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Exploring the Multisensory Interaction between Luminous, Thermal and Auditory Environments through the Spatial Promenade Experience: A Case Study of a University Campus in an Oasis Settlement

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Abstract: This paper aimed to develop a multisensory approach in a university campus, based on quantitative and qualitative approaches, investigating sense walk experiences (thermo-visual sound walk) under interactions of luminous, thermal, and auditory environments. The study was conducted in October 2021, in Chetma university campus in Biskra city, southern Algeria, which remains a famous oasis settlement of arid regions over the country. A comparative and correlation analysis was performed between the physical dimensions collected through a walking experience in three campus routes (outdoor, semi-outdoor and indoor). In addition, a multisensory survey of the walking experience on perceptual dimensions was evaluated in parallel to the empirical contribution. The paper shows that walkers' thermal levels were balanced between neural and slightly hot in different spatial aspects. The glare was almost unperceived regarding the luminous conditions in the study site. The auditory experience reveals that the conducted points were generally quiet and well placed for educational requirements. Findings also show a strong relationship between the physical dimensions of the luminous and auditory environment. Furthermore, the findings suggest that the thermal and luminous environments are more perceptible than the auditory environment for the walkers of the outdoor and indoor routes. In contrast, the semi-outdoor route is often perceptible by the perceptual dimensions of the luminous and auditory environments. The findings on sensorial thresholds and spatial adaption are essential for the educational practices' architectural and urban strategies for the Saharan cities and oasis settlements.

Keywords: sense walk; multisensory assessment; thermo-visual sound walk approach; physical dimensions; perceptual dimensions; university campus promenades; oasis settlement

1. Introduction

Oasis settlements are generally considered common entities of human settlements in the desert [1] or semi-desert regions. Oases are often perceived as places that are in contrast with their environment [2] because they are seen as a particular landscape, composed mainly of water and palm trees surrounded by a sandy desert [3], but also as an overlap between a human settlement with a cultural area in a desert-scape. However, in the scientific literature of architecture, there is a lack of works that focus on the African context [4], and especially on that of North Africa, as the case of oasis regions that are generally characterized by an arid climate, cold in winter and very hot in summer [5]. The

Saharan region of Algeria, where the oases are located, is characterized by a semi-arid climate [6,7], with clear and sunny skies throughout most of the year. For this reason, these areas have sufficient daylight throughout the year, resulting from the totality of visible radiation from the sky and the sun during the daytime hours [8]. Currently, African Sahara oases, especially in Algeria, are increasingly urbanized. Still, unfortunately, their spread has not been shaped in the surrounding desert but rather in the dense and vibrant palm groves [9]. As a result, oasis settlements face several environmental challenges, including climate change, which will make them unbearably hot and unlivable within a few decades [10]. This poorly controlled urbanization strategy will also cause the disappearance of Algerian oases' calm and tranquility [11]. In line with the United Nations Sustainability Goal 11, which aims to make human settlements inclusive, safe, resilient and sustainable, and as the role of multisensory perception of the surrounding environment has become a universally recognized reality [12,13], it is essential to seize the opportunity of investigating these oases' built environments both in terms of architectural and urban spaces, especially since understanding the complex interaction between human perception and the physical environment of the oasis remains a challenge, given the lack of knowledge in the scientific literature.

The physical environment is complex and composed of many factors that represent the space's ambiance because this ambiance is considered a combination of multiple visual, thermal, audible and olfactory perceptions offered by a physical environment for persons at a given time [14]. From this, the perception of space is a multifaceted process in which persons direct their behavior in the environment under the influence of sensory stimuli [15], namely auditory, thermal and visual. However, the combined multisensory interaction between these stimuli and how it affects the occupant's perception and use of the space is not fully understood [16], especially for those users walking in these architectural spaces. This is a crucial issue if we wish to understand how occupants walking in architectural spaces may react to their multiple sensory entries mainly affected by the physical environment. For about thirty years, ambiances derived from experiences of the sensory world have been of increasing interest to researchers from various disciplines, including those interested in evaluation from experiential walks [17], where sound walks [18–20], visual walks, tactile walks [21], light walks and smell walks [22] are considered as examples of sense walking that are based mainly on a particular sense at a time to focus on daily life [23]. In one such attempt, studies have sought to examine the sense walks of walkers in outdoor spaces through the use of combined sound walks and light walks [24,25], while other research aims to make a multisensory representation of physical ambiances (light, thermal and acoustic) [14,26] in order to propose translating over time the experienced sequences of an urban walk through indoor and outdoor public spaces [27]. On the other hand, few studies have focused on the sense walks approach in oasis environments through the sound walk experience in outdoor public spaces [2,11]. Furthermore, no research has been undertaken on the issue of the perception of occupants walking in outdoor, semi-outdoor and indoor spaces at the same time, depending on the physical environment factors.

In the context of the Ziban (an oasis in Berber) of Biskra, which is considered one of the most famous oases in Algeria [28], university campuses are considered the most important institutions that participate in improving the socio-economic level of these Saharan cities. Moreover, the university campuses are also regarded among the few oasis establishments that allow researchers to make a multisensory evaluation of walkers of its outdoor, semi-outdoor and indoor spaces simultaneously. Indeed, one of the most critical issues in the design of these institutions is the recognition and integration of relevant walkability elements in the planning of the university campus [29]. Regarding the outdoor spaces of university campuses, there are guidelines in the scientific literature concerning the design of these spaces to make them more friendly for sustainable mobility modes such as cycling [30] or walking [31]. As far as sense walks experiences on university campuses, it is noted that only sound walks experiences have been found [32–35]. Therefore, through the use of a combined visual walk, sound walk and thermal walk experience (thermo-visual sound walk), the main objectives of this study are:

1. To evaluate the physical and perceptual dimensions of the indoor, semi-outdoor and outdoor luminous, thermal and auditory environment of a university campus located in the oasis of Biskra;
2. To examine if there are correlations between the physical dimensions;
3. To explore whether there are correlations between the perceptual dimensions of the environments of these spaces.

2. Methodological Approach

In order to evaluate and analyze the multisensory perception of walkers in the spaces of the university campus Chetma of Biskra, which contains the Faculty of Humanities and Social Sciences and is located inside Biskra oasis settlement (see Figure 1), two field studies were conducted after the realization of three promenade experiences. Three groups of students participated in these experiences, following the sense walk approach, mainly the visual walk, sound walk and thermal walk (thermo-visual sound walk). Each group's participants walked along a different route: an outdoor route, a semi-outdoor route and an indoor route. The first study was based on an objective approach using several in situ measurements of the physical dimensions of the environment, recorded during the realization of the different walks. The second was based on a subjective approach, based on in situ questionnaire investigations carried out after each walk experience.

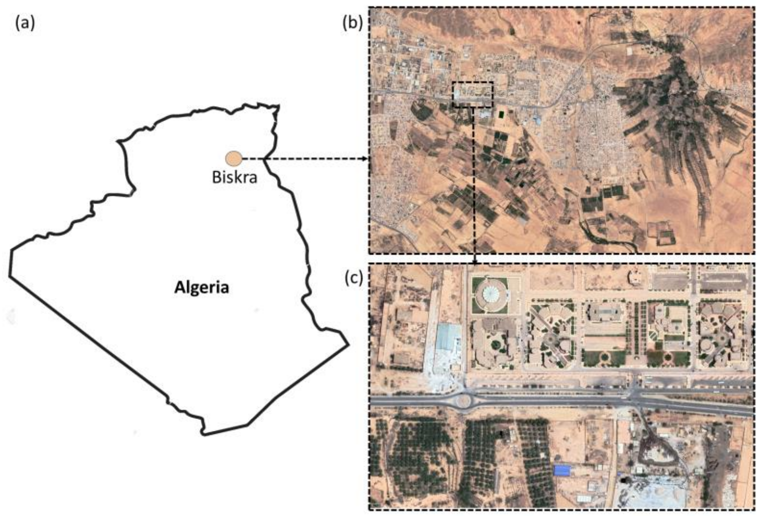

Figure 1. Localization of the Chetma university campus: (**a**) Algeria, (**b**) Biskra city, (**c**) Chetma university campus.

2.1. Physical Context

Following the nature of the campus spaces, three routes were considered in this research: an outdoor route, a semi-outdoor route and an indoor route. The three routes studied in the Chetma University campus have been presented in Figure 2. Figure 2a shows that the outdoor promenade starts with an open space on one side (Zone A), followed by an open space with pergolas on both sides, as well as vegetation and fountains (Zone B), and then a space with a parking lot on one side and with vegetation and fountains on the other side (Zones C and D). The point P6, located between zones E and F, and considered part of the promenade, passes through the U-shape formed by two very close blocks. In point P7, located between Zones F and G, the building morphology is also in a U-shape, but with a slightly greater distance between buildings than in P6. Point P10 represents a covered passage that leads to a large reception hall that gives access to the point P11, which is located in a large courtyard surrounded by educational and administrative blocks. It is interesting to note that the sky view factor (SVF) values calculated in the different points of this external route are in the range of 0.127 to 0.871 (±0.213)—see Figure 3. In the second route, referred to as the semi-outdoor route, from point 1 of zone A, the walker passes through a column gallery that surrounds a large courtyard and connects the lecture halls, the administrative blocks and pedagogical blocks to the arrival point, which is located in the reception hall P24, zone E—see Figure 2b. In the indoor route presented in Figure 2c, the walk begins on the ground floor in a corridor that serves classrooms on two sides, then by a staircase in point 5, characterized by the presence of a large glass window, where the walker passes to the first floor, where he can continue his route in zone B. Zone C also begins with the presence of three large windows, then a long corridor with classrooms on two sides as in zones A and B. Zone D is defined as a long corridor with large classrooms on both sides, with the presence of three zenithally openings all along the corridor. Afterward, the walker can go down a staircase that opens onto a large glass window to arrive at the RDC in zone E.

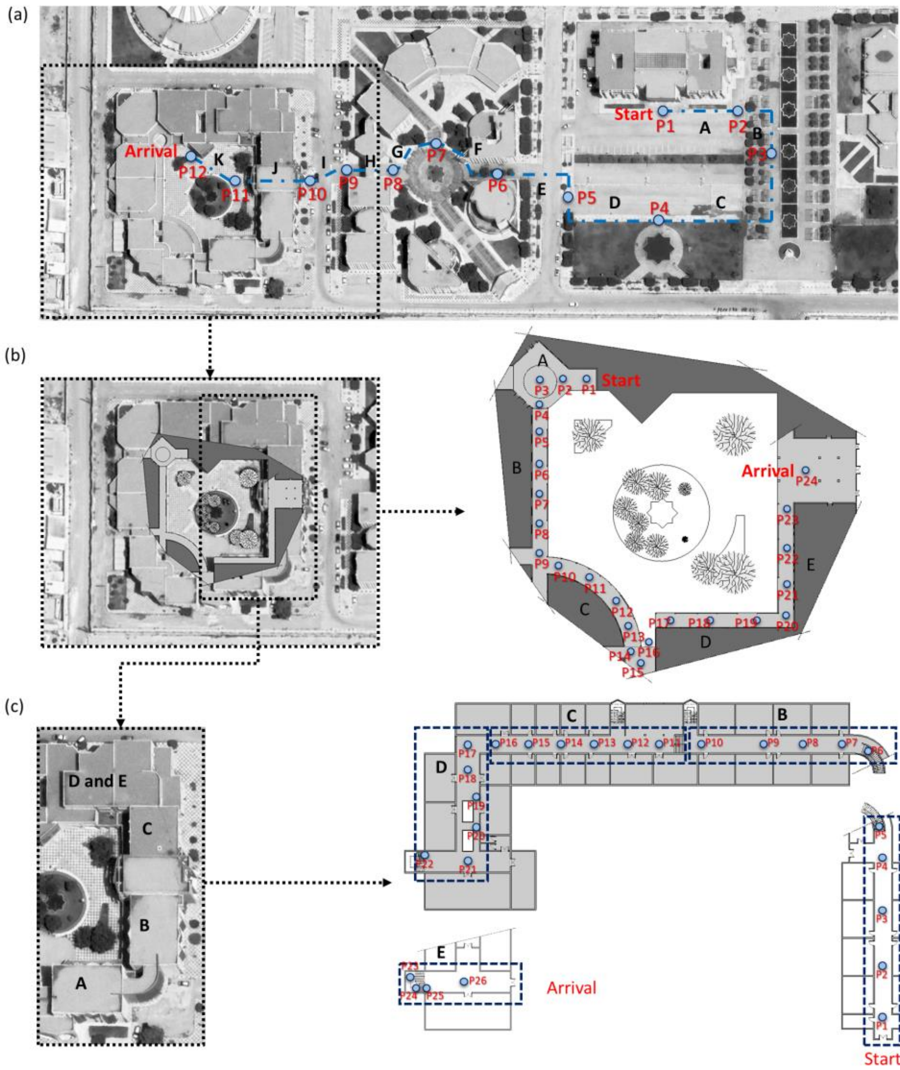

Figure 2. Walking routes in the Chetma University campus: (**a**) outdoor route, (**b**) semi-outdoor route, (**c**) indoor route.

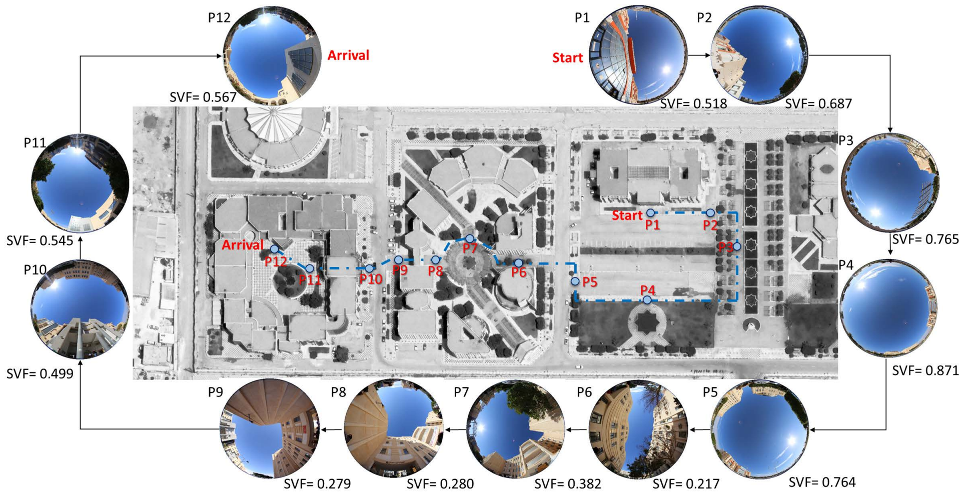

Figure 3. Synthesis of the sky view factor.

2.2. Stage 1: Objective Approach and Materials Used

The first study was based on a quantitative objective approach that was mainly based on the realization of in situ measurements of the different physical dimensions of the environment of the three routes (outdoor, semi-outdoor and indoor), during the thermo-visual sound walk experience, in order to evaluate their distributions on the space during the realization of the different promenades, and to verify if there are significant correlations between these different physical dimensions, corresponding to the luminous, thermal and auditory environment.

To evaluate the physical dimensions of the luminous environment of the different routes (visual walk), this study was based, on the one hand, on the in situ measurements of the illuminance, one of the important indexes in the evaluation of the luminous environment [36], with the use of the "luxmeter kit" compatible with the "Testo 480 multifunctional meter", and on the other hand, on the realization of the fish-eye photos that were taken with a "Canon EOS 6D" camera. This method was completed by the celebration of the captured fish-eye images (CR2 format) by using the plug-in "EvalGlar" integrated into the software "Aftab Alpha", from the illumination values calculated in the field, in order to perform luminance maps, to calculate the Daylight Glare Probability (DGP) [37] and the Average luminance, after the transformation of the captured fish-eye images (CR2 format) to the High Dynamic Range HDR image. This method of HDR image [38] requires three photos (in different exposure conditions) to make the measurements and to determine the luminance maps [39,40].

For the evaluation of the audible environment during the sound walk experience level, the measurement of the Sound Pressure Level (SPL) was carried out during the execution of the sound walk. On the other hand, a measurement campaign was carried out using a sound level meter "Landtek SL5868P", with a temporal (Fast) and frequency (A) weighting in order to measure the Equivalent Sound Pressure Level (Leq1min) [41], known as A-weighted equivalent sound pressure level (LAeq, T) [42], while also taking into account the Percentile Noise Levels (L10, L50, L90) [43]. In the field, a series of binaural sound recordings [44,45] were made using a "Zoom H4" sound recorder, coupled with a "Soundman OKM II Classic" binaural in-ear microphone. Then, the software "Sound Tools Extended (STx)", developed by the Acoustics Research Institute of Vienna, was used to analyze and extract spectrograms from the recorded soundtracks. This step was done because the spectrogram is generally considered as an acoustic image that gives a visual translation of the recorded soundscapes [46].

The Multifunction Meter (Testo 480) was also used to measure the thermal environment dimensions, including ambient air temperature (Ta), relative humidity (RH) and wind speed (Va). The wind speed results were ignored, as they are all below 1.2 m/s for the different routes. However, to collect more information on the outdoor route environments, three dimensions—Ta, RH and Va—were used with the fish-eye images captured towards the sky to measure the Mean Radiant Temperature (Tmrt) and Physiologically Equivalent Temperature (PET). The calculations of Tmrt and PET and the sky view factor (SVF) were done by the software "RayMan Pro". This method has been widely used in the scientific literature [9].

2.3. Stage 2: Subjective Approach and Used Questionnaire

The second study was based on a subjective approach, which was based on the comparison between the evaluation of the Semantic Difference Analysis (SDA) of the luminous, thermal and audible environment from the field questionnaire investigation, which was completed after the realization of the three routes (outdoor, semi-outdoor and indoor), from the thermo-visual sound walk experience in order to evaluate the multisensory perceptual dimensions of each of the outdoor, semi-outdoor and indoor environments of the studied university campus, and to verify the correlations between the different attributes that reflect this multisensory evaluation.

The questionnaire was designed based on 14 different attributes (see Table 1). The first six attributes correspond to the evaluation of the luminous environment, and they are related, respectively, to Uniformity, Brightness, Contrast, Glare, Concentration and Pleasantness. The concentration function and the Attention-Distraction attribute were inspired by the vocabularies of the contrast variables presented in Demers et al.'s works [47,48]. The attributes from n7 to n10 correspond to the soundscape evaluation, where they present the Pleasantness, Eventfulness and Familiarity obtained by Axelsson et al.'s study [49]. The attributes of the thermal environment evaluation—in particular, n11 and n12—were obtained mainly from the questionnaires used in previous studies, such as Hot-Cold, that was used in a thermal sensation vote (TSV) [50,51], and the modified thermal sensation vote (mTSV) [52,53], Humid-Dry, that was used in a humidity sensation vote (HSV) [54], while the attributes n13 and n14 represent, respectively, the Satisfaction and Pleasantness of the thermal environment. For multisensory evaluation, this study proposes a rating scale from 3 to −3 for the different attributes of the questionnaire. The data analysis was performed using the Statistical Package for the Social Sciences (IBM-SPSS) software by performing a principal component analysis (PCA) of the data of the semantic differences analysis of the multisensory evaluation of the different promenades (outdoor, semi-outdoor and indoor). This analysis is widely used in the recent scientific literature, especially in studies interested in soundscape evaluation [55].

Table 1. Questionnaire for multisensory evaluation.

	N		Very	Fairly	Little	Neutral	Little	Fairly	Very	
Luminous environment	1	Uniform	3	2	1	0	−1	−2	−3	Non-Uniform
	2	Bright	3	2	1	0	−1	−2	−3	Dark
	3	Contrast	3	2	1	0	−1	−2	−3	Low contrast
	4	Glaring	3	2	1	0	−1	−2	−3	No glare
	5	Attention	3	2	1	0	−1	−2	−3	Distraction
	6	Pleasant1	3	2	1	0	−1	−2	−3	Unpleasant1
Sound environment	7	Exciting	3	2	1	0	−1	−2	−3	Monotonous
	8	Chaotic	3	2	1	0	−1	−2	−3	Calm
	9	Eventful	3	2	1	0	−1	−2	−3	Uneventful
	10	Pleasant2	3	2	1	0	−1	−2	−3	Unpleasant2
Thermal environment	11	Hot	3	2	1	0	−1	−2	−3	Cold
	12	Humid	3	2	1	0	−1	−2	−3	Dry
	13	Satisfied	3	2	1	0	−1	−2	−3	Dissatisfied
	14	Pleasant3	3	2	1	0	−1	−2	−3	Unpleasant3

2.4. Participants

In this study, the participants in the three sense walk (thermo-visual sound walks) experiences were one hundred and eighty-five (185) students from the Faculty of Humanities and Social Sciences whose age categories ranged from 19 to 32 years. They were grouped into three groups, corresponding to each promenade experience. The first group participating in the outdoor promenade comprised 81% females and 19% males. The second one, which participated in the semi-outdoor walking, comprised 76% females and 24% males. Finally, the third group that participated in the indoor promenade experience was formed by 94% of females and 6% of males.

3. Results

3.1. Stage 1: Physical Data Analysis: On-Site Measurement through Spatial Promenade Experiences

The first stage of this research focuses, firstly, on the distribution of physical environmental dimensions as a function of space, during outdoor, semi-outdoor and indoor promenades. Secondly, it also concentrates on a Pearson correlation study to verify the associations between the different physical dimensions of the environment.

3.1.1. Distribution of the Physical Dimensions of the Environment during the Walks

The distribution of illuminance, sound pressure level, air temperature and relative humidity as a function of space from the walking experience in the different routes (outdoor, semi-outdoor and indoor) is presented in Figure 4. Regarding the dimensions of the luminous and acoustic environment, it is observed in Figure 4a that the outdoor walkers' route is characterized by illumination levels that vary between 217 lux and 1281.83 lux, with an average value of 563.63 lux (±165.64 lux) between the different route zones. The SPL values vary between 52.80 dB and 77.60 dB, with an average value of 59.20 dB (±5.85 dB), while Figure 4b shows that average illuminance levels of 742.92 lux characterize the semi-outdoor route, with a standard deviation of 358.22 lux and average SPL values of 65.24 dB (±5.32 dB). Figure 4c indicates that the indoor route is defined by average illuminance levels of 167.97 lux, with a standard deviation of 147.08 lux and average SPL values of 61.68 dB (±4.97 dB).

In order to evaluate the thermal atmosphere of the different courses outdoor, semi-outdoor and indoor, Figure 4 also presents the values of the ambient air temperature and relative humidity, while Figure 5 shows the Tmrt and PET levels during the outdoor route. The ambient air temperature and relative humidity values during the outdoor walk are shown in Figure 5. In Figure 4a it is seen that the ambient air temperature recorded in the outdoor walking route is with an average value of 21.07 °C (±1.05 °C), linked to an average relative humidity of 44.18% (±2.48%). During the outdoor promenade, the thermal comfort stress level of the walkers is considered neutral (no thermal stress) to slightly warm (slight thermal stress) [56], where the PET values range from 17.48 °C to 34.74 °C with a mean value of 25.44 °C and a very high standard deviation of 5.64 °C. The walkers' discomfort is due to direct exposure to solar radiation, especially in zones A, B, C, D and E. In contrast, in the other zones that are shaded by trees and buildings, there is a significant difference of 9.79 °C between the Tmrt values, concerning the outdoor route zones, which range from 16.12 °C to 46.42 °C, with an average of 33.24 °C. It is seen in Figure 4b that the values of Ta recorded in the semi-outdoor route are higher than those of the outdoor route, where it is found that the average value of Ta of this route is 21.75 °C, with a standard deviation of 5.56 °C, along with a mean value of relative humidity of 44.32% (±5.53%). Figure 4c shows the lowest values of ambient air temperature recorded in the indoor walk experiment, compared to the other promenades, where the average value of Ta was 19.36 °C (±0.51 °C), with an average RH of 49.14% (±0.68%).

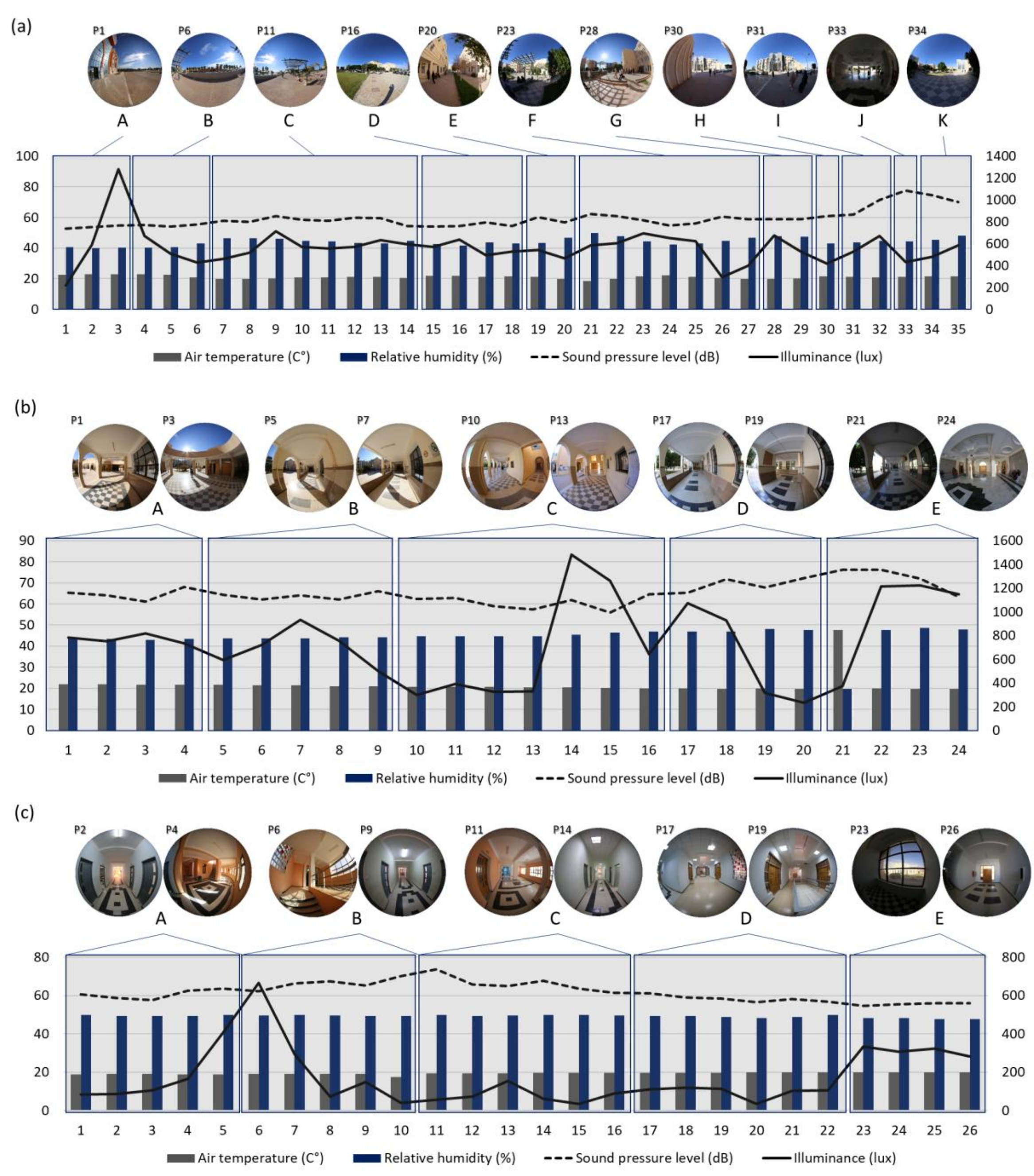

Figure 4. Representation of the physical dimensions' distribution with a few fisheye photographs captured from space: (**a**) outdoor promenade, (**b**) semi-outdoor promenade and (**c**) indoor promenade experiment.

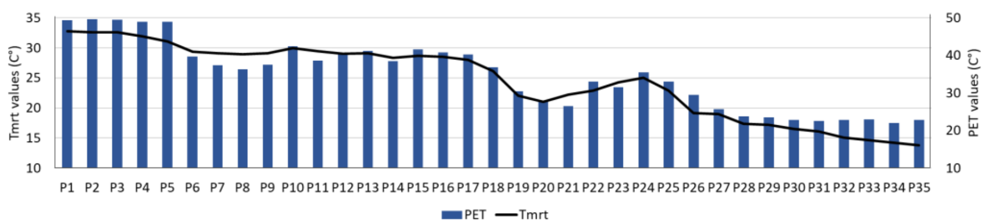

Figure 5. Tmrt and PET values during the outdoor promenade.

The physical dimensions of the luminous atmosphere (DGP and average luminance) are presented in Figure 6 to evaluate the visual perception of the outdoor, semi-outdoor and indoor walkers. Figure 7 presents the luminance maps of these promenades to represent the visual experience by the luminance distribution in the 180° field of view. It is seen in Figure 6a that the glare phenomenon is imperceptible most of the time for the walkers of the outdoor route because the DGP values are very low, where they are varied between 0.019 and 0.39 (±0.13) with an average of 0.13. However, in zones B and C, from point 4 to point 12, the walkers can perceive the glare, but mostly it is not disturbing for them because all the DGP values do not exceed 0.4. On the other hand, the outdoor route's luminous environment is considered non-homogeneous because the average luminance values vary between 308.30 cd/m^2 and 3200.10 cd/m^2 with a very high standard deviation of 789.47 cd/m^2. This non-homogeneity can negatively affect the visual sensation of the walkers passing through zones B and C of the outdoor route, more precisely from point 4 to point 12—see Figure 7a. Figure 6b shows that the DGP values of the semi-outdoor route environment vary between 0.004 and 0.177; this confirms that the glare phenomenon is mostly unperceived by the walkers of this route. The average luminance values vary between 116.97 cd/m^2 and 1076.64 cd/m^2 (±259.39 cd/m^2), with a low average value of 390.04 cd/m^2—see Figure 7b. Moreover, it is also observed in Figure 6c that the luminous environment of the indoor route does not negatively affect the quality of vision of the walkers through the phenomenon of glare, since the DGP values vary only between 0.002 and 0.080 (±0.015). The average luminance values are also very low, varying between 56.13 cd/m^2 and 746.17 cd/m^2, with an average value of 166.33 cd/m^2 (±140.94 cd/m^2)—see Figure 7c.

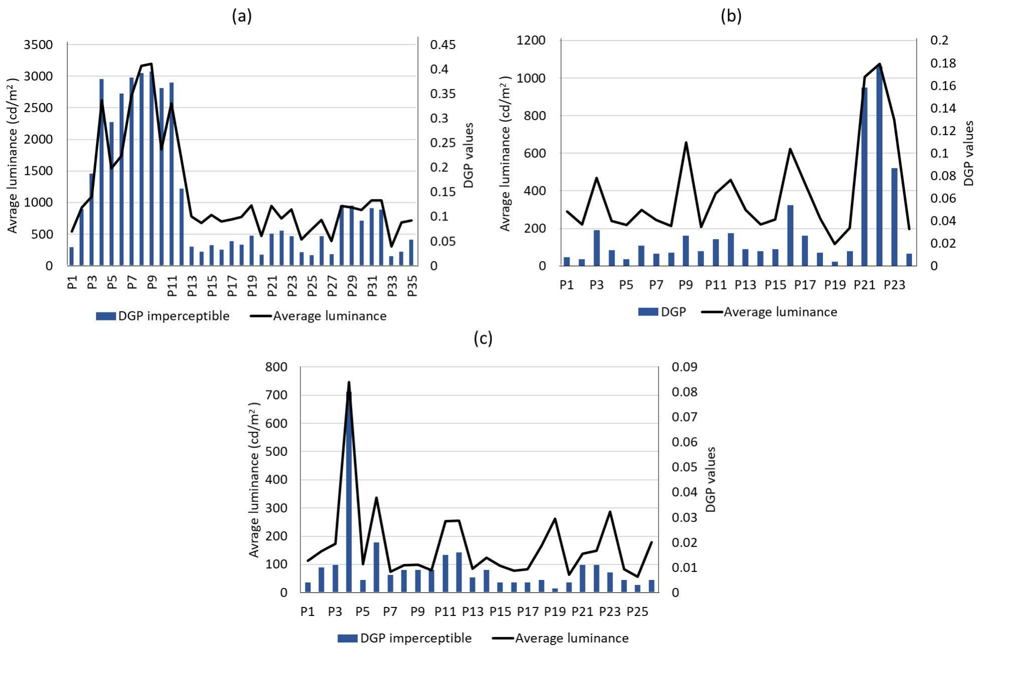

Figure 6. Average luminance mean values as a function of each promenade: (**a**) outdoor, (**b**) semi-outdoor, (**c**) indoor.

To evaluate the audible perception of the outdoor, semi-outdoor and indoor route walkers regarding the noise level, Figure 8 presents the L10, L50, L90 and Leq index values. Figure 8a shows that the noise survey during the promenade on the outdoor route indicates that although the calculated Leq values varied between 52.84 dB and 78.42 dB (± 5.94 dB), the acoustic environment along this outdoor route is perceived as quiet by the walkers, since the average Leq value is 59.40 dB—less than 66 dB, which is the recommended noise limit in urban areas [57]. This is also confirmed by the L10 calculated values, where only for about 10% of the time the sound pressure level is higher than the values of L10, which range from 53.51 dB to 81.25 dB (±6.30 dB), with an average of 60.45 dB. Thus, the remaining time has sound levels below this average (60.45 dB), while the 10% of the time with the highest sounds is probably due to occasional or intermittent events. Therefore, this outdoor route is considered a calm acoustic environment. The values of L50, representing medians of fluctuating noise levels, varied from 52.83 dB to 77.76 dB (±5.87 dB) with an average of 59.21 dB, while the L90 values, which represent the ambient level of a sound environment, ranged between 52.09 dB and 73.80 dB (±5.53 dB) with an average of 57.95 dB. Moreover, Figure 8b shows the absence of noise disturbing for the semi-outdoor walkers because the average value of Leq calculated is equal to 66.17 dB (±5.49 dB), the same as the recommended limit sound level in urban environments (<66 dB), where the noise environment does not cause a danger for the walkers. The mean values of L50 and L90 also fell within this non-dangerous zone (>66 dB), by 65.04 dB (±5.47 dB), and 62.17 dB (±5.38 dB), respectively. The average value of L10: 68.58 dB (±6.01 dB) shows that only 10% of the time spent during the route is considered tolerable for walkers. Furthermore, Figure 8c shows that the indoor route environment is quiet and safe for walkers, where the calculated average Leq value is 62.06 dB (±5.23 dB). The average values of L10, L50 and L90 also belong to the safe zone (>66 dB) of 63.50 dB (±5.78 dB), 61.83 dB (±5.09 dB) and 59.43 dB (±4.28 dB), respectively.

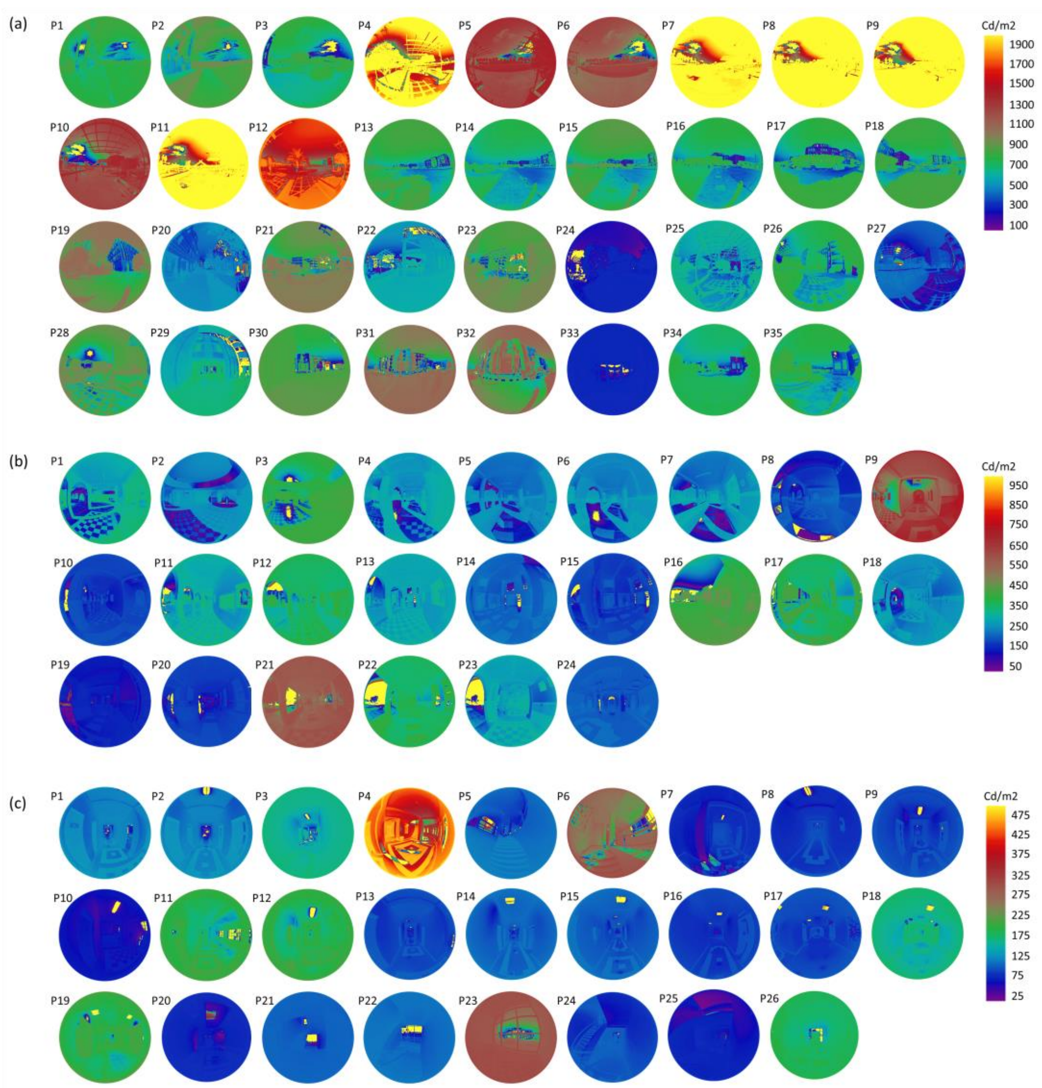

Figure 7. Luminance maps of: (**a**) outdoor promenade, (**b**) semi-outdoor promenade and (**c**) indoor promenade experience.

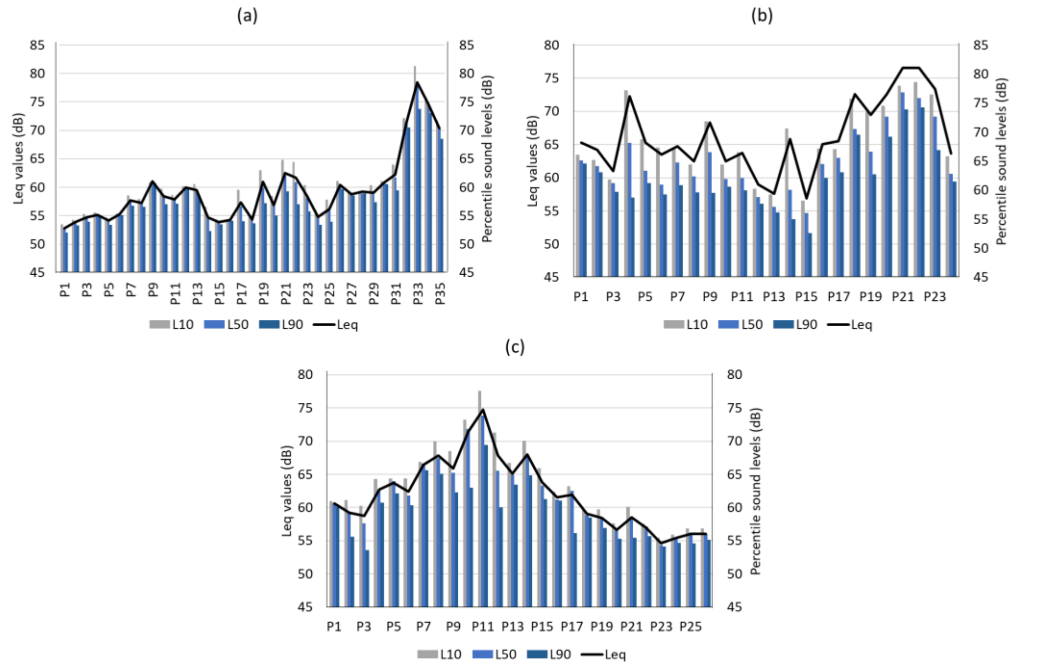

Figure 8. The average values of L10, L50, L90 and Leq indices as a function of each promenade: (**a**) outdoor, (**b**) semi-outdoor, (**c**) indoor.

Spectrograms representing the soundtracks recorded in the three routes are presented in Figure 9. It is seen in Figure 9a that the soundscape of the first section is homogeneous and balanced because no contradictions between the different parts of this soundscape are indicated. This soundscape is marked mainly by the strong presence of human sounds (speech) with different intensities. The biodiversity sounds represent the background sound in this soundscape. The second section of this soundscape is characterized by the water sound emitted by the university campus fountains, which masked the other sounds of anthrophony, geophony and biophony. Afterwards, the soundscape becomes a predominantly shimmering noise with biophonic and geophonic sounds in the background of the soundscapes. Mechanical noise in this sound band is low, in the form of background noise for two short durations, because the road is far from campus, while the low flow and speed of vehicles in the university did not affect the soundscape. Figure 9b shows that the soundscape of the semi-outdoor walk contains two different sonic ambiances, that were mainly human noise and speckle noise. The soundscape was understandable at first; after approaching the lobby, a radical change in the soundscape was marked by an overlay of a large amount of sound information, mainly speckle noise, making the soundscape in this area more animated compared to the first part. The soundscape of the indoor promenade presented in Figure 9c shows that it is defined by two sonic ambiances depending on the intensity of the sound events. The first part is characterized by an animated soundscape with the noise of doors, pats and discussions, while the second part is less animated, with less intense sound events.

3.1.2. Correlations between the Dimensions of the Physical Environment

Table 2 summarizes the correlations between the different physical dimensions collected by the three routes to verify the association between these different variables, which represent the luminous environment (Illuminance, DGP and luminance average), the thermal environment (Ta, RH) and the auditory one (SPL, Leq, L10, L50, L90). Table 2 shows a significant correlation between the dimensions of the luminous environment, especially the luminance average with DGP and illuminance with correlation coefficients of 0.953 and 0.247, with p-values of 0.000 and 0.023, respectively. Concerning the association between the luminous and acoustic environment dimensions, the DGP marks a significant correlation of −0.245 (p-value = 0.024) with the L10. Moreover, it is found that the luminance average has significant correlations with SPL, Leq and L10, with correlation coefficients of −0.213 (p-value = 0.050), −0.230 (p-value = 0.034) and −0.264 (p-value = 0.015), respectively. Regarding the relationship between the luminous and thermal environment dimensions, it is found that illuminance, DGP and luminance average have strong correlations with relative humidity, with correlation coefficients of −0.282, −0.298, −0.312 and p-values of 0.009, 0.006 and 0.004, respectively. In contrast, no significant correlation was observed between air temperature with luminous and acoustic dimensions. The air temperature has only a significant correlation with the relative humidity, with a correlation coefficient of −0.894 (p-value = 0.000). Moreover, it is also seen that relative humidity has no significant correlation with the acoustic environment dimensions. Furthermore, strong correlations were found between the physical dimensions of the acoustic environment (SPL, Leq, L10, L50, L90), with correlation coefficients greater than 0.871 and p-values of 0.000.

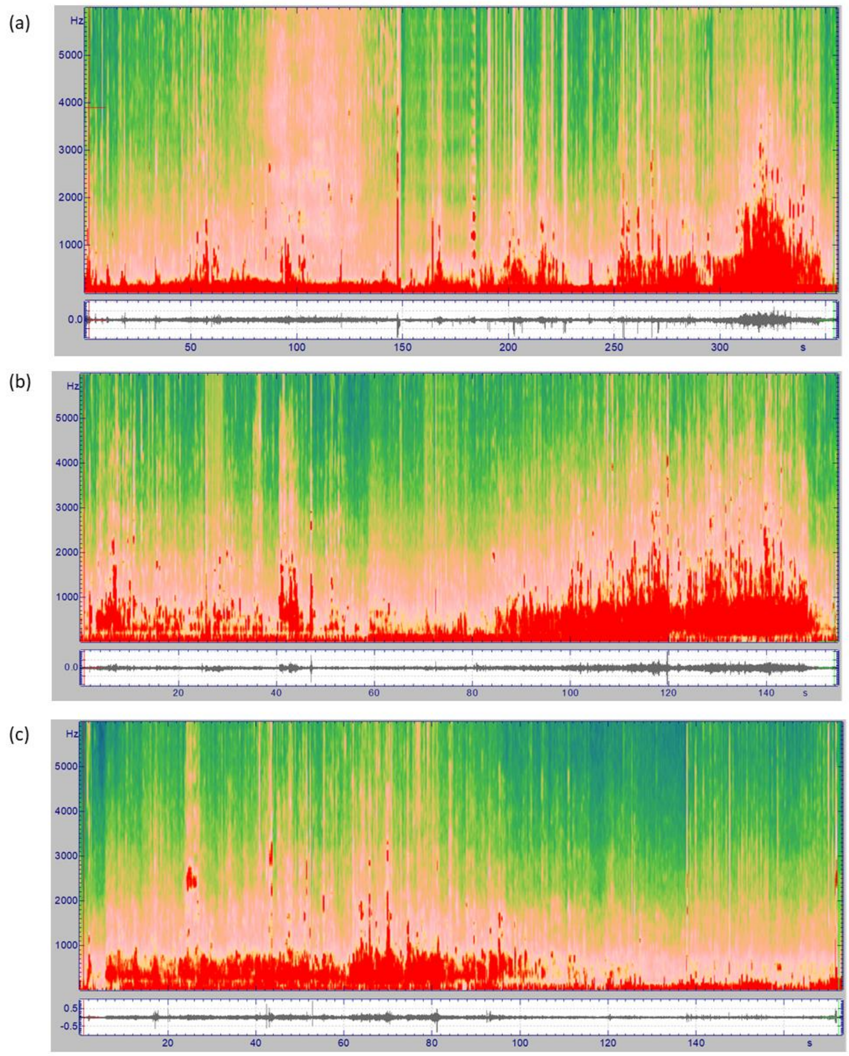

Figure 9. Spectrograms of: (**a**) outdoor promenade, (**b**) semi-outdoor promenade and (**c**) indoor promenade experience.

Table 2. Pearson correlation between physical dimensions (Pearson coefficient [C], Sig. [S]).

	Illum	DGP	Avr Lum	Ta	RH	SPL	Leq	L10	L50	L90
Illum	S C	0.205	0.247 [a]	0.105	–0.282 [b]	0.046	0.071	0.091	0.025	0.031
DGP	0.060	S C	0.953 [b]	0.173	–0.298 [b]	–0.193	–0.210	–0.245 [a]	–0.189	–0.107
Avr Lum	0.023	0.000	S C	0.158	–0.312 [b]	–0.213 [a]	–0.230[a]	–0.264 [a]	–0.210	–0.125
Ta	0.339	0.114	0.150	S C	–0.894 [b]	0.155	0.142	0.119	0.159	0.194
RH	0.009	0.006	0.004	0.000	S C	0.051	0.055	0.067	0.051	0.012
SPL	0.677	0.077	0.050	0.156	0.641	S C	0.993[b]	0.973 [b]	0.997 [b]	0.956 [b]
Leq	0.519	0.054	0.034	0.195	0.616	0.000	S C	0.991 [b]	0.989 [b]	0.920 [b]
L10	0.407	0.024	0.015	0.277	0.542	0.000	0.000	S C	0.964 [b]	0.871 [b]
L50	0.823	0.084	0.053	0.145	0.642	0.000	0.000	0.000	S C	0.951 [b]
L90	0.780	0.330	0.254	0.075	0.916	0.000	0.000	0.000	0.000	S C

[a] The correlation is significant at the 0.05 level (two-tailed). [b] The correlation is significant at the 0.01 level (two-tailed).

3.2. Stage 2: Perceptual Data Analysis: On-Site Questionnaire with Walkers

The second step of this research is based on the comparison between the Semantic Difference Analysis of the multisensory evaluation of the physical environments of the outdoor, semi-outdoor and indoor promenades of the university campus of Chetma, through the evaluation of three groups of students, that correspond to each promenade. Tables 3–5 present the factor analyses used in this study, based primarily on principal component analysis (PCA) as the extraction method, whereas the adequacy of sampling was measured using Kaiser–Meyer–Olkin (KMO), which were 0.69, 0.63 and 0.71 for the three PCA analyses, corresponding to the evaluation of multisensory physical environments of the outdoor, semi-outdoor and indoor promenades, respectively.

Table 3. Factor analysis of the multisensory evaluation of the outdoor promenade environment.

Indices	Factors			
	1 (25.41%)	2 (24.39%)	3 (14.06%)	4 (8.05%)
Humid–Dry	**−0.902**	0.005	−0.091	0.048
Pleasant3–Unpleasant3	**0.895**	−0.001	−0.010	0.038
Satisfied–Dissatisfied	**0.864**	−0.032	0.121	0.006
Hot–Cold	**−0.844**	−0.143	−0.082	−0.094
Contrast–Low contrast	0.100	**0.902**	−0.020	−0.179
Bright–Dark	0.007	**0.901**	−0.067	−0.279
Pleasant1–Unpleasant1	−0.016	**−0.879**	0.067	0.201
Chaotic–Calm	−0.005	0.030	**−0.892**	−0.089
Eventful–Uneventful	−0.027	−0.070	**0.878**	−0.072
Pleasant2–Unpleasant2	0.207	−0.061	**0.652**	−0.048
Exciting–Monotonous	0.330	0.057	**0.350**	0.150
Uniform–Non Uniform	0.038	−0.08	0.026	**0.885**
Glaring–No Glare	−0.066	0.321	−0.066	**−0.731**
Attention–Distraction	0.017	−0.348	−0.071	**0.694**

Table 4. Factor analysis of the multisensory evaluation of the semi-outdoor promenade environment.

Indices	Factors				
	1 (27.26%)	**2 (17.27%)**	**3 (12.23%)**	**4 (9.17%)**	**5 (8.48%)**
Uniform–Non Uniform	**−0.918**	−0.081	−0.080	−0.046	0.010
Bright–Dark	**0.876**	0.165	0.072	0.153	0.059
Glaring–No Glare	**0.861**	0.240	0.021	0.146	0.186
Contrast–Low Contrast	**−0.777**	0.354	−0.062	−0.080	0.098
Attention–Distraction	**0.616**	−0.044	−0.114	−0.164	0.085
Pleasant1–Unpleasant1	−0.481	**0.354**	−0.153	0.034	0.142
Pleasant3–Unpleasant 3	0.253	**0.811**	0.107	−0.028	−0.009
Satisfied–Dissatisfied	−0.137	**0.807**	0.095	0.040	−0.278
Pleasant2–Unpleasant2	0.003	0.014	**0.895**	0.018	0.136
Eventful–Uneventful	0.104	0.169	**0.811**	0.179	−0.192
Chaotic–Calm	−0.060	−0.088	0.016	**−0.877**	−0.162
Exciting–Monotonous	0.039	−0.126	0.244	**0.827**	−0.252
Hot–Cold	0.002	−0.022	0.063	−0.114	**0.900**
Humid–Dry	0.142	−0.459	−0.159	0.171	**0.689**

Table 5. Factor analysis of the multisensory evaluation of the indoor promenade environment.

Indices	Factors			
	1 (28.97%)	**2 (22.42%)**	**3 (14.60%)**	**4 (8.03%)**
Hot–Cold	**−0.941**	0.038	0.009	0.061
Satisfied–Dissatisfied	**0.935**	−0.048	0.013	0.097
Humid–Dry	**−0.931**	0.113	−0.141	−0.023
Pleasant3–Unpleasant3	**0.905**	−0.030	0.091	−0.057
Attention–Distraction	−0.179	**0.868**	−0.051	0.062
Contrast–Low Contrast	0.014	**0.829**	−0.089	0.268
Bright–Dark	0.072	**−0.732**	0.060	0.009
Chaotic–Calm	−0.061	0.117	**−0.901**	0.025
Pleasant2–Unpleasant2	0.034	0.019	**0.895**	−0.085
Eventful–Uneventful	0.097	−0.128	**0.858**	−0.113
Uniform–Non Uniform	0.110	−0.079	0.148	**−0.695**
Glaring–No Glare	0.136	0.517	−0.126	**0.664**
Pleasant1–Unpleasant1	−0.041	−0.482	0.174	**−0.655**
Exciting–Monotonous	0.047	−0.255	0.317	**0.461**

Table 3 shows that the PCA analysis of the multisensory evaluation of the physical environment of the outdoor route resulted in a four-component solution accounting for 71.91% of the variance. Factor 1 (25.41%) is mainly associated with the function of the space's thermal perception, including Humid-Dry, Pleasant3-Unpleasant, Satisfied-Dissatisfied, Hot-Cold, which are related to the sensation of humidity, Pleasantness, Satisfaction and thermal sensation. Factor 2 (24.39%) is generally related to the visual perception of the luminous environment, including Contrast-Low Contrast, Bright-Dark, Pleasant1-Unpleasant, which are linked to the sensation of contrast, Brightness and Pleasantness. Factor 3 (14.06%) is strongly related to the dimensions of soundscape perception including Chaotic-Calm, Eventful-Uneventful, Pleasant2-Unpleasant, Exciting-Monotonous, which are connected to Pleasantness, Eventfulness and Familiarity. Factor 4 (8.05%) is also related to the dimensions of visual environment perception, including Uniform-Non uniform, Glaring-No glare, Attention-Distraction, which are related to Uniformity, Glare and Concentration. From this analysis, it is interesting to note that the main facets of multisensory perception of the physical environment of the outdoor route are the thermal environment (Factor 1) and the luminous environment (Factor 2 and 4) perceptual dimensions, and then the soundscape (Factor 3). This explains why the thermal and luminous environment is more perceptible than the soundscape for students walking in the outdoor route of the Chetma University campus.

Table 4 shows that the PCA analysis of the multisensory evaluation of the physical environment of the semi-outdoor route yielded a five-component solution representing 74.71% of the variance. It is observed that Factor 1 (27.26%) is strongly associated with the dimensions of luminous environment perception, including Uniform-Non Uniform, Bright-Dark, Glaring-No Glare, Contrast-Low Contrast and Attention-Distraction, which are related to Uniformity, Brightness, Glare, Contrast and Concentration. Factor 2 (17.27%) is mainly related to Pleasantness, including Pleasant1-Unpleasant, Pleasant3-Unpleasant and Satisfied-Dissatisfied, which are linked to Pleasantness towards the thermal and luminous environment and to thermal satisfaction. On the other hand, soundscape perception is generally associated with Factors 3 (27.26%) and 4 (9.17%), where Pleasant2-Unpleasant and Eventful-Uneventful indices reflect the Pleasantness and Eventfulness dimensions of the audible environment represented by Factor 3. Chaotic-Calm and Exciting-Monotonous are related to Familiarity presented by Factor 4. Factor 5 (8.48%) is mainly related to the perception of the thermal environment, including Hot-Cold and Humid-Dry, which are related to the thermal and humidity sensation. Interestingly, this analysis shows that the multisensory perception of the semi-outdoor walkers on the Chetma University campus is often mediated by the perceptual dimensions of the luminous and audible environment, which are more perceptible to them compared to those of the thermal environment.

From Table 5, it can be seen that the PCA analysis of the multisensory evaluation of the physical environment of the indoor course yielded a four-component solution representing 74.02% of the variance. Factor 1 (28.97%) is associated with the dimensions of perceived thermal environment, including Hot-Cold, Satisfied-Dissatisfied, Humid-Dry and Pleasant3-Unpleasant. Factor 2 (22.42%) is generally related to the dimensions of visual perception, including Attention-Distraction, Contrast-Low Contrast and Bright-Dark, which are related to Concentration, Contrast, and Brightness. Factor 3 (14.60%) is linked to the soundscape perception dimensions, including Chaotic-Calm, Pleasant2-Unpleasant and Eventful-Uneventful, which are related to Pleasantness Eventfulness towards the audible environment. It is also observed that Factor 4 (8.03%) is mainly related to the dimensions of perception of the luminous environment, including Uniform-Non Uniform, Glaring-No Glare and Pleasant1-Unpleasant, which are associated with Uniformity, Glare and Pleasantness. From this analysis, it is noteworthy that the perception of the environment of the indoor route is similar to that of the outdoor one, where the main facets of the multisensory perception of the student walkers are the perceptual dimensions of the thermal environment (Factor 1) and the luminous environment (Factors 2 and 4), and then those of the soundscape (Factor 3).

4. Conclusions and Discussion

4.1. Synthesizing the Findings

The findings from this study suggest that the thermal comfort stress level of walkers in the outdoor route during the thermal walk experiment are considered neutral and slightly warm (no thermal stress), as the PET values do not move the 34.74 °C [9]. Somewhat surprisingly, the semi-outdoor route is characterized by slightly higher average temperatures than those recorded in the indoor and outdoor routes, and this is possibly due to the effect of the radiant temperatures of the outdoor walls [58], that were very close to the walkers during the walks in this semi-outdoor route.

It is also interesting to note that findings from the visual walk experiment suggest that the glare phenomenon is imperceptible in most cases for walkers on the three routes studied. However, some zones of the outdoor route, particularly zones B, C and D, are marked by the presence of discomfort glare. This discomfort glare [59] is due to excessive brightness, defined by the presence of an excessive luminance range in the field of vision [60], or by extreme differences between bright and dark areas, which is called the contrast effect [61]. However, although the perception of glare has a significant role in the user's visual comfort [39], this discomfort glare causes visual discomfort without necessarily impairing vision.

The findings of the sound walk experiment suggest that the audible environments of the three routes are considered calm for the walkers most of the time, and they do not cause danger for them, because the soundscapes perceived in these three walking experiences are characterized by reliable mechanical noises, with the presence of biodiversity sounds. The absence of mechanical noise in the routes is generally due to the architectural morphology, where the buildings have the role of masks to reduce this type of noise. However, in zones A, B, C and D of the outdoor route, road noise is masked by the sound of water emitted by the fountains that surround the space. This type of natural sound (water sound) can effectively improve the overall quality perceived by people of the soundscapes [62], by masking the road noise. In addition, all types of natural sound perceived in these three routes can have a positive influence [63] on the perception of calm and harmonious sounds [64], so that people may prefer these sounds [65]. On the other hand, the dominant sound on the soundscapes of these three routes is human noise, one of the anthrophony sounds [66–68], including the shimmering which is considered the main sound event that animates the sound atmosphere of the three routes of the university campus of Chetma.

This study also suggests a significant correlation between the dimensions of the luminous environment (luminance average with DGP and illuminance). Strong correlations were found between the physical dimensions of the acoustic environment (SPL, Leq, L10, L50, L90). Moreover, concerning the dimensions of the thermal environment, the air temperature has only a significant negative correlation with relative humidity. Concerning the association between the dimensions of the luminous environment and those of the acoustic one, the DGP marks a significant negative correlation with the L10, while the luminance average presents significant positive correlations with SPL, Leq and L10. Regarding the association between the dimensions of the luminous environment and those of the thermal environment, it is observed that the illuminance, the DGP and the luminance average have strong negative and significant correlations with the relative humidity. On the other hand, no significant correlation was observed between the air temperature and the luminous and acoustic dimensions. Moreover, it is also observed that relative humidity has no significant correlation with the dimensions of the acoustic environment.

In addition, the findings of the PCA analysis explored that the thermal and luminous environment are more perceptible than the sound environment for the students who make outdoor and indoor walks in the university campus of Chetma, because the main facets of the multisensory perception of the outdoor walk are the perceptual dimensions of the thermal (Factor 1) and the luminous environment (Factor 2, and 4), and then those of the soundscape (Factor 3). The semi-outdoor walking route of the university campus of Chetma is often a path for the perceptual dimensions of the luminous and audible environment, that are more perceptible than those of the thermal environment.

4.2. Strengths and Limitations of the Study

The strength of this research is mainly due to its objective and subjective approaches, which were based mainly on a combined experience of three types of sense walk, including visual walk, sound walk and thermal walk (thermo-visual sound walk) in order to evaluate and analyze the physical and perceptual dimensions of the luminous, thermal and auditory environment of the indoor, semi-outdoor and outdoor routes of a university campus located in the Biskra oasis, as well as to determine whether there are associations between the physical dimensions and the perceptual dimensions of the environment of these three spaces. This study is considered a complementary step to the study of Boucherit et al. [69], who investigated the luminous environment in terms of contrast and brightness of the same university campus studied in this research. None of the previously published articles have investigated the multisensory dimension of space through the experience of sense walking in outdoor, indoor and semi-outdoor routes of a university campus located in one of the oases of North Africa.

Our findings are limited to the study of sense walks in a single experiment for each promenade, even though the dimensions of the physical environment also change as a function of time over the long term due to the change of seasons—for example, the thermal sensitivity is seasonally variable from winter to summer [70–72]. Moreover, despite the importance of smell, this study did not consider this type of sense walking [73] because the researchers did not find a method to evaluate the olfactory environment of the different routes quantitatively. Moreover, this research is limited to studying correlations between physical dimensions and verifying perceptual dimension associations. Thus, there remains a gap regarding the determination of the link between the physical dimensions and the participants' qualitative responses.

4.3. Implication on Practice and Future Research

This study allows architects, designers, urban planners and decision-makers to share their insights into the multisensory methods' strategies and their impact on the outdoor practices, especially in arid regions. Regulations, policies and authorities' management should be founded across the on-site sensitive evaluation and the socio-cultural practices for the resilience of the oasis urban system.

Furthermore, the study implication results can lead to revising the spatial configuration within the cities of the oases settlements. Auditory benefit, natural ventilation, indoor thermal improvement, luminous control and shading enhancement are crucial for people's activities, and more specifically for the educational institutions in the Saharan regions. Multisensory applications allow future planners to strongly adapt the built environment within the environmental aspects and rethink the best fit to environmental adaptations and recommendations to design and implement suitable and efficient urban planning elements.

The human being's sensorial dimensions need to be improved and applied to the local strategies. This study provides a wide-ranging reflection about the auditory, luminous and thermal aspects to promote a new operational process for the outside spaces' design and operate throughout the worldwide climate zones and, more specifically, inside the arid urban environments.

The human element is considered as an essential key strategy for governments, that should be considered in early stages in urban and architectural policies. The Algerian government, especially the Ministry of Urban Planning and Housing, the Ministry of High Education and Scientific Research, and the Ministry of Environment, may make an in-depth review relevant to the built environment and the future strategies against environmental conditions changes, in the short-, medium- and long-term periods in Saharan lands, that are becoming more and more vulnerable. Additionally, we believe that architects and urban experts are not the only professionals targeted by this study; environmental scientists can strongly benefit from our key findings, to see beyond the environmental impacts and make recommendations depending on these major changes.

This study invites researchers to explore how architectural or urban spaces' physical and perceptual dimensions can be correlated through the sensory walking approach by using wearable sensors and letting participants use them while walking about.

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