

# The Typology of Transition Zones with Shouldered Arches in Iranian Seljuk Structures

## Architecture Evolving from Sasanian to Seljuk

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### Abstract

Squinches have been historically employed to facilitate the smooth transition from a square base to a circular dome in the transition zone beneath a dome. Their origin dates back to ancient Iranian architecture, and they were invented to address the challenge of supporting a dome on a square base. The shouldered arch style of squinch was initially used in Sasanian architecture. Over time, in Iranian-Islamic architecture, the transition zone with shouldered arches evolved, with Seljuk buildings representing the epitome of this development. The architectural style that emerged during the Seljuk dynasty (1037-1194) in Iran is referred to as Seljuk architecture. This study focused on the transition zones of Seljuk structures with the shouldered arch style of the squinch, examining their typology. The features of the transition zones of eleven case studies were converted into matrices, and the MATLAB programming platform was used for analysis. The findings of this research identified six types of transition zones that are composed of shouldered arches in Iranian Seljuk structures.

### Keywords

shouldered arches, squinch, transition zone, Seljuk, Iran

## 1 Introduction

Building a dome on a square plan chamber was one of the architectural challenges in the history of architecture. This is because the circular cross-section of the dome cannot directly cover a square space, and interface elements must be employed to bring the square shape closer to the circle (Golzari and Rabb, 2022b). The transition zone is used to transform a square chamber into a base for a dome (Moradi, 2020). In Iranian architecture, squinches were the main elements of the transition zone to address this architectural challenge (Edwards and Edwards, 1999). The use of squinches is a characteristic feature of Iranian architecture, and their invention is attributed to Iranian architects (Alkadi, 2016; Arce, 2006; Creswell, 1914).

Squinches fill the upper angles of a square chamber (Harris, 1989), and the dome's forces or weight are transmitted to both sides of the corner by them (Golzari and Rabb, 2022a). Iranian architects developed a variety of squinches, such as shouldered arches, Filposh, and Sekonj. Squinches were widely used in the transition zones of buildings during the Seljuk period. This research aims to

determine their typology to enhance the understanding of the transition zones with shouldered arches in Iranian Seljuk architecture.

The research questions that guided this study were as follows:

1. What were the most and least commonly employed features within the transition zones of Seljuk buildings featuring shouldered arches?
2. How many distinct types of transition zones were observed within these buildings, and what were the defining characteristics of each? Eleven Seljuk buildings with shouldered arches still standing in Iran<sup>1</sup> were identified and studied.

## 2 Shouldered arches

The ribs of the shouldered arches support the dome's downward thrust (Duarte et al., 2021). In Kooh-e-Khaje, the earliest example of this type can be found (Uschidā

<sup>1</sup> Current Iran

(Memarian et al., 2017). The transition zone featuring shouldered arches can be traced back to its earliest known example in the Sasanian architecture, which dates back to the period between 224 and 651 CE. and eventually developed throughout Iranian-Islamic buildings (Golzari and Rabb, 2022a). Fig. 1 illustrates shouldered arches on a cubic space.

### 3 Iranian Seljuk architecture

The Seljuks, who dominated the Eastern Islamic territory, had a Turkic nomadic origin (Alkadi, 2016; Lapidus, 2014; Peacock, 2015). Tughril Beg, a Turkish ruler who ruled Iran from 1037 to 1063 and established his capital in Isfahan, is credited with founding the Seljuk dynasty (Abazov, 2008; Ettinghausen et al., 2001). The Great Seljuk Empire, also known as the Seljuk Sultanate of Iran, was a powerful medieval Muslim empire that ruled over a vast territory in Iran, Central Asia, and parts of the Middle East from the 11<sup>th</sup> to the 12<sup>th</sup> century (Akbari, 2009; Marshall Cavendish Corporation, 2006; Peacock, 2015; Zaki, 1941; Zaporozhets, 2012). The geographical extent of the Great Seljuk Empire is depicted in Fig. 2.

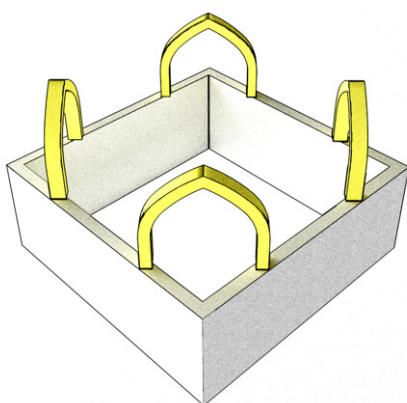


Fig. 1 Four shouldered arches in corners



Fig. 2 Seljuk Dynasty, 1037-1194 (CE), The current nations that make up the Great Seljuk Empire's region are represented by each colour (adapted from League (2010))

The Seljuk era, which lasted from 1037 to 1194, marked a significant period of cultural, artistic, and architectural development in Iran (Bosworth, 2007; Dehkordi, 2017; Nazer et al., 2020; Pope, 1969; The Editors of Encyclopaedia Britannica, n.d.). A vast number of mosques, tombs<sup>2</sup>, and other structures were built during this period. The architecture of this era in Iran is characterized by its unique fusion of traditional Islamic and pre-Islamic Iranian elements, resulting in a distinctively Iranian style (Wilber, 1962). In Iran's pre-Islamic buildings, transitional areas were constructed beneath domes. Later on, this feature was enhanced and embellished with elaborate Seljuk brickwork in the Iranian-Islamic architectural style.

### 4 Seljuk buildings with shouldered arches

Squinches are widely utilized in Seljuk architecture to support domes in various types of buildings, including mosques and tombs (Moradi et al., 2019). Investigations on surviving structures from the Sasanian era to the end of the 12<sup>th</sup> century show that Seljuk constructions in Iran are considered to represent the peak of the evolution of transition zones with shouldered arches.

In the following section, the transition zones of eleven Seljuk monuments with shouldered arches still standing in Iran were identified and analyzed<sup>3</sup>. Table 1 presents the names and corresponding details of the buildings mentioned.

### 5 Methodology


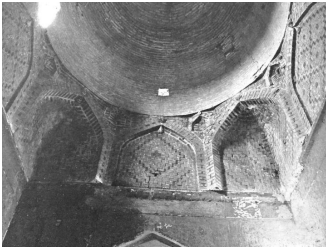
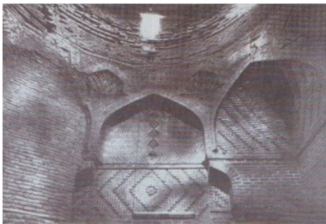

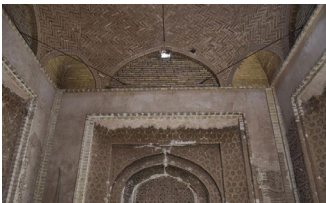
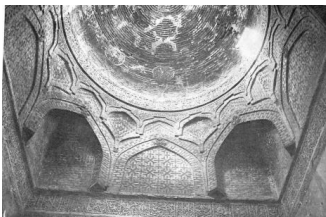

This research is conducted within the framework of interpretive-historical methodology. The emphasis for interpretive-historical research is accessing evidence from the past. At the strategic level, it entails epistemological points of view, acting as "lenses" through which past conditions are interpreted. Tactically, it entails fact-finding, fact-evaluation, fact-organization, and fact-analysis (Groat and Wang, 2013). The research process employed in this study is illustrated in Fig. 3.

The initial phase of this study involved the identification and determination of nine distinct features within the transition zones of the eleven selected case studies. The 3D models of these features are depicted in Table 2.

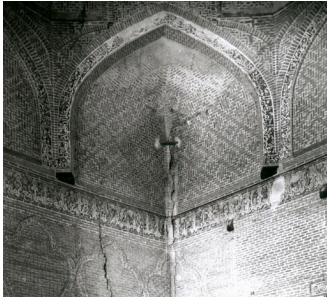



<sup>2</sup> The word "tomb" in this article refers to a structure where a person is buried especially a significant Muslim person.

<sup>3</sup> These structures have been documented in previously published academic works on Seljuk architecture.

**Table 1** Eleven Seljuk buildings with shouldered arches in their transition zones

Letter	Name	Function	City	Transition zone	Sources of pictures
a	Gonbad* Alaviyan	mosque-tomb	Hamedan		adapted from Iranmonument (2023)
b	Tomb** of Pir-i Takestan	tomb	Takestan		Hillenbrand (1972b)
c	Imamzade*** Aqil	tomb	Bijar		Mohammadi et al. (2012)
d	Tomb of Baba Loghman	tomb	Sarakhs		adapted from Nasimesarakhs (2023)
e	Tomb of Khaje Atabak	tomb	Kerman		Tripyar (2023)
f	Jame Mosque of Qorveh	mosque	Qorveh		Hillenbrand (1972a)
g	Jame Mosque of Golpayegan	mosque	Golpayegan		adapted from Wikimapia (2023)

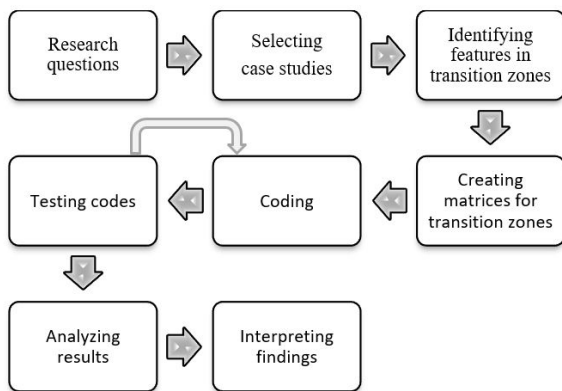
**Table 1** Eleven Seljuk buildings with shouldered arches in their transition zones (continued)

Letter	Name	Function	City	Transition zone	Sources of pictures
h	Jame Mosque of Qazvin	mosque	Qazvin		adapted from Archnet (2023)
i	Heydariyeh Mosque	mosque	Qazvin		adapted from Wikiwand (2023)
j	Jame Mosque of Semnan	mosque	Semnan		Anisi (2006)
k	Jame Mosque of Sojas	mosque	Sojas		adapted from General Office of Cultural Heritage, Tourism and Handicrafts of Zanjan Province (2023)

\* In Persian, "Gonbad" refers to a dome.

\*\* A building that is built on top of the graves of an Imam or a holy person.

\*\*\* A tomb to a Shi'ite Imam who was descended from the Prophet Muhammad



**Fig. 3** The research design

Based on the distinctive features of each transition zone in the selected case studies, a comprehensive and systematic approach was adopted, which involved creating

a matrix of nine entries using MATLAB. MATLAB, a numerical computing software package, has become increasingly popular in architecture research in recent years. The software's capabilities have allowed architects and researchers to develop innovative solutions to answer questions and explore problems.

MATLAB can be used for a range of tasks, from structural analysis and optimization to energy modeling and simulation. In this research, the researchers applied a numerical approach to evaluate the transition zones of the eleven case studies using MATLAB.

In order to assess the presence or absence of particular features within the transition zone of the building under study, a value of 1 was attributed to the relevant entry in the matrix if the feature in question was identified, and



**Table 2** Features in the transition zones of case studies

Number	Description	3D model
1	shouldered arches in corners	
2	arches between shouldered arches	
3	a pendentive between shouldered arches and arches on walls	
4	a filling part between shouldered arches and features on walls	
5	a vertical element between shouldered arches	
6	a small arch on top of shouldered arches	
7	a small feature above the shouldered arches	
8	a small vertical feature in the second layer of the transition zone	
9	a small arch between shouldered arches and other elements	

conversely, a value of 0 was allocated in the event of its absence. Fig. 4 demonstrates the eleven matrices of the transition zones of these buildings. The eleven elements in each row matrix are arranged following the Table 2 feature order.

Subsequently, the individual matrices were aggregated into a composite matrix of eleven rows and nine columns, thereby facilitating the analysis of the features identified within the transition zones of the selected structures. To address the primary research question, the numerical values within each column of the composite matrix were summed, creating a single matrix. Fig. 5 presents the MATLAB code and the resultant output utilized in the analysis process.

The entries within the composite matrix corresponding to the highest and lowest numerical values represent the most and least frequently observed features across all selected case studies. Among the selected structures, nine instances were identified wherein arches were constructed

```

a = [1 1 0 0 1 0 0 0 0];
b = [1 1 0 0 0 1 1 1 0];
c = [1 1 0 0 0 1 1 1 0];
d = [1 1 0 0 1 0 0 0 0];
e = [1 1 1 0 0 0 0 0 0];
f = [1 1 0 0 0 1 0 0 1];
g = [1 0 0 1 0 1 0 0 1];
h = [1 1 0 0 0 1 0 0 1];
i = [1 1 0 0 1 0 0 0 0];
j = [1 0 0 1 1 0 1 1 0];
k = [1 1 0 0 0 1 0 0 1];
    
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**Fig. 4** Matrices of eleven case studies in MATLAB

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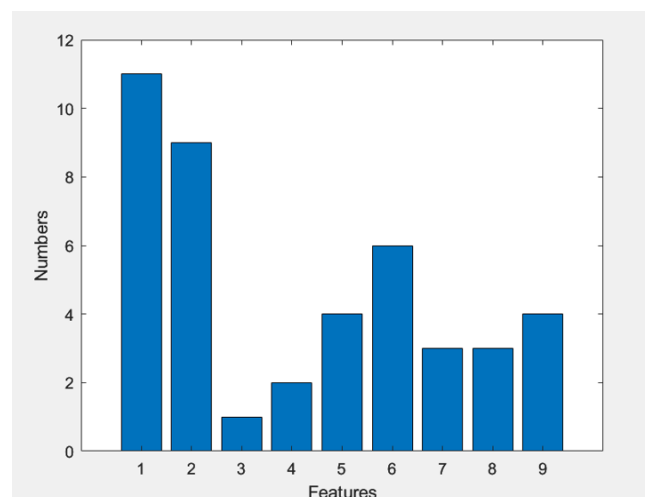
Total = a + b + c + d + e + f + g + h + i + j + k;
bar(Total)
xlabel('Features')
ylabel('Numbers');
    
```

Name	Value	Max	Min
Total	[11,9,1,2,4,6,3,3,4]	11	1

**Fig. 5** Values added together in each column

between shouldered arches, while in one case, pendentives were employed to serve as a transitional component between shouldered arches and completed the transition zone. Fig. 6 demonstrates the sum of features of all case studies in a bar chart.

While the matrix for presenting all the case studies has 11 rows, some of them are identical, indicating that the



**Fig. 6** Most and least features

transition zones are of the same type. To address the second research question, which aimed to identify different types of transition zones of the eleven Seljuk buildings with shouldered arches, the code of unique row in MATLAB was employed. This code allowed for the identification of any similar rows within the matrix of case studies.

By executing this code, duplicate rows were detected and removed, ensuring that only one instance of each unique row remained in the matrix. After running the unique row code in MATLAB, the resulting matrix contained six distinct rows, indicating the existence of six different types of transition zones present in Seljuk buildings with shouldered arches utilized as a squinch. Fig. 7 shows the unique row code and its result for the matrix in MATLAB.

Additionally, considering the number of features and levels<sup>4</sup> found within the transition zone, the categorized types of transition zone were systematically arranged to aid further analysis. Table 3 shows the matrix row related to the type and name of the buildings with this type of transition zone.

Based on the analysis, types one and six were the most common among the identified types of transition zones in Seljuk buildings with shouldered arches. Additionally, for each of these two types, three buildings were identified. For two structures, type five was utilized as the transition zone. For types 2, 3, and 4, only one building was observed to have used each respective type.

In the first two identified typologies of transition zones, it was observed that the initial square plan of the building was transformed into an octagonal cross-section within the transition zone to provide a base for the placement of the dome. In the remaining four types, the square plan was first transformed into an octagonal section and then further into a hexadecagon section, resulting in a transition zone with two distinct levels. The 3D models<sup>5</sup> of the six identified typologies of transition zones featuring shouldered arches in Iranian Seljuk architecture have been included in Table 4.

In Fig. 8, the distribution of typology is shown on the map of Iran. The majority of the identified cases of Seljuk

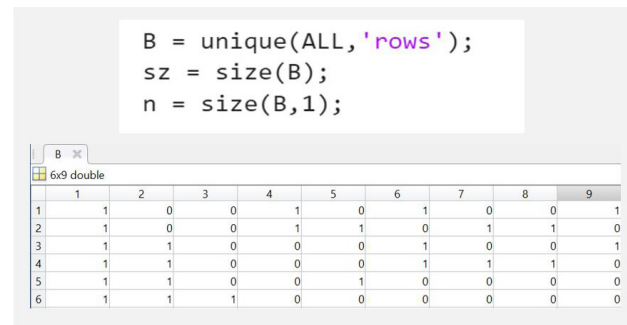


Fig. 7 The code of the unique row and its result

Table 3 Typology of the transition zones

Type	Matrix	Buildings
1	[1 1 0 0 1 0 0 0 0]	Gonbad Alaviyan, Tomb of Baba Loghman, and Heydariyeh Mosque
2	[1 1 1 0 0 0 0 0 0]	Tomb of Khaje Atabak
3	[1 0 0 1 1 0 1 1 0]	Jame Mosque* of Semnan
4	[1 0 0 1 0 1 0 0 1]	Jame Mosque of Golpayegan
5	[1 1 0 0 0 1 1 1 0]	Imamzade Aqil and Tomb of Pir-i Takestan
6	[1 1 0 0 0 1 0 0 1]	Jame Mosque of Qorveh, Jame Mosque of Qazvin, and Jame Mosque of Sojas

\* Jame Mosque is a mosque that is typically constructed in the urban core, and it serves as the gathering place for political, social, and educational events in addition to being the site of religious rites, particularly the Friday prayer.

buildings with shouldered arches in their transition zones are predominantly located in the north-western region of Iran.

Despite the relative proximity of the seven buildings in the north-west region of Iran, compared to the other four buildings, it was discovered that they exhibit a range of three different types of transition zones. Further from that region, three additional types of transition zones are observed, with Baba Loghman being an exception, as it features the first type with less complexity.

## 6 Conclusion

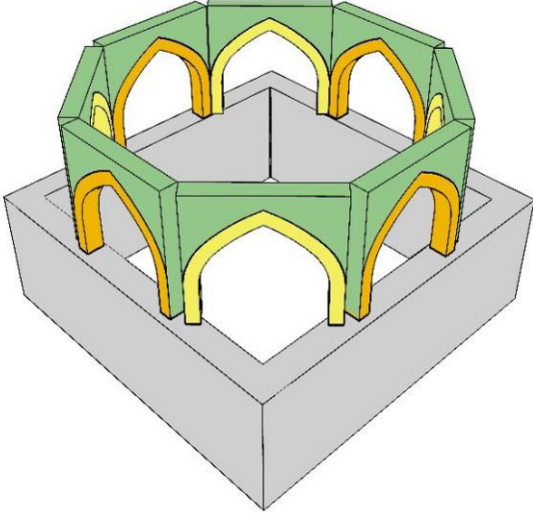
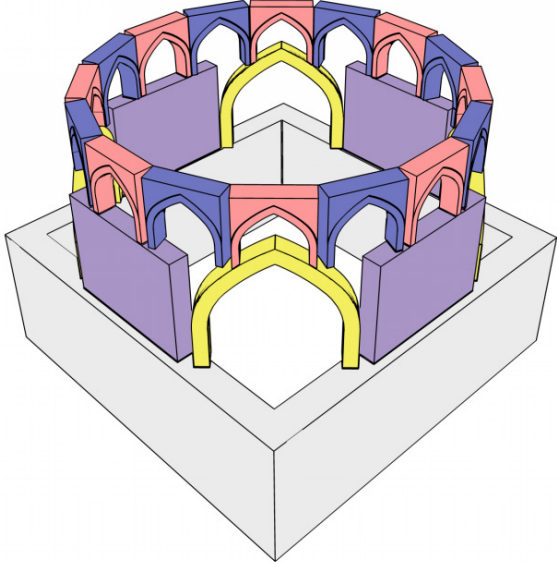
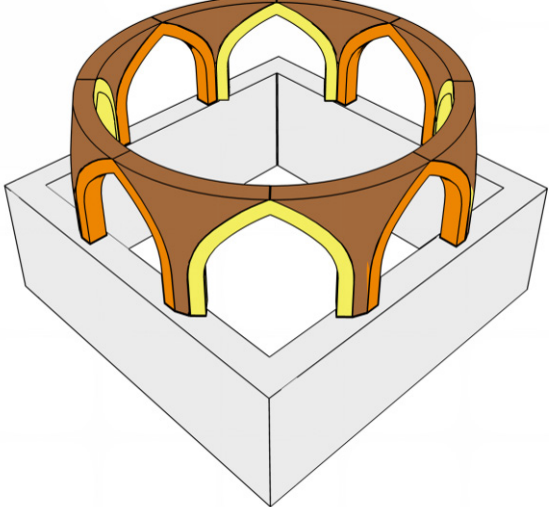
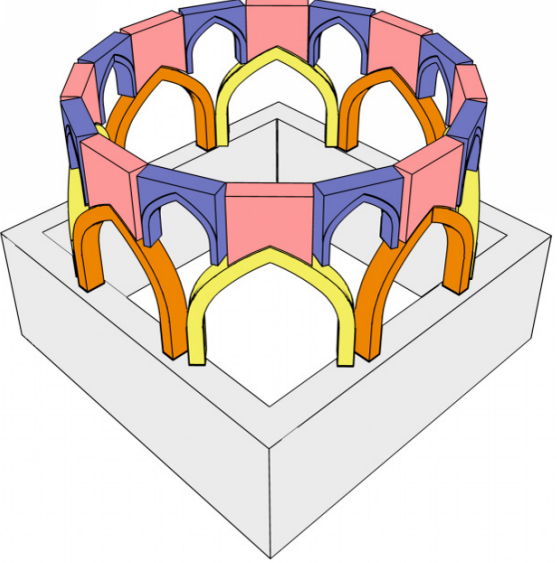
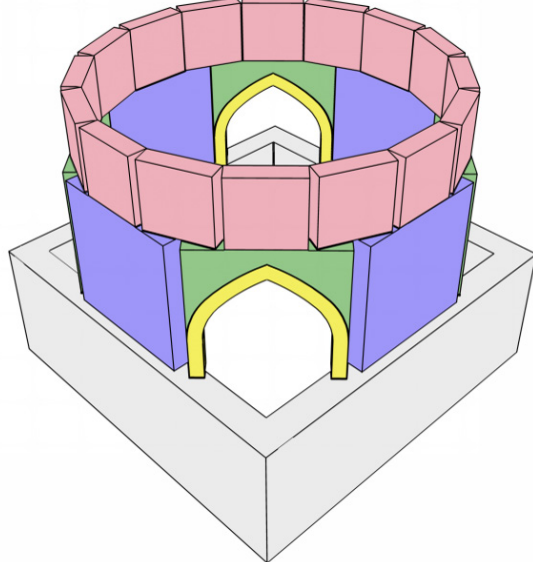
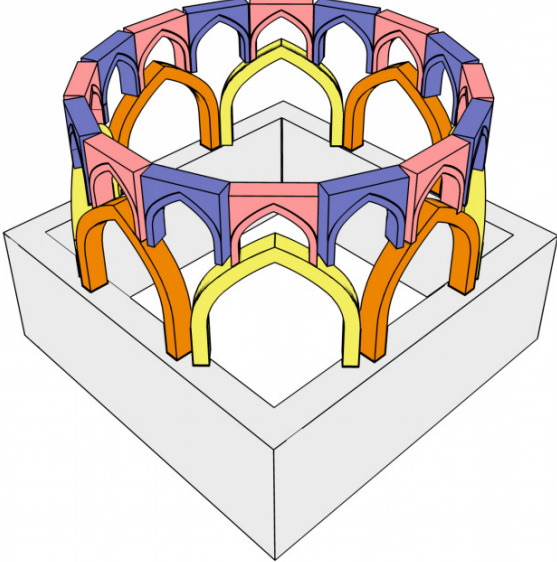
The transition zone, which consists of four-shouldered arches beneath the dome, is one of the key architectural elements that first emerged in the Sasanian era and reached its pinnacle of development during the Seljuk period in Iran.

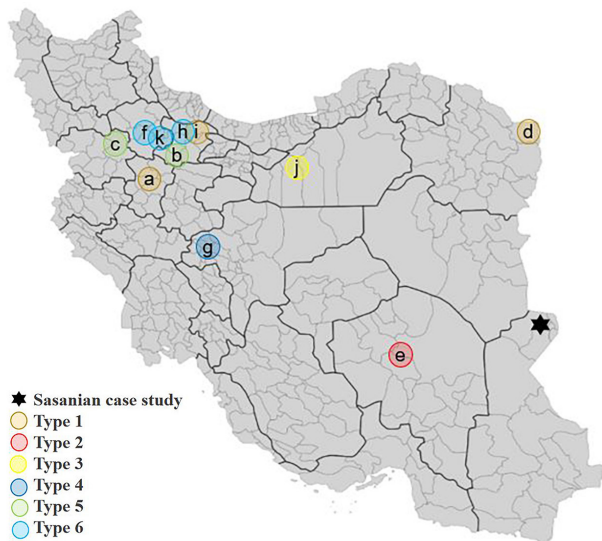
The study's interpretive-historical methodology allowed for a comprehensive analysis of the transition zones in Seljuk buildings with shouldered arches and identified six distinct typologies. The typologies were systematically ordered to facilitate further analysis, highlighting their similarities and differences. The majority of the identified

<sup>4</sup> The transition zones in cases were observed to consist of either one or two levels.

<sup>5</sup> The general 3D models presented do not represent the specific proportions of each transition zone, as they only showcase the overall features of the six identified typologies.

**Table 4** 3D models of the six identified typologies of transition zones

Type	3D model	Type	3D model
1		4	
2		5	
3		6	



**Fig. 8** The distribution of typologies of Seljuk structures with shouldered arches in the transition zone in Iran

types were found in the north-west of Iran, with only a few structures located further away exhibiting different types of transition zones.

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Overall, this study provides valuable insights into the transition zones in Seljuk buildings, contributing to a better understanding of the architectural features and design principles employed in these structures and a deeper insight into the Seljuk architectural style and its evolution. The findings can also be used as a reference for future studies and preservation efforts of Seljuk structures. In addition, the study's insights may prove useful to architects, historians, and researchers interested in Islamic architecture and its historical context, serving as a valuable reference for future studies.

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