Characterization of Sonic Ambiance Generated by an Architectural Device: Case of Traditional *Gannariyya* and Its Contemporary 'Reproduction'

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Abstract

The proposed study concerns the characterization of sound ambiances produced by the traditional architectural device *gannariyya* and its contemporary reproduction, implanted in two different neighboring urban fabrics of the capital Tunis. Thus, we adopted an ambiantal multidisciplinary method based on two approaches. First, quantitative approach involves observations in situ and the processing of audio signal measurements and sound recordings taken simultaneously from both sides of the *gannariyya*. Second, qualitative approach implies interviews with users in addition to recognize their perception of the sound phenomenon. Our field of study is the traditional medina of Tunis and the neighboring modern city. The results collected through measurements, frequency analysis and interviews, show that both types of device filter the sound signal differently. They also reveal that new building materials are responsible of this gap.

Keywords: Soundscape, Sonic ambiances, *Gannariyya*, Reproduction, Sound signal, Propagation's area, Sonic characteristics, Frequency, Perception

1. Introduction

In the nineteenth century[1], new regulations established in the capital Tunis led to decisive change of the built environment, urban and architectural. At the end of the nineteenth and the beginning of the twentieth century[2], the urbanization and modernization operations of the city have been intensified (Ammar 2006)[3]. Consequently, the organization of the traditional urban tissue progressively gives way to a structured urban network. The downtown of Tunis was then marked by the juxtaposition of two contrasted urban forms [Figure 1]. On the one hand, we have the irregular tortuous tissue of the traditional medina, called Arab town too,

> (…) a real labyrinth, where streets and dead ends draw a very complicated urban network, where the most magnificent paths have sometimes only two meters width. (Baraudon 1893)

On the other hand, we have the structured orthogonal plan of the modern city or *European town*.

> It is in front of the existing city and the ancestral urban Tunisian culture, that a new juxtaposed city which triumphs with its rectilinear plans, its new islets square or rectangular, (…), its architectural prescriptions, its equipments and infrastructures. (Ammar 2011)

1. During the nineteenth century, industrialization and urbanization period particularly in the European countries, the city is redesigned and reinvented.
2. Establishment of the French colonization in Tunisia in 1881.
3. Tunisian architect and historian, HDR in architecture (ENAU), specialist in the fields of architectural history, urban history, and spatial analysis.

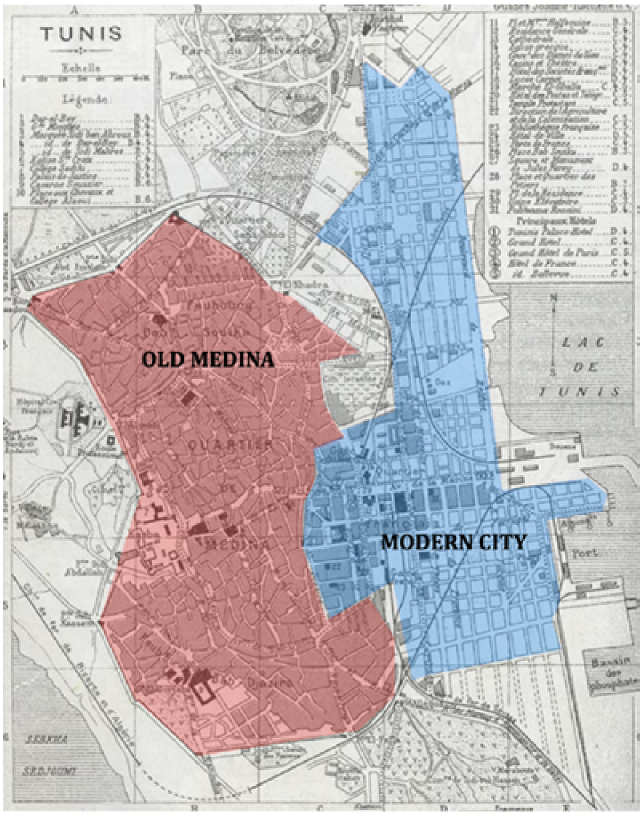

Figure 1. City of Tunis Plan in 1906 (Sebag 1998) .

Besides these urban transformations, the architecture of the city has been also affected; so modern architecture replaced the traditional architecture. However, in order to safeguard architectural heritage, the architects reused several built elements of the medina on contemporary façades in a different way (new shapes and implementation with modern materials).

1.1. New urbanism, new sounds, new soundscape

The new urban design of Tunis City is the consequence of conditions and requirements of this time with firstly the advent of the industrial revolution, and also the development and acceleration of the transport means (cars, buses, trams, trains and plans). Therefore, all these circumstances were at the origin of the appearance of new sound productions, especially mechanical sounds. These new sounds with high intensities and new physical properties are contrasting with the sonic ambiance of the old town.

> We declare that the splendor of the world grew rich by a new beauty: the beauty of speed. A racing car with its ornate chest with big pipes, like snakes with an explosive breath… a car arises which looks to run on grapeshot. (Marinetti 1909)

The urban sound environment two parameters in close interaction: the human, natural, mechanical sounds and the urban space. The propagation's area qualified by the road width, the building heights and the façades materials, influences sound waves and determines traditional and modern soundscapes[4].

To start with, the traditional medina is structured according to a mixed center called *souk*[5] which is very bustling. Its sounds are characterized first by commercial and artisanal activities (beating of the shoemaker, rhythmic sounds of the iron forger, noises of the carts, etc.) and second, by a large, noisy human animation (screams of merchants, laughs, etc.). Around this central core, develops less noisy residential space. Here, the sounds attest especially of the presence of human (discussion, footsteps, children playing, etc.) and natural sounds (singing of birds, wind sound, etc.). The propagation's area of the medina is compound by tortuous paved roads (1 to 4 meters width) and stone constructions with one floor only.

The sound sources and the propagation's area are different in the surrounding modern city where commercial and residential activities are merged. The three types of sounds are defined otherwise. The mechanical sounds of cars and new jobs[6] are very noisy and mask the low intensities of human and natural sounds. We then attend to a form of "progressive devocalization of the city" (Bardyn 2000). In fact the urban fabric, with wide roads and high buildings made with brick, steel and large glazed windows, offers a new propagation's area.

From this brief comparison, we note that the difference is significant between two neighboring soundscapes: distinct sounds and distinct propagation's areas. The reproduction of architectural devices of the medina on contemporary façades corresponds to submit them to new acoustic conditions different from the original sound environment. The aim of their initial design could be distorted.

1.2. The *gannariyya*, ambiantal device extracted from its origi-

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4. Soundscape in a notion introduced by Raymond Murray Schafer in the 1970's, in Schafer, Raymond Murray. *The Tuning of the world*. New York: A. Knopf Inc., 1974.

5. *Souk*, arabic word, means shopping center.

6. Appeared with the industrialization.

nal sound environment, reproduced in a new soundscape

The *gannariyya*, an opening device representative of traditional architecture of Tunis, is a famous example of this reproduction. Called also "light wooden balcony" (Revault 1980), the *gannariyya* is a component of the arab-islamic architecture. It appears on the façade, at the first level and overhangs the entrance door of the beautiful houses enlightening by this way the living room. It may be masonry or wooden. Its most known properties are those of light filtering through the wooden moucharabieh[7] (Fathy 1986), refreshing the air and allowing women to watch outside without being seen [Figure 2]. Its sonic properties, less known, would make urban sounds more perceivable by users thanks to the tight wooden elements. In this case, its extraction from its original sound environment and its reproduction in another soundscape with new physical properties, exposed to the road traffic sounds, might be inappropriate.

Figure 2. Domestic actions and ambiances offered by the *gannariyya*.

Old streets with the voices of passers-by and merchants, the sounds of carts wheels, reflection on the "sound paving stones" (Harry 1910) and massive walls, produce a specific sonic atmosphere. These sounds propagate in the narrow street, enter by the wooden *gannariyya* and arrive amplified at the human ear. This acoustic structure is specific to the couple of parameters: old fabric, traditional *gannariyya* [Figure 3]. Contemporary Street, with its mechanical sounds, its asphalt ground below and the contemporary *gannariyya* made with modern materials presents another acoustic structure [Figure 3].

7. Wooden elements woven together at regular intervals.

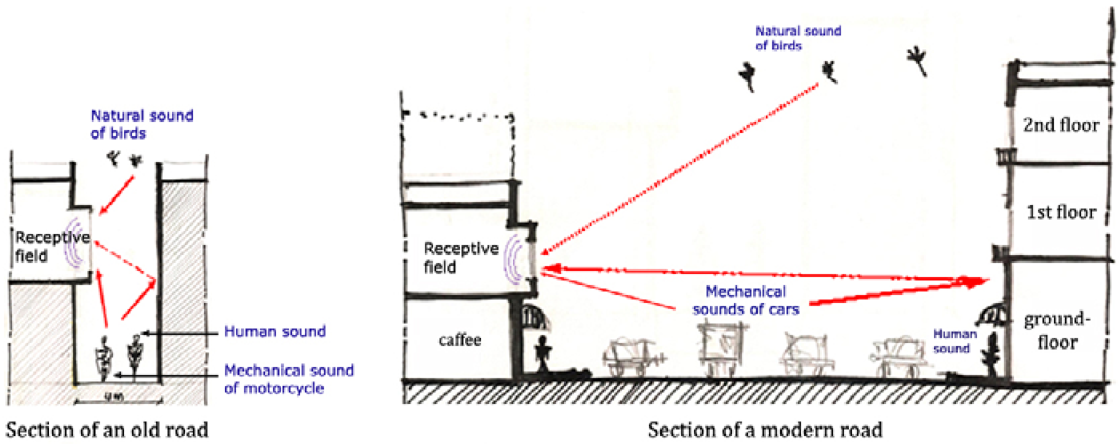

Figure 3. Examples of Sound situations in both types of tissues (drawings by the author).

Being interested on sonic properties, the goal of this research is to develop a methodology to characterize the sonic ambiance generated by an architectural device according to its materials of construction and its site of implant. We then focus on the traditional and contemporary *gannariyya*s located in two different tissues of the downtown of Tunis. We wonder if the reproduction of the *gannariyya* has modified the original extrinsic and intrinsic properties, changing so the sonic quality and the user's perception.

2. Field of study

To obtain rigorous results, we chose the same type of device, heterogeneous masonry wood *gannariyya*s, all salient, localized at the first floor and with close dimensions. In order to reduce the constraints of our experiments, we made abstraction of some criteria such as: the cutting of the *gannariyya*'s envelope, the number of its frontal or lateral spans. We studied six devices: three traditional and three new devices. We will present them according to their site of implantation: traditional or modern city [Figure 4].

Figure 4. Examples of old and new fields of study (photos by the author).

In the medina of Tunis, we chose three devices [GI, GII and GIII]. In a same street, we took a traditional device [GI] and a contemporary *gannariyya* [G.II]. The third device is traditional [G.III] located in the *Pacha*[8] *Road* where exists a large number of richly decorated *gannariyyas*.

For the new city of Tunis, three *gannariyyas* have been selected [GIV, GV and GVI]. We chose an old device [G.IV] belonging to the suburb of medina where the street has been modernized and asphalted. We also retained a contemporary *gannariyya* [G.V] in a boulevard close to the medina[9]. Finally, the last device [G.VI] is originally traditional and it has been modified with modern materials (like double glazing). We will consider it as contemporary device.

Figure 5. Studied devices (photos by the author).

8. The word *Pacha* is an arabic word, it corresponds to the highest Tunisian political class in the past until the independence in 1956 (such as president).
9. The wall of the medina was demolished at the end of the nineteenth century to accommodate the new form of vehicular traffic.

3. Methodological approach

To characterize the acoustical properties of the different devices, we will adopt an ambiantal multidisciplinary approach that will cross various data. Our method consists of sound signal analysis and users' perception.

3.1. Characterizing the sonic ambiance

The sonic ambiance is the conjunction of three parameters in interaction: the sound signal associated to our sense of hearing, the area of its propagation and its perception by a user (Augoyard 2003)[10]. This definition allows us to identify three categories of data which require then three modalities of analysis: observations in situ, audio signal measurements and the user surveys. These types of analysis can be classified into two approaches. An objective approach includes observations in situ, collecting and processing of the sonic corpus. Subjective approach involves the testimony of the users.

Sonic corpus and equipment

We will adopt two techniques made simultaneously by two investigators to collect the sonic corpus: audio signal measurements and sound recordings. Here, the simultaneity is required for two reasons. First, sound levels must correspond to the sound sample recorded. Furthermore, the comparative study must be carried out in the same acoustic conditions (similar sound sources, same intensities and frequency composition).

Audio signal measurements

Audio signal measurements will be captured simultaneously and at equal distances from the *gannariyya*. Two investigators will be equipped with the same equipment[11], decibel sound meter and recorder. The first investigator placed the urban space will bypass the *gannariyya* at the same distance 'd' [Figure 6]. The second investigator will be immobile inside the receptive field at the similar distance 'd' from the center of the *gannariyya*.

The decibel sound meter will register in intervals of 10 minutes[12] in order to get the Equivalent Sound Level L_{eq} and the Maximum Sound Level L_{max} at the entry and the exit of the device. A simple comparison of the numerical values input and output the device will

10. Jean François Augoyard defined the ambiance as the combination of the physical signal related to the senses (hearing, vision, olfaction, etc.), the propagation's area, the psychology, the culture and the perception of users.
11. Equipment was provided by the unit U2S, Research Unit on Systems and Signals of the National School of Engineering of Tunis (ENIT).
12. Minimum time to get significant values of the L_{eq} and L_{max}.

allow us to know filtering properties of the *gannariyya*: reducing or amplifying the audio signal level.

Sound recordings

The sound is complex, composed by various frequencies (low, medium and high) that human hearing is unable to distinguish them. That's why an objective analysis of the physical audio signal is necessary. Therefore, we will begin by taking audio recordings which will be taken, at the same time, in intervals of 10-15 minutes by two investigators equipped with two recorders: a digital recorder Model Micro Track 24/96 outside, a digital Video Recorder Zoom Q3 inside the receptive field [Figure 6].

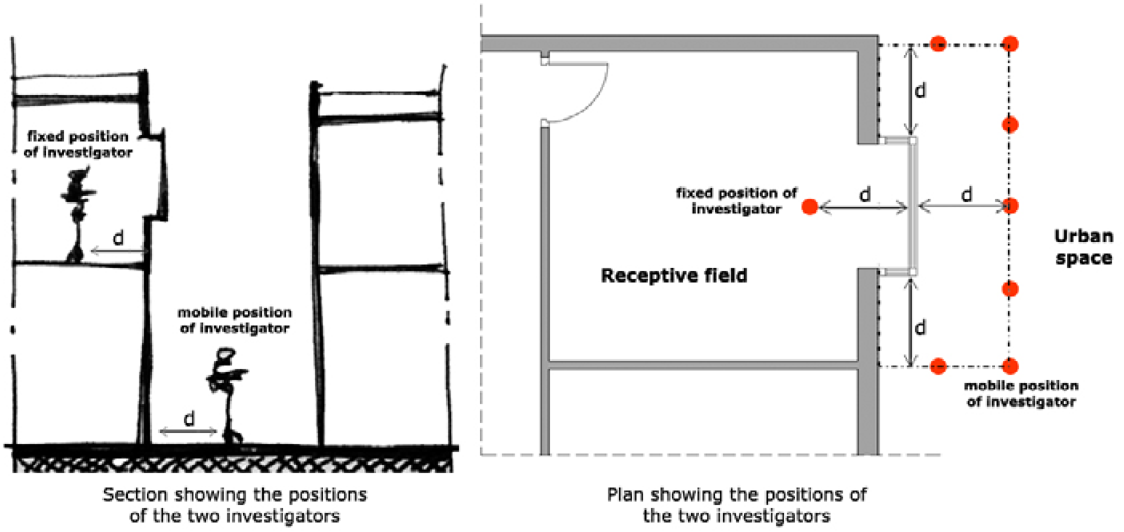

Figure 6. Survey procedure of audio sound measurements and sound recordings (drawings by the author).

Sound recordings will be analyzed by two methods. First of all, a spectral analysis will be done using sound processing software Audacity[13]. The analysis will concerns sound fragments with duration of 15 to 60 seconds and with various sound signals. Exterior and interior sound fragments have to be synchronized. After superposing input and output curves corresponding to the sound fragments, we will compare it. This comparison will allow us to have preliminary results about the filtering of sound waves by the device. The filtering could be significant on low, medium or high frequencies, or be the same on the entire frequency band.

13. Audacity is 'a free software and cross-platform for recording and editing sounds', acceded, April 12, 2014, http://audacity.sourceforge.net/?lang=fr.

Second and for a more detailed analysis of the sound recordings, they will be subject of detailed spectral analysis[14]. The first stage of this work will be the choice of stationary sound fragments having a long duration and rich frequency content. Exterior and Interior fragments will be synchronized. We chose the method of averaged smoothed periodogram of Welch[15] (estimator with low bias and variance) considered after several tries the best for its best results. This method will allow us to make the Transfer Functions[16] of the studied devices. The different curves will be then superposed and used for the comparative analysis.

Perception and qualification of the space with *gannariyya*

We will interview the users to define their positive or negative appreciation of the sonic atmosphere inside the space with *gannariyya*. We will ask them the following questions:

> What do you think of this room with *gannariyya*? How can you qualify its sonic ambiance? (Investigators)

The user will appeal to his memory to answer and will try to describe his perception of the sonic ambiance. Using the different testimonies, we will write a short text summarizing the real life experience of each user. This text will be then analyzed: key words that expose the sound quality, description of the sonic atmosphere of the receptive field (quiet/noisy), remarkable sound sources, etc.

3.2. Cross-analysis

The sequel of the study will concern the confrontation of the different quantitative and qualitative methods. This cross-analysis was proposed by two researchers of the CRESSON[17], G. Chelkoff and J-F Augoyard in 1981, (Chekoff 2008). First, we will compare the results obtained from the sound processing and the frequency analysis. Second, we will correlate the physical results with the survey among the users.

14. This part of the proposed study was developed in the framework of international cooperation CMCU which associates ENAU by its research team ERA, ENIT by its research unit U2S and UMR 1563 of CNRS composed by CERMA and CRESSON in an interdisciplinary research project titled '*Perception altérée des ambiances sonores en milieu urbain. Corrections et caractérisations: apports des textures audio*', 2012.

15. Duration of analysis: 5.6s with a sampling frequency Fs= 44.1kHz, choice of the analysis window: Bartlett type (good power of spectral resolution), length of the analysis frame: 256 samples (Fs= 44.1kHz), average on 976 sequences, overlapping percentage 50%.

16. H(t)=S(t)/E(t), with E(t): the sound at the entrance of the device, S(t): the sound at the exit.

17. CRESSON: Centre for Research on the Sound Space and the Urban Environment, Grenoble.

4. Multidisciplinary results

4.1. Listening and exploring the fields of study

The experimental work has been made in the same way in all studied fields during two weeks. The first observations in situ allowed describing the sonic signals of the urban sound environments of the study. The three sites in the medina are residential; we noticed that human voices and singing of birds were very perceivable. Nevertheless, in the neighboring modern city, human sounds were less heard and bird sounds were heard a little bit. However, the sounds of car engines and car horns were much more perceivable.

For a better understanding of the six receptive fields, we made architectural statements [Figure 7] and drew the organisation of furnitures in the different spaces with Autocad software. We also determinated the habitual places of interviewed users, near or far from the *gannariyya*.

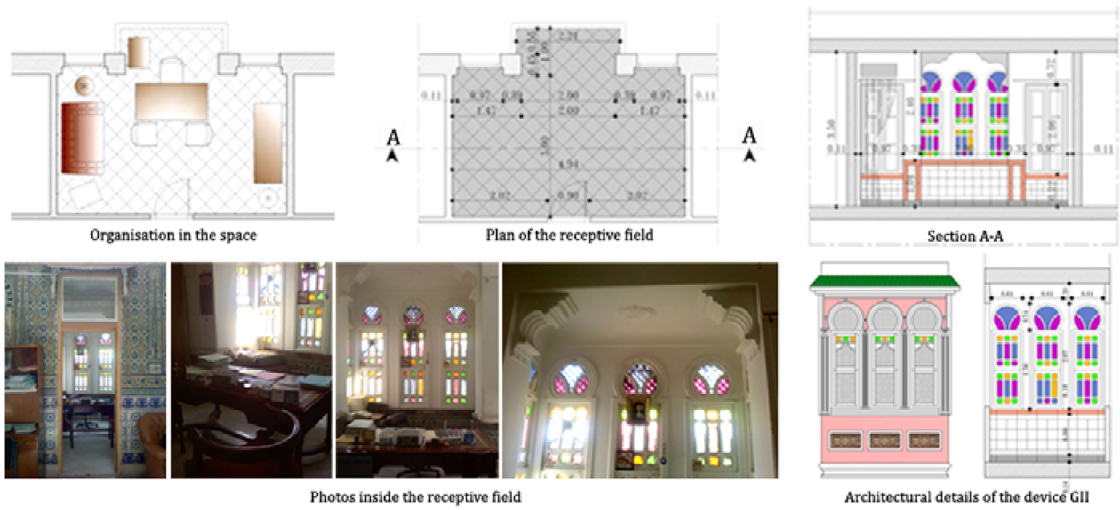

Figure 7. Example of architectural corpus: Traditional device G.II (drawings by the author).

During audio sound measurements inside and outside the receptive field, we described the sound events and the corresponding intensities measured by the decibel sound meter. We noticed that the sound level rose considerably in the presence of the mechanical sounds such as car or motorcycle. We prepared tables which reproduce the values of the L_{eq}, L_{max} and the remarkable sound events inside and outside the receptive fields (example: Table1).

Table 1. Example of audio signal measurement: Field of study 1 in the medina, traditional device G.I.

Device GI	Leq dB(A)	Lmax dB(A)	Remarkable sound events
Outside	66	54	• Most of the time, the sound level is under 60 dB (A) • Continuous sound of hammer • Continuous singing of birds • Passage of people • Sound of the shoes heels of girls • Passage of a noisy motorcycle • A knock on neighboring door, door slamming • Keys sound • Ring of mobile phone • Music, sound of a musical instrument • We hear sounds coming from other streets • Passage of a wheelbarrow clean.
Inside	49.1	47.1	• More than 50% of the time, the sound level is between 39 and 40 dB (A) • At the passage of a motorcycle, the sound level increases • The sound level drops gradually after the passage of the motorcycle • We listen clearly discussions of people. • Door opening, door slamming.

The analysis of indoor and outdoor sound levels showed that the exterior sound levels decreased for all cases in the receptive field. The reduction of L_{eq} for the contemporary devices was significant (reduction of 30 and 21 dB (A) of the exterior L_{eq}) if we compare it to the values L_{eq} input and output the traditional *gannariyya*s (reduction with 16 and 20 dB (A) of the exterior L_{eq}).

The first step of the audio signal processing made by Audacity software allowed drawing the audio spectrums of indoor and outdoor sound fragments [Figure 7 and Figure 8]. The audio spectrum presents the sound levels (kHz) according to the time (minute and second). The pink color represents the sound events and the blue color is the background noise. The comparison of the interior and exterior spectrums of the three contemporary *gannariyya*s showed that the sound levels decreased considerably [Figure 8]. However, this decrease is less important for the three traditional devices [Figure 9].

The confrontation of the results obtained from these two first analyzes showed that, on the one hand they coincide, and on the other hand they attested of the considerable reduction of the sound levels by the three contemporary devices. We can deduce that the devices made with modern materials offer a sound insulation compared to the traditional materials.

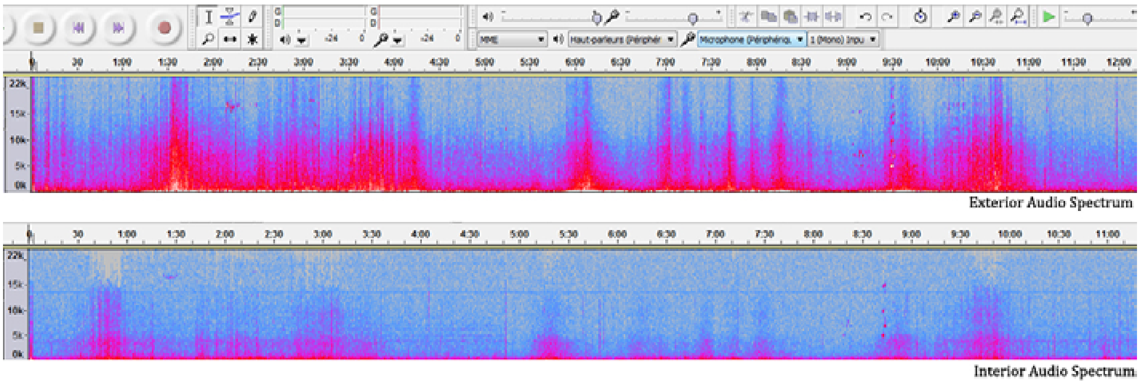

Figure 8. Exterior and Interior Audio Spectrums of traditional device G.II, field of study 2: old medina.

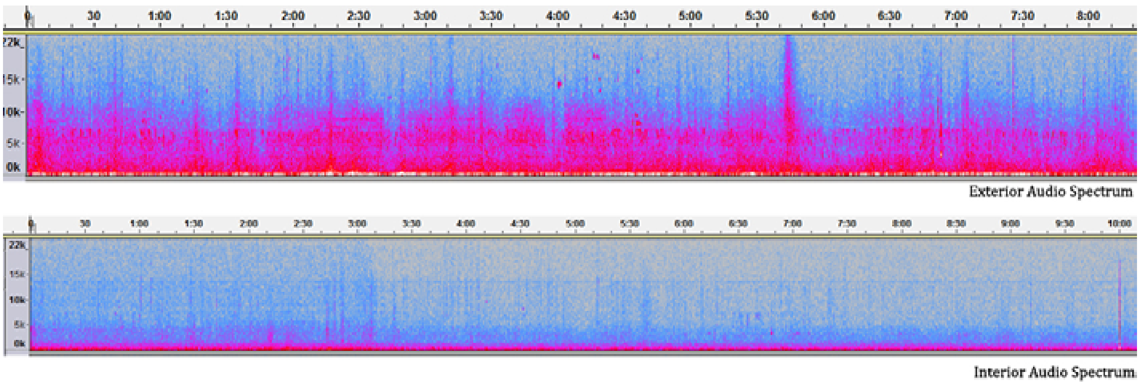

Figure 9. Exterior and interior Audio Spectrums of contemporary device G.V, field of study 5: modern town.

4.2. Frequency analysis

At this stage of study, it appears indispensable to refine the analysis of the sound recordings. To start with, we used the Audacity software to do the frequency analysis of the chosen sound fragments. The obtained interior and exterior sound spectrums have been superposed using Photoshop software. The comparison of the audio spectrums superpositions of the traditional *gannariyyas* gave similar results. Indeed, the profile of the interior spectrum didn't decrease very much; the bass, medium and high frequencies of the interior spectrum were moderately high comparing to the exterior spectrum. Therefore, we can say that traditional devices greatly didn't affect very much these types of frequency. Concerning contemporary devices, the graphs showed a considerable decrease in all the wave band, especially on high frequencies that disappeared beyond 6 kHz. This decrease is less important on the bass and medium frequencies.

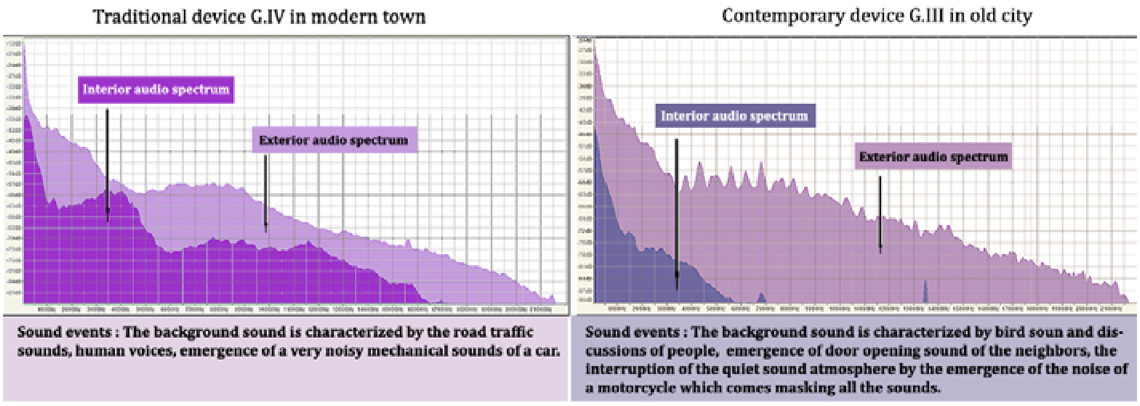

Figure 10. Superposition of interior and exterior Audio Sound Spectrums.

By this first spectral analysis, it must be pointed out that the studied traditional and contemporary devices affect differently the sound waves. This analysis was deepened by the Transfer function method. The work concerned four *gannariyyas*: two traditional devices (G.I and G.II) and two contemporary devices (G.III and G.V). Then, the transfer functions were superposed to facilitate the comparison [Figure 12].

We also tried to define some examples of sounds on the frequency band. We specified their physical characteristics by their spectrum of amplitude. The chosen sounds were motorcycle, bird, human speech and ambulance siren [Figure 11].

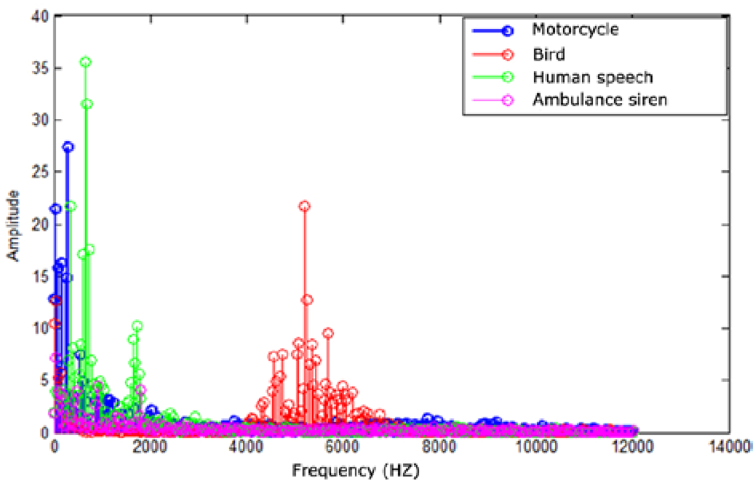

Figure 11. Spectrum of Amplitude of sounds: motorcycle, bird, human speech and ambulance siren.

The spectrum of amplitude of the studied human sound showed that it covers a frequency band [250H-3 kHz]. The spectrum of the considered bird sound proved that it is rich with high frequencies [4 kHz-7 kHz]. The motorcycle sound has low frequencies according to its spectrum of amplitude [0-250Hz].

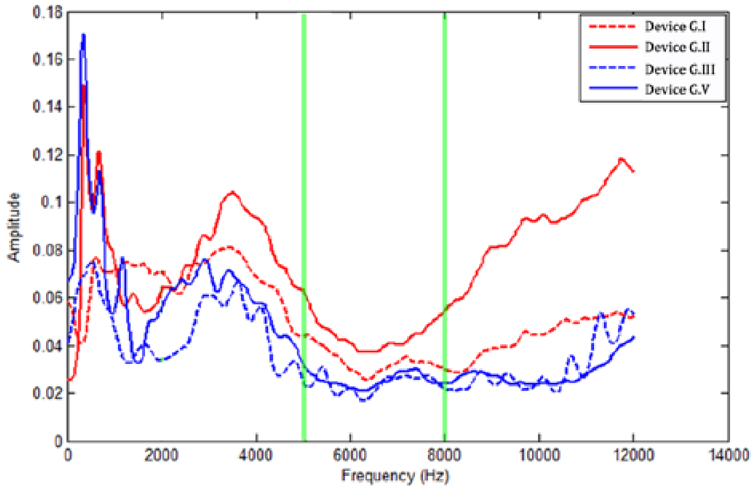

Figure 12. Transfer functions of devices G.I, G.II, G.III and G.V.

According to the appearance of different curves, the analysis was done on three areas:

- <5 kHz: several possible structures, particularly enhancement on the human sound band (250 H-2 kHz).
- [5 kHz-8 kHz]: same decrease for both types of *gannariyya*.
- >8 kHz: the high frequencies are present for the traditional *gannariyyas*. However, these frequencies are low for new *gannariyyas*.

The results obtained from the transfer functions and those reached by the first frequency analysis join. The influence of the traditional *gannariyyas* and its reproductions over the different frequencies is confirmed through this second stage of analysis. Indeed, the studied *gannariyyas* filter the sound signal on the entire frequency band focusing on particular frequency bands characteristic of some sounds. We also noticed an enhancement in the speak band (250h – 3 kHz) for both cases. The traditional examples seem to let entering the high frequencies such as the natural sound of birds which is a high frequency and can exceed 8 kHz. However for the new devices, the filtering is considerable on the high frequencies.

4.3. Users' perception

The interviews with users showed a gap in the qualification of the sonic ambiances in the receptive fields. In the medina or in the modern city, the users of the old devices judge their space noisy (examples: testimonies of the user 2 and 4). In spite of the presence of the noisy vehicular sounds, the users of the new device consider their space quiet (example: testimony of user 5). This result confirmed the sound insulation offered by the contemporary devices that has been proved by the audio sound measurements.

> This space is the office of my boss, but I spend most of my time here working. I appreciate this space especially for the light ambiance, (…). However, I find that it is **noisy, I hear a lot of sounds: discussions** of people, **screaming**, the **laughs** of children, the **carts, tractors**, etc. I understand all the discussions and I find it amusing when I take a little break. But, these sounds become annoying when I try to concentrate in my work. In fact, the **sounds are well heard; I have the impression to be outside** (…). I would say that the **sounds are now part of this space**. (User 2, trainee lawyer)

> I don't stay for a long period of time in my boss's office. (…) I **live the sonic ambiance of this space through my headphones**. My boss dictates me the letters that I have to write by speaker (…). When he speaks, **I hardly badly hear his voice** even if I use my headphones. His **words are mixed with exterior sounds: the traffic sounds** (car, car or other), **discussions of men**. Sometimes, I ask him to repeat the phrases. (User 4, secretary of a lawyer)

> (…) I arranged this room to a living room; all the furniture was custom designed because the standard furniture does not fit into the dimensions of the *gannariyya*. **I think that it is a very calm space. I open the shutters of the *gannariyya* from time to time to listen to the outside animation**. (…) I remember last year in the Ramadan month, musical evenings have been organized. So I took advantage of the show **watching people without anyone seeing me**, because I'm veiled, and then **I listened to good music. It was a real distraction** (User 5, housewife)

The testimonies of users 2 and 4 relating to old *gannariyya*s attested that the human voice is much perceivable. This result confirms the results obtained from the analysis of the transfer functions which testify to the enhancement of the human sound band. The significance of the human sounds for the perception can be explained by the fact that this type of sound source is understandable (Leobon 2011)[18]. This sound is more audible for the human perception in terms of phonetics than the sound of car horns or animals for example.

18. This interpretation is based on the sound classification made by Alain Leobon. He identified six sound sources as references: background sound, mechanical activities, human activities, human presence, language and

5. Conclusion and limit of the research

Using an ambiantal multidisciplinary approach, we appealed to the skills of engineer and architect. It has enabled us to handle different objective, subjective data to study the sonic ambiance provided by of the architectural device *gannariyya*. We also deduced that the simple human perception doesn't allow characterizing this sound atmosphere. It must be supplemented by the companions of sound measurements and the treatment of the physical signal by specialized softwares.

Our research protocol has been applied on two types of *gannariyya*s built with different materials and implanted in two different urban contexts. The sonic ambiance produced by the three traditional *gannariyya*s, located rather in the medina or in the modern city, is the same. The sonic ambiance generated by the three contemporary *gannariyya*s is similar too but contrasting with the old devices. We can say that the new constructive materials changed the original sonic characteristics of the traditional device *gannariyya*.

This study was conducted on a sample of only six *gannariyya*s, and the frequency analysis is still incomplete, especially *gannariyya*'s sonic response against other types of sound sources must be thorough in order to generate architectural conception rules. The acoustical analysis can be supported by the simulation of sound phenomenon using acoustic restitution such as I-Simpa platforms or Acoustica software.

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communication, natural sounds. For this case, human sound is a source of language and communication because it is a highly significant sound.

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