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Typology and Distribution of Squinches in the Transition Zones of Seljuk Square Chambers in Iran

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Abstract

The construction of domes on square-plan chambers in Iranian architecture can be traced back to the pre-Islamic era. In order to address the challenge of building a dome with a circular cross-section on a square space, a transition zone was created using four squinches, with the objective of altering the geometry of the cross-section and making it closer to a circular shape. During the Great Seljuk era, the construction of domes on square-plan spaces became a common practice, with various squinch techniques employed in the transition zones. This paper examines forty-one existing Seljuk chambers in Iran and classifies the squinches in their transition zones into four types: predominantly shouldered arches, Patkaneh, Patkin, and Sekonj. Shouldered arches are principally observed in the transition zones of structures situated in the north-western and north-eastern regions, with a few instances noted in the northern and central parts of the country. The majority of Patkaneh squinches are located in the central region of Iran. Four cases with distinct geometric solutions in the transition zones are situated in north-west Iran, and one example is located in north-east Iran. Additionally, three instances of the Patkin squinch can be observed in a caravanserai located in the north-eastern region. In the northern region, two chambers were identified in two caravanserais with Sekonj squinches in transitional zones. The use of these different squinch techniques reflects the regional preferences in architectural styles and the adaptability of Seljuk builders to local materials and construction methods. This study contributes to the scientific understanding of Iranian architectural history by classifying the squinch techniques used in Seljuk domed chambers. The analysis of forty-one structures provides insights into regional construction practices, geometric innovations, and the evolution of transition methods. The proposed typology enriches architectural historiography and provides a foundation for further comparative studies on structural solutions in Islamic and pre-Islamic architecture.

Keywords: *Iran, Seljuks, Squinches, Transition zones*

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INTRODUCTION

Chahartaqi[1] (Čahārṭāqi), an integral part of Iran's architectural heritage, is believed to have originated during the Parthian[2] architectural era (247 BC - 224 AD) and later became a prominent feature in Sasanian architecture (224 AD - 651 AD) (Vandaee, 2015; Akbari, 2011; Garshasbi and Malekpour Shahraki, 2019). This distinctive design was applied in various contexts during the Sasanian era, including both religious and secular structures. This traditional architectural element was adopted and developed during the Iranian-Islamic era (Golzari and Rabb, 2022b) and was also introduced to the architecture of other nations. A "Chahartaqi" is defined by four arches or short barrel vaults encircling a central square space, with a dome resting above squinches (Huff and O'Kane, 1990). It is characterized by a dome on top of a cube surrounded by four arches and displays a cosmic representation. Its combination of the celestial circle and the terrestrial square is what makes it unique (Ardalan and Bakhtiar, 2000). Chahartaqi stands as an enduring archetype in Iranian architecture, retaining significance across pre-Islamic and post-Islamic eras (Wahdattalab and Ghadimzadeh, 2018).

The earliest instances of domes supported by squinches within Chahartaqi units are discernible in extant Partho-Sasanian structures, prominently represented by architectural marvels such as, Bazeh Hoor Fire Temple, Kooh-e-khaje, Ardeshir Palace, and Dokhtar Castle. These structures exhibit themselves as either an enclosed cube, an autonomous domed chamber distinguished by open arches that permit exposure to the external environment, or as a constituent of a larger architectural edifice demarcated by interconnected chambers and corridors. The transition zones beneath the domes of these pre-Islamic buildings feature four distinct types of squinches, including, Filposh, Patkin, Sekonj, and Shouldered arches (Golzari and Rabb, 2022a).

Following the Muslim conquest of Iran and the demise of the Sassanian dynasty, Iranian-Islamic architecture widely adopted the Chahartaqi form. According to Akbar Tajvidi, during the early expansion of Islam in Iran, many fire temples from the Sasanian era, which are in the chartaqi module, were converted into mosques. The main alteration involved blocking one of the four openings, which were aligned with the Qibla direction, by constructing a wall and incorporating a mihrab. Therefore, mosques with chahartaqi spaces were developed. An example of this can be seen in the Yazdkhast mosque (Tajvidi, 1971), which was a fire temple during the Sasanian empire.

For the first four centuries of the Hijri era, there are a few surviving examples of Chahartaqi structures, such as the Ismail Samani Mausoleum[3] and the tomb of Arsalan Jazeb. The construction of Chahartaqi increased significantly throughout the Seljuk era, particularly in mosques in response to the growing demand for more expansive areas, tombs, palaces (Neyestani et al., 2012), caravanserais, Madrasah, and Khanqah[4]. This period demonstrates an increase in

[1] Chartaqi (Persian: چارطاقی) or chahartaqi (Persian: چهارطاقی). Chartaq (Persian:چارطاق) and chahartaq (Persian: چهارطاق) literally means four arches.

[2] The cruciform ground plan is discernible in a rudimentary manifestation within Parthian structures, exemplified by edifices such as Qalʿeh Zohak (Qalʿa-ye Žaḥḥāk) located in Azerbaijan (Dietrich Huff, Bernard O'Kane, 1990).

[3] The building, which dates back to the Samanid Empire, an Iranian dynasty, according to the current political and geographical map, is situated in Bukhara, Uzbekistan.

[4] A khanqah serves as a dedicated structure for congregations of a Sufi brotherhood or tariqa, functioning as a space for spiritual activities and religious instruction.

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architectural creativity in a wider range of transition zones and squinches beneath domes in square-shaped chambers.

Despite the extensive research conducted on Chahartaqi in relation to its historical and symbolic significance, the transition zones and squinches within these structures have received minimal attention. A paucity of research has hitherto been conducted on the subject of architectural variation in the broader context. Previous studies have focused on individual monuments or regional examples, and as a consequence there are significant gaps in our understanding of broader patterns of architectural variation. The present study aims to classify the types of squinches of transition zones in Seljuk-era square-plan domed structures in Iran, examining both their architectural features and regional distribution. By systematically categorising these elements and their occurrences, this research contributes to the scientific understanding of Islamic architectural evolution and informs preservation strategies.

RESEARCH METHODOLOGY

This study employs a descriptive-analytical approach to examine the typology and regional distribution of squinches in Seljuk square-plan chambers in Iran. A total of forty-one extant chambers were selected based on the availability of architectural documents, the presence of identifiable squinches in their transition zones, and their geographic distribution, in order to capture regional variations. The data were collected through a combination of field surveys, architectural documentation, and archival research, including scholarly publications, historical records, and online repositories. The analysis focused on classifying the squinches in the transition zones into four main types: Patkaneh, Patkin, Sekonj, and Shouldered arches. An examination was conducted of the cases with regard to usage of the chamber, geometric solutions in their transition zones and construction techniques to create the geometry. Photographical evidence and architectural drawings were utilised to ensure precise identification and to facilitate comparisons across structures. Finally, spatial and temporal patterns were analyzed to understand the distribution of squinch types across different regions and periods within the Seljuk era. A cross-referencing of construction dates, geometric solutions and regional architectural influences was undertaken, revealing correlations between squinch type, complexity of the transition zone and local building traditions. This methodology provides a comprehensive framework for understanding both the formal characteristics and regional variations of Seljuk squinches.

TRANSITION ZONES FEATURING SQUINCHES IN SELJUK SQUARE CHAMBERS

The Seljuk dynasty, also known as the Great Seljuk Empire (1037-1194 CE), was founded by Tughril Beg (Abazov, 2008; Ettinghausen et al., 2001). It was a major Muslim power during the medieval period (Peacock, 2015; Akbari, 2009; Zaki, 1941) and emerged from the

ICONARP – Volume 14, Issue 1 / Published: 30.06.2026

nomadic Seljuk tribe (Alkadi, 2016; Peacock, 2015; Lapidus, 2014). Figure 1 shows the Great Seljuk Empire's wide domain, which included Central Asia, Iran, and parts of the Middle East. The Seljuk period is a distinct phase in Iranian architecture, with some roots in Partho-Sasanian art and architecture. One notable development of this period is the use of chahartaq, which features a transition zone under the dome.



Figure 1. The territory of the Great Seljuk Empire (League, 2010)

In this research, forty-one Seljuk square-plan chambers featuring squinches in their transition zones have been identified within the present-day territory of Iran.[5] The details of these structures are set out in Table 1. Among the spaces, six are designated as tombs, with an additional designation of one functioning as a mosque-tomb. In addition, seventeen chambers were allocated to mosques, another to a mosque-madrassa, and another to a mosque in a caravanserai. Additionally, fifteen chambers are service spaces and are identified within two caravanserais. This suggests that religious purposes accounted for most of the uses of these square-planned chambers. In addition, the exterior cross-section of the thirty-eight chambers is square, circular in one, and octagonal in one.

Four main types of squinches were employed in these structures, namely Patkin, Patkaneh, Sekonj, and Shouldered arches, while Filposh was not observed in any instances. The predominant squinch type is the shouldered arch, utilized in twenty-four chambers, predominantly situated in the north-western and north-eastern regions, with four instances in the northern and central parts of the country. Subsequently, Patkaneh is implemented in twelve rooms, predominantly in the central region, specifically within the present-day Isfahan province, in four cases in the northwest, and one case in the northeast of Iran. In addition, three examples of the Patkin are discerned in a caravanserai located in

[5] While the square chambers of Imamzadeh Nur in Gorgan and Pir-Hamzeh Sabzpoosh Tomb in Abarkuh remain, the transition zone has been entirely destroyed. Furthermore, the study did not include the Jame Mosque of Ardabil since its dome and squinches were destroyed with the end of the Seljuk era.

[6] In this building, thirteen chambers have transition zones featuring squinches.

[7] Despite being included in the National Monuments as a mosque-madrasah, certain scholars, such as André Godard, contend that the building was not built as a madrasah.

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the north-eastern part and two cases of Sekonj was found in the northern part of the country.

Table 1. Square-plan Seljuk chambers with transition zones in Iran

Number	Case Studies	Location	Date	Function	Plan		squinches in transition zones
					Exterior	Interior	
1	Jame Mosque of Isfahan (Nizam al-Mulk Dome)	Isfahan	1080 CE (Jabalamel, 2013)	mosque	square		Patkaneh
2	Jame Mosque of Isfahan (Taj al-Mulk Dome)	Isfahan	1103 CE (Jabalamel, 2013)	mosque			
3	Jame Mosque of Ardestan	Ardestan	1158 CE (Arki et al. 2014)	mosque			
4	Jame Mosque of Barsian	Barsian	1133 CE (Khosravi Javid, 2020)	mosque			
5	Jame Mosque Zavare	Zavare	1168-69 CE (Salehi Kakhaki and Azizpour, 2012)	mosque			
6	Jame Mosque of Golpayegan	Golpayegan	1114-15 CE (Korn, 2012b)	mosque			
7	Gonbad Sorkh	Maragheh	1148 CE (Morvarid, 1993)	tomb			
8	Se Gonbad	Urmia	1184 CE (Behzadpour and Aminpour, 2021)	tomb	circle	square	
9	Jame Mosque of Marand	Marand	1092 CE (Anisi, 2023a)	mosque	square		
10	Jame Mosque of Urmia	Urmia	Middle of the 12th century (Anisi, 2023b)	mosque			
11	Jame Mosque of Sin	Sin	1134-35 CE (Hajloo and Neyestani, 2014)	mosque			
12- 24	Ribat-i Sharaf[6]	45 km to Sarakhs	1114 CE (Zamani and Akbari, 2023)	caravanserai	square		Patkaneh(one) Patkin(three) Shouldered arches(nine)
25	Jame Mosque of Qerveh	Qerveh	1179 CE (Korn, 2018)	mosque			Shouldered arches
26	Jame Mosque of Qazvin	Qazvin	1120-1121 CE (Mashkoti, 1941)	mosque			
27	Heydariyeh Mosque	Qazvin	1119-20 CE (Asgari and Chareie, 2020)	Mosque-Madrasah[7]			
28	Jame Mosque of Semnan	Semnan	Between 1117 and 1158 CE (Hatami, 2017)	mosque			
29	Jame Mosque of Sojas	Sojas	3rd quarter of the 12th century (Anisi, 2023a.)	mosque			
30	Jame Mosque of Borujerd	Borujerd	1139-45 CE (Korn, 2019)	mosque			
31	Gonbad Sangan Mosque	Sangan	1140-41 CE (Mollazadeh, 1999)	mosque			

32	Gonbad Alaviyan	Hamedan	Late 12th Century (Shani, 1996)	mosque-tomb		
33	Tomb of Pir-i Takestan	Takestan	12th century (Hillenbrand, 1972b)	tomb		
34	Imamzade Aqil	Bijar	The second half of 12th century (Mohammadi et al. 2012)	tomb		
35	Tomb of Baba Loghman	Sarakhs	Seljuk dynasty (1037-1194)[8]	tomb		
36	Tomb of Khaje Atabak	Kerman	Between 1164 and 1169 CE (Mosavi Haji et al. 2008. 2424)	tomb	octagon	square
37	Ribat of Mahi[9]	Along rout between Sarakhs and Mashhad	Between 1106-1118 CE (Korn, 2020)	caravanserai	square	
38	Jame Mosque of Mehrabad[10]	Abarkuh	Seljuk dynasty (1037-1194)	mosque		
39	Jame Mosque Haftshoyeh	Haftshoyeh	Seljuk dynasty (1037-1194)	mosque		
40	Mohammad Abad Stony Caravanserai	Qom	Between 1114-1119 CE (Arab, 2006)	caravanserai		Sekonj
41	Ali Abad Stony Caravanserai	Qom	Seljuk dynasty (1037-1194)	caravanserai		

The location of these chambers is indicated on the current map of Iran in Figure 2. With two exceptions, this figure depicts the distribution of structures, which are primarily concentrated in the upper half of the map.

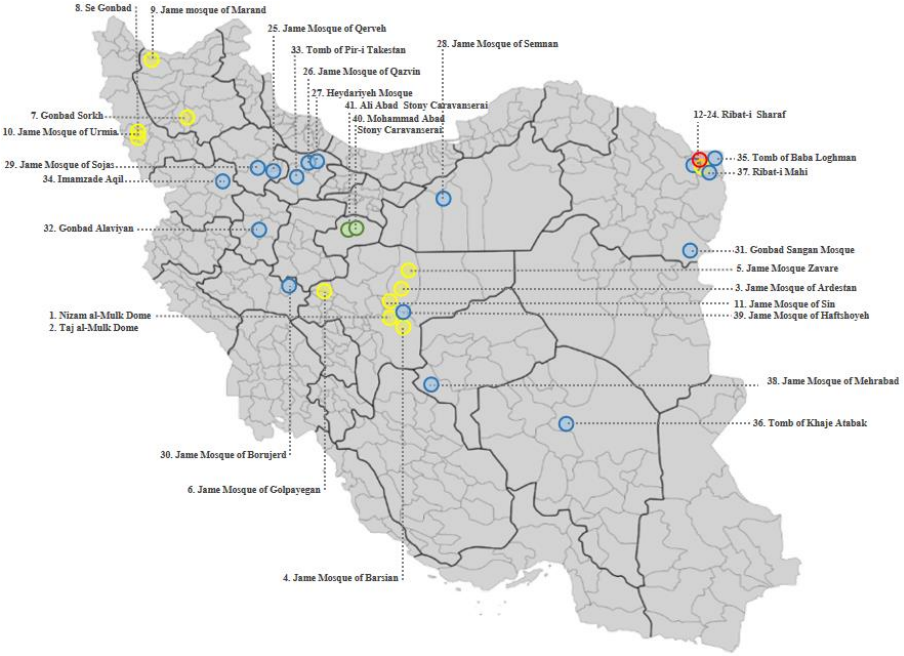


Figure 2. Location of case studies in the present-day territory of Iran

The construction timeline of case studies is displayed in Figure 3. Before the 12th century, Patkaneh was used in two cases, and from then on it was used in successive structures until the end of the era. Shouldered arches became more common in the 12th century, and Patkin and Sekonj were used in a few cases in the first quarter of the

[8] Although Gonbad Khanh's building is listed as having a Seljuk architectural style on the sign adjacent, its exact date is unknown.

[9] According to the plan of caravanserai, several additional rooms had dome roofs, but these had been demolished, and one chamber could be examined using the available photos.

[10] In this mosque, only the Gonbad Khaneh chamber is still in existence and is in critical condition.

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twelfth century. The transition zones with four distinct squinch types in the cases studied were examined in the sections that followed.

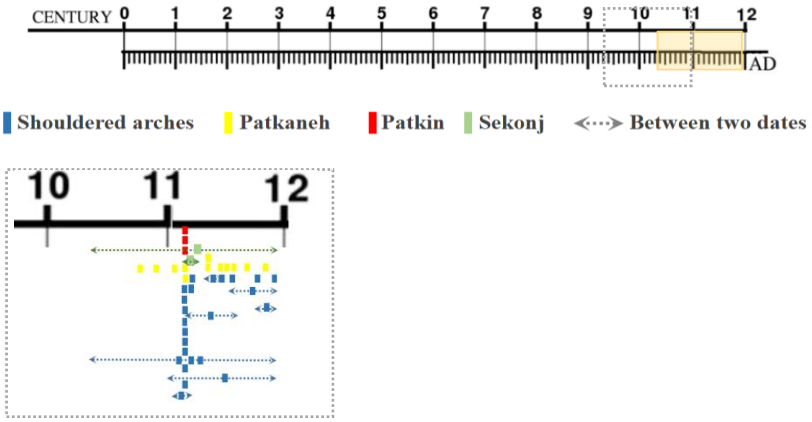


Figure 3. Timeline of instances during the Seljuk era in Iran (1037–1194)

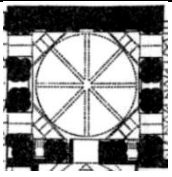
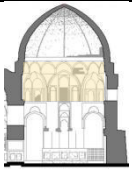
Transition Zones Featuring Patkaneh

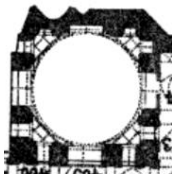
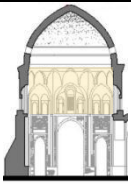
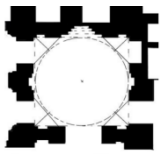
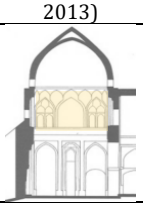
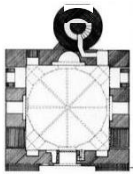
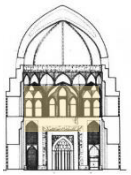
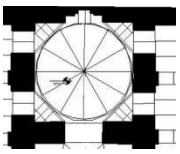
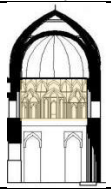
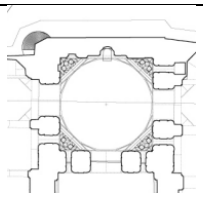
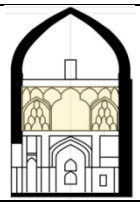
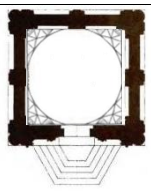
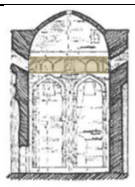
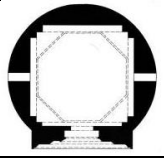
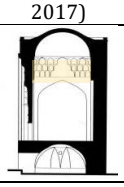
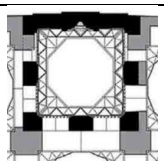
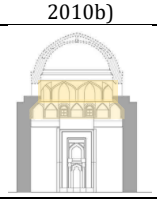
Patkaneh consists of several rows of niches layered on top of each other (Pirnia, 1991; Safaeipour et al., 2013). It can be found as a space covering or as squinches beneath a dome, with a regular and distinct geometry (Memarian and Safaeipour, 2012). The first example of this architectural element is found in Iranian-Islamic architecture, and it was through this method that squinches reached their peak (Golzari and Rabb, 2022a). In three regions of the country, transition zones have been identified, with Patkaneh. These transition zones in the chambers are detailed in Table 2.[11] In the central part, in all six instances, the squinches change the square plan to an octagonal cross section, and then sixteen small arches above them make a hexadecagon base for a dome. The geometry of the squinches in the Jame Mosque of Golpayegan differs from the other cases and there are four layers of niches. The example in the north-east is analogous to these transitional zones in the central region, although it is simpler in design and is likely to have comprised a row of bricks rather than small arches, thus forming a sixteen-sided polygon. In all of the aforementioned cases, the arches were observed to be the final frame in the facade of squinches. Each of the four chambers in the northwest and one example in the central part employ distinct methods for their transition zones, featuring the use of Patkaneh. Two of the cases involved a direct transition of the square cross-section into a sixteen-sided base, one into a 10-sided cross-section, and one case had a direct transition into a 24-sided base for the dome.

[11] This type of squinch was also built under the dome in the Jame Mosque of Gar in Isfahan province, but most of the transition zone has been destroyed and cannot be studied.

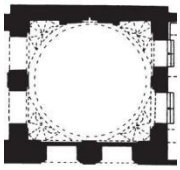
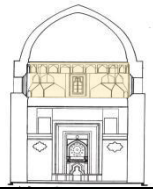
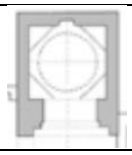
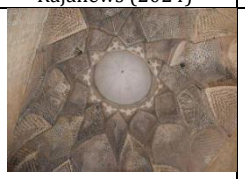
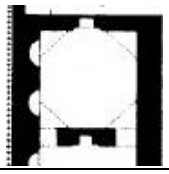
[12] The geometry of the transition zone is expressed in numerical form. For example, the designation "4-8-16" signifies that the transition zone comprises two levels. Initially, the square plan was transformed into an octagon, and subsequently, a sixteen-sided polygon. The designation "4-8" signifies that the final level of the transition zone is an octagonal cross-section.

Table 2. Patkaneh in Iranian Seljuk square chambers

Number	Plan	Section	Transition zone	Geometry of transition zone[12]
1				4-8-16

	(Schroeder, 1931)	(Salehi Khaki et al., 2013)	adapted from Archnet (2023)	
2				4-8-16
	(Schroeder, 1931)	(Salehi Khaki et al., 2013)	adapted from Tovman (2023)	
3				4-8-16
	(Godard, 1965)	(Haji Qasemi, 1996)	adapted from Visitiran (2023)	
4				4-8-16
	adapted from Askdin (2023)	adapted from Askdin (2023)	adapted from Aftabnews (2023)	
5				4-8-16
	(Nasrollahi, 2016)	(Nasrollahi, 2016)	adapted from Jahannews (2023)	
6				4-8-16
	(Korn, 2012a)	(Hagras, 2023)	adapted from Wikimapia (2023)	
7				4-16
	Combination of two plans	(Golchin et al., 2017)	adapted from Lastsecond (2023)	
8				4-16
	(Haji-Qassemi, 2010b)	(Haji Qassemi, 2010b)	adapted from Wikipedia (2023)	
9				4-8
	(Anisi, 2023a)	(Anisi, 2023a)	adapted from	

DOI: 10.15320/ICONARP.2026.358

			Aazaranjoman (2023)	
10	 (Haji-Qassemi, 2004a)	 (Haji Qassemi, 2010a)	 adapted from Rajanews (2024)	4-24
11	 (Hajloo and Neyestani, 2014)	–	 adapted from Sh-seen (2024)	4-10
12	 adapted from Iran-europe (2024)	–	 adapted from Mybrothertraveler (2023)	4-8-16[13]

[13] Two bricks are observed on the top of a squinch and on the small wall next to it. Based on the angle of the bricks with the top of the squinch, it can be concluded that the octagonal row of bricks was used as the last layer of the transition zones.

Two distinct categories can be identified based on the arrangement of the niches. One category is primarily situated in the central region and the second category is primarily situated in the north-west. The geometry of the central type is obtained based on dividing the right-angled triangle created in the four corners of the square plan. In this way, each triangle is divided into two equal triangles. Then, by dividing the sides into two equal parts and connecting the middle points to each other, four triangles are created (Memarian and Safaeipour, 2012). In an article, Edwards termed it a "tri-lobed squinch." (Edwards, 1999). This type is demonstrated in Figure 4. The north-west type does not adhere to a specific geometrical solution. However, the niches are positioned in such a way that it exhibits superior extension in the transition zone in comparison to the other type. This allows for a greater range of geometrical bases to be employed in the construction of a dome.

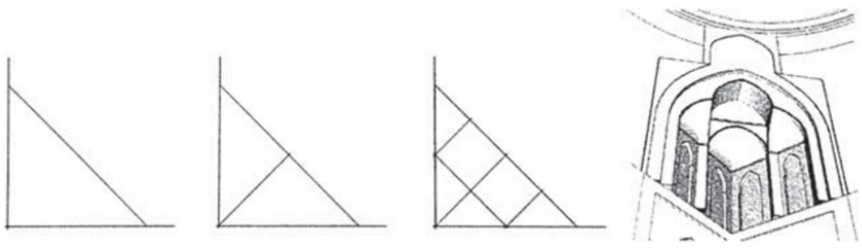


Figure 4. Geometry of Patkaneh in the central type (Memarian and Safaeipour, 2012)

Transition Zones Featuring Patkin

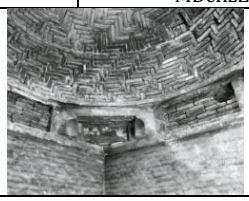
Patkin is a type of squinch in which construction materials are positioned to overlap at corners (Golzari and Rabb, 2022a) between two intersecting walls. The horizontal rows of bricks are advanced in such a way, creating a step-by-step appearance when viewed from below (Ghouchani and Mokaberian, 2022). As per Pirnia, this technique is referred to as "Encrobellement" in French, which can be translated as

gradually advancing the wall forward (Pirnia, 1991; Pirnia, 2019). The Bazeh Hoor fire temple, an ancient pre-Islamic structure in Iran, presents the earliest surviving example of this technique, crafted from wood (Benghida, 2015; Safaeipour et al., 2013: 6; Ghouchani and Mokaberian, 2022). In Iranian-Islamic architecture, Patkin was eventually built using adobes and bricks.

Patkin as a squinch in the transition zone is seen in three chambers of the Ribat of Sharaf[14]. In two rooms, bricks are progressively advanced in four corners, forming an octagon portion in the transition area. Though no arch was constructed for the transition zone, the facade of the squinches and the brick placing in walls between them resemble pointed arches. The next phase of the transition zone consists of placing a row of bricks to cross the octagon corners, creating a sixteen-sided geometric form, and then building a dome on top of it. In the third instance, an unusual module including two layers of overlapped layers of bricks was created to make the squinch. Then, on the facade of the squinch, a squat corbelled arch was formed with two niches. Edwards assert that the unusual structural role these niches play as corner corbels in this sturcutre is distinct from the constituent elements of superimposed tiers of small squinches. He is also adamant that it is as an articulating device that these niches demonstrate their additional role, rather than structural purposes (Edwards, 1999). Table 3 presents images of these transition zones.

[14] This technique was also used under another dome in this building, between the squinches, on the second level of the transition zone.

Table 3. Patkin in Seljuk square chambers

Number	Picture		Geometry of transition zone
13-14			4-8-16
	adapted from wikimedia (2024)	https://www.youtube.com/watch?v=MDcIizZFMLg&t=7s	
15			4-8
	adapted from Archnet (2024)		

Transition Zones Featuring Shouldered Arches

An arch with two bases positioned on the walls that cross at a corner is called a "shouldered arch". Figure 5 illustrates this type of squinch on the walls of a chamber with a square floor plan. These ribs support the downward thrust of the dome (Duarte et al., 2021). The earliest surviving example of this style can be found in Kooh-e-Khaje (Memarian et al., 2017), which dates back to pre-Islamic Iranian architecture. This squinch was later widely employed to construct a transition zone beneath a dome in Islamic-Iranian architecture. By including various

DOI: 10.15320/ICONARP.2026.358

features and levels, the geometry of the transition zone evolved, enabling the cross-section to approach the circle and support the construction of a dome.

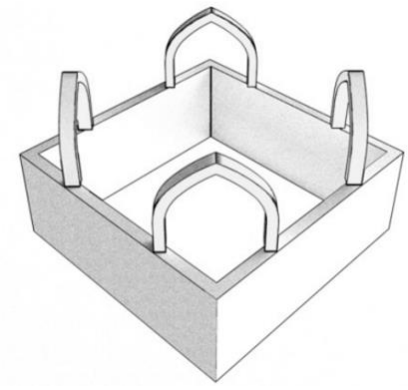
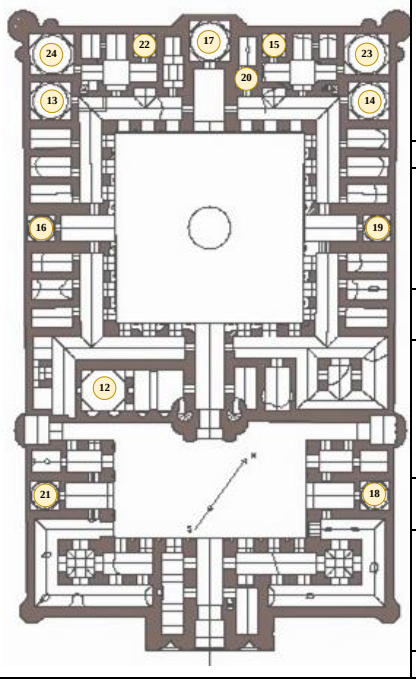
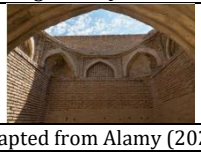
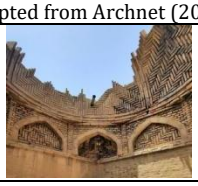
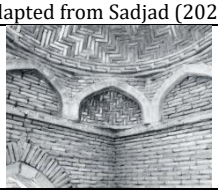
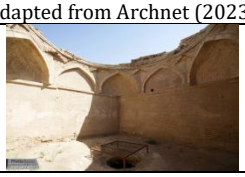


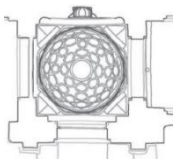
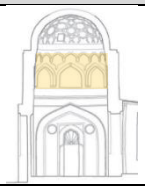
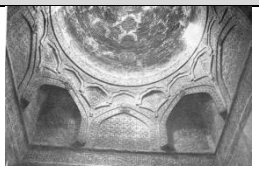
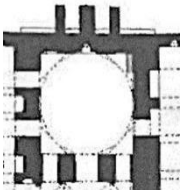
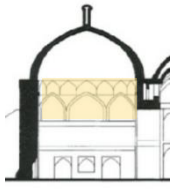
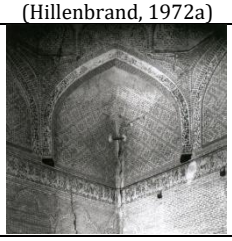
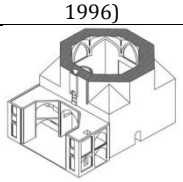
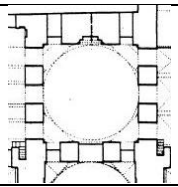
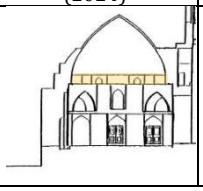
Figure 5. Four shouldered arches in corners (Golzari and Rabb, 2023)

Twenty-four square chambers with shouldered arches in the transition zone have been identified. Table 4 provides data on these transition zones in these structures. Nine instances were built in the Ribat of Sharaf caravanserai. Some scholars regard this caravanserai as a museum of brickworks. It might also be of interest to note that the different transition zones and squinches in this building could be seen as symbols for the range of methods and geometrical solutions. In four chambers, octagonal bases were constructed in the transition zone in order to build a dome on top. It is noticeable that in one chamber, pendentives were built between the arches, and two niches were made between the ribs of each arch as part of the filling of the void. In four chambers hexadecagonal cross sections were created, in three cases with a row of bricks as the second layer of the transition zone and in one case the Patkin method was used between arches.

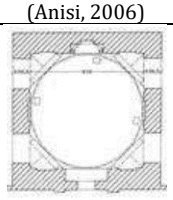
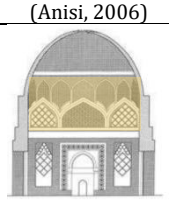
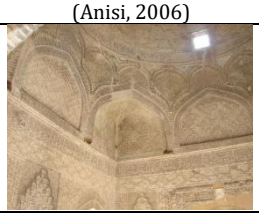
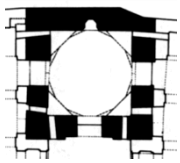
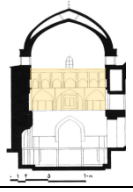
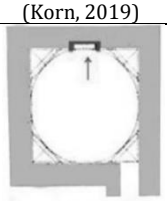
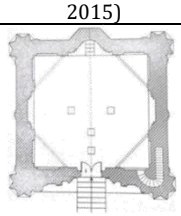
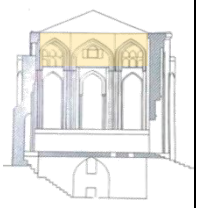
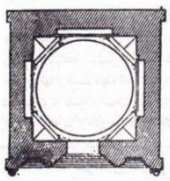
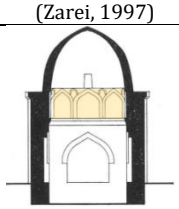
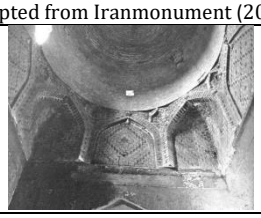
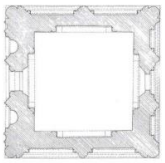
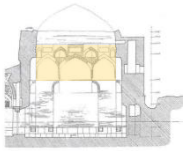
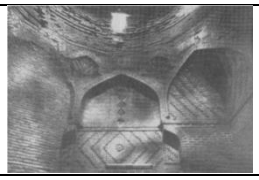
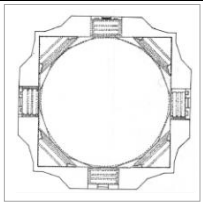
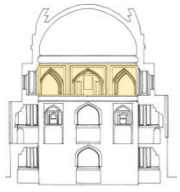
Table 4. Shouldered arches in Seljuk square chambers

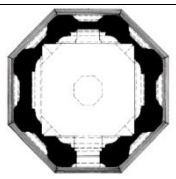
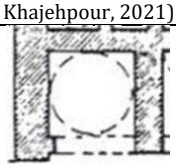
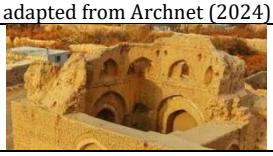
Number	Plan	Transition zone	Geometry of transition zone
16		 adapted from Archnet (2023)	4-8
17		 https://www.youtube.com/watch?v=MDcIizZFMLg	
18		 https://www.youtube.com/watch?v=T1IUg0sb6uQ&t=7s	
19		 Adapted from Alamy (2024)	

20			 adapted from Archnet (2023)	4-4
21			 adapted from Sadjad (2023)	4-8-16
22			 adapted from Archnet (2023)	
23			 adapted fro Karnaval (2024)	
24			 https://lh3.googleusercontent.com/p/AF1QipMgW7j3rLOnsjfwEVdcTyzvOjMg1MSLm0FfrHc8=s1360-w1360-h1020	
	ICHDC (1999)			

Number	Plan	Section	Transition zone	Geometry of transition zone
25	 (Korn, 2017)	 (Korn, 2017)	 (Hillenbrand, 1972a)	4-8-16
26	 (Shahnawaz et al, 2013)	 (Haji Qassemi, 1996)	 adapted from Archnet (2023)	4-8-16
27	_	 adapted from Cgie (2024)	 adapted from Wikiwand (2023)	4-8
28				4-8-16

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	(Anisi, 2006)	(Anisi, 2006)	(Anisi, 2006)	
29				4-8-16
	(Bakhtiari, 2012)	(Bakhtiari, 2012)	adapted from General Office of Cultural Heritage, Tourism and Handicrafts of Zanjan Province (2023)	
30				4-8-16
	(Korn, 2019)	(Korn, 2019)	adapted from Zerk.ir (2023)	
31		–		4-8
	(Ashori and Sheikhi, 2015)		adapted from ISNA (2024)	
32				4-8
	(Zarei, 1997)	(Zarei, 1997)	adapted from Iranmonument (2023)	
33				4-8-16
	(Molazade and Mohammadi, 1999)	(Hillenbrand, 1972b)	(Hillenbrand, 1972b)	
34				4-8-16
	(Nikzad and Esfanjari Kenari, 2006)	(Nikzad and Esfanjari Kenari, 2006)	(Mohammadi et al., 2012)	
35				4-8-16
	adapted from Memari98 (2024)	adapted from Memari98 (2024)	adapted from Nasimesarakhs (2023)	

36	 (Raoufi and Khajehpour, 2021)	 (Raoufi and Khajehpour, 2021)	 adapted from Tripyar (2023)	4-8
37	 (Aslanapa, 1993)	–	 adapted from Archnet (2024)	4-8-16
38	–	–	 adapted from Reiseniran (2024)	4-8
39	–	–	 adapted from ISNA (2024)	4-8-16

In the remaining fifteen cases, an octagonal cross section was used in five cases and a sixteen-sided base in ten cases. No correlation has been found between the geographical location of the structures and the different geometric methods used. Small arches were made in seven cases, a row of bricks was erected in two, and small walls were built in one case to form the second level of the transition zone, which has a sixteen-sided cross-section. It is evident that the north-east buildings employed a row of bricks, while the north-west structures used little arches as the second level. Furthermore, the diversity of architectural options and decorative styles found in the transition zones in examples along the Khorasan route demonstrate the significance of these structures during the Seljuk period.

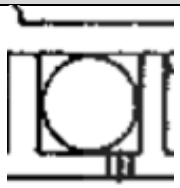
Transition Zones Featuring Sekonj

Sekonj is composed of two curved triangles with a shared central side in space (Hosseini, 1999). Each of these two triangular components is called "Taseh" and later this technique was evolved into Patkaneh and repeated in space with various geometries (Safaeipour et al., 2013). The squinch was first seen in the pre-Islamic architecture of Iran, for instance in the two square rooms of the Sarvestan Sasanian Palace. Subsequently, it was used in the Iranian Islamic architectural tradition. This type of squinch has been identified in the caravanserai of Mohammad Abad and Ali Abad. In these transitional zones, the predominant building material is rubble. In the chamber of Mohammad Abad caravanserai, an octagonal base for the dome was constructed by building one Sekonj in each of the four corners and four vertical small walls between squinches to complete the transition zone. In the room of the Ali Abad caravanserai, pendentives with a very rustic technique

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were constructed between squinches and small walls to form the octagonal base of the dome. The case studies are illustrated in Table 5.

Table 5. Sekonj in Seljuk square chambers

Number	Plan	Picture	Geometry of transition zone
40			4-8
	(Arab, 2006)	adapted from Mehr News Agency (2023)	
41			
	(Maxim Siro, 1970)	Adapted from Wikimapia (2024)	

COMPARISON

Table 6 summarizes the number of transition zones with four distinct squinch types found in the case studies as well as the number of geometric cross-section types identified in the transition zones. Shouldered arches are the most prevalent type of squinch, followed by Patkaneh, Patkin, and Sekonj. It is possible to draw the conclusion that, in comparison to other squinches, shouldered arches were primarily utilised for transition zones because of their simpler geometrical solution and quicker construction time. The transformation of a square into an octagon and then into a hexadecagon in twenty-three chambers is the most common geometrical solution. An octagonal cross section under domes in thirteen chambers is the next most frequently observed. In two of the cases, the square ground plan was directly transformed into a sixteen-sided base for the dome. In addition, transition zones with a decagon, an icositetragon, and a square section have been found in each case.

Table 6. Typology of transition zones in case studies

Squinch	Geometry of the transition zone						Total number
	4-4	4-8	4-8-16	4-16	4-10	4-24	
Patkaneh	0	1	7	2	1	1	12
Patkin	0	1	2	-	-	-	3
Shouldered Arches	1	9	14	-	-	-	24
Sekonj	0	2	-	-	-	-	2
Total number	1	13	23	2	1	1	41

Analogous squinch techniques have been observed in other Seljuk-era buildings across the broader territory of the Seljuk Empire. In the Central Asian region, while a limited number of edifices remain extant,

three distinct forms of squinches have been identified: Patkaneh, Patkin, and shouldered arches. The following edifices are located in present-day Turkmenistan: Patkin in Dayahatyn Caravanserai, Shouldered Arches in Mausoleum of Muhammad ibn Zayd and Talkhatan Baba Mosque, and Patkaneh in Abu Said Meikhene Mausoleum. It is important to note that the Iranian squinches, employed beneath domes, were introduced to Central Asian architecture either prior to the Seljuk dynasty or during the rule of other dynasties in this area, such as the Samanids, Kakuyids, Qarakhanids, and Ghaznavids.

Most Anatolian Seljuk buildings, located in present-day Turkey, employ pendentive or triangular squinch[15], architectural solution that were later adopted and further developed in Ottoman architecture. However, a limited number of examples demonstrate the use of alternative techniques. Notably, Patkaneh squinches are present in the Sultanhani Caravanserai, the Ağzıkara Han Caravanserai, and the Great Mosque of Malatya. In addition, shouldered arches can be observed beneath the domes of the Hoca Hasan Mosque and the Abdulaziz Mosque in Konya. It could be argued that the eastern region of the Seljuk Empire, which encompassed Central Asia, was of greater significance to the subject of the Iranian squinches than the western region, which is the territory of the Anatolian Seljuks.

[15] This type of squinch is referred to as Türk Üçgeni.

CONCLUSION

The distribution of case studies' construction times, squinch types, and transition zones' geometry on the map is depicted in Figure 6. This architectural diversity reflects the intricate craftsmanship and design preferences of Seljuk constructions, contributing to Iran's rich cultural and historical heritage. The following points could be drawn from this:
The locations of the structures are indicative of the importance of the regions during the Great Seljuk Empire, as they functioned as the capital of the Great Seljuk Empire, such as Rayy, Isfahan, Nishapur and later Hamadan, or were under the rule of regional Seljuk Sultans (Atabek), for instance the Kerman Seljuk Sultanate, or were on the main trade routes, for example the Khorasan Route. The structures in the north-west, with the exception of the Jame Mosque of Marand, were built when the region became important as the capital of the Great Seljuks moved to the city of Hamedan. It is important to note the unusual transition zone of the Jame Mosque of Marand, which had its influences on the rest of the later structures in the area.

The majority of the central structures date back to the days when Isfahan served as the region's capital. It is evident that structures in this region, such as the Jame Mosque of Zavare and the Jame Mosque of Marand, were constantly constructed using the same squinch and transition zone technique, and even the capital was relocated. It shows that the technique became a regional architectural type used by local architects.

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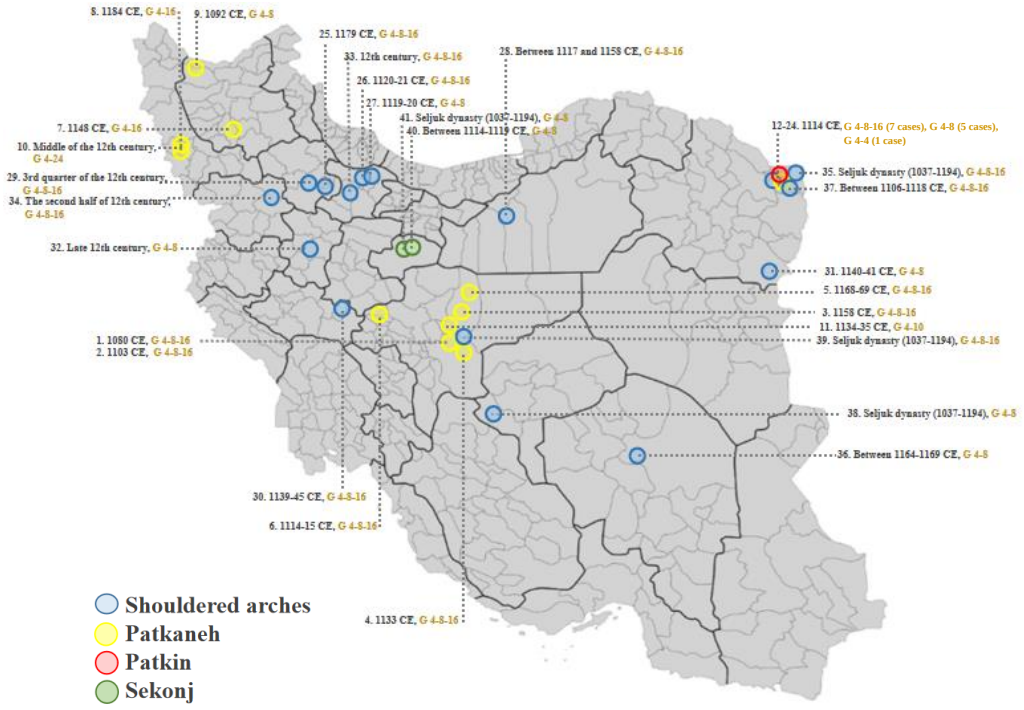


Figure 6. Four Case studies' construction time and geometry on the map

The northeast was important to the Seljuk Empire because of its advantageous position as a commercial route and the fact that Nishapur functioned as one of the empire's capital during its rule. The transition sections of the north-eastern structures are clearly linked to the central structures for the Patkaneh squinch and the north-western buildings for the schouldered arches. It is interesting to note that, despite the obvious influence, the approaches of the north-eastern buildings were simpler.

Additionally influenced by the transition zones featuring shouldered arches in northeast and north-west structures and simpler than them was the tomb of Khajeh Atabak, which is located in the southernmost point on the map. Remarkably, the building was constructed during the rule of the Kerman Seljuk sultanate in this area. The majority of structures with octagonal cross-sections in the transition zone, which serve as the basis for the dome, are located in the eastern part of the country. The sixteen-sided sections, representing the final layer of the transition zones, are observed to exhibit no particular regional preference.

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