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ACOUSTIC TRANSFORMATION OF ROCK-CUT CAVES INTO PERFORMANCE SPACES

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ABSTRACT*

Cappadocia Region in Turkey is a center of attention as a tourism destination with its rock-cut caves, some of which are being used as performance spaces for concerts, festivals and local entertainment activities. However, these spaces are not fully investigated for their acoustic performance before being transformed into performance venues. This paper reports on the findings of an initial survey which presents a systematic mapping of the rock-cut caves used as performance spaces to locate, explore and document a sample of structures scattered in this historic district. A typological classification based on volume, size, type of tuff rock material and historical original use has been proposed and an acoustic analysis of some selected rock-cut caves has been carried out. The acoustic analysis included reverberation time calculations and simulations based on apparent volume, and tuff stone absorption characteristics, which were studied by other researchers in the area.

Keywords: *rock-cut caves, amorphous space acoustics, acoustic classification, Cappadocia*

1. INTRODUCTION

Cappadocia holds significance as a cultural and historical landmark and is known for its fairy chimney formations and rock-cut spaces. In 1985, a part of the Cappadocia region was included in the UNESCO World Heritage List based on these unique natural rock formations [1,2]. These formations serve as essential cultural assets that offer insights into the social, economic, and religious structures of the time when they were constructed. [3].

Cappadocia's rock-cut spaces have become increasingly popular tourist destinations, and gained attention for their unique architectural and acoustic properties, which have made them ideal for various musical performances. Hotels and private companies often use these spaces to host events, music festivals, and wedding ceremonies. However, geometry of these rooms is mostly amorphous and their acoustic performance is of a challenge to predict. Also, the surface and material properties of tuff stone which is the main surface finish in these spaces is significantly different than the conventional stone material in terms of acoustics. There is limited research whether these rock-cut spaces comply with acoustic performance criteria for different types of music. Therefore, a PHD study by the first author of this paper was started to focus on analysis of rock-cut caves in Cappadocia in terms of their room acoustics performance to explore their existing acoustic performance, their compliance with acoustic criteria and propose acoustic measures for mitigation.

The main objective of this particular paper is to report on an initial survey of rock-cut spaces which are currently used for musical performances and moreover, figure out rock-cut spaces that have potential to be used as performance venues in the Cappadocia. It is aimed to define criteria for typological mapping and to examine acoustical performance of selected caves for music. To achieve this, various rock-cut spaces in different regions of Cappadocia are investigated through their physical characteristics, internal finishes and shape. Acoustic performance of investigated caves was further predicted by simulations. In addition, informal interviews were made to assess the acoustic quality.

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2. AN INITIAL SURVEY OF ARCHITECTURAL AND ACOUSTIC FEATURES

This study constitutes the preliminary research phase of the study involves comprehending the architectural features of the rock-cut spaces and discerning their potential for use as a performance venue. Taking into account the wide range of rock-cut caves in Cappadocia, different caves of various functions and volumetric sizes were selected and examined on-site, with dimensions measured and impressions of reverberation noted. In consideration of the varying rock types found in different districts of Cappadocia, examples were selected from different districts. In this context, a total of 35 different rock-cut spaces that once originally used for various functions were investigated on-site (Table 1). A number of procedures were systematically applied to identify the investigated rooms to be acoustically examined. The procedures consist of the following steps: measuring the approximate volumes of the rooms, identifying their original and current functions and getting impressions of reverberation as a quantifiable acoustic attribute.

Different categories were established for each analysis criterion. Three different categories are proposed based on the volume of spaces. These categories are denoted as V1 (15-249 m^3), V2 (250-799 m^3), and V3 (800-2000 m^3), respectively. Six main categories stand out based on original function of these rock-cut spaces: underground city living areas, horse stables, churches, museums, warehouses, and production workshops.

To gain preliminary insight into the acoustic characteristics of the spaces, a quantifiable acoustic study was not carried out at this stage of the project. Instead, an empirical method was used, whereby impressions of reverberation were gathered using hand clapping and critical listening. The classification scale proposed for assessment of reverberation (RTmid) for music was proposed is as follows: dead (RT<0.3 s), dead-to-mid (0.3<RT<0.8 s), mid (0.8<RT<1.2 s), mid-to-live (1.2<RT<2 s), and live (RT>2 s).

Alongside the physical evaluations conducted in the examined spaces, some informal interviews were carried out with the venue managers and users of spaces to understand the functioning of these caves as performance spaces. Moreover, based on the initial assessment of various spaces two rock-cut spaces were chosen and modelled in a room acoustics software. The main reason to choose modelling over measurements at this stage is due to the prolonged time scales to obtain permission from the Cultural Heritage Preservation Board and the Ministry of Culture and Tourism institutions. The study here has its limitations; however, later stages of the project will seek required permissions to do acoustic measurements.

3. PREDICTION OF ACOUSTIC PERFORMANCE

3.1 Typological Categorization

In the current study, it was decided to select certain spaces among the 35 examined locations as case study rooms and to carry out RT simulations to assess acoustic performance. The spaces examined in this initial survey are denoted as Room 1, Room 2 and so on as it is indicated in Table 1. Two rock-cut caves in the V2 and V3 categories are selected for the simulations. Because it was assumed that spaces in the V2 and V3 categories, due to their larger audience capacity potential, have more possibility to be used as performance spaces.

According to this examination, Rooms 26 and 27 of "Performance Hall in Uchisar", Room 32 of "Underground City in Acigol", Room 28 of "Church in Acigol", Room 22 of "Church in Goreme", Room 14 of "Church in Urgup", Rooms 19, 20 and 21 of "Museum in Avanos" were found to be prominent in volumetric sizes, with volumes between 276 and 2000 m^3. The rooms 1-12 in "Underground City in Nevşehir Centrum and Room 13 "Cave Café in Avanos" are predominantly small volumes (16-160 m^3). The RT impressions of the rooms are typically directly proportional to their volumes; however, it is noteworthy that certain rooms (Rooms 2, 8, 11, 13), despite belonging to the V1 volumetric category, have been noted to exhibit "mid-to-live" RT impressions. Additionally, "live" RT impressions have been obtained in all of the rooms belonging to the V2 and V3 volumetric categories.

According to the informal interviews conducted with the venue managers, it is understood that some rock-cut venues are already being used for performances. For instance, two of the art galleries in the museum complex in Avanos (Rooms 19 and 20) are occasionally rented to be used for music performances. In addition, the performance hall in Uchisar (Rooms 26 and 27) regularly hosts classical music concerts. Therefore, the potential of these two rock-cut venues to be used as concert halls was found to be significant.

Furthermore, Room 20 and Room 26 were identified as case studies for this study, according to the reverberation impression values that are in the "live" category in both spaces and all the aforementioned selection criteria.

Table 1. Complexes examined throughout Cappadocia, with their number of spaces, districts they are located in, volumetric ranges, original functions, current functions, and impressions of reverberation time (RT) at mid-frequencies (500-1000 Hz).

Name of the complex	Range of Room Numbers	Range of Approximate Volume	Original Functions	Current Function	Range of RT Impression
Underground City in Nevsehir Centrum	1-12	V1 m³	Atelier, horse stable, chapel, winery storage	Natural history museum	dead / mid-to-live
Cave café in Avanos	13	V1 m³	Horse stable	Cafe-Bar	mid-to-live
Church in Urgup	14-18	V1-V2 m³	Naos, Entrance Hall, Priests' quarters	Non-functional	dead / live
Church in Goreme	22-25	V1-V2 m³	Church, Hermitage, Lower chambers	Non-functional	mid-to-live / live
Museum complex in Avanos	19-21	V3 m³	Museum	Museum halls, exhibition hall	live
Church in Acigol	28-29	V1-V2 m³	Church	Non-functional	mid-to-live / live
Underground City in Acigol	30-35	V1-V2 m³	Kitchen, living room, storage, stable, graves	Natural history museum	mid-to-live / live
Performance Hall in Uchisar	26-27	V2 m³	Oil mill	Performance spaces	live

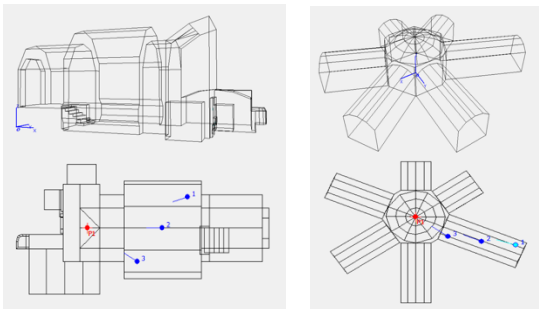
3.2 Acoustic Simulations

The 3D models of the two sample rooms were created using the SketchUp program, and the acoustic calculations were performed using Odeon 16 Acoustic software. When assigning surface materials used in these spaces, some of the calculated acoustic absorption coefficients in relevant literature was taken into account [4]. Thus, the options that reflect the acoustic properties of the changing types of stones specific to the region were preferred. This absorption coefficient data is given in Table 2. Given its proximity to the Goreme district (approximately 5 km), the acoustic performance of the Room 26, located in Uchisar, was estimated using absorption values of Goreme tuff stone, which is the closest tuff stone type documented in the literature. Therefore, it is assumed that the sound absorption capacity of this tuff stone is compatible with the Uchisar stone. For Room 20, Avanos tuff stone absorption coefficient values are assigned as the material since the museum building is located in Avanos.

In both rooms, considering the performance layout, an omni-directional sound source is placed at the most probable source location within the space, and 3 receivers are placed in the audience area. The height of the source from the floor is set at 1.5 meters and the height of the receivers from the floor is set at 1.2 meters. The geometries of the rooms, source and receiver positions are indicated in Figure 1.

Table 2. Sound absorption coefficients of Goreme (Room 26) and Avanos (Room 20) tuff stones [4].

District	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Goreme	0.06	0.29	0.39	0.40	0.39	0.49
Avanos	0.01	0.05	0.07	0.13	0.17	0.24



a b

Figure 1. Geometry and source-receiver positions in (a) Room 26 and (b) Room 20.

The RT of the rooms is evaluated based on the reference values in literature for classical music performance as

indicated in Table 3 [5]. The reference values in this context are explained considering the occupied state of the spaces. However, in the current study, the RT values are calculated for the unoccupied state. Consequently, when the spaces are occupied, the RT values will decrease proportionally to the number of people.

Table 3. Recommended mid-frequency (500-1000 Hz) averaged reverberation times in seconds [5].

Function	Room Volume	
	V2 (250-799 m^3)	V3 (800-2000 m^3)
Music	1.10-1.40 s	1.40-1.60 s

The RT values obtained for the 125-4000 Hz spectrum in Room 26 and Room 20 spaces are presented in Table 4.

Table 4. Frequency distribution of calculated averaged reverberation time (RT) in Room 26 and Room 20.

Room	Volume	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Room 26	276 m^3	2.88s	1.24s	0.98s	0.94s	1.09s	0.61s
Room 20	1900 m^3	11.62s	4.91s	3.10s	1.90s	1.27s	0.85s

According to the obtained RT values, the Room 26 has a higher reverberation time in 125 Hz which decrease towards the mid frequencies (500-1000 Hz). The RT values in 500-1000 Hz bandwidth is not compatible with the RT impression value previously noted, which is "live (RT>2 s)" but compatible with "mid (0.8<RT<1.2 s)" RT impression value. The RT value decrease to 0.61 s towards higher octave bands. Room 20 has fluctuating results in different frequencies in a range between 0.85 and 11.62 seconds. There is an excessive reverberation value at 125 Hz which is 11.62 s and the value drastically drops to 4.91 s at 250 Hz. The RT values decrease to 3.10 s and 1.90 s towards 500 Hz and 1000 Hz respectively. The mid frequency averaged value of RT is 2.50 s and is compatible with the RT impression value which is "live (RT>2 s)".

Based on the mid-frequency averaged reference values provided in Table 3, the mid frequency averaged RT value of Room 26 (0,96 s) falls below the reference limits. On the other hand, Room 20 is also not compatible with the reference values since, the 500-1000 Hz averaged RT of the room (2,5 s) is above the recommended reverberation time range indicated for music function. The increase in reverberation time (RT) in "Room 20," which has a larger volume, was observed to be greater compared to "Room 26," which has a smaller volume, due to the differences in sound absorption properties of the tuff stones.

4. CONCLUSION

Regarding the correlation of space volume and the acoustic performance, it is found that there is a proportional relation between the volume and the reverberation time. However, specification of type of the tuff has also a significant effect. Absorption coefficients of tuff for the selected caves will be measured in the next phases of the study. It has been observed that the V2 volume range does not fulfill the music function according to the recommended values. In addition, the RT values obtained in V3 volume range is found significantly higher than the recommended limits for music.

This study is an initial investigation conducted to assess the acoustic performances of potential adaptive reuses of rock-cut spaces as performance venues. To understand the acoustic performances in these spaces, further examples of spaces need to be studied, and these spaces should be systematically evaluated through acoustic measurements. Building upon this motivation, the continuation of the study aims to assess a wider range of acoustic parameters through acoustic measurements and simulations.

5. REFERENCES

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