandār	1495/6 BA	stone	III d	none	none	2	1	2												C
164	44/2	Tomb of Qānṣh Abū Sa'īd	1499 M	stone	IV b	17-foil	none	9	0	1	2	3	4	5	6	7	36					C
360	44/9	Tomb of Qānṣh Abū Sa'īd	1499 W	brick	II c	5-foil	5foil*	3	5	5	24											C
2	46/1	Tomb of al-'Adīl Tūmānbay	1501 M	stone	IV b	15-foil	none	8	0	1	2	3	4	5	6	32						C
248	47/6	Tomb at mosque of Khayrbak	1502-21 BA	stone	III d	foil	none	9	0	1	2	3	4	5	6	7	36					C
255	47/13	Tomb of Ṭarābīy al-Sharīfī	1503 W	stone	IV b	17-foil	none	9	0	1	2	3	4	4	6	7	36					C
67	47/10	Dome at Khānqāh Sulṭān al-Ghawrī	1502-04 BA	wood	III b	none	none	7	1	3	5	7	9	11	13	15						C
67	47/10	Tomb of Sulṭān al-Ghawrī	1502-04 BA	stone	IV b	25-foil	none	13	0	1	2	3	4	5	6	7	8	9	10	11	52	
87	47/12	Tomb of Azrumuk	1503/04-04/05 M	stone	IV a	13-foil	none	6	0	1	2	3	4	5	6							C
294	47/16	Tomb of Sūḍān Amīr al-Majlis	1503/04 M	stone	IV b	19-foil	none	10	0	1	2	3	4	5	6	7	8	40				C
286	47/33	Tomb of Inām al-Layth	1505 M	brick	II f	9-foil	7-foil	5	0	3	7	7	28+4*									C
136	47/7	Tomb at Qanbay al-Sayrī Amīr Akhūr	1506 BA	stone	III c	17-foil	none	8	0	1	2	3	6+1*	5	6	32						C
132	47/37	Qubbat 'Asfur	1506 M	stone	III b	foil	none	6	0	3	2+1*	4	5	8								C
162	47/36	Tomb at Khānqāh Qurqumās (Amīr Kabīr)	1506/07 BA	stone	III d	none	none	10	0	1	2	3	4	5	6	7	8	44				C
129	42/106	Tomb of Janīm al-Bahlawān	1510 W	stone	IV b	11-foil	none	6	0	1	2	3	4	24								C
170	47/36	Tomb of Qurqumās	1511 W	stone	IV b	9-foil	none	5	0	1	2	3	20									C
191	47/100	Tomb of Baybars al-Khayyāt	1515 W	stone	IV b	17foil	none	9	0	1	2	3	4	5	6	7	36					C

Muqarnas may look very complicated, but they do have geometrical regularity when projected onto a plane seen from above (see Fig. 2). This is also apparent from the thirteenth-century stucco plate containing a plan of *muqarnas* excavated at Takht-i Sulaymān, Iran (Harb 1978) and the plans drawn on the fifteenth-century Timurid Topkapı Scroll, Hazine 1956 (Necipoğlu and al-Asad 1995). In this article, when the geometrical feature is considered, the quarter plan of a room between the square walls and the circular or polygonal dome base is used because of the symmetrical nature of the transitional zone. Fig. 2 illustrates the four types of *muqarnas* and the following discussion describes them together with their various sub-types.

Fig. 2: The Four Types of *Muqarnas*, Plan (left) and Perspective Drawing (right)

1. Type I (13 examples)

Type I has a diagonal (squinch) arch at the corner and vertical panel at the wall that rises from a square base to an octagonal top, and the *muqarnas* are found in the diagonal arch. There are two sub-types: type I-a, which uses a trefoil arch (9 examples) and type I-b, which uses a pointed arch (4 examples).

Type I-a is similar to the Persian *muqarnas* transitional zone of the eleventh century, for instance that seen at Gunbad-i Khākī in Isfahan, although there are some differences (Fukami 1998, 27). The Egyptian examples have two fan facets in the lower layer instead of vertical facets, two petal facets in the upper layer instead of two semi-tunnel facets, and no pointed arch covering the trefoil corner arch. These features are common in all nine examples of type I-a.

Type I-b has a simple squinch arch, and the *muqarnas* are formed in the squinch arch.

2. Type II (52 examples)

Type II has an integral transitional zone with horizontal layers of *muqarnas* rising from a square base to a polygonal top. It has multi-foil³ arches on the surrounding four walls and the multi-foil diagonal arches that connect adjacent walls can be traced in the layers of *muqarnas*.

There is clear evidence of a series of geometrical developments in this type (Fig. 3). By focusing on three geometrical aspects, 1) the number of layers, 2) the polygon on the top and 3) the multi-foil arches at the walls and corners, it can be seen that there are six sub-types.

Each sub-type, type II-a to type II-d, can be defined in terms of these three aspects as follows and as illustrated in Fig. 3 (a)–(d) below:

Type II-a (16 examples): 1) two layers, 2) 16-sided polygon, 3) 3-foil/3-foil

Type II-b (11 examples): 1) three layers, 2) 20-sided polygon, 3) 5-foil/3-foil

Type II-c (10 examples): 1) three layers, 2) 24-sided polygon, 3) 5-foil/5-foil

Type II-d (1 example): 1) four layers, 2) 28-sided polygon, 3) 7-foil/5-foil.

There are also two further sub-types that demonstrate a different geometrical development from that of type II-a to type II-d, and these are named type II-e and type II-f (Fig. 3 (e), (f)). Type II-e (10 examples) is a derivation of type II-a with double-arch curved facets (Fig. 1) at the top layer of *muqarnas*. Double-arch curved facets are introduced to connect a small inner arch and a large outer one in the form of a tilted belt. Five of the examples reduce their diameter and have trefoil arches at the walls and corners, similar to type II-a, but have an octagon at the top instead of a 16-sided polygon (Fig. 3 (e), upper half). The other five examples,⁴ also employing double-arch curved facets, have 5-foil arches at the walls and corners instead of trefoil arches and do not reduce their diameter, but they do have a 16-sided polygon at the top as in type II-a (Fig. 3 (e), lower half).

Type II-f (4 examples) cannot be traced directly back to types II-a to II-d in terms of the three geometrical aspects mentioned above. However, type II-f does have multi-foil arches at the walls and leads to a 32-sided polygon at the top, so it is still possible to regard this type as a deviation from type II. Based on the geometrical development seen from type II-a to type II-d, it is reasonable to assume that ideal type II-f would have consisted of a 32-sided polygon with 7-foil arches at walls and corners in four layers, as in Fig. 3 (f). However, this ideal type II-f would not have been fully realized because the formation of facets at the corner becomes too complex to allow the presence of regularly shaped multi-foil diagonal arches.

Fig. 3 shows this geometrical development in the division of the edge at the bottom and the division of the angle at the top from type II-a to type II-e, as well as the ideal type II-f.

From Figs. 2 and 3, it is clear that type II is an improvement on type I. As shown in Fig. 2, type I is based on the regular octagon made by a $1 : \sqrt{2} : 1$ deviation of each edge of a square room,

³ In this article, the term “multi-foil arch” refers to a step-like arch consisting of curved facets that all have the same span and rise.

⁴ One of these, the rectangular tomb of Abū al-Ghaḍanfar al-Fā’izī (restored in 1462, No. 3) is an exception. The top of the transitional zone is a 14-sided polygon, so there are two trefoil arches and two pentafoil arches on the wall. In addition, a double-arch facet is placed in the center of the second layer on a shorter wall of the room. The tomb of Jamāl al-Dīn al-Ustādār (1408, No. 35, moved in 1952) has 7-foil arches and reduces its diameter through the use of double-arch curved facets.

**Fig. 3: The Six Sub-Types of Type II Muqarnas
(Geometrical Perspective of Quarter Projected Plans)**

Note: The value in < > shows the number of equal divisions on the quarter plan of the dome and the value in [] shows the number of *muqarnas* petal facets on the whole dome.

and it begins to bisect the equilateral edge of an isosceles right-angled triangle at the corner. This formation is similar to that seen in the corner of types II-a and II-c (Fig. 3 (a), (c)). However, as shown in Fig. 2, in type II *muqarnas*, facets are inserted in the upper layers to fill the gap between adjacent multi-foil arches and to make a regular polygon at the top of the transitional zone.

In summary, type II is formed with eight multi-foil arches, four at the edges and four at the corners, surrounding the transitional zone. At first, type II-a was developed from type I-a to make a regular 16-sided polygon instead of a regular eight-sided polygon at the top of the transitional zone. Type II-b to type II-d were then devised as variations of these geometrical concepts. Type II-e was another development based on type II-a, but deviated from the standard type through the use of double-arch curved facets. Type II-f was also a development of type II-a to type II-d, but there was no further development beyond this type, most likely because this would have led to the introduction of irregular geometrical features by giving up its reasonable geometrical development of type II.

3. Type III (43 examples)

This type and type IV have been called “stalactite pendentive” in previous studies, but it has been noted that there is no structural meaning inherent in the term pendentive (Ibrāhīm 1975, 11). However, in those previous studies variation and direction have not been considered. In the context of this study,⁵ the technical term pendentive has been used to denote the technique where the transitional zone starts from the four corners of the room and leads to a circle or polygon at the top.

From a detailed analysis of the type III examples, they can be considered a progression toward type IV, which has multi-foil arches on the surrounding walls and which increases the number of one petal facets when it rises one layer (Table 2).

Table 2: Differences in the Sub-Types of Type III and Type IV *Muqarnas*

	Bottom	Top	Corbeling		Wall	
	starts from four corners	series of <i>muqarnas</i> ; polygon or circle	without star pattern	one facet by one layer up (in an arithmetical series)	step-like	multi-foil arch
Type III-a	○	○	×	×	×	×
Type III-b	○	×	△	×	×	×
Type III-c	○	△	△	×	○	○
Type III-d	○	△	○	○	○	×
Type IV-a	○	×	○	○	○	○
Type IV-b	○	○	○	○	○	○

Note: ○ denotes always has, × does not have and △ sometimes has the feature.

Type III does not have multi-foil diagonal arches, but it does have an inverted triangular curved surface with many facets starting from the four corners of the room. Generally, type III starts at the corner of a room with one fan facet. Also, most examples contain a unit in the shape of a half star that occupies two layers or more (Fig. 4, type III-a to c). This unit has partite petal facets in the upper layer, followed by kite-shaped curved fan facets and petal curved facets placed alternately in the lower layers, and could be used to increase the length of corbeling.

By focusing on three key aspects, 1) the form of the base, 2) the top of the transitional zone and 3) the form of the surrounding walls, it is possible to categorize type III into four sub-types, III-a to III-d, as illustrated in Fig. 4.

Type III-a (24 examples) starts from the base at four corners each with one fan facet (there are two exceptions)⁶ and leads with a succession of *muqarnas* facets (including the vertical facets) to a circle or multi-polygon at the top, without a multi-foil arch at the surrounding wall.

Type III-b (6 examples) also starts from the base at four corners, but instead leads to the four

⁵ Ibrāhīm (1975) classifies *muqarnas* into three categories: squinch, pendentive, and pendentive-squinch (hybrid type), and exceptions (three examples). Also, she considers these exceptions to be similar to the semi-dome that was used at entrances.

⁶ The exceptions are the tomb of ‘Abd Allāh al-Dakrūrī (1339/40, No. 280) and the north dome of Sulṭāniyya (1349/50, No. 288). These examples have some petal facets and fan facets at the lowest layer (Table 1).

Fig. 4: The Four Sub-Types of Type III

edges below the dome or below the lower part of a drum at the top, so *muqarnas* occupy only the corner parts at the top.

Type III-c (7 examples), like type III-a, starts from the four corners at the base and leads to a circle or multi-polygon at the top with a succession of *muqarnas* facets or an arcaded drum, but it has multi-foil arches at the surrounding walls with encircling *muqarnas* facets or a drum part. This is similar to type IV, but there is a difference between them because type III-c does not increase by one facet when it rises one layer in an arithmetical series. Thus type III-c is a precursor of type IV.

Type III-d (6 examples), like type III-b, starts from the four corners at the base and leads to the four edges of the dome or lower part of the drum at the top, but it increases one petal facet by one layer up.⁷ Therefore, it makes a half multi-foil arch at the wall. However, the top is truncated, so it cannot form a complete multi-foil arch at the wall. Thus, this type also shows evidence of a transition to type IV.

4. Type IV (18 examples)

As described above, type IV starts from the base at the four corners each with one fan facet and

⁷ The transitional zone of the two domes at the *khānqāh* of Sulṭān Faraj b. Barqūq (1400–11, No. 149) does not increase by one facet per layer in an arithmetical series (Table 1). However, in this article, it is included under sub-type III-d because it represents the first example of step-like half-multi-foil arches at the walls. See footnote 11.

increases by one petal facet when it rises one layer in an arithmetical series (Table 2). It also has regular multi-foil arches at the surrounding walls. There are two sub-types (a and b), as illustrated in Fig. 5.

Fig. 5: The Two Sub-Types of Type IV

Type IV-a increases one petal facet every layer to form a multi-foil arch with a drum part. In other words, the top foil of the multi-foil arch is located at the drum. Type IV-b also forms a multi-foil arch but with *muqarnas* facets encircling the drum. Type IV-b seems to be the complete type. Hence it is possible to consider type IV-a as a predecessor of type IV-b.

IV. The Six Periods of *Muqarnas* in Transitional Zones

Based on the morphological classification above, it is hypothesized that there are six periods⁸ that can be associated with the six sub-types of *muqarnas*. The periods are determined based on the appearance of new types or sub-types, as shown in Table 3 and discussed in more detail below.

Table 3: Proposed Evolution of *Muqarnas* by Sub-Type and Period

	I		II						III				IV		Number of examples
	a	b	a	b	c	d	e	f	a	b	c	d	a	b	
1 st : 1050s–1230s	9	2													11
2 nd : 1240s–1310s		1	6	3	9	1	1								21
3 rd : 1320s–1360s		1	5	8			3	2	12	1				1	33
4 th : 1370s–1400s			2				2		1	2	4				11
5 th : 1410s–1450s			3				2		10		1	3	4		23
6 th : 1460s–1510s					1		2	2	1	3	2	3	2	11	27
Total	9	4	16	11	10	1	10	4	24	6	7	6	6	12	126

⁸ It is difficult to decide on an exact year at which to divide each period, so for the sake of convenience the noughties of the Christian era have been selected in this article.

The first period is from the 1050s to the 1230s with only type I. The technique of type I originated from a local brick dome and type I was used in the transitional zone of many small brick domes.

The second period is from the 1240s to the 1310s. Type II first appeared in 1242/43 in the tomb of the Abbasid caliphs.⁹ Type II developed geometrically with the division into equal parts at the top, and multi-foil arches at the diagonals and walls of a room.

The third period is from the 1320s to the 1360s. During this period, there was the sudden appearance of totally new types like type III-a in 1322¹⁰ and type IV-b in 1324, which may indicate that they were foreign imports. However, the local type II remained in predominant use.

The fourth period is from the 1370s to the 1400s. Type III-c, which has multi-foil arches at the surrounding walls, appeared in 1370. As the stone dome started to replace the brick dome, type III became predominant.

The fifth period is from the 1410s to the 1450s. Type III-d, which creates a step-like half arch at the wall, appeared around 1410.¹¹ Type IV-a also appeared in the 1410s. Type IV established the use of multi-foil arches at the surrounding walls by increasing by one petal facet in one layer. This development was also local with its origins in Cairo and was based on the geometric development of the styles of type III-a to type III-d.

The sixth and final period is from the 1460s to the 1510s when several examples of type IV-b appeared. It should be noted that the earliest existing instance of type IV is a type IV-b example that was created sometime between 1324 and 1339/40 while the next instance of a type IV *muqarnas* is a type IV-a example dated to 1413. However, it was from 1460 onward that type IV-b reappeared and became the major form. Then, after the 1520s when Egypt was under Ottoman rule, different vaulting techniques¹² became dominant.

In the following, the above hypothesis regarding the six periods will be substantiated by examining typical examples as well as some that are particularly noteworthy.

V. The First Period: From the 1050s to the 1230s

There are nine examples of type I-a and two examples of type I-b, all of which appeared during the first period. Furthermore, all type I-a examples were made during a one hundred year period from the middle of the eleventh century to the middle of the twelfth century. These examples were made

⁹ The construction date of the tomb of the Abbasid caliphs was 1242/43 according to Creswell (1952). See also footnote 15.

¹⁰ An example at Qubbat al-Muẓaffar ‘Alam al-Dīn Sanjar (1322, No. 261) seems to be the earliest existing example of this type.

¹¹ Although the transitional zones of the two domes in the *khānqāh* of Sulṭān Faraj b. Barqūq (1400–11, No. 149) predate the fifth period, they are included here to be discussed with other type III-d examples as well as type IV-a examples that appeared in the 1410s. See footnote 37.

¹² Ibrāhīm described this technique as trilobed squinch arch (Ibrāhīm 1975, 21–22) and Behrens-Abouseif called it trilobed pendentive (Behrens-Abouseif 2007, 257). The new technique appeared from the 1440s in the transitional zone of the *zāwiya* at the funerary *khānqāh* of Barsbāy (1432–40, No. 121), Qubbat Amīr Yashbak at Maṭariyya (1477, No. 502), Qubbat al-Fidāwiyya (1479–81, No. 5) and the *zāwiya* of Shaykh Damirdash (1470s–90s). Also, the semi-dome of the entrance portal to the mosque of Qāḍī Yahyā Zayn al-Dīn (1444, No. 182) shows the same “new” technique. These examples consist of two layers with trefoil arch, so they can be considered a regression of type I. This technique appears in only four domes from the 1440s to the end of Mamluk era, and as there is a need to discuss the vaulting in its entirety, not just *muqarnas*, these examples are not considered in this article. In short, the new trend of vaulting toward the broad dome instead of the high dome occurred due to the influence from Ottoman architecture.

of brick, and the inner diameter of the domes concerned is around 3 m. The largest dome can be found in the Mashhad Yaḥyā al-Shabīh (ca. 1150, No. 285), which has an inner diameter of 7.58 m.

Not only in Cairo, but also in Aswān (Creswell 1952, 222–224) and Qūṣ (Creswell 1952, 236–238), most examples of type I-a are in tomb chambers, although one example can be found in the Coptic chapel of Abū al-Sayfayn. Furthermore, the detail of the trefoil diagonal arch is different from the Persian examples mentioned above. Based on this reasoning, it is assumed that the vernacular squinch arch of the brick domes¹³ might have evolved into the trefoil arch (Creswell 1952, 251–253).

There are two layers of *muqarnas* in the trefoil arch. The lower layer consists of two fan-shaped facets and three petal-shaped facets and the upper layer consists of two petal-shaped facets. There is a small decorative change in Qūṣ, although the same style was used for one hundred years.

As for type I-b, there are examples in the church of Abū al-Sayfayn (1094–1121) and in Bāb Zuwayla (1092, No. 199). The former can be regarded as having omitted the upper layer from type I-a, so this means it is a variation of type I-a. In the latter, the squinch in a semi-domed recess is made of stone, and is a special case found only in Egypt. It has two conch-shaped facets.¹⁴

The transitional zone of the Mashhad Yaḥyā al-Shabīh (ca. 1150) is the last known example of type I-a. From 1150 to 1250, there are few architectural examples, so it is very difficult to estimate the extent of evolution during the changeover years from the Fatimid to the Ayyubid dynasties. Of the few surviving monuments from this period are the Tomb of Imām al-Shāfiʿī (1211, No. 281) and the Tomb of Ismāʿīl b. Thaʿlab (1216, No. 282) but the dome of the former was reconstructed in the fifteenth century and the latter had a tunnel vault instead of a dome. There is a possibility that the change in style of *muqarnas* could have occurred during the first half of the thirteenth century because the transitional zone of the tomb of the Abbasid caliphs (1242/43, No. 276) had changed totally from type I to include the new type II-a *muqarnas*.

It is important to note that the *muqarnas* that were used for the transitional zone of the dome have no relationship with the decorative *muqarnas* used for the cornice of minarets, such as those at the mosque of al-Juyūshī (1085, No. 304), and those used for the façade niche, such as those in the mosque of al-Aqmar (1125, No. 33). The *muqarnas* in the transitional zone were restricted to brick masonry and originated from the vernacular transitional zone of brick domes.

VI. The Second Period: From the 1240s to the 1310s

The construction of the tomb of the Abbasid caliphs (1242/43 or 1260–77,¹⁵ No. 276) marked a complete change in the design of the transitional zone. Until the twelfth century, *muqarnas* facets occupied the corner trefoil diagonal arches, but later the *muqarnas* facets came to form a link between multi-foil diagonal arches and multi-foil wall arches. In other words, the transitional zone

¹³ These vernacular squinch arches are seen in several tombs in Aswān, namely Nos. 5, 7, 13, 14, 17, 19, 23, 24, 46, 54, and in the dome of the mosque of al-Juyūshī (1085, No. 304).

¹⁴ The conch-shaped facets, which originated in pre-Islamic architecture around the Mediterranean world, are similar to those in the squinch in the dome constructed in 864 in the Great Mosque at Qayrawān. It is known that there were also conch-shaped facets in Fatimid *miḥrābs* in Cairo, although there were no examples of the conch shape in the transitional zone or in *muqarnas* facets in Egypt until the fifteenth century. Conch-shaped petal facets of *muqarnas* are seen in the tomb of al-Sulṭān Muʿayyad Shaykh (1415–20, No. 190), the tomb of Jānibak al-Ashrafi (1426, No. 122), and the *zāwiya* of al-Fayrūz al-Sāqī (1426, No. 192).

was integrated with *muqarnas* facets by articulating the multi-foil wall arches into small arches and hexagons.

From a comparison of type I-a and the type II-a example of the tomb of the Abbasid caliphs, it can be seen that both consist of two layers (Fig. 2), although the former becomes an octagon and the latter becomes a 16-sided polygon at the top of the transitional zone. If these *muqarnas* are examined by making a projected quarter plan, at the bottom the articulation ratio is $1 : 1 : \sqrt{2}/2 : \sqrt{2}/2$ (Fig. 3 (a)) while the half span of each layer of the multi-foil arch is $\sqrt{2}/2$.

Three points are worth considering with respect to the appearance of type II. Firstly, small trefoil arches were inserted in the upper layer of the Fatimid tomb at Qūṣ (1120–30) and a 16-arched drum was created in the upper layer. Secondly, a single opening in the integrated shape of the trefoil arch on each of the four walls observed in the domes built before 1130 evolved to become articulated into three separate openings, that is, two arches in the lower layer and one arch in the upper layer, as seen in the Mashhad Sayyida Ruqayya (1133, No. 273) and the Mashhad Yahyā al-Shabīh (ca. 1150, No. 285). Thirdly, there is a clear similarity between type II-a and Iranian examples¹⁶ in the early thirteenth century.

While it is unclear how the technique spread from Iran to Egypt, it is known that there were innovations of technique to make approximate circles at the top of the transitional zone in both regions.¹⁷ Considering the relation between Egyptian *muqarnas* and those in Syria, the stone transitional zone in Firdaws madrasa (1235) at Aleppo might not have a direct relationship with type II-a based on the size and formation of the *muqarnas* facets, even though it has a strong similarity with type III that occurred after 1320.

It is clear that this development of type II had become well-established in the transitional zone by the time that the tomb of al-Ṣāliḥ Najm al-Dīn Ayyūb (type II-b, No. 38) was constructed in 1250. This example has three layers with 5-foil arches on the walls and trefoil arches in the corners, and a 20-sided polygon was created at the top of the transitional zone. When this *muqarnas* is examined by means of a projection plan, it can be seen that at the bottom the articulation ratio is $1 : 1 : \sqrt{2}/2 : \sqrt{2}/2 : \sqrt{2}/2$ (Fig. 3 (b)). This means that to enlarge type II-a in terms of both the width and height of the wall multi-foiled arches, their design was changed from trefoil to 5-foil. For the tomb of al-Ṣāliḥ Najm al-Dīn Ayyūb, a large dome was required; the diameter is approximately 10 m and thus of a size that had never previously been seen in Egypt.¹⁸ Therefore, it may be concluded that

¹⁵ A construction date of 1242/43 has been suggested by Creswell (1952), but a date during the reign of al-Zāhir Baybars (r. 1260–77) has been proposed by Behrens-Abouseif (2007, 126). However, the division of the layers of *muqarnas* facets located between the trefoil arches on the wall and the corner in the tomb of the Abbasid caliphs is not conspicuous, so the facets of the two layers appear to be combined to form a hexagon, although the division of the layers is articulated in the later examples of type II, where instead of a hexagonal facet, two vertical facets on the lower layer and one petal facet on the upper layer are recognizable. Therefore, this article suggests that the construction of this transitional zone took place in 1242/43 before the tomb of al-Ṣāliḥ Najm al-Dīn Ayyūb and the tomb of Shajar al-Durr were constructed in 1250.

¹⁶ In Iran, there are similar *muqarnas* in the transitional zone of the domes in the mosque at Marand (mid-twelfth century), Imāmzāda Karrār at Buzān (thirteenth century), the tomb of Shaykh Sa'd at Isfahan (thirteenth century) and an anonymous tomb at Zavān (thirteenth century) (Fukami 1998, 70–118).

¹⁷ Such a geometrical development like that seen in the progression from type II-a to type II-f is not observed in Iran. Therefore, even if there were some Iranian influence on the creation of type II in Egypt, the geometrical development of type II could only have originated from local tradition.

¹⁸ To put the size of this dome in context, the diameter of the dome in the tomb of the Abbasid caliphs (1242/43) is 6.76 m and in the tomb of Shajar al-Durr (1250) is 7.17 m (Creswell 1952; 1959).

the geometrical challenge involved in this construction was overcome through the use of type II-b.

The appearance of type II-c occurred more than thirty years later, as evidenced in the transitional zone of Zāwiyat al-Abbār¹⁹ (Khānqāh al-Bunduqdāriyya, 1284/85, No. 146) where a 24-sided polygon was placed above three layers in this new type. On the quarter projection plan, the articulation ratio of type II-c is $1 : 1 : 1 : \sqrt{2}/2 : \sqrt{2}/2 : \sqrt{2}/2$ at the bottom (Fig. 3 (c)). Both the wall 5-foil arch and corner 5-foil arch have the same dimensions so that structural stability could be achieved, and the construction method might have been easier than that involved in making type II-b, which exhibits a similar effect with three layers. The nine examples of type II-c are concentrated in terms of date from 1284 to 1321.²⁰ After this time, there is only one example of type II-c²¹ until the end of the Mamluk era.

The first appearance of type II-e occurred in 1291, at the Ribāṭ Aḥmad b. Sulaymān (No. 245). Type II-e was an innovation of type II-a that allowed a decrease in the diameter of the dome and an increase in the height of the transitional zone; it has double-arch facets (Fig. 1) in the third layer that reduce the diameter from this point. These facets also appeared in the tomb of Fāṭima Khātūn (Umm al-Šāliḥ, 1250, No. 274), and have only been found in Egypt.

Type II-d first appeared at the Khānqāh Baybars al-Jāshnakīr (No. 32), which was constructed between 1307 and 1310. Type II-d leads to a 28-sided polygon at the top of the fourth layer here. It is a geometrical development of type II, as mentioned above. On the quarter projection plan, the articulation ratio is $1 : 1 : 1 : \sqrt{2}/2 : \sqrt{2}/2 : \sqrt{2}/2 : \sqrt{2}/2$ at the bottom (Fig. 3 (d)). It has a 7-foil arch on the wall and a 5-foil arch in the corner. However, this is the only example across all six periods.

It should be noted that type II challenges to approximate a circle at the top of the transitional zone instead of an octagonal drum of type I. In geometrical terms, this type is based on the division of a $1 : \sqrt{2}$ ratio at the bottom edge and the creation of a polygon (16- or 20- or 24-sided) at the top of the transitional zone.

The geometrical changes that occurred in the type II sub-types might have required a change in the structural method employed to construct the brick transitional zone. However, they all continue to use the corner and wall multi-foil arch. The morphological analyses of the type II examples suggest a process of constructing *muqarnas* as follows: 1) the bottom edge of the square room was divided by a ratio of a line segment, 2) the falseworks of the multi-foil arches on the walls and in the corners were constructed, 3) the falsework of the circle at the top of the transitional zone was constructed, 4) the circle at the top was divided into equal arcs, and 5) the regular polygon was made. Based on these falseworks, the construction would progress layer by layer, as is clear from the articulation of the lines of each layer. Only the first example of type II-a, found in the tomb of

¹⁹ Zāwiyat al-Abbār has two domes, one transitional zone is type II-c and the other is type II-a.

²⁰ It should be noted that there is a lack of consensus on the construction date of two of these examples. Firstly, two construction dates have been suggested for the tomb of ‘Alī Badr al-Dīn (No. 292, Meinecke’s monument number Nr. 9C/145, type II-c). Creswell (1959) dates it to 1300–10, which falls in the second period, while Meinecke (1992) suggests that it dates from 1321/22 to 1340, which falls in the third period. In this article, the former date is adopted, because of the morphological similarity to the other examples of type II-c. Secondly, the tomb of Ḥasan Ṣadaqa (madrasa of Sunqur al-Sa’dī, 1315–21, No. 263) is included in the second period, which ends in 1319; although it was constructed from 1315 to 1321, the majority of the work took place in the second period.

²¹ Only the tomb of Qānṣūh Abū Sa’īd (1499, No. 360) uses type II-c for its small brick dome, which is different from another tomb built for him in the same year (type IV-b, 1499, No. 164) (Warner 2005, 148). The former has distorted geometrical features, so it can be considered a retrospective example of type II-c.

the Abbasid caliphs (1242/43), uses hexagonal facets to link the upper and lower layers; the other examples of sub-types II-a–f always have clear lines at each layer. This shows the key role that *muqarnas* played in the corbeling of each layer.

From 1242 to 1319, there are twenty examples of type II; six of type II-a, three examples of type II-b (Fig. 6), nine of type II-c, one of type II-d and one of type II-e. The examples of each type are similar, and most of them have a multi-arched drum on the top of the polygonal transitional zone to increase the height. However, there are a few variants. For example, the *muqarnas* of Qubbat al-Şawābī (type II-a, ca. 1285/86,²² No. 296) is similar to that of Gunbad-i Khākī in Isfahan that uses vertical facets, and the wooden transitional zone of the *miḥrāb* dome in the mosque of Ibn Ṭūlūn (No. 220) which was rebuilt in 1296 by Sulṭān Lājīn has a half-star unit with a partite petal facet like that seen in Syrian stone *muqarnas*.²³

Fig. 6: Tomb of Zayn al-Dīn Yūsuf (1298–1325, No. 172, type II-b)

There is only one type I-b in this period, namely that found in the tomb of Fāṭima Khātūn (1283/84, No. 274). The transitional zone of this tomb is an authentic squinch technique and the *muqarnas* are used to articulate it. However, it is important to note that the double-arch facets were used in the corbeling and that the shape of *muqarnas* begins (like type IV) from one fan facet at the bottom layer and increases by one petal facet in each additional layer.

So, why did type II occur? As mentioned above, the increasing diameter of the domes being constructed during this period seems to be one of the triggers for type II. However, there appears to have also been a desire for geometrical variation because type II-e appears in the dome of Ribāt

²² Meinecke (1992, Nr. 9C/315) suggests that the construction of Qubbat al-Şawābī took place in 1334/35.

²³ The entrance of ʿĀdiliyya madrasa (Damascus, 1212–22) has two 8-petal domelets at the top of the *muqarnas* while the entrance of Kāmiliyya madrasa (Aleppo, 1238) has two five-eighths of domelets with four-partite petal facets in the upper layer and four petal facets and five kite-shaped fan facets in the lower layer (Fukami 1998, 174 and 176 respectively).

Aḥmad b. Sulaymān (1291, No. 245), the diameter of which is only 3.3 m.

VII. The Third Period: From the 1320s to the 1360s

In the early 1320s, a new type of *muqarnas* (type III) started to appear in the transitional zone of domes.²⁴ Type III-a was used in 1322 in the first stone dome in Egypt, at Qubbat al-Muẓaffar ‘Alam al-Dīn Sanjar (No. 261, Fig. 7) (Ibrāhīm 1975, 15;²⁵ Meinecke 1992, 1:89; Warner 2005, 136). Furthermore, type IV also appeared around the same time, in the brick dome of Turbat al-Sitt (Qubbat ‘Abd Allāh al-Manūfī, No. 300),²⁶ which was constructed in 1324 (Ibrāhīm 1975, 11). These examples mark the beginning of a new period in the evolution of *muqarnas*.

The transitional zone of Qubbat al-Muẓaffar ‘Alam al-Dīn Sanjar is similar to that of examples in Syria, namely the stone dome in Firdaws madrasa (Aleppo, 1235), the east chamber of Mashhad Ḥusayn (Aleppo, late thirteenth century),²⁷ and also similar to an example in Egypt, namely the *muqarnas* of the entrance semi-dome in the *khānqāh* of Baybars al-Jāshnakīr (Cairo, 1306–10, No. 32). These examples suggest that the Syrian stone *muqarnas* technique was introduced to Cairo in the early fourteenth century, and it has been stated that this technique was used in Cairo for not only the semi-dome, but also the transitional zone of the dome (Meinecke 1992, 1:89–91).²⁸

Fig. 7: Qubbat al-Muẓaffar ‘Alam al-Dīn Sanjar (1322, No. 261, type III-a)

²⁴ Before type III appeared in the transitional zone of domes in Egypt, a similar new stone *muqarnas* technique was introduced from Syria to Cairo in 1298, as seen in the entrance semi-dome of the madrasa and tomb of Zayn al-Dīn Yūsuf (No. 172). This was the first usage of stone *muqarnas* in a semi-circular vault (Fukami 1998, 196). However, Behrens-Abouseif insists that the first appearance of Syrian portal *muqarnas* in Cairo occurred in the entrance portal of the madrasa of al-Zāhir Baybars (1266–69, No. 1), although it could not be confirmed on site (Behrens-Abouseif 2007, 86 and 121). On the other hand, Baybars built Zāhiriyya madrasa at Damascus using stone *muqarnas* in the semi-dome (1281), a building that still exists today.

²⁵ Ibrāhīm (1975) asserts that this tomb was built later than the tomb at the mosque of Ayduṇmur al-Bahlawān (1346, No. 22) and insists that construction of the stone dome started in around the mid-fourteenth century.

²⁶ There are other opinions, for example, that it was constructed in the thirteenth century (Comité 1951) and from 1324 to 1339/40 (Meinecke 1992, Nr. 9C/166 and Nr. 9C/391).

Subsequently, type III-a was used in the wooden transitional zone of the big dome in front of the *miḥrāb* in the mosques built in the 1330s, such as the mosque of Sulṭān al-Nāṣir Muḥammad (1335, No. 143) and the mosque of Altunbughā al-Māridānī (1339/40, No. 120). There are five wooden examples and seven stone examples of type III-a prior to 1370.

The tomb and mosque of Sulṭān Ḥasan (1356–63, No. 133) contain some splendid *muqarnas* not only in the semi-dome at the main entrance of the building, but also in the transitional zones of the domes at the antechamber connected to the main entrance and at the tomb. The *muqarnas* in both of the transitional zones are type III-a; the one in the antechamber is a stone *muqarnas* with eleven layers and the one in the tomb is a wooden *muqarnas* with eight layers, which are the highest ever seen.²⁹ The former has arithmetic progression from the first to the seventh layer, but it has a pointed arch under the *muqarnas* at four sides of the room, so it might not be connected to type IV with its multi-foil arches and arithmetic progression. Type III-b, which can be seen in the stone transitional zone of the south dome of Sulṭāniyya (1349/50, No. 288), does not encircle the dome with *muqarnas* facets, and it is the earliest extant example of type III-b.³⁰

For the construction of type III-a and b *muqarnas*, some ingenuity in structure was required. For example, considering the inscribed circle (with radius r) of the square (where the length of each side is $2r$), the distance between the circle and the square becomes $(\sqrt{2}-1)r$ at the corner, and it becomes zero at the center-point of the edge. Thus from a three-dimensional model, it becomes clear that the length of the corbeling required is greatest at the corner. To solve this problem, star-shaped units consisting of two layers were inserted into type III-a.³¹ Decorative projections in the shapes of teardrops and stalactites, which are often observed in Syrian and Anatolian stone *muqarnas*, are sometimes added to extend the corbeling, as seen in the mosque of Ayduṇmur al-Bahlawān (1346, No. 22) and in the antechamber at the tomb and mosque of Sulṭān Ḥasan (1356–63). The construction of a big dome necessitated the use of wood as a building material, and a wooden dome, in turn, required a wooden transitional zone of *muqarnas*, as seen in front of the *miḥrāb* at the mosque of Sulṭān Ḥasan and in the tomb of the same sultan. This lightweight material gave the transitional zone more structural flexibility for type III-a than stone.

The brick dome of Turbat al-Sitt (Qubbat ‘Abd Allāh al-Manūfī, 1324, No. 300) is the unique example of type IV from this period and there are no other examples of this type in Egypt until 1413. The transitional zone of Turbat al-Sitt is a rare example, and was made of stucco on a masonry framework. It has four layers and starts at the four corners with one fan facet and increases by one petal facet in each layer, so the fourth layer has three petal facets and two vertical facets in

²⁷ See <http://www.sonic.net/~tallen/palmtree/ayyarch/ch5.htm> (accessed August 31, 2016). Similar transitional zones were also seen at Qubbat al-Awḥadiyya (Jerusalem, 1298) and Turbat al-Jāliqiyya (Jerusalem, 1307).

²⁸ Meinecke (1992) suggested that the Syrian technique appeared in the transitional zone of the dome of the *īwān* of Sulṭān al-Nāṣir Muḥammad (1334, Nr. 9C/104, Abb. 65), and this transitional zone seems to be type III-a made of wood.

²⁹ These two examples at the tomb and mosque of Sulṭān Ḥasan have multiple layers encircling the drum, similar to a *muqarnas* vault. Together with the transitional zones, the layers appear to cover a large area with *muqarnas* extending toward the dome, but it should be noted that the *muqarnas* vault that extends over the entire dome ceiling, like the one at Imām Dūr in Sammara, did not appear in Egypt.

³⁰ The transitional zone of the north dome of the same building, however, is type III-a but it has two petal facets in the first layer instead of a fan facet. See footnote 6. The transitional zones of these two domes of Sulṭāniyya can be regarded as trial examples during the formative period of type III.

each quadrangle, and in other words the fourth layer becomes the transitional zone with 16-petal facets, resulting in 7-foil arches on the surrounding walls.

There are a few earlier examples of this type in Syria and Egypt. Some corbels in Syria start with one fan facet and increase by one petal facet per layer (although they have no multi-foil arches on the walls).³² The semi-dome at the entrance to the madrasa of Zayn al-Dīn Yūsufī (1298, No. 172) is the first example of a stone *muqarnas* in Egypt that exhibits a strong Syrian influence and uses three layers in arithmetic progression. The tomb of Fāṭima Khātūn (type I-b, 1283/84, No. 274) also uses three layers starting from a fan facet (Ibrāhīm 1975, 11); this rare example in Egypt can be regarded as a local test case for constructing the transitional zone of a big dome. At Turbat al-Sitt, the local tradition is also apparent in the upper two layers of the transitional zone, which have *muqarnas* of type II-a; thus, both Syrian and Egyptian elements can be found here.

The use of stone for types III-a and III-b in the transitional zone was introduced from Syria. Type III was tried out using wooden *muqarnas* in the transitional zone of the big wooden domes in Cairo before the full adoption of stone *muqarnas* for the transition of the stone domes in Cairo. However, the multi-foil arch on the surrounding wall was neglected in this type in this period.

At this time, the new type III appeared, but the old type II still existed as there are five examples of type II-a and eight examples of type II-b during this period. Except for the transitional zone of the tomb of Bashtāk³³ (type II-a, 1347/48, No. 221) and of the tomb of Tatar al-Ḥijāziyya³⁴ (type II-b, 1348 and 1360, No. 36), which were of stone, the others were made of brick. This suggests that type II was preferred in brick domes.

In addition, there are three examples of type II-e in the third period. The type II-e *muqarnas* in the transitional zone of the tomb of Aḥmad al-Qāṣid (1335, No. 10) and in that of the tomb of Khawand Ṭulbāy (Qubbat al-Amīra Ṭulbiyya, 1364, No. 80) are the same as that of the Ribāt Aḥmad b. Sulaymān (1291, No. 245) which decreases the diameter to an octagonal at the top (Fig. 3 (e), upper half). However, the type II-e example in the tomb of Qūṣūn (1335/36, No. 291) is different (Fig. 3 (e), lower half). It uses a 5-foil diagonal arch and a 5-foil wall arch like type II-c, and also uses a double-arch facet to make a 16-sided polygon at the top.

As for type II-f, there are two examples: the tomb of Amīr Sarghatmish (1356, No. 218) and the *qā'a* of Muḥibb al-Dīn al-Mutawaqqi' (1350, No. 50). These both culminate in a 32-sided polygon at the top, the former with a 9-foil arch and the latter with a 5-foil arch on the surrounding wall, although they do not have an intentional diagonal arch. This type suggests that the brick transitional zone was separated from the diagonal arch that had already lost its structural or constructional meaning. This indicates that a new wave of stone *muqarnas* was used for the transitional zone, in a clear break from the brick type II sub-types.

Also during this period, a type I-b example in the tomb of Āqbughā min 'Abd al-Wāḥid

³¹ This technique is also considered as the import from Syria because preceding examples existed there in the first half of the thirteenth century, for example, the *muqarnas* at the entrance portal of 'Adiliyya madrasa (Damascus, 1212–22), Firdaws madrasa (Aleppo, 1235) and Kāmiliyya madrasa (Damascus, 1238) (Fukami 1998, 174 and 176).

³² There are similar corbeling *muqarnas* at Mashhad al-Muḥassin in Aleppo; the one on the portal was constructed in 1181–83 and the other in the transitional zone was made in 1237–60.

³³ The use of the half-star unit in the transitional zone here is an indication of Syrian influence.

³⁴ This transitional zone is unusual; the usual transitional zone starts on the frieze, but the transitional zone of this tomb starts above the frieze, which increases the height of the dome.

(1339/40, No. 299) is a rare instance in Egypt because it uses a diagonal arch filled with *muqarnas* facets.³⁵ It is similar to the brick squinch of the mosque at Gulpāygān (1104–18) in Iran and the stone squinch of the caravanserai of Sulṭān Khān (Niğde-Aksaray, 1229) in Turkey.

Thus a new technique, that of a stone transitional zone, was introduced in this period, while at the same time the old technique of a brick transitional zone still existed albeit with some improvements.

VIII. The Fourth Period: From the 1370s to the 1400s

In the early 1370s, a further new sub-type of type III appeared, type III-c (Fig. 4 (c)). This sub-type represented a new phenomenon where transitional zones were designed to incorporate a multi-foil arch on the surrounding wall. The multi-foil wall arch was a common feature of type I and type II, but it only occupied part of the wall edge. In contrast, the multi-foil wall arch of type III-c occupied the whole edge at the bottom and reached one point at the top. Type III-c was used in the transitional zone of the tomb of Ibrāhīm al-Anṣārī (1370, No. 310) and in that of the tomb of Uljā'y Yūsufī (1373, No. 131). A further two examples can be found in the tomb of Īnāl al-Atābakī (1392/93, No. 118) and in the tomb of Maḥmūd al-Kurdī (1395, No. 117).³⁶ Except for the tomb of Uljā'y Yūsufī, the type III-c examples use the half-star unit in two layers to increase the length of corbeling.

Generally speaking, type III tends to have more layers than type II, and this tendency becomes particularly evident in the fourth period. One example of type III-a and two examples of type III-b occur in this period. *Muqarnas* facets encircling the dome are rare for type III in this period; there are only two among the seven examples of type III (Table 1; note (3)). Usually there is an arcade around the drum and the top layer of *muqarnas* facets does not reach the drum.

Continuing from the third period into the fourth, there are two examples of type II-a and two examples of type II-e. The type II-a *muqarnas* in the tomb of Aytamish al-Bajāsī (1383, No. 250) was made of stone, but other examples of type II in this period were made of stucco.

In the fourth period, the stone transitional zone became predominant. Also, the layers of the transitional zone increased. Furthermore, as mentioned above, wall multi-foil arches appeared for the first time in type III-c.

IX. The Fifth Period: From the 1410s to the 1450s

The transitional zones of the two domes at the *khānqāh* of Sulṭān Faraj b. Barqūq (type III-d, 1400–11,³⁷ No. 149) are epoch-making. The diameters of the domes are both 14.2 m, and these are the largest stone domes in the Mamluk era (Behrens-Abouseif 2007, 234). The transitional zone of each of the two domes starts from one facet at the corners and increases upward by one petal facet each by one layer, except in the third and ninth (top) layers. Despite the lack of increase in the

³⁵ It uses two fan facets between the diagonal arch and the wall arch, so it leads to a 16-sided polygon at the top of the transitional zone.

³⁶ The top of the transitional zones in the tomb of Ibrāhīm al-Anṣārī, in the tomb of Uljā'y Yūsufī and in the tomb of Maḥmūd al-Kurdī make a multi-foil arch with a row of arches at the drum like those seen in type IV-a. However, the tomb of Īnāl al-Atābakī makes a multi-foil arch by using *muqarnas* facets as in type IV-b.

³⁷ The inscription states that the northern dome was completed in 1405 and the southern dome in 1410/11 (Behrens-Abouseif 2007, 231).

number of facets in two of the layers, these examples can still be classified as type III-d (Fig. 4 (d)) because they have a step-like shape similar to a half multi-foil arch and they do not have half-star units. To increase one facet by one layer up without half-star units requires complete corbeling of the total curved surface of transitional zone. This was a huge structural challenge.

The next example of type III-d to appear in this period is that in the tomb at the mosque of Sulṭān al-Ashraf Barsbāy (1432, No. 121), which has nine layers, increasing one petal facet by each layer, and this occurs in all layers so it can be classified a complete type III-d. To make the wall multi-foil arch with *muqarnas* increase one petal facet by one layer without using half-star units would have been difficult because the transitional zone had to be heightened vertically, while at the same time, the length of corbeling had to change gradually from the center of the room's edge to the corner of the room in each layer horizontally. However, despite the lack of wall multi-foil arches in type III-d, it is close to type IV in appearance. Type III is the predominant form in this period; ten examples of type III-a and one example of type III-c are known to exist.

In addition, the new type IV appeared in the 1410s, of which there were two sub-types. The type IV-a (Fig. 5 (a)) examples in the tomb of Qānībāy al-Muḥammadī (1413, No. 151), the tomb of Sulṭān Mu'ayyad (1415–20, No. 190), the tomb of Jānībak al-Ashrafī (1426, No. 119) and the tomb of Sulṭān Īnāl (1453–61, No. 158) have wall multi-foil arches and increase one petal facet per layer. However, they make wall multi-foil arches with a drum arcade at the top. This differs from type IV-b that appeared after the 1460s; type IV-b makes multi-foil arches with *muqarnas* facets and the *muqarnas* facets encircle the dome.

There are only a few examples of type II during this period, three examples of type II-a and two examples of type II-e. One of the type II-a examples, that in the tomb of Taghrī Bardī (1440, No. 209), was made of stone instead of stucco, and both of the type II-e examples in the domes of the mosques of Qādī Yaḥyā Zayn al-Dīn (1448–50, No. 344 in Būlāq and 1452, No. 204 in Habāniyya) were made of wood.

It is clear from the examples of this period that the stone transitional zone has a tendency to increase the height of the transitional zone by the addition of wall multi-foil arches and by increasing each layer by one petal facet upward at the corner. Yet the major type in this period is type III-a without wall multi-foil arches (ten examples).

X. The Sixth Period: From the 1460s to the 1510s

The type IV-b examples in the tomb of 'Umar b. al-Farīd (1460/61, No. 601), the tomb of Timrāz al-Aḥmadī (1482, No. 216) and the tomb of Sulṭān Qāyrbāy (1472–74, No. 99, Fig. 8) show how complete stone transitional *muqarnas* lead to a high transitional zone, a multi-foil wall arch and an increase in the number of petal facets in each layer. The first two buildings mentioned contain small domes, but that in the latter is much bigger at 9 m. This suggests that after a successful trial attempt in a smaller edifice, type IV-b was adopted for a more important building, that of the sultan's tomb.

As mentioned above, the first example of type IV-b actually appeared in Turbat al-Sitt (Qubbat 'Abd Allāh al-Manūfī, 1324, No. 300) in the third period. However, that example was made of brick and had only four layers. This brick example cannot be said to be directly connected to the

Fig. 8: Tomb of Sulṭān Qāyṭbāy (1472–74, No. 99, type IV-b)

tomb of ‘Umar b. al-Farīd and the tomb of Sulṭān Qāyṭbāy in the 1460s and 1470s. In fact the type IV-b examples of these two tombs are quite similar to type III-d and type IV-a in the fifth period, in terms of the large number of layers and the small ratio of petal facet width to wall length.

A total of eleven examples of type IV-b appear after 1460, and the one in the tomb of Sulṭān al-Ghawrī (1502–04, No. 67) has thirteen layers. There are only two examples of type IV-a. This suggests that the complete type IV-b superseded type IV-a in terms of popularity.

One example of type II-c,³⁸ two examples of type II-e and two examples of type II-f occur in this period. The type II-e examples appear in the tomb of Abū al-Ghaḍanfar al-Fā’izī (1462, No. 3), which was rebuilt in 1462, and the tomb of Imām Shāfi’ī (No. 281), which was rebuilt by Sulṭān Qāyṭbāy in 1480. The type II-f examples can be found in the tomb at the mosque of Abū al-‘Ilā (1485/86, No. 340) and the tomb of Imām al-Layth (1505, No. 286). These examples of type II in the sixth period are archaic in style.

The addition of one petal facet per layer is an important feature as it could be used to make the length of corbeling equal. In fact, the whole *muqarnas* can be viewed as a big corbel. In the largest stone dome at the *khānqāh* of Sulṭān Faraj b. Barqūq (1400–11, No. 149), the inner diameter of the bottom of the dome and the length of one side of the tomb chamber are each 15.4 m, so the longest corbeling distance between the wall to the dome as a horizontal distance becomes 3.2 m at the middle point of the quarter drum with nine layers. Due to the largeness of the stone dome, a wall multi-foil arch may not have been applied in this case. Later, after some trial and error, the inclusion of multi-foil arches was achieved in the stone dome at the tomb of Sulṭān Qāyṭbāy (1472–74, No. 99), where the inner diameter of the bottom of the dome and the length of one side of the tomb chamber are each 9 m, so the longest corbeling distance between the wall to the dome

³⁸ See chapter VI, footnote 21.

as a horizontal distance becomes 1.3 m at the middle point of the quarter drum with ten layers and 19-foil arches on the walls. Even though the brick dome collapsed in the early twentieth century at the tomb of Sulṭān al-Ghawrī (1503/04, No. 67), it is still clear that its diameter of the upper point of the transitional zone is 12.3 m and there are 25-foil arches at the walls. It would seem that in this sixth and final period the creation of a complete multi-foil arch on the wall was a more important aim than enlarging the size of the tomb.

XI. Conclusion

In Egypt, the local brick dome technique was already in existence when new stone *muqarnas* techniques imported from Persia via Syria were adopted in minarets and friezes in the eleventh century. At this time, the local style of *muqarnas* (type I) was favored for the transitional zone of small brick domes. However, after an intervening period from the 1150s to the 1240s, a transformation to type II transitional zones took place, where the focus was on the creation of geometrical variation based on the use of diagonal multi-foil arches and wall multi-foil arches. The variations that occurred from the 1240s to the 1310s (the second period) are a special feature of the Egyptian *muqarnas* that were used in the transitional zone.

In addition, new stone *muqarnas* vaulting techniques were introduced from Syria around the last decade of the thirteenth century to the early fourteenth century. Shortly thereafter, further new types of transitional zone (type III and type IV) started to appear in the 1320s. In addition, the construction material of the dome changed from brick to stone after 1350 as the transitional zone of *muqarnas* changed from stucco on brick masonry to curved stone. However, brick transitional zones continued to be developed in many small domes (type II) during the third period.

From the third period, there was an apparent aspiration to increase the diameter of the dome and the height of the transitional zone. However, type II was unable to fulfill this aspiration as it was limited in terms of height because of the requirement for diagonal and wall multi-foil arches, based on the geometrical relation between the number of layers, the polygon on the top of the layers and the dividing edges. The difficulty in attaining more height is assumed to have caused a divergence between actual examples and the geometrical ideal, that of type II-f. Therefore, as the material of the transitional zone changed from brick to stone and the requirement for a higher transitional zone arose, type III-a was conceived. Yet type III-a meant the abandonment of multi-foil arches in *muqarnas*. However, the later type III-c had wall multi-foil arches that started from the end of a wall edge, and it could be used to make a higher transitional zone.

The stone transitional zone of type III was developed in an effort to overcome exceptional challenges in the construction of the large wooden domes of type III-a in the third period and the sultan's large stone domes of type III-d in the fifth period. After some successes from the 1320s to the 1340s, type III stone *muqarnas* were widely used for general stone domes for some time thereafter. Then, in the 1350s, a new trend appeared as shown in the transitional zone of the antechamber and the tomb of Sulṭān Ḥasan mosque. This trend was an Egyptian variation of the Syrian stone technique that included increasing the use of star-shaped corbeling, encircling *muqarnas* around the dome and increasing the number of layers. However, succeeding stone *muqarnas* did not follow this trend. Rather, another new trend appeared in the 1370s, which

became dominant, namely the local multi-foil arch and simple corbeling that originated in the *muqarnas* itself.

Essentially, over a period of two hundred years from the 1320s to 1510s, type III gradually evolved into type IV. The new technique from Syria that appeared in Egypt in the early fourteenth century acted as a trigger for change, but innovation in the *muqarnas* technique occurred in Cairo itself, where new elements were accepted and incorporated. At that time, wooden construction became one step in that transition. There was a clear desire for a triangular-shaped multi-foil arch that originated in a brick transitional zone (type II). Thus it can be argued that the vernacular transitional zone of type I became the basis of the transformation to stone.

Through a consideration of the *muqarnas* that were adopted for use in the transitional zone of various buildings in Egypt, the local development of geometry and corbeling becomes clear, and the recurrence of the vernacular motif, namely the multi-foil arch, seems to have continued despite the influences of foreign *muqarnas*.

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Figs. 1-4: Original drawings by the author and CAD drawings by Katsumi Shishido.

Figs. 5-7: Photographs by the author.

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