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Research Article

Sound Atmospheres of Ben Youssef Madrasa in Marrakech (Morocco)

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Abstract

This study investigates architectural acoustics in heritage building that is the *Ben Youssef Madrasa* in Marrakech (Morocco). It aims to characterize the sound atmospheres in this place of learning and community life of *el-Tolba* (plural of *el-Tãleb*: student). For this purpose, the study is divided into three parts. The first is the literature review in which we present the definitions of the key concepts, some research on the sound atmospheres in heritage buildings, the different materials and methods used. The objective of this part is to have an overview of the topic of atmospheres. The second consists of architectural conformation reading which is devoted to the identification of the architectural and spatial devices participating in the creation of these sound atmospheres. Special attention was given to the prayer hall as a place of teaching and prayer. The third part focuses on the quantitative characterization of the acoustic environment through computer simulation. The prayer hall and the central courtyard were chosen for the simulation which was done through the Ecotect V5.50. The simulation analysis is limited to three criteria: the uniformity of the sound in the prayer hall, the sound behavior and the degree of the presence of reverberation. The results show that the builders of the *madrasa* paid attention to the architectural acoustics. Several strategies and devices were adopted to have sound atmospheres appropriate to this building.

Keywords: Sound Atmospheres, Heritage Buildings, Architectural Conformation Reading, Computer Simulation, Ben Youssef Madrasa.

Marakeş'teki (Fas) Ben Youssef Medresesi'nin Ses Atmosferleri

Öz

Bu çalışma, Marakeş'te (Fas) miras yapı olan Ben Youssef medresesindeki mimari akustiği araştırmaktadır. *El-Tolba*'nın (*el-Tãleb*'in çoğulu: öğrenci) öğrenim ve topluluk yaşam mekanındaki ses atmosferlerini karakterize etmeyi amaçlamaktadır. Bu amaçla çalışma üç bölüme ayrılmıştır. Bunlardan ilki, anahtar kavramların tanımlarını, miras binalarındaki ses atmosferleri üzerine bazı araştırmaları ve kullanılan farklı yaklaşım ve yöntemleri (nitel ve nicel karakterizasyon) sunulduğu bir literatür taramasıdır. Bu bölümün amacı, akustik mimari atmosferlere genel bir bakış sağlamaktır. İkinci bölüm, bu akustik atmosferlerin yaratılmasında yer alan mimari ve mekansal unsurların belirlenmesine ayrılmıştır. Bir öğretim ve dua mekânı olarak ibadethaneye özel bir önem verilmiştir. Üçüncü bölüm, bilgisayar simülasyonu yoluyla akustik ortamın niceliksel karakterizasyonuna odaklanmaktadır. Ecotect V5.50 ile yapılan simülasyon için ibadethane ve orta avlu seçilmiştir. Simülasyon analizi üç kriterle sınırlıdır: ibadethanedeki sesin tekdüzeliği, ses davranışı ve yankılanma varlığının derecesi. Sonuçlar, medreseyi inşa edenlerin mimari akustiğe önem verdiklerini göstermektedir.

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Bu binaya özgü akustik bir atmosfer elde etmek için farklı stratejiler ve mimari ve mekansal unsurlar benimsenmiştir.

Anahtar Kelimeler: Ses Atmosferleri, Miras Binalar, Mimari Konformasyon Okuma, Bilgisayar Simülasyonu, Ben Youssef Medresesi.

1. Introduction

Unlike other arts such as painting and music, architecture involves all the senses (Zaredar, 2019, p.1). The architectural space we occupy is not an object for the gaze; we experience it through other sensory modalities (Elsen and Heylighen, 2014, p. 241; Palassma, 2018, p. 13). The sensory design of buildings becomes a priority to have spaces that ensure people's well-being and performance (Lehman, 2011, p.46). Designing spaces that emit sensations must be the main concern (Beressani and Sprecher, 2019, p.2). Several researchers have discussed the relationship between architecture and the other senses, namely sound, touch, smell, etc. Authors of different specialties have highlighted the multisensoriality of the architectural space (Spence, 2020, p.2). Thus, awareness initiatives for the designers have been announced by Hall who has valued the sensory qualities of space (Hall, 1966, p.83). In his book "The Look of Architecture", Rybczynski focuses on the palpable experience of the architectural space, which is defined by the atmospheres that reign there: light, sound, volume, materials, textures, etc. (Rybczynski, 2001, p.89). For his part, Palasmaa expresses his intentions regarding the sensory perception of architectural space. He defines architecture as the art of reconciliation of man with the world through the mediation of the senses (Palasmaa, 2012, p.72). For him man with his body and his senses is the center of the world, a place of reference, a memory and imagination.

Throughout history of architecture, many renowned architects, such as Le Corbusier, Frank Lloyd Wright, Rasmussen, and Norberg-Schulz, have emphasized the importance of atmosphere and sensory qualities in architecture (Martin et al, 2020, p.63). The architect Peter Zumthor is also passionate about the architecture of the senses. He is interested in the relationship between man, his space and the prevailing atmospheres. His architecture is materialized by the conscious use of architectural elements, such as light, materials, sound, plants, minerals, etc. It is based on his reflections on memories and the phenomenology of place. For him, architectural quality remains in the experience (Zumthor, 2006, p.16). In the last decades, several researchers are interested in the question of atmospheres in heritage buildings. Each heritage building has a spatial specificity that is materialized by several visible and invisible factors that define its character. The notion of character simultaneously links tangible and intangible elements. The tangible elements are: the proportions, shapes, textures, building materials, etc., while the intangible elements are the sensitive qualities of the architectural space, such as sound, light, smell, temperature, color, etc. Zardini defines the character as the specificity of the place that refers not only to visual dimensions but also to other sensory dimensions that could be experienced in a place (Zardini, 2005 p.23). For his part, Norberg-Schulz sees that the place is composed of a plurality of concrete elements having material substances (forms, textures, colors, etc.) and which, in their turn, define its character of atmospheres even its essence (Norberg-Schulz, 1980, p.14-15). Therefore, the sensory dimensions of the heritage building are essential to define its character. Two interesting books are devoted to the soundscape of historical cities: "The Voices of Marrakech" (Canetti, 1982) and "City of noise: Sound and Nineteenth-Century Paris" (Boutin, 2015). In the first, the author described the soundscape of the *medina* of Marrakech. He records noises, voices, gestures etc. He

transmits the sound identity of this historical city. In the second book, Boutin proposes several research techniques for studying the soundscape in historical cities.

Therefore, the present study focuses on the original sound atmospheres of one of the Islamic heritage buildings, namely the *Ben Youssef Madrasa*. It aims to characterize qualitatively and quantitatively the acoustic environment of this traditional teaching place in Marrakech (Morocco). We try to highlight another object of the architectural heritage which is the sound atmospheres. It focuses on another aspect of architectural heritage, namely the atmosphere. It differs from other archeological and historical research that only addresses the materials and structural systems of historical buildings.

2. Sound as a Heritage Atmosphere

With the development of the notion of heritage, historical places are not only considered as a material heritage, it includes intangible elements. In order to preserve this tangible and intangible heritage, it is necessary to focus not only on the visual sense but on all other senses (Djimantoro et al, 2020, p.847). Research on the heritage atmosphere is growing considerably. In recent years, this notion has aroused the interest of researchers and practitioners of architectural and urban heritage, cultural landscape heritage etc. It emphasizes another aspect of heritage that has been less discussed previously. Indeed, its objective is to highlight the sensory qualities of heritage buildings and cities at a time when vision is almost totally focused on their visual and structural aspects. Several researchers have illustrated the importance of heritage atmospheres and sensory thinking of Islamic built heritage in the Maghreb (Morocco, Algeria, and Tunisia). In his research on the architectural atmosphere in the railway stations of the 19th century, Ben Hadj Salem sees that the built heritage is a living memory that invokes all the senses and it could be approached by other dimensions; tactile, sound, olfactory, etc. (Ben Hadj Salem, 2009, p.11).

Belakehal considers the architectural and urban atmospheres in the Maghrebian medinas as a forgotten heritage and that it is time to think about the sensory dimension of the historical cities (Belakehal, 2012, p. 509). He states that the operations of safeguarding heritage buildings do not take into consideration their sensory dimensions, which negatively affects their interior atmospheres. He adds that the main concern of these operations is no longer to keep the building alive but to recreate and enhance its authentic atmosphere. For her part, Simonnot argues that sensory features are among the indispensable elements that make up the identity of a place and that we must think about the conservation of this fragile heritage (Simonnot and Siret, 2014, p.131-132). According to her, to interrogate the sensitive configurations of buildings of the past sometimes left on the sidelines is to highlight one of the strengths of architectural history (Simonnot et al, 2016, p.5). In fact, the perceptible qualities of the building are of primary importance, not only in the rehabilitation and restoration actions, hence the need to classify it as cultural heritage. Also, to preserve this heritage, it is necessary to conserve its originality. To do this, knowledge of the evolution of the building and the alterations it has undergone is essential to maintain its original aspect. On the other hand, the transmission of heritage through the transfer of heritage atmospheres into contemporary architecture could be an effective strategy to give places the sensory identity of the past (Ziani and Belakehal, 2018, p.298). In the seventies, the notion of soundscape appeared in the research of Schafer (Axlesson, 2020, p.551). He proposed a new concept which is sound heritage. Schafer emphasized the importance of acoustic space, not only in architectural projects but also in the restoration and rehabilitation of historical buildings. He also stated that each place has a sound identity; a unique sound characterized by

the society that inhabits it (Dal, 2010, p.70). Schafer gives an example of the famous house, Fallingwater designed by the architect F. L. Wright where there is a strong correlation between the house and its acoustic environment (waterfall and nature) that cannot be dissociated. On the other hand, Sahraoui asserts that certain sounds are considered a cultural heritage and create a specific sound identity to historical cities (Sahraoui, 2006, p.4). With the aim of restituting vanished soundscapes; Pardeon uses the concept of soundscape archaeology. She adopted a transdisciplinary approach to study the soundscapes of the city of Paris between the 18th and 19th centuries. To do this, she based on historical writings and virtual reality (Pardeon, 2020, p.4-9). For his part, Chtara has used content analysis of travelers' accounts in order to qualitatively characterize the sound atmospheres of the Souks of the Medina of Tunis in the 19th century (Chtara, 2016, p.886).

Several researches have shown the great place of water in Islamic architecture and the sound atmosphere it generates. More than a vital and refreshing element in Islamic architecture, water goes beyond its utilitarian role (Di Salvo, 2017, p.114). In addition, it generates sensitive effects that affect the user and creates thermal and sound atmospheres in the space. Moreover, light and sound have been used as therapy tools in another characteristic institution of Islamic civilization, the *Bîmãristãn* (Ziani, 2020, p. 25). Like other civilizations, the Islamic civilization has used music therapy as a medical treatment to provide a quiet and calm environment that relieves pain. The means used are not only instrumental music but also natural sounds such as el-Adãn, the sound of water in basins and fountains, the recitation of the Quran, the sounds of birds, etc. (Sidik et al, 2021, p.9).

3. Religious Space Acoustics

Many researchers are focused on the characterization of the acoustic environment using several research techniques (Nur Hundryant, 2020, p. 229; Sari and Zulfian, 2020, p.28; Safi et al, 2020, p.123; Boren, 2021, p.3; Kanev, 2020, p.399). This reflects the important role of sound management in these religious buildings to generate sacred atmospheres. One of the studies that highlight the importance of acoustic quality in religious buildings is that of El-Khateeb. The objective of this study is the identification of the acoustic environment of the mosque and *madrasa* of Sultan Hassan in Cairo (Ali El Khateeb and Ismail Refat, 2007, p.109) In situ measurements and simulation process using Odeon software are the techniques adopted for this research. Another research on the acoustics of Mosques is that of Ridzwan Othman and Rizal Mohamed. It aims to study the influence of the proportion of the prayer hall on speech intelligibility (Ridzwan Othman and Rizal Mohamed, 2012, p.324). Six Mosques around Kuala Lumpur were chosen which have various shapes and proportions. As for the building materials used, they are the same. In situ measurements and computer simulation are the techniques adopted in this research. Another research focuses on archaeoacoustics[3] identity for religious space (Omar et al, 2020, p.4160). Its aim is to obtain documentation for the acoustical identification of the mausoleum at Sultan *Barquq* Complex. It focuses also on the relationship between acoustical environment, form, and texture. In situ measurements and room simulation using Odeon are the techniques used to characterize the acoustic environment of the complex. In addition, several researchers have highlighted the importance of architectural acoustics in Mimar Sinan's architecture. Zühre Sü Gül and

[3] Archaeoacoustics or the archaeology of sound is a field of study which combine archaeology and acoustics. It is interested in sound characteristics of archaeological sites and historical buildings.

Mehmet Çalışkan considered Süleymaniye Mosque as a source of inspiration especially in the field of architectural acoustics. According to them, it is vital to conduct research on the acoustical features of the Mosque in relation to architectural elements and interior materials in order to overcome the lack of knowledge on its authentic acoustical characteristics (Zühre Sü Gül and Mehmet Çalışkan, 2014, p.2). Acoustical simulations are carried out using ODEON Room Acoustics Software to examine the acoustical characteristics of the Mosque.

Churches represent a unique architectural heritage in which hearing is certainly one of the main senses for perception and communication in Christian worship. To study the sound in these heritage buildings, a multidisciplinary approach is required (Beradji et al, 2020, p.14; Sygulska 2020, p.2; Alberdi et al, 2021, p.2-3). Sound is one of the main parts of a place's identity that must be preserved (Garrioch, 2003, p.5). To achieve this, it is essential to study it from a historical, naturalistic, and social point of view (Bartalucci and Luzzi, 2020, p.5). To assess the cultural value of the cultural heritage soundscape, Maffei proposes a triangulation methodology that consists of three analyses: physical analysis, historical analysis, and social analysis (Djimantoro et al, 2020, p.848). After the synthetic reading of studies done in religious space acoustics cited above, several research materials and methods from different disciplines were used (architecture, archaeology, physics, etc.)(Figure 1).

Therefore, the present study is part of the studies that address the sound atmospheres of Islamic architectural heritage in this case the *madrasa*. It focuses on their qualitative and quantitative characterization. Thus, three aspects are combined: theoretical (definitions and literature review), architectural (identification of architectural elements that generate sound atmospheres), and technical (identification of sound characteristics by the use of simulation process).

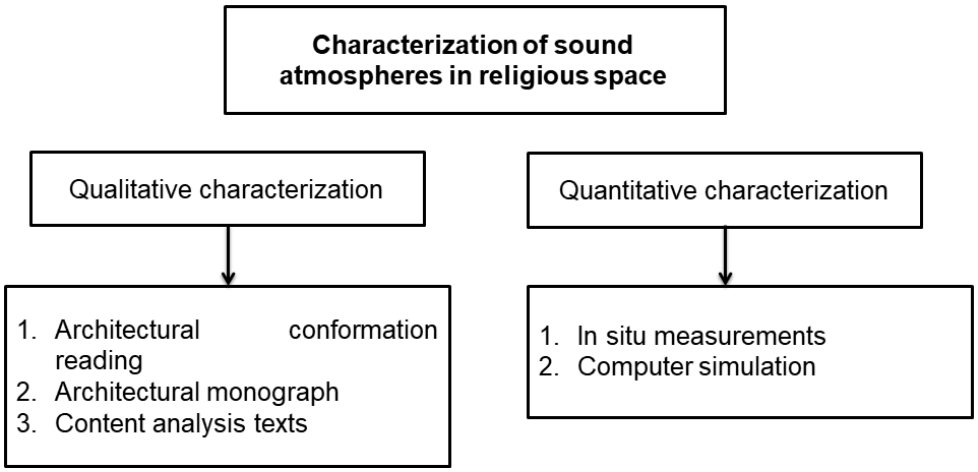

Figure 1. Different materials and methods used in studies on the acoustics of religious spaces

4. Case Study

The Maghreb has a rich and varied architectural heritage which is composed of several buildings with different vocations (religious, commercial, educational, etc.). The inherited historical buildings and monuments, including the *madrasas*, represent in the most eloquent way the forms and the space in Islamic architecture. *Madrasa* represents the place of learning in the Medieval Islamic world. It was financed by the *waqf* or donation of the founder. As a place of formation for future imams*, fuqahā*, muezzins and

theologians, the madrasa represents the Islamic university in the Middle Ages which can be assimilated to the current universities. Given the architectural and architectonic richness of the Islamic *madrasa*, it arouses the interest of art historians and archaeologists such as Golvin and Marçais[4]. This richness is evident through the diversity of plans, forms, and structures. The *madrasa* was differentiated from other Islamic buildings by the function and purpose of the spaces that compose it which are: prayer hall, ablution area, central courtyard, gallery, student rooms, and sometimes the tomb of its founder. All the dynasties (Hafsid, Marinid, Saadian, Ottoman, Husainid) have left *madrasas* in several Maghreb cities. The Maghrebian *madrasas* have an architectural quality rich enough by the various architectural and spatial devices they have, in order to give each place composing the *madrasa* its specific character.

The present study is limited to one *madrasa* which is the Moroccan *madrasa* of *Ben Youssef* in Marrakech. This building, whose architecture is not mentioned in the primary sources of the region's history, attracted the interest of French travelers (historians, politicians, etc.) who visited or lived in Morocco in the 19th century. Since the advent of the Saadians in Morocco, several buildings were built, such as the *Ben Youssef Madrasa*. This historical building was founded by the Marinid Sultan *Abù el-Hassane*, and then it was rebuilt by the Saadian Sultan *Moulay Abdallãh el-Ghãlib Billãh* in 972H/1564 (Triki and Dovifat, 1999, p.11). Three criteria led to choosing this *madrasa*: the feasibility of access, which facilitates the investigation (architectural survey, observation, and photography), the good condition of the building, and its authenticity because it has not undergone many alterations. Also, its architectural richness as well as its spatial organization around a central courtyard and courtyards on the sides makes it the unique and largest *madrasa* in Maghreb. It should be noted that the *Ben Youssef Madrasa* was mentioned many times in the texts of French travelers[5]. Fascinated by its architecture and its atmosphere, the authors transmit their sensory experience in this traditional teaching place. Several visits were carried out in which an architectural survey of some spaces was made, such as the prayer hall and the central court. Moreover, pictures of different spaces of the madrasa were taken. The building has two floors (Figure 2), it is accessed through a door that opens onto a long corridor with a painted ceiling and walls decorated with *zellij*[6] (tilework) and chiseled plaster. This leads to a vestibule opening onto the central courtyard and two other corridors that lead to the rooms of *el-Tolba* surrounding the small courtyards and the ablution area[7]. The lower part of the vestibule walls is decorated with *zellij* panels while the upper part is decorated with chiseled plaster. Next, there is a large, richly decorated central courtyard with a rectangular shape and a large pool reflecting the sky (Figure 3). On the west side is the prayer hall with its three entrances (Figure 4). On the upper floor, there are rooms

[4] In his book published in French in 1995, entitled 'Medieval Medersa: Muslim Architecture', Golvin studies the evolution of madrasa architecture by focusing on the following elements: (history, architectural elements, studies of plans and masses, analysis of decorative forms, relationship with the private house). Marçais discusses madrasa architecture in his book published in French 'Muslim Architecture in the West: Tunisia, Algeria, Morocco, Spain and Sicily'. He describes these educational buildings through architectural surveys.

[5] The *Ben Youssef Madrasa* is one of the most described Maghrebian madrasa by French traveles, we can quote: Henri Terrasse (1937), Marc De Maziéres (1937), André Chevrillon (1919), Gaston Deverdun (1959).

[6] *Zellij* is one of defining features of Maghrebian architecture. It is enameled tiles used to decorete the walls of indoor spaces of buildings (mosque, *madrasa, Bîmãristãn*, etc.)

[7] The medersa is made up of a number of places where students move around to practise their daily rituals, including prayers, teaching and rest. *El-Tâleb*'s daily route consists of: vestibule, prayer hall, room, courtyard, ablution area.

overlooking the central courtyard (Figure 5), and others opening onto small courtyards (Figure 6). This *madrasa* is among the great *madrasas* in the Maghreb.

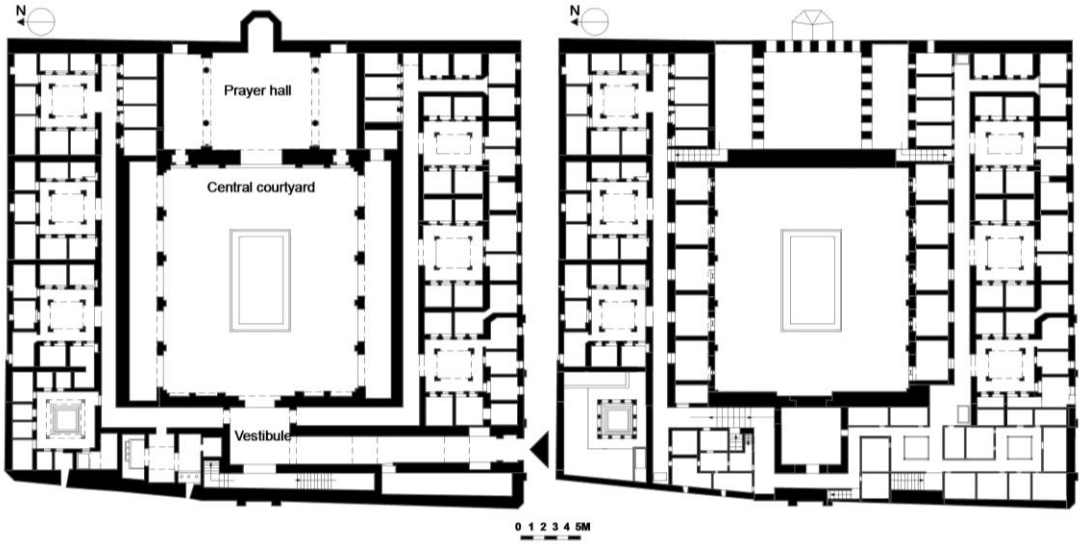

Figure 2. Plan of Ground Floor and First Floor of *Ben Youssef Madrasa* (Triki and Divifat, 1999, p.162-164)

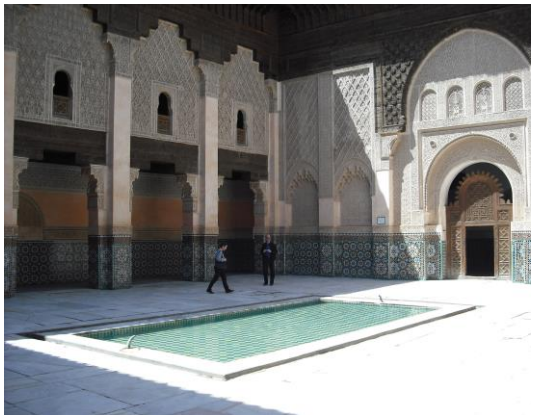

Figure 3. Central Courtyard of *madrasa* (Authors, 2020)

Figure 4. Prayer Hall of *Madrasa* (Authors, 2020)

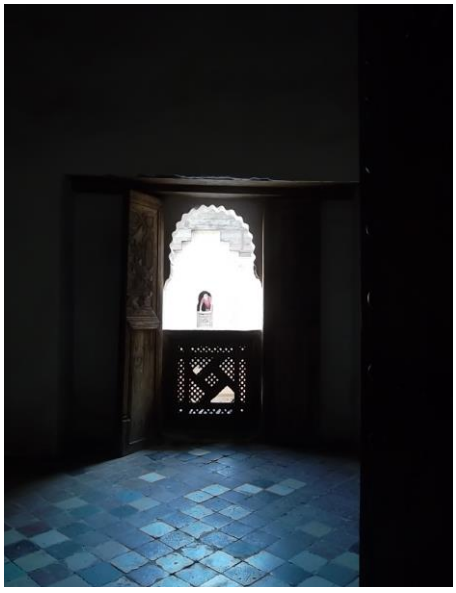

Figure 5. *El-Tãleb*'s Room (Authors, 2020)

Figure 6. Small Courtyard (Authors, 2020)

To study the sound atmospheres in *Ben Youssef madrasa*, we opted for two characterizations: qualitative and quantitative (Figure 7).

5.1. Qualitative Characterization: Architectural Conformation Reading

A partial model for the study of architectural conformation has been developed using architectural acoustics books[8]. The model is limited describing the different devices and the strategies adopted in the architectural acoustics design of the *madrasa* (Figure 8). Particular attention has been focused on the prayer hall as a place of teaching and prayer. In this space, the sound is emitted from one or more sound sources, namely the voice of *el-Sheikh* giving lessons, *el-Tolba* reciting the Qur'an together, and the practice of daily prayers. The sound level gradually fades away as one moves away from the sound source. Also, the sound reaches *el-Tãleb* directly or indirectly by reflection. Indeed, the sound reflects one or more times on the walls, the floor, and the ceiling. The elements that could influence the acoustic environment in the *madrasa* and that make up the model developed for the study of architectural conformation are:

1. The location of the *madrasa* in relation to external sound sources.
2. The introverted architecture and the role of the courtyard in reducing external noise.
3. The architectural form (volume and shape of the roof).
4. The acoustic characteristics of the building materials used.
5. The surface coatings of walls, ceilings, and floors.

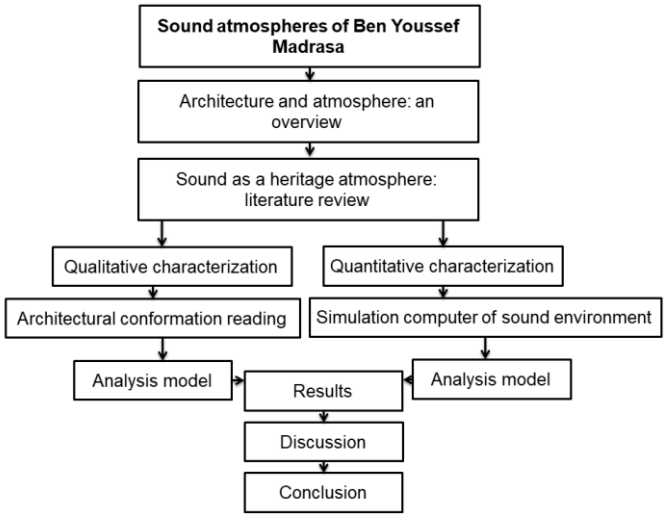

Figure 7.The Methodology Used to Characterize the Sound Atmospheres in *Ben Youssef Madrasa*

[8] Several books on architectural acoustics were consulted. The authors are: René Vittone (2010), Loic *Hamayon (2006)*, *Loic Hamayon* (2008), Marshall Long (2006), Clause-Alain Roulet (2004), M. David Egan (2000) etc.

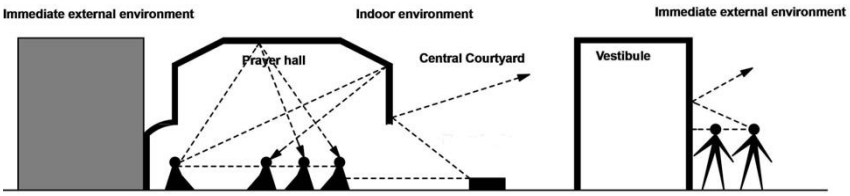

Figure 8. The Elaborate Model of Architectural Conformation Reading

5.2. Quantitative Characterization: Computer Simulation of the Acoustic Environment

The prayer hall and the central courtyard were chosen for the computer simulation. One of the most important criteria in prayer hall is the intelligibility of speech. Indeed, the main activity is verbal communication between *el-Sheikh* and *el-Tolba*. Like the prayer halls of mosques, speech intelligibility is closely related to the speech signal, the reverberation time, the level of background noise, the volume and geometry of the space, and the reflective and absorbent surfaces (Yelkenci Sert and Yılmaz Karaman,2021, p.560; Ridzwan Othman and Rizal Mohamed, 2012, p.322, Refat Ismail, 2012, p.34). As far as background noise is concerned, its origin is the external and internal sound sources that can disturb *el-Tolba* in their teaching or prayer. For physical indicators, we limit ourselves in this research to: i) sound behavior (distribution of the sound in spaces), ii) the degree of the presence of reverberation which mainly determines the intelligibility of speech.

Therefore, the analysis is made according to three criteria: the uniformity of the sound in the prayer hall, the sound behavior (direct and reflected sound, masked sound, echo etc.), and the degree of the presence of reverberation. The partial model developed for the computer simulation of the acoustic environment of the prayer hall consists of: the architectural conformation, namely the shape, the surface, the volume, the building materials, and the sound source; the voice of *el-Sheikh* and the voice of *el-Tãleb*. The computer simulation of the sound behavior is carried out using the software "Ecotect V5.50" after integrating the meteorological data of the city of Marrakech, the architectural conformation of the prayer hall, and the construction materials adopted. In order to structure the scenarios of the sound simulation of the prayer hall, we have based ourselves on some research dealing with architectural acoustics in mosques and *madrasas*. In addition, the scenarios were developed on the basis of the restitution of the daily life and scenes of *el-Tolba* described in the text. The description of the way of teaching in the Zianid *madrasas* cited by Qoryãne is very illustrative (Qoryãne, 2011, p.268-272). The teaching scene is as follows; after introducing the course by *el-Sheikh*, one of *el-Tolba* begins to read the course partially and *el-Sheikh* explains it paragraph by paragraph. Therefore, three scenarios were chosen for the sound simulation (Figure 9). In the first, *el-Sheikh* sits on the ground, the only sound source, and gives the daily course or sermon while looking towards *el-Tolba*. In the second, one of the seated *el-Tãleb* reads the course while looking towards the mihrab. In the last scenario, it is during the prayer where the sound source is *el-Sheikh* standing looking towards the mihrab. In this sound simulation, we focus on two main sound sources: *el-Sheikh* and *el-Tãleb* who reads. Thus, the voices of other students are neglected because they are silent and listening to *el-Sheikh* or the student who reads.

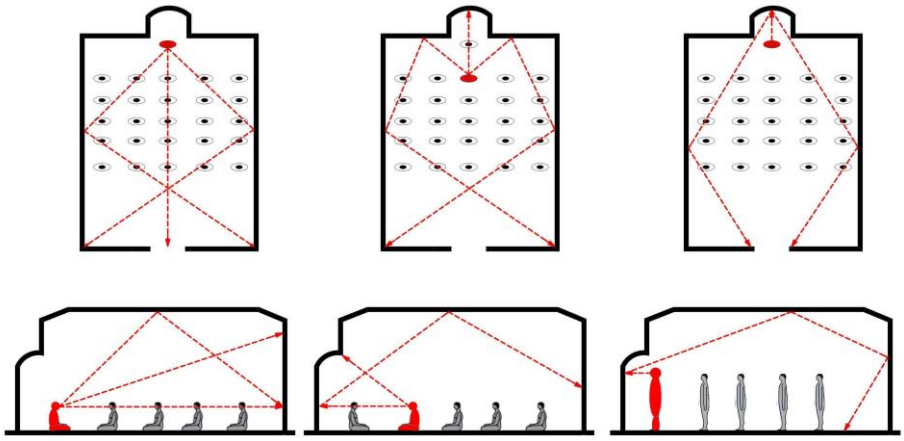

Figure 9.The Three Scenarios of the Computer Simulation of the Acoustic Environment in the Prayer Hall

6. The Architectural Conformation reading

Very present in the literary texts that had produced the travelers visiting the *Ben Youssef madrasa*, the sound atmosphere is generated by several signals[9] (both high and low-frequency sound), such as the voice of el-*Sheikh*, the recitation of the Qur'an, the noise of *el-Tolba*, the sound of water and birds, the calm, etc. These generators give a sound specificity of this place of teaching and life. In this *madrasa*, several architectural devices and environmental strategies have been adopted by the builders to have an acoustic environment appropriate to its function.

6.1. The Introverted Architecture of the Madrasa

The hierarchy of urban spaces in the *medina* of Marrakech provides a characteristic sound environment. Access to the *Ben Youssef madrasa* is indirect. From the large alley to the small one, the noise gradually fades away until it reaches the *madrasa*. This sound distribution favors a quiet acoustic environment disconnected from the noise of the outside (Figure 10). Therefore, the compactness of the building generates an acoustic environment favorable to teaching. The central courtyard, surrounded by high and thick walls, generates acoustic privacy (Hosseini et al, 2015, p.15). Another spatial process plays the role of a sound filter, even a buffer that reduces the noise emanating from the outside, it is the vestibule. More than a daylighting device and a thermal regulator, the central courtyard is a noise buffer that ensures a quiet interior atmosphere (Haj Hussein, 2012, p.60) (Figure 11). The presence of a large pool in the central courtyard, leads to the cooling of the *madrasa* while decreasing the noise.

[9] The medersa is considered as an quiet place. There are some sound signals with low frequency sound (human conversation, recitation of the Quran etc) and high frequency sound (sound of birds). The prayer hall is a place of prayer and teaching,so the reverberation must be minor to enhence speech intelligibity in the prayer hall.

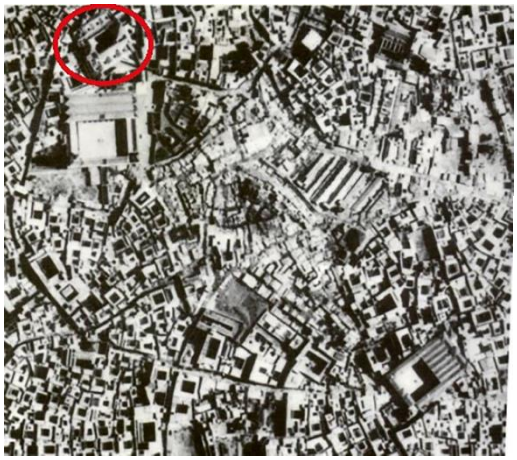

Figure 10.The Location of the Madrasa in the Medina of Marrakech (Triki and Divifat, 1999)

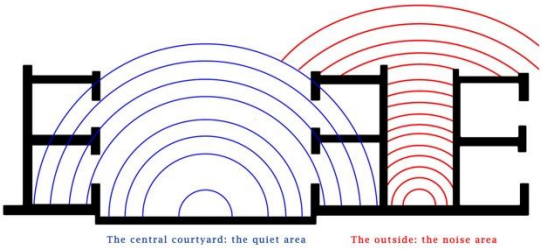

Figure 11.The Acoustic Environment of the Madrasa Based on the Scheme Developed by Haj Hussein (Haj Hussein, 2012, p.61)

6.2. The Architectural Form of Prayer Hall

In the prayer hall of the *Ben Youssef madrasa*, *el-Sheikh* sitting next to the mihrab, gives lessons to *el-Tolba* sitting in different places (Figure 12). To make *el-Sheikh*'s speech clear, the architectural acoustics of this learning space must promote the intelligibility of the speech. The shape of the prayer hall is rectangular. Indeed, right angles and rectangular spaces favor the uniform distribution of sound.

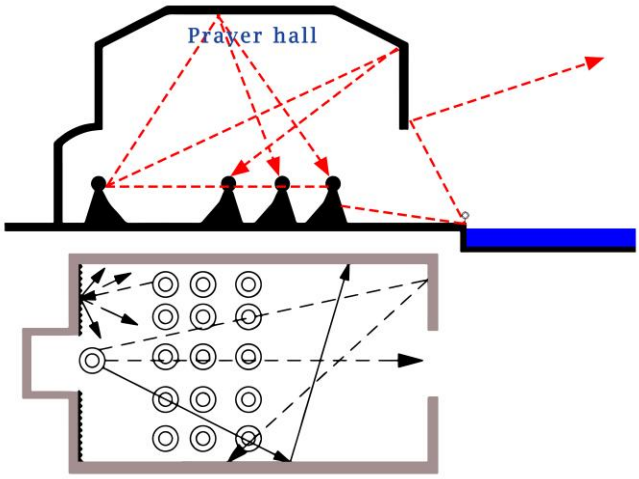

Figure 12. Sound Behavior in Prayer Hall

6.3. Acoustics Characteristics of Buildings Materials

The acoustic quality of the *madrasa* is achieved through the construction materials used. They are acoustically efficient in order to generate a calm acoustic environment appropriate for teaching. Indeed, wood has a better behavior given its low modulus of elasticity. Stone and clay brick are also sound insulators. The absorbing materials adopted generate a very short reverberation time which favors the emission of *el-Sheikh*'s speech in the prayer hall. The wall, floor, and ceiling surfaces promote the propagation of sound waves in this space.

The use of smooth surfaces at the level of a seated person allows the first reflections of sound from *el-Sheikh* to the back of the prayer hall. The rest of the walls are lined with chiseled plaster that serves to diffuse the sound (Figure 13). The ceilings are built by absorbing or diffusing materials to avoid the late reflections and the phenomenon of focusing of the sound. For the floor, it is naturally treated by *el-Tolba* with their absorbent clothing, which avoids disturbances due to multiple reflections of sound on the smooth surfaces and the echo.

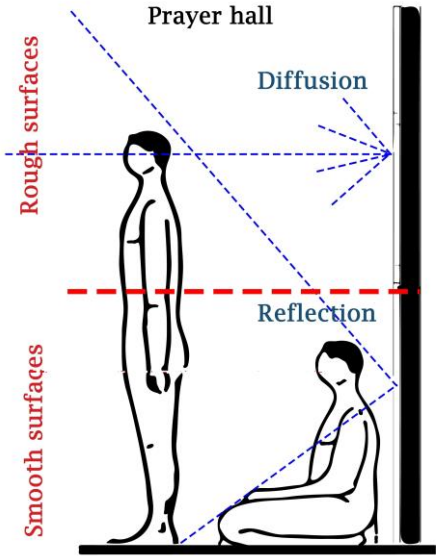

Figure 13.The Wall Surfaces of the Prayer Hall

7. The Acoustic Environment of the Prayer Hall

It should be remembered that the *Ben Youssef Madrasa* is one of the great *madrasas* in the Maghreb. It has a large prayer hall that exceeds 1000 m^3; it is topped by a wooden roof with three access doors opening onto the central courtyard. Smooth plaster, chiseled plaster, and marble are the surfaces covering the mud brick walls[10]. The values obtained from the simulation of the acoustic environment at the height of a seated person reveal an almost uniform distribution of the space. In the first scenario where *el-Sheikh* is the sound source, the sound value gradually decreases towards the back of the prayer hall and towards the ceiling. In the farthest point from *el-Sheikh*, the sound weakens by 2.8 dB compared to the initial value inside the prayer hall. The first rows of *el-Tolba* near the Mihrab hear *el-Sheikh* better. People in the courtyard can hear *el-Sheikh*'s voice, but at a lower intensity than in the prayer hall. The direct sound represents the highest percentage followed by the reflected sound and the masked sound. The reflection of the sound is found on the lower parts of the wall surfaces covered with smooth plaster. The reverberation is minor, very weak within the space but it occupies the surfaces of the walls. The echo does not exist in the prayer hall.

[10] It should be mentioned that reverberation time calculations such as Sabine's formula and Eyring's formula were not used in this study. The quantitative characterization of the sound environment in the prayer hall is limited to simulation process. The sound absorption coefficients of building materials have been introduced into the software: marble (0.1), wood (0.15), plaster (0.02) and natural brick (0.03).

In the second scenario, where *el-Tãleb* is sitting on the ground reading the course aloud, the space is divided into two areas (Figure 14). The first occupies the mihrab and the sixth of the space closest to the sound source. As for the rest of the space, the sound weakens as it moves away from the access door and the ceiling. The difference between the minimum and maximum values is 2.8 dB. The reverberation remains minor in the space, while the direct sound represents the highest percentage followed by the reflected sound (Figure 15). The masked sound is high compared to the first scenario. It is also noted the total absence of the echo. Two areas were recorded in the third scenario at the time of the prayer aloud. The sound source is the voice of *el-Sheikh* standing and facing the mihrab. The first zone occupies the mihrab and a sixth of the space closest to *el-Sheikh*, while the second zone occupies the rest. The sound gets weaker as you move towards the door to the prayer hall. The difference between the minimum and maximum value of the sound is 2.8 dB. The direct sound represents the highest percentage followed by the reflected sound and the masked sound. The reverberation remains low and occupies the wall surfaces. The echo is totally absent in the space.

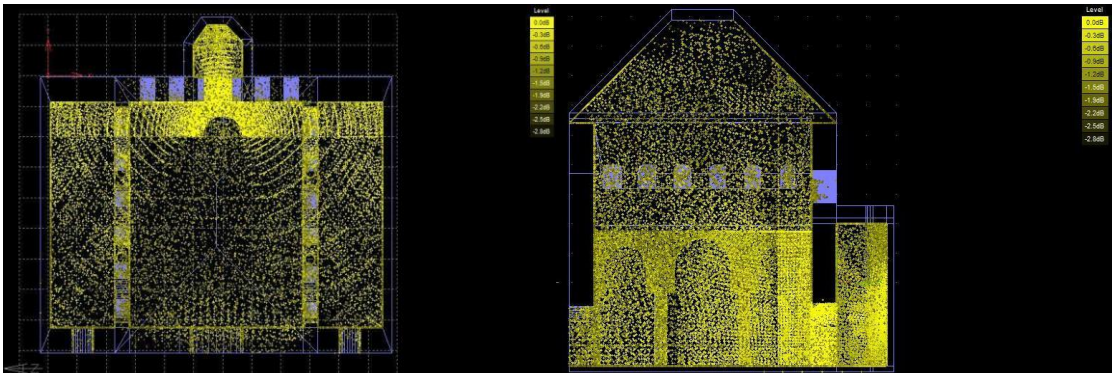

Figure 14.The Sound Propagation in the Prayer Hall and the Central Courtyard (Second Scenario)

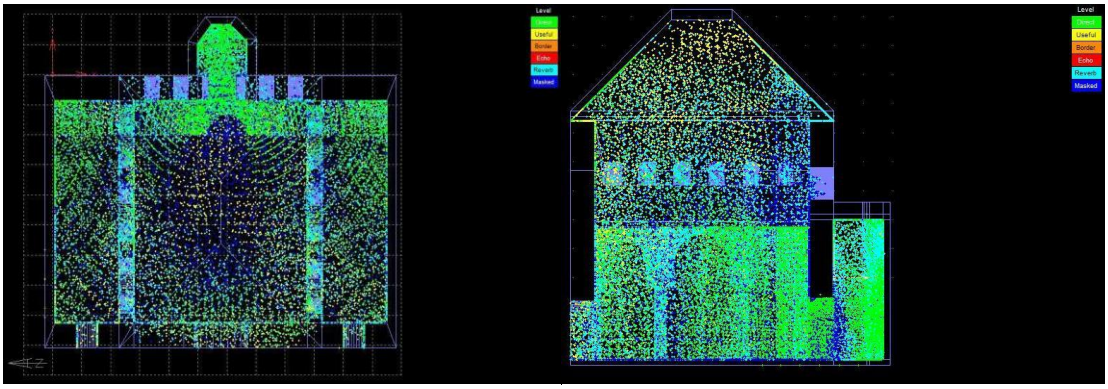

Figure 15.The Characteristics of the Sound Wave in the Prayer Hall (Second Scenario)

8. Discussion

In the three scenarios, the acoustic environment of the prayer hall is divided into two zones, the first zone is the closest to the sound source (*el-Sheikh* or *el-Tãleb*) while the second zone occupies the remaining part. The rectangular shape of the space favors the distribution of sound. In addition, their volume affects the distribution of sound, which shows the values from the simulation. In the case of the central courtyard, the sound is received differently in the three scenarios. The sound reaches the courtyard with a more or less low intensity when *el-Sheikh* gives the lesson by looking towards el-*Tolba*. On the other hand, the sound intensity weakens in the courtyard during the prayer and when

el-Tãleb recites the lessons. Thus, the distribution of sound in the prayer hall and in the central courtyard is due to the position of the sound source and the volume of the prayer hall. In the *madrasa*, the direct sound represents the highest percentage followed by the reflected sound. A strong reflection is observed on the lower parts of the walls covered with smooth plaster. A sound diffusion is recorded on the wall surfaces in chiseled plaster. This material composition of the walls ensures a distribution of the acoustic environment in the prayer hall. The placement of the coated surfaces on the walls suggests that the desired distribution of the acoustic environment depends on the intelligibility of speech. The rough surfaces are located in the upper parts to diffuse the sound and avoid the focusing phenomenon generated by the concave shapes of the ceilings. The smooth surfaces are installed in the lower parts of the walls. Their purpose is to favor the reflection of the sound to reach the bottom of the prayer hall.

The reverberation is minor and it occupies the wall surfaces. The absence of reverberation within the space is due to the sound absorption coefficient of the construction materials used and the volume of the space. The absence of reverberation generates an absence of the effect of the echo, which was confirmed in the simulation results. Due to their location, their introverted architecture, and the insulating building materials used, the *madrasa* is characterized by a quiet acoustic environment dissociated from external noise, which is conducive to teaching and prayer. The absence of background noise and existing sound generators (water noise and others) ensures calm and does not interfere with the propagation of sound. Based on the book 'Music, Acoustics and Architecture', by Beranek (Hamayon, 2008, p.77) in which, the author cites the criteria for characterizing the acoustics in a room, the prayer hall of *Ben Youssef Madrasa* as a place of teaching is acoustically efficient (Table 1).

The almost total absence of background noise and reverberation, confirmed by computer simulation and architectural conformation reading in this space, offers good speech intelligibility. This analysis allows us to suggest that the builders of the *madrasa* paid attention to the architectural acoustics of the prayer hall. The rectangular shape with right angles, the material composition of the walls, the avoidance of the focusing effect of the concave shapes of the ceilings by favoring a distribution of the sound to the bottom of the space, and the insulating and absorbing building materials, are the processes put in place in order to guarantee a quiet learning environment and good intelligibility of the speech so that *el-Tolba* can hear and understand the lessons taught by their *el-Sheikh*.

Table 1. The Criteria of Characterizing the Acoustics in a Room According to Beranek and their Projection on the Ben Youssef *Madrasa*.

Criteria	**Advice of Beranek**	**The architectural acoustics of the prayer hall**
Reverberation time	A room must have a reverberation time that is appropriate for its use	The results obtained from the simulation of the acoustic environment show that the reverberation is minor in the building, which guarantees a good intelligibility of speech
Direct sound and intelligibility of speech	A room must favour the sound level of the message reaching the listener, in other words, it must favour the level of direct sound and that of the first reflections	In the prayer hall, the direct sound represents the highest percentage followed by the sound reflected on the wall surfaces.
Distribution of sound level in space	A room must ensure a good distribution of the sound by a good diffusion	The simulation analysis shows that an almost uniform horizontal and vertical (yellow areas at a level of a person standing in prayer) distribution of sound in the prayer hall. A difference of 2.8 dB between the sound source and the farthest point, so a person sitting in the central courtyard (the part closest to the prayer hall) can hear the speaker's voice.
Sound phenomena and background noise	In a room, it is necessary to avoid disturbances inside by controlling echoes, the focusing of the sound. It is also necessary to avoid disturbances coming from outside the room.	The results obtained by the simulation of the acoustic environment show an almost total absence of echo. Due to the location of the *madrasa* and its introverted architecture, it is disconnected from external noise.

9. Conclusion

The *Ben Youssef Madrasa* has a specific sound atmosphere that is embodied not only by architectural and spatial devices but also by natural sound signals providing characteristic sounds to this place. The architectural conformation reading relating to the acoustic environment in this historical building, allowed us to grasp the importance brought to the architectural acoustics. Its sound atmosphere is the result of a set of architectural elements that participate together to promote an acoustic environment

conducive to teaching. Due to their location and compact form, the acoustic environment of the *madrasa* is described as quiet. The background noise is only the sound of *el-Tolba* and the natural sound (water, birds, etc.). The values from the simulation of the sound behavior show that the distribution is almost uniform. The wall surfaces also promote the first reflections of sound in space, which gives good intelligibility of speech, an important criterion for a place of learning.

The present research studies another aspect of traditional architecture in Morocco. It differs from other historical research on *Ben Youssef Madrasa* which was limited to the description of spaces and architectural elements. In addition, the study of atmospheres in historical buildings allows us to know their characteristics in order to restore this heritage in these buildings.

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