Analysis of the impact of architectural variables on acoustic perception in concert halls

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Abstract

Acoustic quality of a music hall has been a topic of research of great interest over the last century. It has been studied through physical parameters (reverberation time, clarity factor, initial time delay gap, etc…) and also subjective parameters (intimacy, enveloping sound, warmth, etc…). Nevertheless, a concert in an auditorium is a multi-sensorial experience; so that the acoustic perception may be influenced by other non-acoustical parameters.

Therefore, the aim of the present study is to analyze whether architectural variables (visual component) affect acoustic perception in concert halls and quantify this influence.

This analysis is carried out implementing the Semantic Differential method and differentiating among experts and non-experts collectives. A total of 310 subjects participated in a field study in which the human response about acoustic and architectural parameters of 19 concert halls was collected.

Results show that acoustic perception in music halls is influenced by the visual component and acoustic parameters have an influence on the assessment of architecture as well. This relation does not occur due to a conceptual confusion between both kinds of variables; since the entire set of users proved capable of gathering acoustic parameters apart from the architectural ones.

On the other hand, when separating expert users in the musical field from non-expert users, it was found that experts, unlike non-experts, are able to isolate acoustic variables from architecture when evaluating the sound quality of a venue. This means that this collective is not influenced by the perception of architecture when judging the acoustics of a concert hall.

Keywords: Acoustic quality; Music hall; Acoustic perception; Architectural acoustic

1. Introduction

Acoustic perception in concert halls (opera houses, theatres and venues for classical music and orchestra performances) has been a topic of great interest for many years [1-9]. At a certain moment, it was thought that only one parameter was able to explain the acoustic quality of a music hall: the reverberation time [10]. However, later on, researchers came to realize that other physical parameters also influenced acoustic perception such as early decay time [11]; initial time delay gap [5], spatial impression [12], clarity factors [13], gain factor [14] and interaural cross-correlation [1].

Some studies began to relate all these physical parameters to human response and the subjective evaluation they evoke in the listener such as intimacy, enveloping sound, clarity, loudness, balance and warmth [4,5,7,9,14,15]. This fostered the development of psychoacoustics, a new branch which studies acoustic subjective perception. However, attending a concert in a concert hall is a multi-sensorial experience [3,6,8]. This means that many variables may influence concertgoer perception besides acoustics; such as the visual component, temperature, lighting, comfort, or the architecture of the venue. Attending a concert in an emblematic and prestigious auditorium may exert a power of positive suggestion on the audience, even if the acoustics are not excellent: "Acoustics are a bit disappointing but "La Scala" has a great atmosphere and this distracts from the objective perception of acoustics…. testimony of a conductor" [7].

Following this reasoning, a poor environment may cause a negative impact on acoustics perception, even if the sound quality of the concert hall is good. In this line, few studies have analyzed the influence of other non-acoustical parameters on users' assessments of a concert hall [3,6,8], or the influence of the visual component [16]. None of these works, however, has specifically studied the influence of architectural attributes on subjective acoustics perception, or have even quantified this influence.

The present proposal is aimed at analyzing the effect of architectural attributes on the acoustic assessment of concert halls, posing the following questions: To what extent do architectural attributes influence acoustic perception in concert halls? which specific architectural parameters exert this influence? can it be quantified? to achieve our goal it is essential to define the affective significance of concepts in an appropriate way.

Many works have studied concertgoers' subjective responses through questionnaires and tests to evaluate the acoustic quality of concert halls. Some of these experiences have analyzed the response of expert users (professional musicians, acousticians, conductors…) [2-4,7], non-expert users [6,8,17], or both collectives [18]. However, in all these experiences the concepts and attributes for evaluation were always set by experts; thus the mental scheme of non-experts was not taken into account when designing the questionnaires. This approach could lead to erroneous results since non-experts may misunderstand concepts set by experts. In fact, some studies have shown that professional musicians have a different conceptual structure from non-musicians [19-23] making the results difficult to interpret. Moreover, as experts filter the information to assess, some of the parameters appreciated by non-experts may never be evaluated. These specific drawbacks have been tackled by techniques such as the Semantic Differential method (SD).

SD is a tool that allows the affective meaning of concepts to be measured [24]. It was developed by Osgood et al [25] to analyze semantic structures and to quantify the affective meaning of things. This method studies product semantics by means of adjectives and expressions which reflect users' emotional impressions and measures users' perceptions on a Likert scale. It is a standard procedure that assumes an underlying structure in the semantic evaluation of products which it analyses using factor analysis. This technique studies the correlation matrixes for the scores for terms over a set of products. Many researchers have successfully used this technique to investigate users' perceptions of product form in different market sectors: housing design [26], the construction industry [27,28], automotive industry [29], mobile phone industry [30], environmental acoustics [31], or computer rendering [32]. This present work applies SD in the field of concert halls.

This paper aims to analyze the relation between acoustic and architectural variables in concert halls from a perceptual point of view. This analysis uses the SD method and differentiates between experts and non-experts. This will enable us to determine whether the interaction between acoustics and architecture perception occurs in both groups, or whether the collective of experts is able to isolate acoustic perception from architecture.

2. Material and Methods

The methodological development focused on a field study which collected interviewees' evaluations of the stimuli.

2.1. Subjects

A total of 310 subjects participated in the study (74 experts and 236 non-experts). This sample comprised users of concert halls in different towns and cities in the region of Valencia. The selection technique was simple random sampling for non-expert users, who were contacted before the performance at the concert hall. Expert users (professional musicians, acousticians and conductors) were contacted through the chiefs of the auditoria who provided a list of experts willing to participate in the study. Then, simple random sampling was used to select them. Table 1 shows statistical data on the participants.

2.2. Questionnaire

Three blocks composed each questionnaire. The first block gathered objective information on the subject (gender, age, concerts attended per year, kind of music mostly listened to at the concert hall and usual location in the venue). The second block contained subjective information on the perception of acoustic parameters, and the third block contained subjective information on the perception of the architecture. These parameters were expressed through a group of 27 acoustic adjectives and 26 architectural expressions in spanish. The first step to obtain this set of expressions involves collecting as many adjectives as possible (*kansei words*) to describe the product domain [33]. All available sources must be used to obtain the most comprehensive choice of words: scientific papers, specialized bibliography, acoustic journals, magazines and the internet. The aim of collecting as many adjectives and expressions as possible, was to gather a set of words able to reflect any possible perception about a specific acoustic and architectural attribute of a concert hall. The process finishes when no new words appear. According to Schütte et al [33], the final set can vary between 50-600 words depending on the particular field of study. These kansei words form the *initial semantic universe*, which in our case comprised 162 acoustic adjectives and 259 adjectives related to architecture. However this number of words is too large to be included in a questionnaire. Hence, it was necessary to reduce the initial number of words and several techniques can be used for this purpose [34]. In this study the *Affinity Diagram* was used, which groups semantic descriptions according to their affinity [35]. The grouping was made by 2 professional musicians, 2 acousticians, 2 architects and 2 non-expert users as follows: (a) the kansei words were transferred onto post-it notes, so that each note contained only one expression; (b) the notes were grouped by similarity or affinity, the grouping process ended when all the ideas or words were grouped and (c) each group was given a title or heading that represents all the kansei words in the group. The set of expressions finally obtained formed the *reduced semantic universe*, which comprised 27 adjectives related to acoustics and 26 architectural expressions. These were evaluated on a 5 point Likert scale ranging from totally disagree, disagree, neutral, agree to totally agree.

Two new variables were also included to show global user opinion with the expression "Considering the entire set of features I think this is a good concert hall from the architectural point of view" and idem about acoustics. These parameters were also evaluated through the 5 point Likert scale.

2.3. Stimuli

The stimuli for the field study consisted of 19 concert halls (opera houses, theatres and venues for classical music and orchestra performances) located in two regions of the Comunitat Valenciana (Spain) with a long musical tradition: Valencia and Alicante. These concert halls were selected to ensure variety: large concert halls in big cities like Valencia (8.10^5 inh.), Alicante ($3,5.10^5$ inh.), Torrent (8.10^4 inh.), and Gandía ($7,5.10^4$ inh.), and more modest auditoria in smaller towns. In order to increase the variety of the sample of stimuli we also chose concert halls newly built or recently restored concert halls as well as historical ones. The stimuli were (see Table 2).

The subjects had to evaluate the acoustics and architecture of the concert hall *in situ*, so that they were "immersed" in the stimulus. It was decided to undertake the field study under these conditions rather than in the laboratory because lab conditions cannot represent the real settings with 100% reliability.

Figure 1 shows examples of auditoria used in the field study. The most relevant data for each venue was collected.

2.4. Development of the field study

The field study was developed as follows: participants were handed a questionnaire before the performance took place. Subjects were personally informed of the study objectives although the questionnaire included instructions on how to fill it in correctly. Moreover, participants were asked to respond the questionnaire as soon as the performance had finished so that they had all the stimuli fresh in their minds. In addition, they were told to express their opinions in a spontaneous way to catch their first, true impressions. Finally, the completed questionnaires were collected. It took an average time of 15 minutes to fill in the questionnaires which was considered a reasonable interval to answer the questions before losing interest.

The order of the questions was randomized and five different models of questionnaire were created in order to avoid any bias in subjects' responses.

2.5. Data processing

Data base of answers was statistically processed with specific software: SPSS. 17.0. Then, the following data processing procedure was applied in two phases: Phase I, in which perceptions of the entire set of evaluators were analyzed; and Phase II, where differences of perception between experts and non-experts collectives were identified.

2.5.1. Phase I. Analysis of the set of evaluators' perceptions

2.5.1.1. Obtaining the semantic space of a concert hall

In a first step, the authors wanted to determine if the total set of subjects was able to clearly differentiate in their mental scheme the acoustic parameters from architectural ones, using the entire set of adjectives. However, the amount of information had to be reduced in order to facilitate the next steps. Hence, it was essential to group the set of adjectives into major structures: the semantic axes. These are uncorrelated variables that characterize the perception of a specific product; a concert hall in this study. A combination of adjectives from the original set (acoustic and architecture) composes each axis so that these attributes present significant correlations with users' responses. The technique used to identify and extract the semantic axes was principal components factor analysis (PCA) [36]. Only principal components with eigenvalues greater than one were selected. Axes with an eigenvalue greater than one suggest that it contains a portion of variability greater than that of an original variable. The contributions analysed were obtained after a Varimax rotation of the axes. Then, each semantic axis was given a representative label for the set of factor variables, where concepts with the highest contributions were the most representative. Finally, internal consistency of the axes was evaluated by Cronbach's alpha coefficient [37].

2.5.1.2. Visualizing evaluators' perceptual space

The factors that define the perceptual space of the concert halls were then represented graphically. However, graphic interpretation of all the dimensions obtained from PCA is very complex when there are several axes. Therefore, it was facilitated by only representing the two dimensions (axes) with the greatest explained variance. This preference mapping enables visualisation of the set of expressions analysed in a common space. Moreover, if vectors representing the variables are temporarily removed, distances between points can be interpreted in terms of similarity. Thus, the semantic distances, understood as similarities and differences between concepts, can be analysed as well. Besides, if the sample of stimuli is also added to this perceptual space (through their scores for the two components) it is possible to determine the position of each stimulus in the space and therefore, determine its assessment.

This tool is basic for evaluating products from the user’s point of view, by permitting identification of the differences and similarities between them.

2.5.1.3. Preference models for the set of evaluators

The aim of this step was to determine whether architectural factors influence the subjective assessment of the acoustics and whether acoustic factors influence the evaluation of the architecture of the concert hall. Therefore, it was essential to analyse the influence of each axis on the global assessment (acoustic and architecture) since it may be different.

The attributes associated to the semantic axes represent common concepts which explain perceived differences between acoustic and architectural properties. Thus, in order to quantify the influence of each axis, linear regression analysis was applied.

2.5.2. Phase II. Exploring perception differences between experts and non-experts

2.5.2.1. Identifying perception differences between experts and non-experts

In order to determine significant differences of perception between these collectives, an ANOVA was run. Factors that constitute the semantic space were used as dependent variables, while the variable that represents “acoustic formation” acted as factor. The purpose was to confirm, as established in prior studies on the subject [16,32,38], that both collectives present significant differences in perceptions and must therefore be analyzed independently.

2.5.2.2. Obtaining preference models for experts and non-experts to assess a concert hall from acoustic and architectural perspectives.

Regression analysis was used to rank the axes which influence the global assessment of a concert hall from the acoustic and architectural point of view for each collective of subjects. This analysis enabled identification of significant factors in the evaluation of these venues by experts and non-experts.

2.5.2.3. Identifying semantic distances in the assessment of the concert halls by experts and non-experts

In this phase, the perceptions of experts and non-experts were analyzed for each concert hall in order to identify the auditoria showing greater discrepancies between the assessments of both collectives. Therefore, perceptual space was built and semantic distances were calculated. These distances show the degree of consistency in product perception for two different groups of subjects; so that the greater the distance, the worse the consistency. Considering the two dimensions depicted in the perceptual space, the semantic distance between experts and non-experts' assessment can be measured through the expression [30]:

$$d_i = \sqrt{(x_{exp} - x_{non\_exp})^2 + (y_{exp} - y_{non\_exp})^2}$$

where *x* and *y* are the average scores for the venues in the sample for axes 1 and 2.

3. Results

3.1. Phase I. Analysis of the set of evaluators' perceptions

3.1.1. Obtaining the semantic space of a concert hall

Factor analysis compiled the initial set of 53 expressions (27 acoustics + 26 architecture) to 10 independent factors, able to explain 63.84% of the variance (see Table 3). However, according to Cronbach's alpha coefficient [37], values below 0.6 show an unacceptable level of reliability in exploratory studies. Therefore, the 10 dimensions obtained were reduced to 7 whose values ranged from 0.608 to 0.937; showing that these scales have considerable reliability.

According to Table 3:

Axis 1 represents "acoustic quality, harmony and balance". It is composed of the following acoustic items: good pitch quality, harmonious, balanced, good direct sound, clear sound, powerful, warm, bright, homogeneous, natural, close, with texture, not weak, not dull, wide dynamic range, faithful sound, not distant, enveloping sound, soft and not dissonant. It explains 28.76% of the variance in the original variables.

Axis 2 represents "original and innovative architecture" and it comprises solely adjectives related to architecture: original-different, innovative, elegant, luxurious, modern, lively, stylish shape, emblematic-prestigious, quality materials, light-filled. It explains 8.84% of the variance.

Axis 3 corresponds conceptually to "well organized-functional", including expressions exclusively related to architecture: organized, ordained, practical distribution, wellproportioned, good view of stage, good interior circulation, quiet-peaceful, comfortable, incomparable setting, wide, versatile, formal. This factor explains 5.53% of the sample variability.

Axis 4 represents the concept “classic-baroque style”, whose main descriptors are: classic architecture, very ornate, baroque. It explains 4.68% of the variance.

Axis 5 refers to the dimension “reverberant” and is composed of the acoustic items: reverberant, resonant and dissonant. It explains 3.43% of the variance in the original variables.

Axis 6 represents the sensation of “intimacy”. The descriptors that contribute to this dimension are: intimate, cozy, warm, soft and close. It explains 3.09 of the variance.

Axis 7 corresponds to “no background noise”, which comprises the items: no background noise perceived, timeless, faithful sound and wide dynamic range. It explains 2.80% of the sample variance.

Finally, factors with Cronbach’s Alpha values below 0.6 were eliminated due to their low consistency: Axis 8 “treble enhanced”, Axis 9 “bass enhanced”, Axis 10 “without echoes”.

3.1.2. Visualizing evaluators’ perceptual space

The structure built by first and second principal component loadings was represented graphically (Figure 2). The x-axis is represented by the factor with the highest load “acoustic quality, harmony and balance”, followed by the factor “original and innovative architecture” in the y-axis. Along the first factor, there is an opposition between the concepts: pitch quality, direct sound, balanced, harmonious, clear sound (on the right) and weak, dull, distant, dissonant (left). This axis therefore separates concert halls perceived as venues with high acoustic fidelity from halls that lack those qualities. The second factor (y-axis) contrasts the expressions: original, innovative, elegant (upper) and dark, classic (lower). This axis separates auditoria with original and singular architecture from those perceived as classic and obscure.   Other structures can be found in addition to these factors, for example, the opposition between: “close-distant”, “powerful-weak”, “clear-resonant”, “modern-classic”, and so on.

In order to obtain more information, the sample of stimuli (19 concert halls) was included in this perceptual space. The outcome is Figure 3. This image is very useful for determining whether a specific concert hall is well or badly rated and why; according to its distance from each adjective. The closer to the top right quadrant, the better the evaluation of the concert hall according to the two main dimensions. In contrast, the further away it gets (left-lower quadrant) the poorer the perception of the venue. Therefore, observing Figure 3 it can be seen that concert hall number 16 obtained a very good evaluation since it was perceived as an auditorium with original, singular architecture and good acoustics. However, on the opposite side, venue number 4 obtained a negative rating on the two main axes. Thus, distance between concert halls depicted in this space implies similarity or differences in perception.

The utility of this graph is that it allows measurement of differences of perception between concert halls on the basis of a set of attributes.

3.1.3. Preference models for the set of evaluators

Once the axes have been obtained, the next step is to determine whether factors related to architecture have an impact on the acoustics assessment, and whether acoustic factors affect the architectural evaluation. Therefore, these axes were analysed in order to quantify their influence on the overall evaluation. As a result, two linear regression models were obtained for the sample of subjects and the influence of the axes on the overall opinion could be quantified.

In order to obtain this model, the variable "acoustics global assessment" was taken as the dependent one, while the 7 axes obtained before were the independent variables. The linear regression model showed 5 significant factors (s.l.<0.05) while the rest were excluded. The factor "acoustic quality, harmony and balance" mainly determined the overall evaluation with a high positive correlation of 0.735. Next in importance appeared the axis "Well-organized, functional" with a correlation of 0.295; followed by the axis "original and innovative architecture" with a load of 0.155. In the last positions appear the axes: "intimacy" which contributed with a correlation of 0.121 and "reverberant" with a negative correlation of -0.104. This analysis showed a high linear correlation coefficient (0.788) which confirmed the power of the model:

{1} Acoustics Global Assessment = 0.597 + 0.735 (Acoustic quality, harmony and balance) + 0.295 (Well-organized, functional) + 0.155 (Original and innovative architecture) + 0.121 (Intimacy) – 0.104 (Reverberant)

Observing model {1} it can be seen that not only acoustic factors but also architectural ones are taken into account by the entire sample of subjects when evaluating the acoustics of a concert hall. Logically, the factor with the highest load is related to acoustic quality. However, the influence of architectural factors is not negligible since the second and third axes with the most influence relate to different architectural aspects: good interior organization, functionality, originality and innovation.

Also remarkable is the fact that reverberation is perceived as a negative attribute, while it has been traditionally considered as a determinant parameter of concert halls. It is possible that this concept was misunderstood since subjects related it to the item "resonant".

In this case, the variable "architectural global assessment" was taken as the dependent one, and the 7 axes worked as independent variables. The linear regression model showed 6 significant factors (s.l.<0.05) while the other one was excluded. This analysis showed a high linear correlation coefficient (0.797) which confirmed the power of the model:

{2} Architectural Global Assessment = 0.441 + 0.612 (Well-organized, functional) + 0.414 (Original and innovative architecture) + 0.302 (Acoustic quality, harmony and balance) + 0.162 (Intimacy) + 0.121 (No background noise) – 0.104 (Reverberant)

As can be seen in model {2}, the factors with the highest impact on the assessment of the architecture are: "well-organized, functional", "original and innovative architecture" and "acoustic quality, harmony and balance", with high positive loads: 0.612, 0.414 and 0.302 respectively. It is noteworthy that an acoustic factor is the third in importance. Next, appears the axis "intimacy" with a correlation of 0.162, followed by "no background noise" (0.121). As in model {1} the axis "reverberant" appears in the last position contributing with a small negative correlation of -0.104. The negative sign reveals that this factor was not positively appreciated by the subjects. Model {2} suggests that, not only architectural axes, but also acoustic factors influence users when evaluating the architecture of a concert hall. In summary, models {1} and {2} show that acoustics influence the perception of the architecture and vice-versa.

3.2. Phase II. Exploring perception differences between experts and non-experts

3.2.1. Identifying perception differences between experts and non-experts

ANOVA was used to determine the existence of significant differences between experts and non-experts based on the semantic space. These differences were found (s.l. < 0.05) in the perceptions of "original and innovative architecture", "classic, baroque style", "reverberant", "intimacy", "no background noise" (Table 4). That is, 5 out of the 7 factors that shape the semantic space, present significant differences. These results show that experts and non-expert users have different perceptions and therefore need independent analysis.

3.2.2. Obtaining preference models for experts and non-experts to assess a concert hall from acoustic and architectural perspectives

At this point, the perception factors were ranked according to their relation with the global evaluation of acoustics and architecture of the concert halls. For this purpose, regression analysis was used and models for both collectives were generated.

For the collective of experts this model includes 2 significant factors, with a correlation coefficient of 0.784. The axis with major influence was "acoustic quality, harmony and balance" with a load of (0.711); followed by the factor "reverberant" with a negative correlation of (-0.284). That is, only acoustic factors affect this evaluation:

{3} $(\text{Acoustics Global Assessment})_{\text{experts}}$ = 0.556 + 0.711 (Acoustic quality, harmony and balance) - 0.284 (Reverberant)

In contrast, the model for the group of non-expert users reflects 5 relevant factors, with a correlation coefficient of 0.801. The axis with the greatest influence was "acoustic quality, harmony and balance" with a load of (0.745); followed by the factor "well-organized, functional" (0.280). The rest of axes that affect this evaluation are "intimacy" (0.149), "original and innovative architecture" (0.136) and "no background noise" (0.124). In this case, it can be observed that acoustic and architectural factors affect the evaluation:

{4} $(\text{Acoustics Global Assessment})_{\text{Non-experts}} = 0.606 + 0.745$ (Acoustic quality, harmony and balance) + 0.280 (Well-organized, functional) + 0.149 (Intimacy) + 0.136 (Original and innovative architecture) + 0.124 (No background noise)

The model for the experts collective includes 4 significant factors, with a correlation coefficient of 0.761. In the first position appears the factor "well-organized, functional" with a load of (0.544). It is followed by perceptions of "original and innovative architecture" (0.380); "reverberant" (-0.262) and "acoustic quality, harmony and balance" (0.245). Thus, acoustic and architectural factors participate in the model:

{5} $(\text{Architecture Global Assessment})_{\text{Experts}} = 0.462 + 0.544$ (Well-organized, functional) + 0.380 (Original and innovative architecture) -0.262 (Reverberant) + 0.245 (Acoustic quality, harmony and balance)

Finally, the model for non-experts is composed of 5 significant factors with a correlation coefficient of 0.811. First in importance is the dimension "well-organized, functional" (0.617). Then appears the factor "original and innovative architecture" with a load of (0.423), followed by the axes "acoustic quality, harmony and balance" (0.311), "intimacy" (0.154) and "no background noise" (0.124). The resulting model is:

{6} $(\text{Architecture Global Assessment})_{\text{Non-experts}} = 0.420 + 0.617$ (Well-organized, functional) + 0.423 (Original and innovative architecture) + 0.311 (Acoustic quality, harmony and balance) + 0.154 (Intimacy) + 0.124 (No background noise)

3.2.3. Identifying semantic distances in the assessment of the concert halls by experts and non-experts

Once the relevant factors in the assessment of the concert halls have been identified, the intention is to determine where the greatest differences in evaluation are found.

The degree of consistency in the opinions of expert and non-expert groups can be measured through semantic distances. These distances are calculated on the basis of the scores obtained in the two dimensions with the greatest explained variance: factor 1 "acoustic quality, harmony and balance" (x-axis) and factor 2 "original and innovative architecture" (y-axis). Table 5 shows the calculation of the semantic distances for each venue.

4. Discussion

The purpose of this paper has been to analyze the influence of architectural attributes on the assessment of concert hall acoustics and, moreover, to quantify this influence. Two collectives of users were tested for this purpose: experts (professional musicians, acousticians and conductors) and non-experts.

The findings of this study provide the following important outcomes:

Firstly, analysis of the entire set of users (experts and non-experts) provided 7 axes which represented their mental schemes (Table 3). Moreover, it was observed that each axis gathered items exclusively related to its field: either acoustic items or architectural ones. This is a remarkable result since it confirms that users clearly separate acoustic and architectural attributes in their minds. That is, the conceptual structure is clearly defined since users are able to group acoustic concepts and separate them from the architectural attributes.

Some of these axes can be compared to previous studies by other authors:

The main axis determining acoustic comfort "acoustic quality, harmony and balance" represent attributes which have been widely studied by other authors who agree on its importance (clarity of sound [5,9,12,13], direct sound [7,8,13]; loudness [1,3,10,14]; enveloping sound [2,13]; spatial impression [12,14]; balance and warmth [2,3,7,14]).

In contrast, the second and third factors in the order of importance "original and innovative architecture" and "well-organized, functional", represent aspects entirely related to the architecture of the venue. These features have not been deeply studied before or considered as important attributes themselves. However, some authors have studied attributes related to perception of architecture in concert halls: Beranek mainly studied dimensions and materials [3], Hidaka studied the view of the stage and space between seats [7], and Satoshi Kawase studied how visual factors influence the audience when selecting a seat [16].

The axis "reverberant" that is related to acoustic perception has been also studied by many authors. Sabine was the very first [10] by means of the objective parameter "reverberation time"; followed by many other authors [3,11,12,13]. This parameter has been traditionally related to the acoustic quality of a venue. However, as can be seen from the results of the linear model in this present paper, perception of reverberation was understood by users as a negative attribute for the quality of the venue.

Finally, the axis "intimacy" which is related to acoustic perception, has been studied by other authors; in particular in the study by Beranek [3]. In his research he concluded that the sensation of intimacy contributed up to 40% of the perceived quality of a concert hall. As noted below, the linear model obtained in the present work shows that intimacy is an important factor for acoustic evaluation, but not the main one. Other authors also studied the "intimacy" factor [1,4,6,9,15].

In addition to this comparison with other studies, it is also remarkable that the two axes that explain the most of the variance in the present experiment, represent the two most important factors when evaluating a concert hall: one acoustic ("acoustic quality, harmony and balance") and the other architectural ("original and innovative architecture"). These are the axes that represent the semantic space for the entire set of users, which graphically depicted allows analysis of the relations between the perceptions of different concepts.

When separating experts and non-experts, important differences may be observed in the set of factors (Table 4).These differences not only affect the perception of acoustic attributes but also the architectural ones. These facts are in line with other studies that have shown that professional musicians have a different conceptual structure from that of non-musicians [19-23].

Some important aspects of the linear regression models are worth pointing out:

As already established, the entire set of subjects (expert and non-experts) has a defined mental scheme since they clearly separate acoustic concepts from architectural ones; however, models show that in the process of evaluating a concert hall both kinds of attributes interact with each other. That is, architectural attributes influence acoustic perception (model {1}), and acoustic features also influence the perception of the architecture of the concert hall (model {2}). This means that both fields interact when users evaluate a particular venue.

This fact changes, however, when the sample of subjects is analyzed independently. Models for non-experts also show the influence of architecture on acoustic perception and vice-versa (models {4} and {6}). But models for the collective of experts show a remarkable fact: model {3} confirms that when experts evaluate the acoustics of a concert hall, they only take into account acoustic attributes. There is no influence of architectural variables. This suggests that experts act very consciously when assessing acoustics, which may confirm their expertise in this field. Again, this finding agrees other experiments that show that professional musicians and non-musicians have a different mental scheme [19-23]. Nevertheless, when experts assess the architecture of the venue, acoustics do have an influence over it (model {5}).

Finally, it is also remarkable that the axis "reverberant" is only included in the models set by experts ({3}, {5}) and with a negative correlation. It means that this factor is not relevant for the collective of non-experts, and moreover, experts do not appreciate a concert hall that is perceived as reverberant. This is a significant finding since the physical parameter "reverberation time" has traditionally been a measure of acoustic quality for this kind of venue [10]. Therefore, it is worth noting that the subjective perception of reverberation is not clearly linked with this parameter, or is even misunderstood.

The semantic space is a useful tool for expressing differences of perception between experts and non-experts in graph form. This tool has also been used in other works [32]. Figure 4 shows that experts are more critical in their evaluations since several of the venues they evaluated are located at the extremes of the graph. However, most of the ratings by non-experts are in the centre of the graph (more moderate opinions).

The greatest semantic distance between experts and non-experts (greater differences in perception) can be observed in venues 4 and 17. The graph indicates that this difference of perception is mostly due to "axis x" since these venues are far apart in the horizontal dimension. This means that experts and non-experts' assessments are very different because of the evaluation of "acoustic quality, harmony and balance", so they perceive this acoustic factor in a very different way.

Similarly, concert halls that are very far apart in the vertical dimension are perceived in a very different way according to axis y: "original and innovative architecture". Thus, the cause of the difference in perception is mainly due to architectural factors.

In summary, the semantic space is a very useful tool, since it allows study of the differences in perception between both collectives, and also indicates the cause of this difference: whether it is due to acoustic attributes (axis x) or architectural ones (axis y).

As regards the limitations of this study, the main one has been working with real venues. In order to control for the effect of architectural variables on acoustics, one component should remain constant while testing different configurations of the other; and real venues do not allow this. However, it was very interesting for the authors to work in actual concert halls where architectural variables cannot be modified but the user is immersed in a 100% real experience. Nevertheless, in order to reduce the impact of this bias, the sample of venues was broad enough to guarantee variability: large and small concert halls, new and traditional, located in big cities and small towns so that the variables were randomized [39].

The definition of these perceptions or independent attributes is the first phase of Kansei Engineering (KE). So, further research may be conducted to identify the design elements that a concert hall needs to provoke an affective response in users (KE phase II); the ultimate purpose is to understand the relationships between the physical variables and perceived acoustic and architectural quality in concert halls.

It would also be very interesting to study this topic in further experiments: if the collective of experts comprised only architects, would they evaluate the architecture of the venue taking into account only architectural factors without any influence of acoustics? Hence, it would be very useful to repeat this experience with a set of architects and non-architects.

5. Conclusions

The present work has analyzed the influence of architectural attributes on the acoustic assessment of concert halls. This has been studied for the collectives of experts (professional musicians, acousticians and conductors) and non-expert users.

The main conclusion is that perception of architectural attributes influences the acoustic evaluation and, moreover, acoustic parameters influence the assessment of the architecture. That is, both kinds of attributes interact with each other in the evaluation process. However, this fact does not occur because users cannot differentiate acoustic concepts from architectural ones, since PCA showed the contrary. In addition, analyzing both collectives of users it was observed that only the group of experts proved capable of isolating acoustic variables from architecture when evaluating the acoustics of a concert hall. This means that they only take into account acoustic parameters when evaluating the sound quality of a venue.

Furthermore, the Semantic Differential method can be used to identify the subjective preference factors behind the evaluators' assessment of a product, in this case, concert halls. This technique (in the context of KE) enables the definition of subjective evaluation scales adapted to the evaluators, since the symbolic attributes are expressed in their own language. In the present work, this methodology has been used to obtain the response of experts and non-expert concertgoers, regarding the perception of acoustic and architectural attributes of concert halls. In addition, differences in perception between these two collectives have been identified and analyzed. The use of PCA (Principal Component Analysis) has enabled the quantification of subjective perceptions, and determination of their impact on the acoustic and architecture assessment of concert halls through linear regression models.

Finally, the results of this research may be useful for future studies on acoustic and architectural quality, since the set of concepts representing the affective response to the visual and acoustic field in concert halls has been identified.

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Table Legends

Table 1. Data on the sample of subjects participating in the study

Table 2. Concert halls in the stimuli sample

Table 3. Range of meaning of kansei factor axes and representative terms for the entire sample of subjects (experts + non experts). α is the Cronbach's Alpha coefficient

Table 4. Comparison of axes scores across ANOVA analysis (experts and non-experts) results

Table 5. Semantic distances between experts and non-experts for each concert hall (by descending order)

Figure Legends

Figure 1. Example of concert halls in the stimuli sample (a) Palau de les Arts de Altea (Alicante) (b) Teatre Serrano de Gandía (Valencia).

Figure 2. Perceptual space for the entire sample of subjects (expert + non experts). Acoustic attributes are depicted in red; architectural attributes in blue.

Figure 3. Perceptual space for the entire sample of subjects (experts + non experts), including the sample of stimuli (concert halls). Acoustic attributes are depicted in red; architectural attributes in blue.

Figure 4: Perceptual space for expert and non-experts including the sample of stimuli (concert halls). Acoustic attributes are depicted in red; architectural attributes in blue.