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A New Look at Excavation Techniques and Design of Rock-Cut Architectures

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Abstract: Rock-cut architecture is an essential yet little-known type of vernacular architecture whose nature is different from what we understand by the term "architecture". This research seeks to answer the question of which technics, designs and digging procedures have been applied in this type of vernacular architecture. Out of the 300 rock-cut buildings and complexes found in Iran, nearly 70 were functionally assessed. Ten complexes were found to serve residential functions in different climates. Technique, type and the settlement context material were also briefly compared and contrasted, and thus, three general excavation techniques were recognized. The largest rock-cut residential complex in Iran, Meymand, was selected as the main case study. Fifty residential units in the oldest part of the village in two regions on both sides of the main valley were studied in terms of technique and design style. They were also compared and contrasted. The quantitative data obtained in this section were compared and contrasted using the descriptive statistical method. Although the rock-cut buildings are dispersed throughout Iran, three main techniques were employed to excavate them. Most of them were excavated using two or three of the said techniques. Application of the fine technique and the size of the particles constituting the settlement context are the two factors determining the quality of excavation. The findings in the area of special climatic design standards and technologies not only give us a better insight into rock-cut architecture but also contribute to setting some standards for design and construction of rock-cut buildings in the present era.

Keywords: rock-cut architecture; Meymand; vernacular architecture; architectural framework; earth-shelter; cave dwelling; underground architecture

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1. Introduction

Building space through hollowing out solid rock in the absence of common building materials is an extraordinary architecture technique whose study demands special attention [1–3]. Rock-cut architecture, as a type of earth-shelter architecture, enjoys considerable diversity, as particularly the Iranian plateau and generally the world host its manifestations, which have taken different forms and functions due to climate considerations [4–6].

Common building materials and techniques are not used in rock-cut architecture [7]. Instead, space is built through hollowing out a natural solid context either in the form of a flat horizontal land under which the rock-cut buildings are excavated or the steep surface of foothills or gently sloping to upright hills, which provide the best context for rock-cut architecture [8–10]. The context should mainly be softer than granite, so that it could be excavated with simple tools, and harder than soil, so that it would not fall apart [11].

It is a hard task to understand the techniques used in this singular type of underground architecture [12] since there is a lack of historical documentary evidence about the excavation processes of rock-cut buildings. Moreover, it is no longer practiced in Iran [13]. The only way to find some evidence about the excavation technology of rock-cut architecture is to refer to interviews held with informed people and physical analysis of the architecture.

It is also useful to compare and contrast the architectural styles of rock-cut buildings in different regions.

2. Statement of the Problem

One of the most significant challenges in understanding rock-cut architecture is to answer the fundamental question of how the buildings were designed and excavated [14–16] and what process was performed to build them. Due to lack of historical evidence and documents, the answer to this question requires understanding the process in which the background and the excavation technique were selected [17]. In other words, one should think as similarly as possible to the men who excavated the buildings in the past. Therefore, the main question is what techniques could be used to excavate an architectural space with the least tools. The answer could partly remove the ambiguity about the nature of rock-cut architecture [18]. Unfortunately, the Iranian works of rock-cut architecture are in danger of destruction due to different reasons [19], and thus, it is necessary to gain a fundamental insight into the manner in which they were formed [20].

3. Materials and Methods

The four-year research is a case study of rock-cut architecture in the world heritage site of Meymand village. Excavation techniques and design patterns of the buildings were assessed on the basis of background and historical evidence found in the architectural body of the village. Then, the excavation process of the buildings was sketched out on the basis of the settlement context. Two general sketches were drawn that were very similar to each other and were only different in terms of the steepness of the surface of the excavation context. Later, building plans were recognized and classified into two broad types: linear plan and radial plan.

Out of the 300 rock-cut buildings and complexes found in Iran, nearly 70 were functionally assessed. The existence of this architecture throughout Iran shows the widespread use of this local architecture type. Ten complexes were found to serve residential functions in different climates (Figure 1). The general classification of context and excavation of these assemblies were determined based on the geological zoning of Iran [21]. The slope of the construction site of this building was also recorded in Table 1 based on field observations. Then, by selecting 3 buildings from each complex, calculating the amount of excavation, the area of the building and the area of the surfaces, the percentage of each of the three main digging methods in this building was estimated (Table 1).

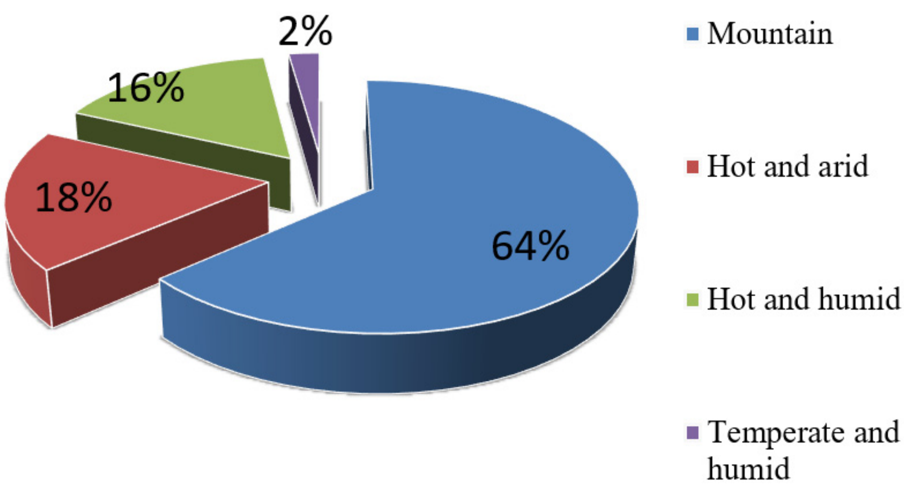

Figure 1. Climate ratio of Iranian rock-cut regions.

Table 1. Technical characteristics of well-known Iranian rock-cut residential complexes.

Name.	Main Excavation Technique	Climate	Context Rock	Context Steepness	Mass Excavation Technique (%)	Steady Excavation Technique (%)	Fine Excavation Technique (%)
Meymand	Rough out	Cold mountain	Pyroclastic	Steep hill and upright wall	8	88	4
Kandovan	Fine	Cold mountain	Pyroclastic	Upright wall	4	44	52
Hilevar	Rough shaping	Cold mountain	Pyroclastic	Steep hill	12	66	22
Savar	Rough out	Cold mountain	Pyroclastic	Steep hill	52	40	8
Arzanfoud	Rough shaping	Cold mountain	Metamorphic	Steep hill	20	75	5
Bafran	Rough shaping	Hot and arid	Sedimentary	Upright wall	30	65	5
Kouhpayeh	Rough shaping	Cold mountain	Sedimentary	Upright wall	30	60	10
Khorrambid	Rough out	Cold mountain	Sedimentary	Steep hill and upright wall	45	40	15
Abazar	Rough out	Cold mountain	Pyroclastic	Upright wall	45	40	15
Viand	Rough shaping	Cold mountain	Pyroclastic	Steep hill and upright wall	30	60	10

Technique, type (Figure 2) and the settlement context material (Figure 3) were also briefly compared and contrasted, and thus, three general excavation techniques were recognized. The largest rock-cut residential complex in Iran, Meymand, was selected as the main case study. A total of 50 residential units in the oldest part of the village in two regions on both sides of the main valley were studied in terms of technique and design style. They were also compared and contrasted. Archaeological evidence shows that the tradition of excavation of this building existed until recent decades [20].

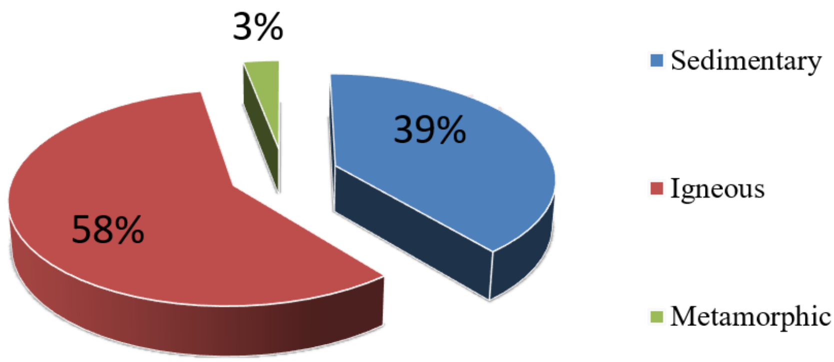

Figure 2. Context-type ratio of Iranian rock-cut buildings.

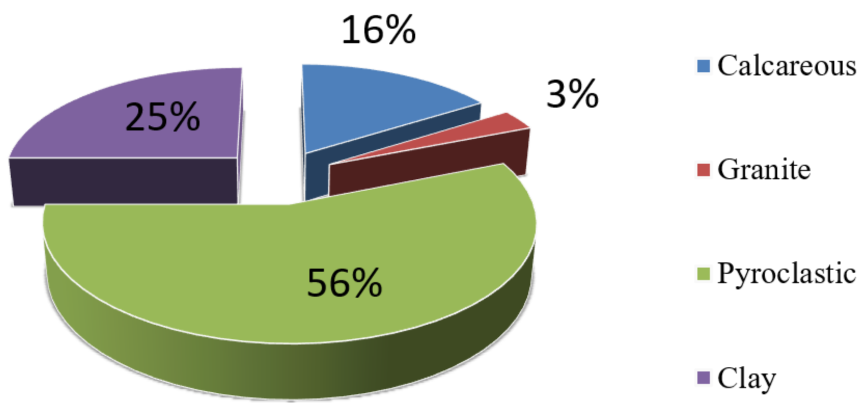

Figure 3. Context-material ratio of Iranian rock-cut buildings.

Animal husbandry and living with livestock have formed the main structure of society and livelihood of the inhabitants in the rock-cut architecture complexes of Iran. Agriculture and horticulture were also seen to a limited extent due to the lack of water around these complexes. The preference of the people of these areas due to climatic issues and access to a suitable context for excavation (mountains and rocky hills) has been the reason for using this type of architecture [19].

The quantitative data obtained in this section were compared and contrasted using the descriptive statistical method. It was found out that the rock-cut architecture of Meymand village follows a certain process and a general technical standard.

Meymand is a historic rock-cut village located in eastern Shahr-e Babak, in the northwest of Kerman province, Iran (Figure 4). Its latitude is 11°13′ N, and its longitude is 55°22′ E. It is 2220 m above the sea. Meymand is located in the southern slope of the Masahim dormant volcano. The village is cut into volcaniclastic rock known as pumice. The five-story village consists of almost 360 houses [22]. Meymand region generally enjoys a mountain climate, but its neighboring plains have a semiarid climate. The history of its formation is unknown; however, Shahr-e Babak was built in the Sassanid era [23]. Archeological excavations at Meymand castle and carbon-14 tests on its remnants date it back to the Parthian era [24]. Earthenware found in Maymand bears significant resemblance to that of the Sassanid era (500–200 A.D.) [25]. Rock carvings around Maymand demonstrate that men lived in Meymand region several millennia ago [26].

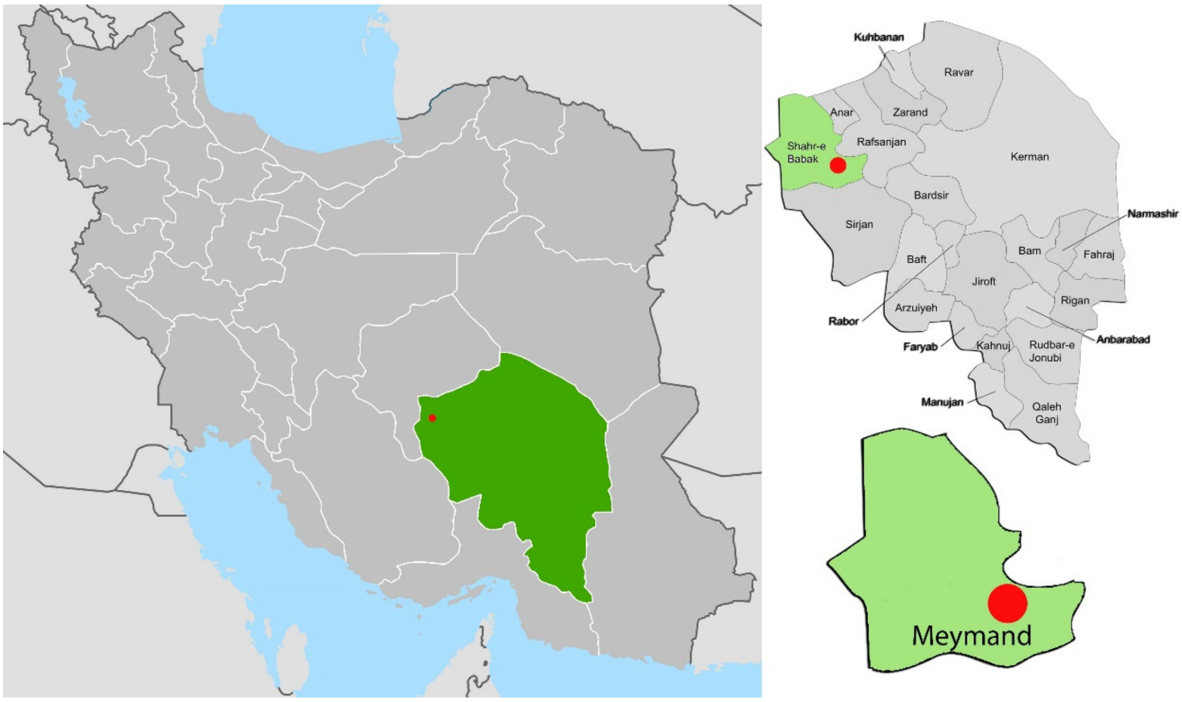

Figure 4. Location map of Meymand in Iran.

The village is located on the edges of a shallow valley less than one kilometer in length (Figure 5). The majority of its buildings serve residential purposes, and only a few buildings were used as school, mosque, hussainiya (congregation hall for Shia commemoration ceremonies), bath and fire temple. Intra-village communications are carried out through a central floodway as well as narrow paths that discharge surface waters and reduce the risk of flooding when it rains. The fabric was formed in several stages that can be distinguished from each other according to the architectural characteristics of each era [19].

Figure 5. Eastern view of Meymand village.

In this World Heritage Site, a historic bath, a school, a mosque, a Hussainiya, a fire temple and the remaining 360 buildings were used for residential purposes. Each of the residential buildings of this complex has their own architectural aspects.

The required water for this village was supplied from a spring at the bottom of the central river in the village, and these buildings did not have direct access to water. To heat these buildings in winter, burning coal and wood were used, and the resulting smoke was discharged by a convective flow through the wooden doors of the rooms.

People of Meymand used to live in the village only in the cold months of the year and were busy farming and stockbreeding in the neighboring plains and valleys in the rest of the year [27]. Because of the cold climate of the valley, their houses have short and small openings that are proportional to their dwellers' height and minimize heat loss (ibid.). Moreover, the blackened and soot-covered rooms have thick walls that reduce heat loss to a minimum. They are cold in summer and quite warm in winter. They reach the comfort zone with minimum energy. Rural density and cohesion, as well as the multistory structure of Meymand village, have made its spatial communications dense and close (Figure 6). The village has distinct neighborhood divisions on the basis of the families who lived there [28].

Limited tools were used to dig these buildings, and the 3 main common tools of all diggers in all historical periods are a carving pen, hammer and carving pickaxe [22]. In Meymand, through interviewing local people and observing the common tools used for stonework, it was determined that the three mentioned tools were the main drilling tools of this building in the past (Figure 7).

Figure 6. Aerial image of Meymand village.

Figure 7. Sample of equipment used for excavation.

4. Results

4.1. Excavation Techniques

Three distinct excavation techniques were employed in the rock-cut architecture of Meymand village. They vary according to the area in which they were used. In simpler words, in areas where delicacy in construction was necessary, light tools and fine techniques such as chiseling were employed. On the contrary, more sophisticated techniques were used when the volume of excavation was considerable. In sum, the excavation techniques are included as follows:

4.1.1. Excavation Method

The excavation technique was chosen by the architect and the excavator. However, three distinct techniques were employed to excavate rock-cut houses. Apart from edges, niches and sills, which demanded delicacy in excavation, the main space inside the rooms was excavated steadily in small pieces, or huge pieces of rock were removed. The context material plays a fundamental role in the excavation technique. The said techniques were applied only in buildings whose context was made of pyroclastic rocks such as tuff and pumice. These buildings are found in Meymand, Hilevar, Kandovan and Abazar (Figure 8).

Figure 8. Pumice stones found in Meymand, Kandovan and Abazar and their difference with the dense sediment found in Bafran.

In buildings whose context was made of dense clay sediments, a steady excavation technique was used. Examples of this technique are found in Kouhpayeh village of Kerma and Bafran near Naein (Table 1). The difference in context material was accompanied by difference in structural system, and an arched system was used in contexts such as clay, which have less strength (Figures 9 and 10). The arrangement of selected layers is also important in excavation, and the rock-cut architects always sought to choose a context that was either a solid mass free of layers or had horizontal layers (Figure 11). Therefore, the context may have better borne the compressive forces and would not slide under the pressure of gravity.

Figure 9. Arched excavation in the form of barrel arch in Koupayeh of Kerman and Bafran of Naein.

Figure 10. Flat roof in Maymand buildings.

Figure 11. Horizontal arrangement of layers in pyroclastic context of Qebleh Daghi of Azarshahr and sedimentary context of Kouhpayeh.

4.1.2. Rough out Excavation

In this technique, heavy pickaxes are used to excavate large and deep grooves around a huge mass. Then, the surface of the mass between the grooves is divided into distinct spots against which a wedge is placed and hammered to the point when the mass crumbles into small pieces [29]. This technique requires considerable skill because failure to control the blows and locate the early grooves leads to the improper demolition of the rock, and thus an irregular room space (Figure 12), yet it accelerates the excavation process.

Figure 12. Mass excavation technique in Meymand houses.

4.1.3. Fine Shaping and Detailing Excavation

This technique has limited application. In this technique, light tools such as light pickaxes are used to excavate doorways, carve façade decorations, polish the corners, level out the floor and ceiling and excavate lock holes (Figures 13–15). In the fine excavation technique, light yet continuous blows remove small particles from the surface; therefore, the rough surface will turn into a level one, and the desired form takes shape. Simple and limited tools are among the characteristics of this architecture. Heavy and light pickaxes, small and large chisels, heavy mallets and light hammers, metal wedges and wheelbarrows are the said tools. This is interesting because each stage of the architecture of the construction demands the use of several tools whose application sometimes adds to the complicacy of the task. Therefore, it is an advantage of rock-cut architecture that it uses a limited range of simple tools. Moreover, it is possible to make the tools available in the region with simple industrial facilities such as traditional blacksmithing.

4.1.4. Rough Shaping Excavation

In this simple technique, heavy pickaxes are used to strike consecutive blows up and down at an almost 45 degree angle to remove small pieces of stone, and the process continues steadily until the whole mass breaks up. This technique enables the excavator to control the volume of excavation and reduce the roughness of the surface. In general, the three techniques were all applied in rock-cut buildings. However, the steady excavation technique was more prevalent thanks to executive balance (Table 1). The walls should also be varnished to reach the desired internal form. This also demanded the application of the steady excavation technique.

Apart from space creation and excavation techniques (Figure 16), the quality of excavation in Meymand was dependent on the size of the particles constituting the settlement context. In other words, the finer the grains, the finer the excavated area. The context masses are mainly made of tuff, which is a fine-grained rock and thus gives the excavator a free hand to excavate the corners, niches and openings. On the contrary, spaces excavated in agglomerate and breccia masses are organic and have no corners and angles. Tuff and

Pumice particles are round, while Agglomerate and Breccia particles are large and angular. This difference also changed the quality of excavation.

Figure 13. Fine excavation technique used in doorways, niches and interior space of rock-cut rooms in Meymand.

Figure 14. Fine excavation technique used in interior surface of rooms.

Figure 15. Difference in the size of the particles led to difference in the quality of excavation in Ansaroud Grand Mosque and Pish Avesta Temple.

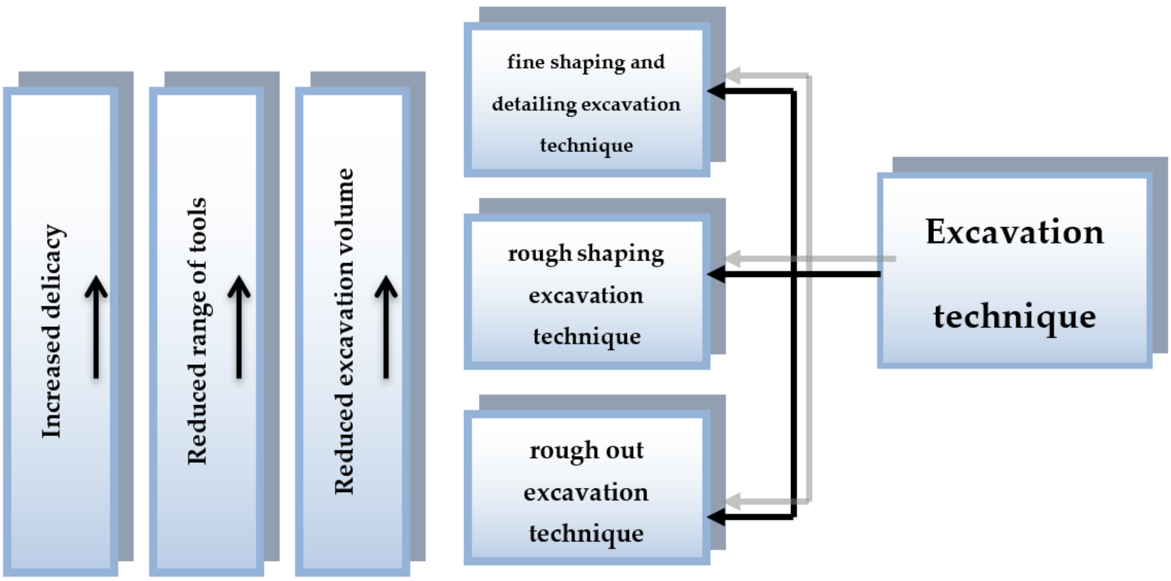

Figure 16. The impact of excavation technique on volume, delicacy and tools.

5. Discussion

5.1. Excavation Design

Apart from appropriate excavation techniques and tools, a predetermined design was needed to excavate the buildings. In other words, observing the excavation prerequisites and conducting the excavation process required a detailed plan. The process covered the following stages: excavation of the trench to reach the upright surface needed to excavate the building; excavation to reach a semi-open space in front of the entrance; fine excavation of the entrance; and simultaneous and parallel excavation of rooms. Each of the above stages required certain techniques and tools (Table 2).

Table 2. The relationship between architectural elements and excavation tools used in Meymand.

Architectural Element	Excavation Technique	Excavation Tool
Kicheh (entrance trench)	Rough out	Mallet and wedge
Soffeh (semi-open space next to kicheh)	Rough shaping and fine shaping and detailing	Heavy and light pickaxe
Dargah (Doorway)	Fine shaping and detailing	Light pickaxe
Room	Rough out and rough shaping	Heavy pickaxe, wedge and mallet

5.2. Excavation Stages

The buildings of Meymand were generally excavated in the following order:

5.2.1. Stage 1: Excavation of Kicheh (Entrance Trench)

The aim of this stage is to turn the steep surface into an upright one in order to excavate the interior spaces of the building, a surface in front of which the excavator can easily stand and perform the excavation. The excavators first located the excavation path and determined its length, and then applied the mass excavation technique with heavy tools to excavate the trench. This architectural element is similar to an inverted triangle. Its total length depends on the steepness of the context. The less steep the context, the longer the trench. For instance, if a house is built on the surface of a hill that is 30 degrees steep, the trench will be longer than six meters. The excavation was performed roofless until an upright surface with a reasonable height proportional to the excavator's height (2.5 to 3 m) took shape. The upright surface acted as the proper and standard context for building the interior semi-open and closed space of the building (Figure 17). The difference between the highest level of the valley, which naturally has upright surface for excavation, and the lower levels, which have steep surfaces, lies in this stage. In fact, the houses built at the highest level did not need this stage of excavation. Therefore, their volume of excavation was less than that of the houses built in the lower levels. The main difference made by the absence of this architectural element is that houses built in the lower levels are more compatible with the climate conditions because they have an extra element (i.e., the trench) which makes balance between the inside and outside temperature. The dwellers of the houses which are equipped with trenches acknowledge that they are more comfortable.

5.2.2. Stage 2: Excavation of Soffeh (Semi-Open Space)

In this stage, the roofed spaces of the building were excavated mainly using the steady excavation technique, for the general shape of the spaces was important and appropriate upright surfaces should be reached to excavate the room entrances. As soon as this element took general shape, the surface of the walls was excavated using the fine excavation technique. At this stage, semi-open spaces took shape, which acted as intermediaries between the outside space and the closed rooms inside the house. In fact, they acted as distribution space. In addition, the dwellers of the house performed most of their daily activities in this part of the building. The excavators performed the excavation from above when necessary and then shaped the floor of soffeh to reach the desired height level. The bottom level was usually excavated 20 to 30 cm deeper than the entrance trench's (Figure 18). The rock layer of the ceiling in the thinnest part where the soffeh and kicheh meet is above 50 cm thick to lend the building enough strength. As we moved inside the building, the thickness increased due to the steep surface of the settlement context.

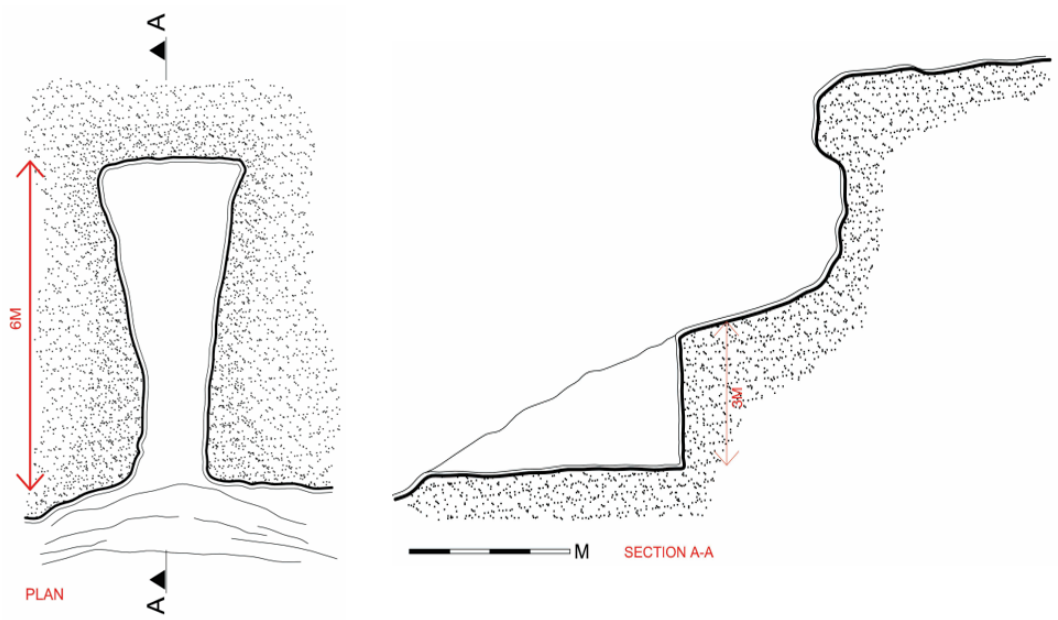

Figure 17. The first stage of excavation (excavation of entrance trench, i.e., Kicheh) in cross-section and plan view.

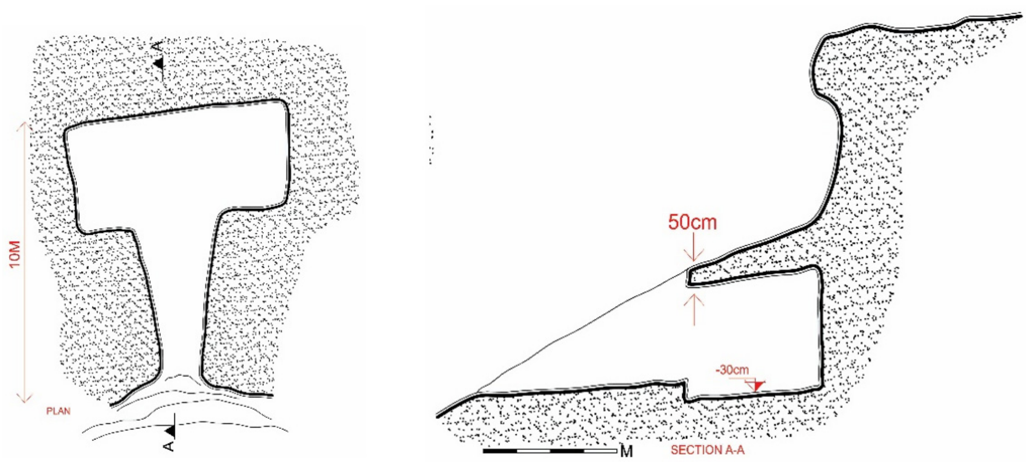

Figure 18. The second stage of excavation (excavation of semi−open space, i.e., Soffeh) in cross-section and plan view.

5.2.3. Stage 3: Excavation of Dargah (Doorway)

This is technically the most sensitive stage of the excavation. It was performed using the fine excavation technique and light tools. In this stage, the surface was lightly scraped. Usually, three sides of the soffeh were ready to excavate the rooms; therefore, the doorways were first located and then excavated (Figure 19). The average thickness and depth of the doorways were approximately 50 cm. This stage is really sensitive because the excavators are able to correct their mistakes only in this stage. In fact, it is not possible to correct the mistakes in later stages since there is no surface to rebuild the doorways (Figure 20). On the other side, the need to build doors in sizes compatible with the cold climate of the region adds to the sensitivity of the stage because the measures of the entrance should be selected in a manner that minimizes the thermal exchange in the hot and cold seasons of the year (Figure 21). Furthermore, they should be excavated in shapes that make it possible to install or change wooden doors and their locks.

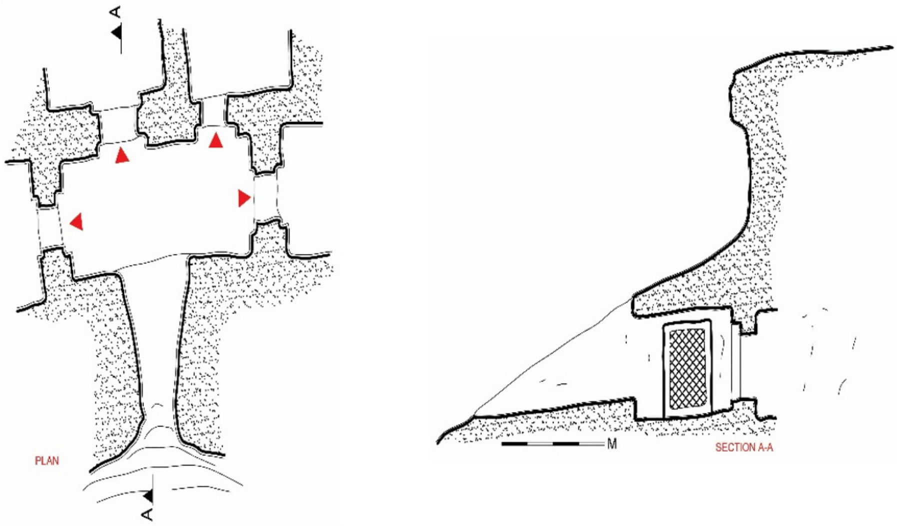

Figure 19. The third stage of excavation of doorways (Dargah) in cross-section and plan view.

Figure 20. An unfinished kicheh in Meymand shows that the doorways should be completed before moving to other elements.

Figure 21. Details of a front door from inside.

5.2.4. Stage 4: Excavation of Room

Steady excavation is the main technique used in this stage. The excavator first excavated the general shape of the room with desired measurements, size and height. Then, he employed the fine technique and used light tools to scrape the surface of the walls, floor, ceiling and corners to reach the desired shape (Figure 22). The quality of excavation is dependent on the size of the particles constituting the excavation context. The finer the grains, the smoother and more appropriate the form of the rooms. If there is no restriction in the neighborhood of this building and the bedrock has a uniform texture in terms of strength, it is possible to add space inside these buildings by drilling. Evaluation of the average penetration depth and opening width of the rooms in Meymand houses shows that the diggers tried not to penetrate more than 18 m and the width of the openings more than 6 m, because as the openings increase their strength decreases. Additionally, by increasing the penetration depth, the ventilation and the lighting of the building are also reduced (refer to the doctoral dissertation). According to archaeological evidence, it took at least 3 weeks to prepare and dig a room in this village.

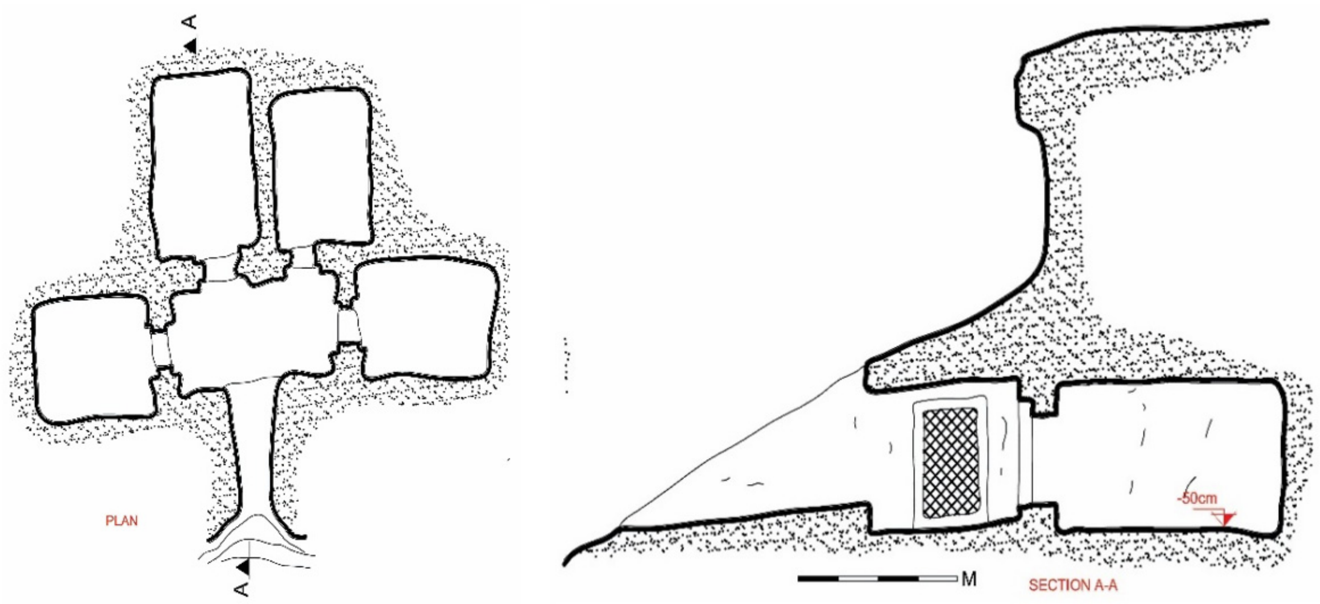

Figure 22. The fourth-stage fulfillment of excavation of rooms in cross−section and plan view.

Due to the primitive lifestyle of the people of Meymand, the furniture and equipment of this building are very simple and primitive, but some elements such as ledges, stoves, clamps (akhieh) and the installation of a weaving machine were carved inside the stone wall of the building. In the entrance trench (kicheh) of some buildings, dug ledges were used for people to sit. The function of the rooms includes the main living space of human life, livestock storage space, fodder storage and storage of living items and foodstuffs. The kitchen does not exist separately and is part of the main rooms (Figure 23, Table 3).

5.2.5. Stage 5: Construction of Other Elements

In this stage, wooden doors, canopies, stone restrooms and stone walls were constructed, and the building reached the point of completion (Figure 24).

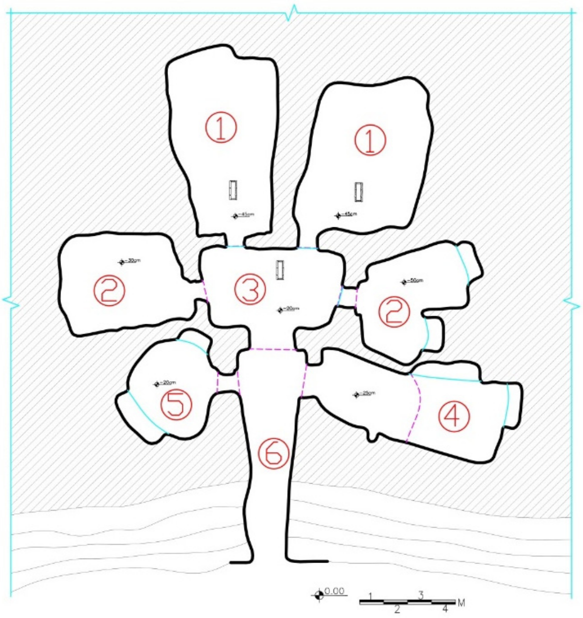

Figure 23. The function of rooms in Maymand's house architecture.

Table 3. The description of the function of rooms in Maymand's house architecture according to Figure 23.

Number	Local Name	Name	Function	Description
1	Otaq Boni	Main room	Living and kitchen together	Room quite dug in bedrock used as main livelihood place
2	Anbar	Side room or store room	Store and bedroom	Room quite dug in bedrock used as subsidiary space
3	Soffeh	patio	Semi-open space	Restricted by 3 rock-cut walls and rocky or wooden roof and 1 side open to air by entrance trench
4	Aqol	cratch	Livestock care place	Dug in rock and located in entrance trench used for livestock
5	Kahdoon	Hay loft	Fodder warehouse	Dug in rock and located in entrance trench used for storage
6	Kicheh	Entrance trench	corridor	Entrance and connector between outside and inside and introducing a residential unit

Figure 24. Hippophae wood and wormwood shrubs form the canopy of a house in Meymand village.

In Meymand, the only opening in the building through which light and ventilation of the rooms are provided are their wooden entrance doors, the height of which has been shaved to the minimum required to reduce the surface heat exchanges. An evaluation of about 50 buildings in this study showed that the average height of the doors is 130 cm and their width is about 82 cm. As a result, the light penetration into the rooms is very low. There are no windows in any of Meymand's residential houses.

5.3. Excavation Design Measures in Meymand Buildings

5.3.1. Arrangement of Buildings in Different Levels

One of the main principles observed by the excavators was to avoid arranging two buildings on each other in two different levels (Figure 25). They usually tried to excavate the buildings in places where there was no house immediately above or below the excavation site. They took this measure to increase the thickness of the layers between the buildings that were excavated near each other in two different height levels. Therefore, the rock layer became thicker, and the strength of the buildings increased. This technique minimized the overlap of plans in buildings excavated in two levels.

Figure 25. Special arrangement of buildings (excavators avoided laying two buildings on each other in two different levels).

5.3.2. Varying Height of the Longitudinal Sections

Comparison and contrast of the longitudinal sections of the buildings reveals a fundamental similarity in alignment. This principle was carefully observed in large units. In other words, the bottom level of the units was by average 40 to 60 cm lower than that of the main entrance. This has some advantages: first, it facilitates ventilation, and thus, the smoke of cooking fire is better removed. Second, the thickness of the rock layer of the ceiling is increased thanks to this creative measure. Third, thermal exchange is reduced in the cold season of the year because the room ceilings are lower than those of the semi-open entrance trench (Figure 26).

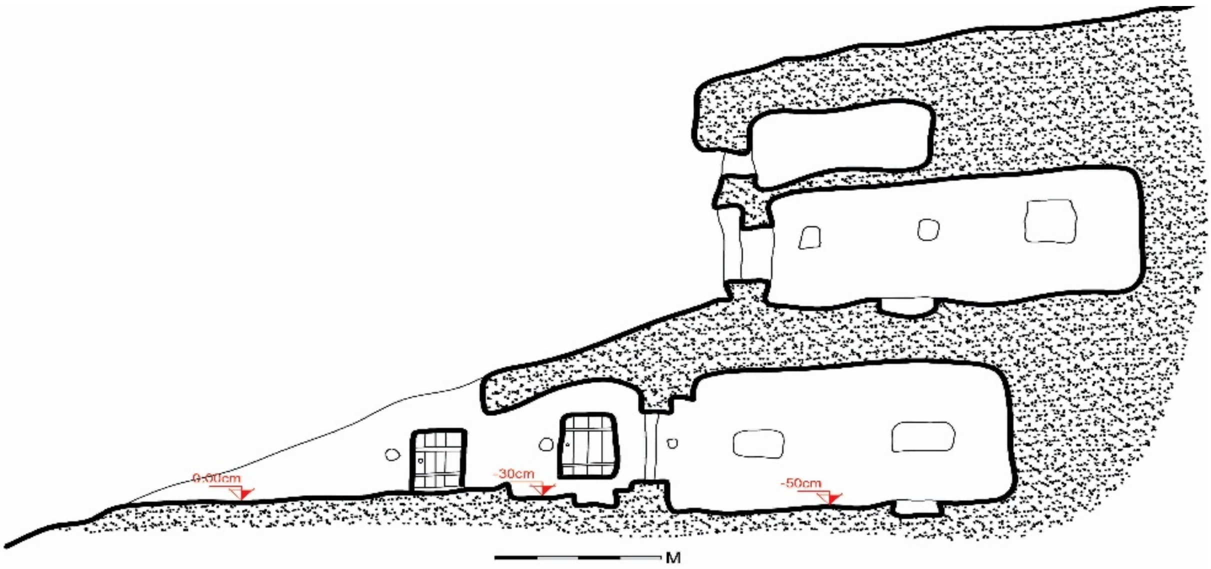

Figure 26. Bottom level of the rooms are lower than that of the entrance trench.

5.3.3. Increasing the Area by Increasing the Depth

In parts of the village, there are natural upright walls suitable for excavation due to geomorphological conditions. Compared to the buildings excavated in steep surfaces, buildings excavated in natural upright walls are harder to be expanded radially. Therefore, the excavators neither expanded the buildings radially nor increased the span of the surfaces. Instead, they excavated as deeply as possible to increase the number of the rooms, and consequently, the general length of the building (Figure 27). Comparison between the buildings excavated in the highest level and those excavated in the lower levels reveals that the total length of the rooms in the highest level is by average 30 percent more than those excavated in the lower levels. The former have one or two rooms while the latter have by average four rooms (Figure 28). The excavators generally increased the depth of these buildings because they did not have the semi-open space. The absence of the semi-open space led to increased thermal exchange in the cold seasons of the year. The depth was increased in order to decrease the thermal exchange.

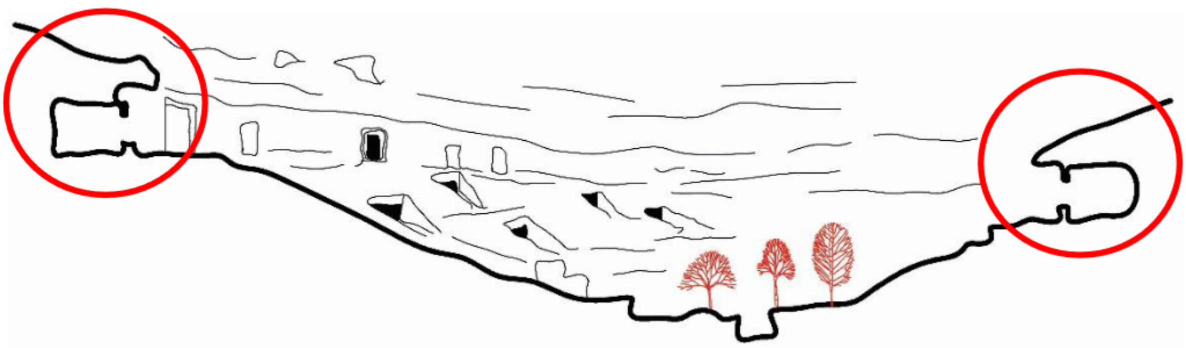

Figure 27. There are upright walls in the highest level of the village in which deep spaces are excavated.

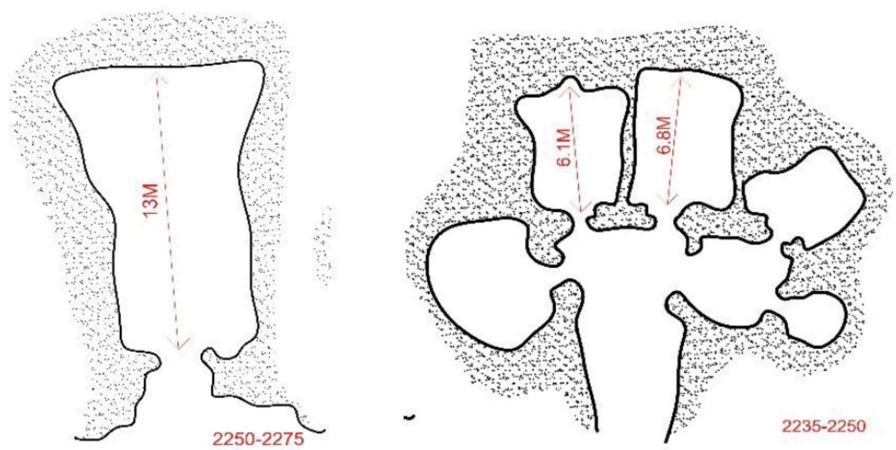

Figure 28. The difference in plan between the houses in the highest level (2250–2275) and those in the lower levels (2235–2250) from the sea level and increasing the area of rooms by increasing their depth.

5.3.4. Special Design of the Entrance Trench (Kicheh)

Comparison of the general shape of the entrance trenches in houses excavated in the steep surface of the hills reveals that the width of the entrance is less than that of the space in which the semi-open space and rooms are located. This creates a triangular shape in the plan of this part (Figure 29). Therefore, the volume of excavation is reduced, and more light is allowed into the building without increasing its contact with open air. Thermal exchange is also reduced thanks to the triangular shape of the entrance trench (Figures 30–34).

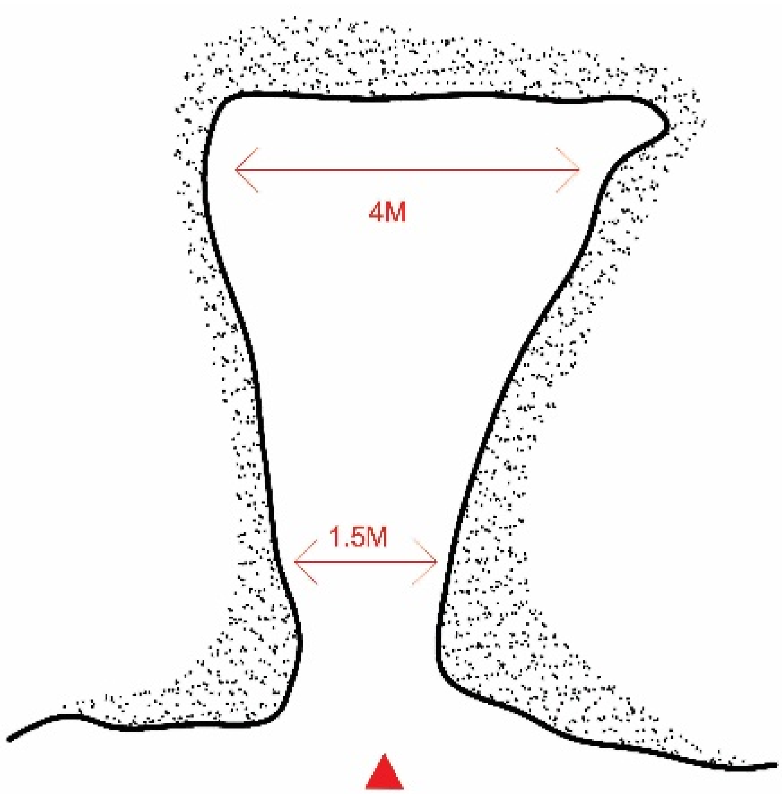

Figure 29. Triangular shape of the rock-cut architecture of Meymand.

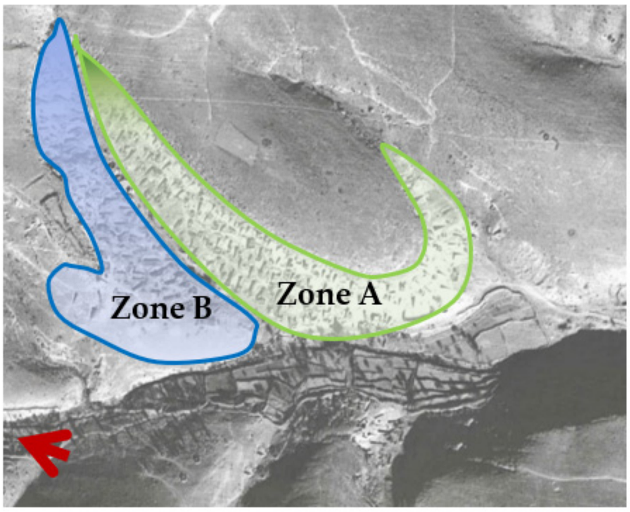

Figure 30. Zone A and Zone B located on the aerial image of Meymand village.

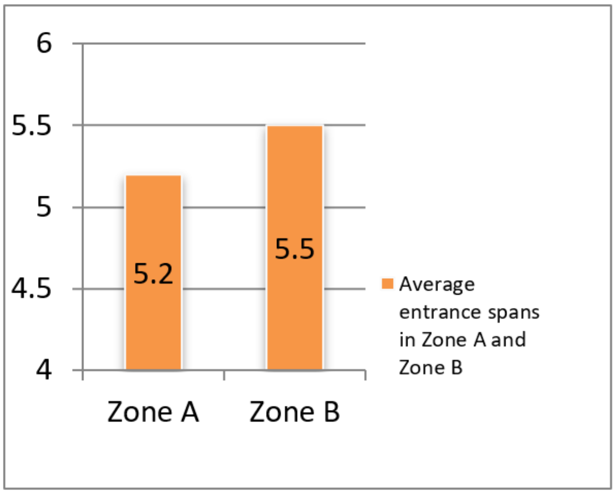

Figure 31. Average entrance spans of rooms in Zone A and Zone B.

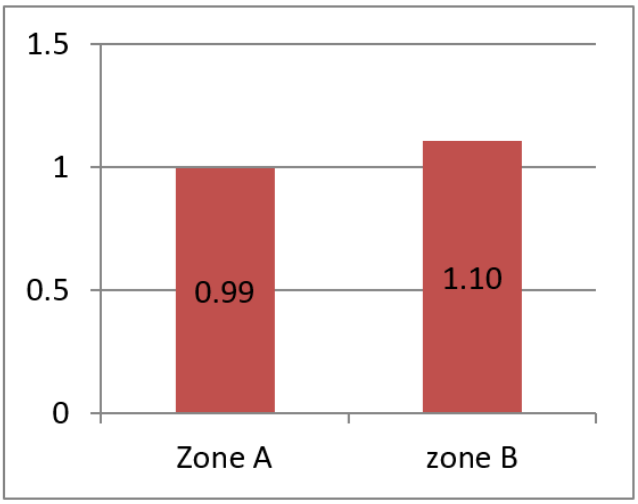

Figure 32. Average areas of front doors in Zone A and Zone B.

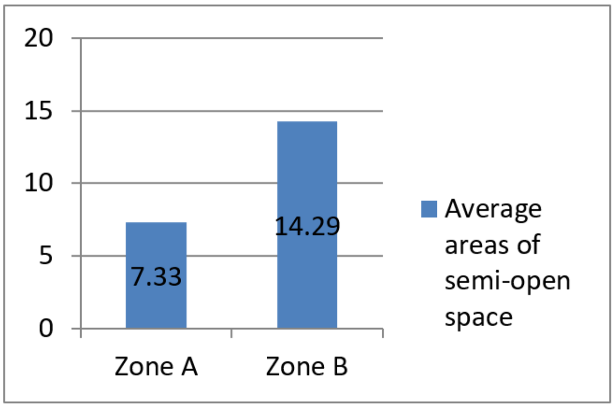

Figure 33. Average areas of semi-open spaces in Zone A and Zone B.

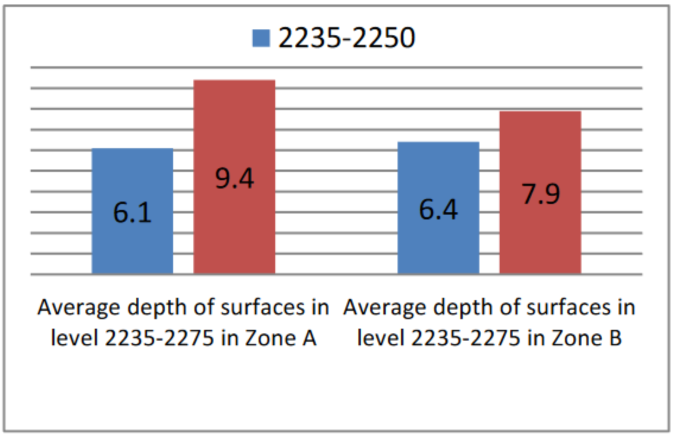

Figure 34. Average depth of the rooms in different height levels in Zone A and Zone B.

6. Conclusions

Rock-cut architecture is a special type of vernacular architecture. It uses a rock context that is excavated to create the architectural space. In fact, it is a productive type of architecture. The rock excavation is almost an irreversible act, something that the following generations can hardly restore.

In general, it follows distinct design patterns and employs certain techniques. Rock-cut architecture is dependent on the tools available to the architects, geomorphological conditions of the excavation area and the type and material of the settlement context. Most of the Iranian rock-cut residential buildings have similar design standards and spatial measures due to structural, climate and measure similarities. The standards were mainly set to guarantee climate and life comfort. Although the rock-cut buildings are dispersed throughout Iran, three main techniques were employed to excavate them. Most of them were excavated using two or three of the said techniques.

The main point that can be concluded from the study of the rock-cut architecture of Meymand is that the most important design approach was achieving a space with minimal dimensions in accordance with the basic needs of daily life and avoiding harsh environmental conditions. The fine excavation and precise digging of surfaces in the buildings of this site have not received much attention and were only the creation of shelter without any decorations with minimal energy consumption and spending time. Therefore, the excavation of surfaces is limited to removing large protrusions and leveling them. This feature can be seen in all types of buildings in this complex.

Application of the fine technique and the size of the particles constituting the settlement context are the two factors determining the quality of excavation. Iran provides the proper background for excavation and construction of rock-cut buildings in the future. Low costs of construction, reduced energy consumption and building materials, and climate compatibility are the advantages of rock-cut architecture that can serve as a model for contemporary architecture. Revival of rock-cut architecture and excavation of rock-cut buildings requires a deeper insight into the body and technology of this unknown architecture.

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References

1. Fabbri, K.; Pretelli, M. Heritage buildings and historic microclimate without HVAC technology: Malatestiana Library in Cesena, Italy, UNESCO Memory of the World. *Energy Build.* **2014**, *76*, 15–31. [CrossRef]
2. Zhu, J.; Tong, L. Experimental study on the thermal performance of underground cave dwellings with coupled Yaokang. Renew. *Energy* **2017**, *108*, 156–168. [CrossRef]
3. Martínez-Molina, A.; Tort-Ausina, I.; Cho, S.; Vivancos, J.L. Energy efficiency and thermal comfort in historic buildings: A review. *Renew. Sustain. Energy Rev.* **2016**, *61*, 70–85. [CrossRef]
4. Del, M.S.T.T.; Sadooghi, Z.; Tabrizi, S.K. Recognition of defensive factors in the architectural heritage of Iran's organic ancient shelters. *Front. Archit. Res.* **2022**, in press. [CrossRef]
5. Zhao, X.; Nie, P.; Zhu, J.; Tong, L.; Liu, Y. Evaluation of thermal environments for cliff-side cave dwellings in cold region of China. Renew. *Energy* **2020**, *158*, 154–166. [CrossRef]
6. Cozzolino, M.; Caliò, L.M.; Gentile, V.; Mauriello, P.; Di Meo, A. The Discovery of the Theater of Akragas (Valley of Temples, Agrigento, Italy): An Archaeological Confirmation of the Supposed Buried Structures from a Geophysical Survey. *Geosciences* **2020**, *10*, 161. [CrossRef]
7. Goudini, J. Defining Troglodytic Architecture and its Design Methods Based on Iranian Examples. *Tunn. Undergr. Space Eng.* **2020**, *9*, 285–304. [CrossRef]
8. Barbero-Barrera, M.M.; Gil-Crespo, I.J.; Maldonado-Ramos, L. Historical development and environment adaptation of the traditional cave-dwellings in Tajuña's valley, Madrid, Spain. *Build. Environ.* **2014**, *82*, 536–545. [CrossRef]
9. He, Y.; Chu, Y.; Song, Y.; Liu, M.; Shi, S.; Chen, X. Analysis of design strategy of energy efficient buildings based on databases by using data mining and statistical metrics approach. *Energy Build.* **2022**, *258*, 111811. [CrossRef]
10. Rostam, N.G.; Hojjati, A.; Mahdavinejad, M.; Mirlohi, M. Natural energy efficient materials for rock cut architecture in case of Kandovan, Iran. *Adv. Mater. Res.* **2014**, *935*, 202–206. [CrossRef]
11. Alkaff, S.A.; Sim, S.C.; Efzan, M.N.E. A review of underground building towards thermal energy efficiency and sustainable development. *Renew. Sustain. Energy Rev.* **2016**, *60*, 692–713. [CrossRef]
12. Hanachi, P.; Mehran, M. Politics, paterns and rehabilitation patterns in Meymand village fabric. *J. Fine Art* **2007**, *30*, 53–62.
13. Mehran, M. *Statement of Restoration and Design in Meymand's Historic Fabric*; Tehran University: Tehran, Iran, 2007.
14. Ozturk, F. Negotiating between the Independent and Groups of Courtyard Complexes in Cappadocia. In Proceedings of the 30th Annual Conference of the Society of Architectural Historians, Australia and New Zealand, Gold Coast, QLD, Australia, 2–5 July 2013.
15. Zhu, J.; Tong, L.; Li, R.; Yang, J.; Li, H. Annual thermal performance analysis of underground cave dwellings based on climate responsive design. *Renew. Energy* **2020**, *145*, 1633–1646. [CrossRef]
16. Zhu, J.; Liu, Y.; Li, R.; Chen, B.; Chen, Y.; Lu, J. Thermal Storage Performance of Underground Cave Dwellings under Kang Intermittent Heating: A Case Study of Northern China. *Processes* **2022**, *10*, 595. [CrossRef]
17. Wootton, W.; Russell, B.; Rockwell, P. Stoneworking Techniques and Processes. The Art of Making in Antiquity. Stoneworking in the Roman World. 2013, pp. 1–35. Available online: http://www.artofmaking.ac.uk/content/essays/3-stoneworking-techniques-and-processes-w-wootton-b-russell-p-rockwell/ (accessed on 7 January 2022).
18. Lamesa, A. Methods for Rock-hewn Worksite Analysis: The Church of Göreme n° 4b (Cappadocia): A Case Study. *Anatolia Antiq.* **2020**, *XXVIII*, 23–45. [CrossRef]

19. Mangeli, M. The Impact Modality of Climate and Context in Rock-Cut Architecture Genesis in Meymand Village Shahre Babak; (With Conservation Approach). Ph.D. Thesis, Isfahan Art University, Isfahan, Iran, 2018.
20. Ashrafi, M. A Study in Troglodytic Architecture Typology. *Archit. Urban. Lett.* **2012**, 25–47.
21. Kiani, M.; Hashemi, M.; Ajalloeian, R.; Benavente, D. Investigating the geological and geomechanical characteristics governing the weathering behavior of Meymand tuff. *Environ. Earth Sci.* **2022**, *81*, 45. [CrossRef]
22. Mangeli, M.; Abouei, R.; Saradj, F.M. A New Look at Unique Characteristics of Iran's Rock-Cut Architecture Settlements (Case Study: The World Heritage Site of Meymand Village, Shahre Babak). *J. Stud. Hum. Settlements Plan.* **2017**, *12*, 785–802.
23. Hoseini, Z. *Shahr-e Babak the Land of Turquoise*; Kermanology Center: Kerman, Iran, 2002.
24. Heritage, O.C. *Documenting Reports of Meymand*; Cultural Heritage Organization of Iran: Kerman, Iran, 2006.
25. Asadabadi, R. *Study and Recognition of Meymand Area*; Cultural Heritage Organization: Kerman, Iran, 1996.
26. Karimi, F. New look at the Iran's Rock art based on field and ancient study. *Iranology Q.* **2007**, *3*, 50–62.
27. Ashrafi, M. Architectural Sustainability in the Cultural Landscape of Maymand. *J. Iran. Archit. Stud.* **2022**, *9*, 97–122. [CrossRef]
28. Mangeli, M.; Sattaripour, A. A report on potentials of restoration and revitalization of Meymand historical village. In Proceedings of the 4th International Conference of Sustainable Development and Planning, Limassol, Cyprus, 13–15 May 2009. [CrossRef]
29. Bessac, J.C. Étude technique et interprettations du monument rupestre de Qadamgah (Fars). *Iran. Antiq.* **2007**, *42*, 185–206. [CrossRef]