Subjective evaluation of music hall acoustics: Response of expert and non-expert users

Miguel Galiana [a]*, Carmen Llinares [a], Álvaro Page [b]

[a] Escuela Técnica Superior de Ingeniería en la Edificación, Departamento de Organización de Empresas, Universitat Politècnica de València, Camino de Vera, s/n, Valencia 46022, Spain

[b] Instituto de Biomecánica de Valencia, Universidad Politécnica de Valencia, edificio 9-C, Camino de Vera, s/n, Valencia 46022, Spain

ABSTRACT

Many studies have attempted to measure human response in music halls in order to determine acoustic quality. However, all these works have used parameters defined by experts. This approach may be an important drawback since users who have to evaluate such concepts may not understand or misunderstand parameters which do not correspond to their own conceptual structure. This paper attempts to establish a methodology to define valid evaluation scales for different collectives and determine evaluation criteria related to the overall assessment of music hall acoustics. It analyses music hall acoustics from the user's perspective and investigates the differences of perception between experts and non-experts through Semantic Differential within the frame of Kansei Engineering. The research was carried out through a field study in 17 auditoria of the Valencia Region (Spain). Perceptions regarding the acoustic quality of these venues were studied in a group of non-experts (236) and other of experts (74). Differences of perception between both collectives were identified and analysed. The main factors characterising the subjective preference of each group were determined (5 factors for non-experts and 6 for experts) and their influence on the global acoustic assessment was quantified. Furthermore, predicting perceptual models were built and the utility of the methodology was tested through the semantic profiles of two venues not included in the above analysis. This methodology was useful for studying music hall acoustics from the viewpoints of experts and non-experts and it may also enable optimization of design features of music halls.

Keywords: Music hall, Acoustics, Semantic differential, User-oriented, Subjective preference, Kansei engineering.

INTRODUCTION

Study of perception in the field of music hall acoustics (opera houses, theatres and venues for classical music and orchestra performances) has been of great interest over the past and present century [1-9]. Many studies have attempted to find the physical parameters which determine whether the acoustics of a venue are good or not. In the early 1920s, Sabine's study [10] led to the general view that reverberation time was the only parameter that represented the acoustic quality of a music hall. This idea remained for several years and researchers focused their efforts on studying the absorbing properties of new materials in order to control reverberation time and maximize acoustic quality. However, researchers came to realize that other parameters also influenced acoustic perception in addition to the universal criterion of reverberation time. This fact led to many other studies related to new physical parameters influencing the perception of acoustic comfort, including Early Decay Time (EDT) [11], Initial Time Delay Gap (ITDG) [5], Spatial Impression [12], Clarity Factors C50 and C80 [13], Gain Factor (G) [14], Interaural Cross-Correlation (IACC) [1] and Speech Transmission Index (STI) [4,15].

Some studies also began to relate all these physical parameters to human response and the subjective evaluation that they evoke on the listener (intimacy, enveloping sound, clarity, loudness, balance, warmth, etc.) [4,5,7,9,14,16]. This led to a new branch of acoustics known as psychoacoustics. Many authors have conducted research in this field and in particular, Leo Beranek [3]. He was the first author to establish a new parameter different from reverberation time which, according to his research, had a great influence on the listener. He stated that the feeling of intimacy in a music hall (directly related to ITDG) contributed up to 40% of the global assessment of the venue. After him, many other authors studied and quantified the influence of other acoustic parameters on the listener's perception, including the influence of Lateral Energy Fraction (LF) on the perception of enveloping sound [2]; influence of Clarity Factor C80 on perceived subjective clarity [5]; influence of Gain Factor G(A) on perceived loudness [14]; influence of IACC on the diffusion of sound [7]; influence of STI on the perceived intelligibility of sound [4].

All these studies have something in common: they evaluated listeners' impressions through questionnaires and tests. The sample of listeners was composed of experts in some cases (musicians, acousticians, conductors, etc.) [2-4,7]; and nonexperts in others (students or habitual listeners) [6,8,17]. However, in these experiments all the concepts and attributes for evaluation were always set by experts (professional musicians, conductors, acousticians). That is, 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. Studies have shown that professional musicians have a different conceptual structure from that of the non-musicians [18-22]. For instance, the interviewee and the interviewer may interpret the attribute reverberant differently, and this would make the results difficult to interpret. Furthermore, as experts filter the information to assess, some of the parameters appreciated by non-experts may never be evaluated. These particular disadvantages have been tackled by techniques such as the Semantic Differential method (SD).

SD, also known as Differential Semantics, is a useful tool designed by Osgood et al. [23] to quantify the affective meaning of concepts. It is very often used to investigate users' perceptions of product form. This method studies product semantics by means of adjectives and expressions which reflect users' emotional impressions and measures users' perceptions on a Likert scale. Many researchers have used this technique to study particular aspects of product form: colours, shapes, styles, comfort and many other attributes in product design. Furthermore it has been applied in different market sectors, including the automotive industry [24], housing design [25], building sector [26,27], mobile phone industry [28], and environmental acoustics [29].

SD is the main tool for applying Kansei Engineering. KE is an ergonomic consumer-oriented technology for new product development [30]. It was developed in the 1970s at the Kure Institute of Technology (Hiroshima, Japan). This technique is based on the principle that an individual's judgement is not only influenced by the stimuli (combination of objective and subjective parameters) but also by the scheme of concepts of a concrete group of users (semantic space). Thus, this method allows quantifying users' perceptions of a product in their own language and relates these subjective responses to particular design features. KE consists of several phases. In the first stage, users' perceptions of a particular product must be captured in their own words by collecting as many expressions and words (kansei words) as possible to define the semantic space of the product. In this stage, SD is an essential and useful instrument for achieving this objective. Then, the semantic space must be reduced to a limited number of words, and the Affinity Diagram is an appropriate technique for this purpose [31]. These words are then transformed into several uncorrelated factors that define users' perceptions of the product. Principal components factor analysis is a very useful tool in this step [32]. Finally, these factors must be translated into design elements in the real product to satisfy individual preferences. Therefore, KE is a very useful instrument for studying users' emotional impressions which may differ from those of experts [33-35]. Many studies have used SD, within the frame of KE to analyse users' perceptions of a multitude of products: automotive industry [24,36]; mobile phones [37]; office furniture [38]; footwear design [39,40], beer cans [41] and even acoustics and sound perception [42-44]. Nevertheless, to our knowledge, this technique has been not applied to date in the field of music hall acoustics with the aim of measuring the human response of users. This paper therefore aims to establish a methodology to define valid evaluation scales for different collectives and determine evaluation criteria related to the overall assessment of the acoustics of music halls (opera houses, theatres and venues for classical music and orchestra performances). The objective was to determine the evaluation concepts used by experts and non-experts collectives to express their value judgements in this field of study. The SD method within the frame of Kansei Engineering was used to achieve this purpose. In this way, it was possible to identify which attributes determined the overall opinion of users to evaluate music hall acoustics from criteria defined by the users themselves; and the same in the case of experts. The evaluation concepts were then used to analyse differences between the emotional responses of both collectives. Since perception depends on two main aspects: physical-objective parameters and subjective evaluation; the ultimate and future aim of this research is to detect and try to improve emotional response, link it to physical parameters and finally translate it into design elements that improve the overall quality of music halls. This issue has been never tackled before in the sphere of music halls and this research may help to shed some light on this empty field of study.

2. MATERIALS AND METHODS

The methodology consisted of two main activities: firstly, select a representative sample of expert and non-expert users of music halls. Secondly, select a sample of music halls across the region of Valencia (Spain) to be assessed by the sample of users according to a set of acoustic qualities. The region of Valencia was chosen for its long and rich musical tradition. In this region there are more than 350 musical societies, and an annual international music contest has taken place in the city of Valencia since 1886 with the participation of leading orchestras from Europe and around the world.

2.1. Subjects

A sample of 310 participants (74 experts and 236 non-experts) was collected. 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 music 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.

A control sample which did not participate in the initial study was reserved to validate the results. This sample consisted of 29 questionnaires related to two particular concert halls.

2.2. Questionnaire

Two blocks composed each questionnaire. The first block gathered objective information on the individual (gender, age, relation with music halls, concerts attended per year, preferred type of concert and usual location in the venue). The second block contained subjective information about the perception of acoustic parameters represented by a group of 27 adjectives and expressions. The first step to obtain this set of expressions involved applying the SD method to collect as many adjectives as possible (kansei words) to describe the product domain [35]. 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 attribute of a concert hall. The process finished when no new words appeared. According to Schütte et al. [35], the final set can vary between 50 and 600 words depending on the particular field of study. These kansei words form the initial semantic universe, which in our case comprised 162 adjectives related to music hall acoustics. 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 are available for the purpose [45]. This study used the Affinity Diagram, which groups semantic descriptions according to their affinity [31]. The grouping was made by 2 professional musicians, 2 acousticians 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 (Fig. 1); the grouping process ended when all the ideas or words were gathered, and (c) each group was given a title or heading that represented all the kansei words in the group. The set of expressions finally obtained formed the reduced semantic universe, which in our case was composed of 27 adjectives. These adjectives were evaluated through a 5-point-Likert scale ranging from totally disagree, disagree, neutral, agree and totally agree.

A new variable was included to show the global opinion of the user from the expression "Considering the whole set of features I think this is a good music hall from the acoustic point of view". This variable was also evaluated through the above Likert scale.

2.3. Stimuli

The stimuli used to carry out the field study consisted of 17 concert halls: opera houses, theatres and venues for classical music and orchestra performances (Table 2) in two provinces of the Valencia region with a long musical tradition: Valencia and Alicante (Fig. 2). These music halls were selected so as to have a variety of large music halls in big cities like Valencia, Alicante, Xàtiva or Gandía and more modest venues in smaller towns. Fig. 2 illustrates their location in Spain. In order to increase variety in the stimuli we also chose newly constructed or recently restored auditoria and others with a long tradition. The extraction of semantic axes involves establishing relationships between many variables, and so responses in a broad range of judgements are needed. It is therefore advisable for users to give their opinions on a sample of music halls with a variety of characteristics. The subjects had to evaluate the acoustics of the music hall in situ, so 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 real settings with 100% reliability.

2.4. Development of the field study

The subjects participating in the experiment were handed a questionnaire before the performance took place. Subjects were personally informed of the study objectives although the questionnaire also included instructions on how to fill it in correctly. Participants were asked to complete the questionnaire as soon as the performance had finished so that all the stimuli were fresh in their minds. In addition, they were told to express their opinions spontaneously to capture their first, true impressions. Finally, the completed questionnaires were collected.

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

Completing the questionnaires took an average time of 10 min which was considered a reasonable interval to answer the questions before losing interest.

2.5. Data processing

Database answers were statistically processed with specific software: SPSS. 16.0. The following data processing procedure was applied:

2.5.1. Identifying differences of perception

To assess differences in perception between expert and non-expert users, the following analysis were made:

(a) Differences in perception of the 27 acoustic expressions. Firstly, discriminant analysis was applied using 'expert-non-expert' as a grouping variable and the scores for the 27 adjectives as independent variables. Thus, it was possible to verify the hypothesis that expert and non-expert users have a sufficiently different perception structure to be able to classify subjects by their responses. Efficiency of the discriminant function was evaluated by the eigenvalue of the discriminant function, canonical correlation and Wilks' Lambda value. Then, the mean scores for each adjective were calculated for both collectives. Differences in the scores for experts and non-experts were analysed for each adjective to detect which parameters showed more differences in perception. Finally, ANOVA was used to determine whether the differences were significant (s.l. <0.05).

(b) Differences in the importance of the 27 adjectives over the global assessment variable. The relationship between the 27 adjectives and the global assessment variable "good music hall alcoustics" was also studied using Spearman's correlation coefficient for expert and non-expert collectives.

2.5.2. Identifying semantic axes

Once differences of perception between expert and non-expert users were confirmed with the previous analyses, it was necessary to reduce the amount of information, in order to facilitate the next steps. Hence, it was essential to group the set of adjectives into semantic axes. These are uncorrelated variables that characterize the perception of a concrete product; a music hall in this case. Each axis is made up of a combination of adjectives from the original set so that it presents significant correlations in users' responses. Thus, adjectives that usually have similar valuations are grouped and they are supposed to represent common concepts that users implicitly use to assess properties. Principal components factor analysis (PCA) was used to identify and extract the semantic axes [32]. Only principal components with eigenvalues greater than one were selected. Then, Varimax rotation was applied to obtain the factors.

2.5.3. Perceptual space

Once the semantic axes were determined, they were graphically represented so as to construct a visual perceptual space of the product "music hall acoustics". However, the graphic interpretation of all the dimensions obtained from the factor analysis is very complicated when there are several axes. Therefore, only two main dimensions were represented; that is, the two axes which explain most of the sample variance. The advantage of this graph is that it shows the whole set of analysed attributes at once. Moreover, if vectors representing the variables are temporarily removed, distances between parameters can be interpreted as similarities between them. Thus, it was possible to measure the semantic distances: the similarities and discrepancies between different concepts. Then, if the sample of stimuli evaluated by their scores on the two main axes is added to this perceptual space, it is possible to determine the position of each stimulus on this space.

The perceptual space is a fundamental tool for evaluating a product from the user's point of view, since it enables the identification of differences and similarities between music halls and their evaluation by the group of subjects.

2.5.4. Ranking semantic axes according to importance in the global assessment

In the next step, it was necessary to analyse the influence of each axis on the global assessment since it may be different. The attributes associated to the semantic axes represent common concepts which explain the perceived differences between acoustic properties from the user's point of view. Therefore, in order to quantify the influence of each axis, linear regression analysis was applied and nonparametric Spearman correlation coefficient between factors scores and the overall opinion were used to obtain this ranking.

2.5.5. Validation of the regression models and semantic profiles

Finally, the previously obtained linear regression models had to be tested. A control sample which did not participate in the initial study was reserved for this purpose to validate the results. This sample consisted of 29 questionnaires related to two particular concert halls. The process consisted in comparing the real answers of the subjects with those predicted by the models. Thus, scores were obtained for each adjective in the questionnaires and then transformed into scores for the corresponding semantic axes. Using these scores, the predicted values were obtained through the linear regression models. Finally, these values were compared to the subjects' responses to the global assessment. Results achieved in this stage were used to build the semantic profiles of the venues in order to compare them. The semantic profile is a diagram that represents the scores obtained in each semantic axis. Since factorial analysis provides scores centred in relation to the average of the analysed sample, the semantic profile allows visualisation of the relative position of a particular product (music hall) with respect to the mean. Moreover, it is possible to represent two or more profiles to compare their features.

RESULTS

3.1. Identifying differences of perception

a. Differences in perception of the 27 acoustic expressions

Table 3 shows the result for the discriminant analysis between experts and non-experts, revealing significant differences in the set of attributes assessed by both collectives (s.l. < 0.01). Table 4 shows significant differences between experts and non-experts in the ANOVA, for adjectives: powerful, reverberant, resounding, balanced, dissonant, harmonious and no background noise. Fig. 3 shows the averages for each adjective for the two groups ordered according to the magnitude of the difference. In general terms, experts are more critical, giving lower scores than non-experts.

b. Differences in the importance of the 27 adjectives over the global assessment variable.

Table 5 ranks the importance of the adjectives in the overall opinion by means of correlation coefficients for expert and nonexpert users; appearing in order for the column of non-experts. It can be noticed that these correlations were significant (s.l. < 0.001 in most cases), and there were many high correlation coefficients (>0.5), what means very strong correlations between attributes and overall assessment. Results show that both collectives had different opinions when evaluating music hall acoustics so the adjectives were ranked in a different way. Focusing on the first positions, non-experts ranked: good direct sound; clear sound, sharp, well-defined; while the collective of experts ranked: clear sound, sharp, well-defined and not dull. Hence, it can be seen that Table 5 also presents attributes with negative correlations, whose "non presence" was evaluated in a positive way. Examination of these data evidence that experts appreciate the absence of certain defects: sound not dull (2nd place), not weak or poor (7th) and not distant (10th).

3.2. Identifying semantic axes

Table 6 shows the 5 uncorrelated factors obtained for the collective of non-experts by reducing the original set of 27 adjectives using principal components factor analysis (PCA). These factors explained 61.55% of the variance in the original variables:

- 1st axis: it presents a strong correlation with the adjectives "accurate", "wide dynamic range", "good pitch quality", "homogeneous", "harmonious", "with texture", "balanced", "no background noise", "bright", "clear", "good direct sound", "warm", "natural" and "enveloping sound". It has been interpreted as the dimension Fidelity and quality and explains 22.45% of the sample variance.

- 2nd axis: it represents the dimension Power. It shows high positive correlation with the attribute "powerful" and negative correlation with "weak", "distant" and "dull". It explains 14.43% of the variance.

- 3rd axis: it groups the adjectives "intimate", "soft" and "close" which have been interpreted as the dimension Intimacy. This axis explains 12.95% of sample variability.

- 4th axis: it includes the attributes "bass enhanced", "reverberant", "resounding", "dissonant". It reflects the dimension Reverberation and explains 6.98% of the variance.

- 5th axis: it represents the dimension Sound defects. It shows a positive correlation with the adjective "treble enhanced" and a negative value for "without echo". It explains 4.74% of the sample variance.

These 5 factors represent the semantic space for non-expert users, associated to music hall acoustics. Table 7 presents the 6 uncorrelated factors obtained for the group of experts. They explained 67.87% of the variance in the original variables:

- 1st axis: it represents the dimension Balance and pitch quality understood as "good direct sound", "good pitch quality", "balanced", "clear", "warm", "harmonious", "close", "accurate"; and has a negative relation with "weak", "dull", "distant" and "dissonant". It is the main axis and explains 24.94% of sample variability.

- 2nd axis: it reflects the perception of Intimacy and wide dynamic range. It shows high positive correlation with the attributes "intimate", "wide dynamic range", "homogeneous", "with texture" and "natural". Variance explained by this axis goes up to 15.17%.

- 3rd axis: it refers to Power and brightness of the perceived sound. This factor includes the kansei words: "resounding" "treble enhanced", "bright", "reverberant" and "powerful". It explains 7.42% of the variance.

- 4th axis: it shows the perception of “soft” acoustics so it represents the dimension Softness. It explains 7.14% of sample variance.

- 5th axis: this axis presents high correlations between the adjectives “bass enhanced” and “enveloping sound”. It is associated with the concept Bass enhanced and it explains 6.98% of sample variability.

- 6th axis: it shows the absence of sound defects; understood as “no background noise” and “without echo”. Thus, it represents the axis Without sound defects and explains 6.03% of the variance.

As before, these 6 factors related to music hall acoustics compose the semantic space for expert users. Comparison of Table 6 and Table 7 shows that both collectives used different factors to evaluate the music halls.

3.3. Perceptual space

The perceptual space was built for both collectives taking as a basis the two main axes of each group: Fig. 4 shows the perceptual space for non-experts. The x-axis is represented by the factor with the higher load “Fidelity and quality”, followed by the factor “power” in the y-axis. Along the first factor, there is an opposition between the concepts: wide dynamic range, accurate, harmonious, good pitch quality, homogeneous (right) and bass enhanced (left). This axis separates music halls perceived as venues with high acoustic fidelity and rich in nuances from halls that lack those qualities. The second factor (y-axis) confronts the expressions: powerful, clear, balanced, bright, good direct sound, warm (upper side) with reverberant, resounding, dissonant, dull, distant, and weak (lower side). Therefore, this axis separates auditoria whose acoustics were appreciated for being powerful and clear from those whose acoustics were weak, poor and booming. Other structures can be found in addition to these factors: it is possible to find the opposition between “powerful-weak”, “clearresounding”, “good pitch quality-dissonant”, etc.

After visual analysis of the semantic space, the sample of stimuli (numbered dots) was included in this space to examine the relationships between the music halls and the set of expressions. The point of this graph was to study the similarity or discrepancy in individual perceptions of the different venues. The distance of each music hall to the concepts depicted in the semantic space allows each venue to be evaluated through these emotional impressions. Hence for instance, music hall number 12 was perceived as powerful, clear, balanced and with good direct sound; while music hall number 11 was perceived as dissonant, resounding, reverberant and dull. Therefore, the perceptual space is a useful tool for evaluating a music hall according to emotional impressions.

At this point, it is possible to compare the results in Table 5 and Fig. 4. It can be seen that the concepts that mainly influenced the overall opinion of non-experts (those ranked first in Table 5: good direct sound, clear-well defined, good pitch quality, balanced, harmonious, bright.), are located in the upper-right side of the perceptual space (Fig. 4). Thus, venues positioned in that area should be the best considered. Therefore, it can be observed that music halls placed in the upper-right side of the graph are the best evaluated according to acoustic fidelity and power of sound (12, 4, 9, 7), while venues placed in the lower-left side are the least appreciated (1, 11, 16, 2, 3). The distance between music halls depicted in this space implies similarity or difference in perception; for instance, venues number 12, 4 and 9 evoke similar sensations, whilst they are perceived totally different from number 2 and 3 which appear opposite to them.

Fig. 5 presents the perceptual space for the group of experts. This is ruled by the two main factors for this collective: “Balance and pitch quality” in the x-axis, and “Intimacy and wide dynamic range” in the y-axis. The first factor separates concepts such as: good direct sound, warm, harmonious, clear, balanced (on the right side) and distant, dull, weak, dissonant (on the left side). It means that this axis differentiates music halls with balanced and clear acoustics from those whose sound quality is poor and weak. Along the y-axis, the expressions confronted are: intimate, wide dynamic range, homogeneous, natural (in the upper side) and reverberant, resounding (in the lower part). Thus, it separates venues whose acoustics were perceived as intimate and homogeneous, that is, a sensation of well-being for the listeners; from those whose acoustics were perceived booming and resounding, which transmitted a sensation of discomfort. It is also possible to find opposing terms such as: “good pitch quality-resounding”, “clear-reverberant” or “harmonious-dissonant”.

Once more, when placing the set of stimuli in the graph (numbered dots) it can be observed that music halls located in the upper-right side (9, 10, 15, 11) received a positive evaluation for their balanced acoustics, good pitch quality, as well as for immersing the listener into an intimate atmosphere. In contrast, auditoria located in the lower-left side received negative scores in both axes. Therefore, acoustics of venue number 2 were perceived with a poor balance and pitch quality and lacking the sensation of intimacy. Others such as 3, 8, 17, lack balanced acoustics but had a positive rating on the intimacy axis. Opposite them, we find music halls numbers 13 and 14, perceived as venues with good pitch quality and balanced acoustics but lacking intimacy. As before, it can be seen that stimuli located close together in the space were perceived in a similar way; while the greater the distance between them, the larger the difference in perception.

3.4. Ranking semantic axes according to importance in the global assessment

Linear regression model (Eq.(1)) was obtained for non-experts collective and it showed that the axes “Fidelity and quality” and “Intimacy” mainly determined the overall evaluation with high positive coefficients: b 0.636 and b 0.455 respectively. Next in importance appeared the axis “Power” with b ¼ 0.359. Last, the axis “Sound defects” contributed with a small negative coefficient of b 0.099. Finally, the axis “Reverberation” was excluded from the model since it did not have a significant influence on the global assessment (s.l. 0.065). This analysis showed a high linear correlation coefficient (0.809).

Acoustics Global Assessment (non-experts) (1)

In the case of expert users, the axes were ordered in the linear regression model (Eq. (2)) as follows: first the axis “Balance and pitch quality” with a coefficient of b 0.705. Second, the axis “Intimacy and wide dynamic range” whose load in the overall assessment was b 0.451; and last the axis “Bass enhanced” with a negative coefficient b 0.220. The remaining axes: “Power and brightness” (s.l. 0.271); “Softness” (s.l. 0.081) and “Without sound defects” (s.l. 0.395) were excluded from the model. The linear correlation coefficient of this model was 0.848.

Acoustics Global Assessment (experts) (2)

Comparing (Eqs. (1) and (2)) it can be observed that, even if all factors were rated 0 in both models, the collective of non-experts tend to give higher valuations (0.633) than the experts (0.431).

3.5. Validation of the regression models and semantic profiles A control sample which did not participate in the initial study was reserved for this stage. The sample consisted of 29 questionnaires related to two particular concert halls (Fig. 6).

Table 8 shows the real and predicted values for the global assessment variable and deviation, for experts and non-experts. The real value corresponds to the mean of the real scores for the global assessment. Then, the predicted value is obtained by replacing the mean scores for each factor of the regression models. As Table 8 shows, the real and predicted values were very similar in all cases. Thereby apparently confirming the reliability of the models and their validity for this research.

Once the strength of the models was tested, it was interesting to compare the evaluation of the music halls in the control sample by means of their semantic profile. These represent the scores obtained in each semantic axis, and they were calculated for the expert and non-expert collectives. Fig. 7 shows the semantic profiles of venue V1 and V2 for the non-expert group. It can be seen that evaluation of the axes with higher loads (F1: “Fidelity and quality”; F2: “Power” and F3: “Intimacy”) had a direct impact on the global assessment, as the previous models predicted. Hence, Fig. 7 shows that venue V1 received positive ratings on these axes and therefore the global assessment reached 1.58. However, venue V2 obtained poorer ratings for F1, F2 and F3, so its global assessment was lower (0.31).

The same graphs were calculated for experts (Fig. 8). In this case, the main factors F1: “Balance and pitch quality”; and F2: “Intimacy and wide dynamic range”; received positive scores for venue V1 and consequently its overall assessment reached a good value: 1. On the contrary, music hall V2 received a very negative evaluation on F1 and, despite having a positive value for F2, the score for its global assessment was considerably reduced: -0.5.

DISCUSSION

This work aims to apply SD in the frame of Kansei Engineering to define valid evaluation scales for different collectives and determine evaluation criteria related to the overall assessment of the acoustics of music halls. This is the first step in defining subjective evaluation scales that enable perceptions to be related to physical acoustic variables.

The studies consulted on the subjective evaluation of music halls reflect the opinions of experts [2-4,7] or non-experts [6,8,17] based on concepts or attributes always defined by experts (professional musicians, conductors, acousticians). That is, the mental scheme of non-experts was not taken into account when constructing the questionnaires. This approach could lead to erroneous results as the criteria and qualities reflected in the assessment questionnaires might not be recognised by users, thereby conditioning the evaluation process itself. In this work the use of SD is proposed to obtain subjective evaluation scales adapted to the language of each group without expert intervention. This technique has often been used in the field of Kansei Engineering for product design, but has not been used to design music halls.

The results of the first comparison (Section 3.1) confirm the initial hypothesis that experts and non-experts understand the acoustic qualities in a different way. This finding has been demonstrated by the application of multivariant techniques (discriminant analysis, Table 3) and univariant techniques (ANOVA, Table 4). Thus, the results show that expert and non-expert users have a different mental scheme and, therefore the significance of the set of attributes on the overall acoustic assessment of a venue is different for each group (Table 5). These differences in perception make it clear that data should be treated in a separate way for both collectives.

Furthermore, it can be observed that experts are more critical in their evaluation. This finding is explained by the fact that for this collective the “non presence” of several qualities in a music hall is also important. For them it is very important that the acoustics are not dull, weak, poor or distant. That is, experts not only evaluate the presence of “good attributes” but also the absence of non desirable ones. In any case, Table 5 shows that both collectives present high correlations among the adjectives and the global assessment variable, which confirms that non-experts also have a coherent criterion although different from the experts. The different evaluation structures can be seen in the semantic axes obtained from the PCA for each group. The non experts identified 5 factors or independent axes (Table 6) whereas the expert users appear to be more demanding when assessing a music hall since they use one more factor (6 factors; Table 7). This may also confirm that this collective perceive more nuances in the acoustics. The axes cannot be compared directly as they gather different information; however, the first two axes or any other pair can be used to represent the music halls graphically in the perceptual space to see how the two groups of users perceive them. Hence, observing Figs. 4 and 5 some similarities and discrepancies may be carefully established for both collectives. Acoustics of venues numbers 2 and 3 were perceived by experts and nonexperts as dull, distant, weak, poor and dissonant. Both collectives agree in their opinions about the acoustics of venue number 12 which were perceived as clear-well defined, good direct sound and warm. Conversely, both groups differ completely when evaluating other music halls. Venue number 10 was perceived by nonexperts as reverberant, resounding and dissonant; while experts evaluated it as balanced, with clear sound and good pitch quality. Venue number 11 was perceived by non-experts as dissonant, dull and resounding; while experts judged it as powerful, bright and harmonious. We can find another example of disagreement in music hall number 16 which was perceived by non-experts as resounding and dissonant; while experts perceived it as warm and harmonious. Nevertheless, these comparisons must be taken as an orientation since, as it has been said, both collectives interpret some attributes in a different way.

Furthermore the axes are independent of each other for each group, so the impact of each attribute on the global assessment of the music hall can be identified. The evaluation schemes obtained from the regression models (Eqs. (1) and (2)) show some interesting results. For the non-experts collective (Eq. (1)) the most influential factor was number 1 “Fidelity and quality”. This axis contained items related to accuracy of sound, wide dynamic range, good pitch quality and homogeneity of sound among others. This factor represents the attributes that this collective values most in a music hall. The second factor in the model was “Intimacy” which gathered the attributes: intimate, soft and close sound. The third axis in importance on the global assessment was “Power”, composed by the items: powerful, not weak, not distant and not dull. Finally, the absence of “Sound Defects”, understood as sound without treble enhanced and without echo was also appreciated by this collective. In contrast, analysing the model for the expert group (Eq (2).) it can be seen that the most influential factor on the global assessment was “Balance and pitch quality”. This axis joined attributes such as: good direct sound, good pitch quality, balanced, clear, warm, harmonious among others. The next factor in importance was “Intimacy and wide dynamic range” which contained the items: intimate, wide dynamic range, homogeneous, with texture and natural. Finally, the absence of “Bass enhanced” was relevant for this collective as well. Therefore, as it can be seen, both collectives use different models for evaluating the acoustics of music halls. The axes appear to be reliable as they have a high correlation with the global evaluation in both regression models. In addition, they were independently validated with 29 questionnaires on 2 halls which did not intervene in the definition of the axes, showing an adequate level between the observed values and those forecast by the model.

The results of this study are difficult to compare with other studies as no previous studies have applied Kansei Engineering to the activity of music halls. However, it is interesting to contrast some of the findings with previous works. The main axis determining acoustic comfort for non-experts “Fidelity and quality”, and for experts “Balance and pitch quality” represent emotional attributes which have not been deeply studied before as single factors. This fact must be taken into account in order to define specific design features of music halls which maximize the rating of these axes. In contrast, it is possible to find many studies on the attributes “Intimacy” and “Power”. It is worth noting the study by Beranek, L. [3], who concluded that “Intimacy” contributed up to 40% of the perceived quality of a music hall. In his study, made with expert subjects, this quality was three times more important in the overall assessment than the other attributes. Results of the present study show that “Intimacy” is also an important factor. Non-expert users ranked it 3rd in explained variance (12.95%; Table 6) and 2nd in importance in the overall assessment with a score of 0.455 (Eq.(1)). Besides, for expert users, the factor related to intimacy occupied the 2nd position in explained variance (15.17%; Table 7) and also ranked 2nd in the overall assessment with a score of 0.451 (Eq.(2)). These results confirm that intimacy is an important factor for both collectives but not the main one. Regarding the axis “Power”; this attribute understood as loudness and power of sound, has been considered of great importance for many authors in their research [7,9,14,16]. Findings in the present study point in the same direction. Non-expert users ranked this factor 2nd in explained variance (14.43%; Table 6) and 3rd in importance in the overall assessment with a score of 0.359 (Eq.(1)). Expert users, however, ranked power in 3rd place (7.42%; Table 7).

Although Kansei Engineering has been much used in the field of user-friendly product design [24,36-41], it has not been applied to measure the acoustic quality of a music hall. SD can be used with different applications to hall design. Firstly, it offers a systematic method for obtaining subjective evaluation scales using independent valuation scales adapted to each collective’s conceptual scheme. This step is fundamental for studying, in a subsequent phase, the relationship between the physical parameters of music halls with subjective judgements, as that relationship can hardly be established if the users do not understand the concepts. This part is developed by Inverse Kansei studies [25]. Secondly, SD offers valuable information for design. Thus the semantic profiles in Figs. 7 and 8 show the differences in the evaluations of the expert and non-expert groups in each of the axes. This evaluation is interesting for acousticians and music hall designers since it enables visual comparison of a “product” (music hall) with its competitor; identifying and analysing its main features. This approach is fundamental when defining a future design or restoration strategies for this kind of venues.

As regards the limitations of the study, the PCA technique extracts independent axes which explain more variance than the set of responses. Therefore, the stimuli must have sufficient variability. Because the study of acoustic perceptions requires work with real stimuli and not simulations, we had to use a sample of hall rooms broad enough to guarantee that variability: large and small concert halls, new and traditional, located in big cities and small towns, etc. The drawback is that the possible combination of design elements that may influence perception of the acoustics was given by the availability of those combinations in the real product. However, this limitation is not relevant in this stage of KE where the aim is to obtain a representation of the opinions of the music halls and it must be as varied as possible. The aim of the second stage of KE is to relate subjective perceptions with objective acoustic variables. In this phase it is necessary to have a sample of music halls that combine all the potential design elements in a balanced way, in order to obtain predictive models. In any case, we consider that this technique can provide valuable information that takes into account the differences in perception in different collectives.

CONCLUSIONS

Semantic Differential offers a systematic procedure for identifying the attributes and qualities that best explain the differences in product evaluation (music halls in this case) for a given collective. Thus SD enables the definition of subjective evaluation scales adapted to each study collective, contrasting the extent to which the concepts being dealt with are appreciated by all the collectives and the degree of independence between those concepts. The use of PCA enables opinions on a wide variety of attributes to be grouped in a small number of variables to obtain axes adapted to users' conceptual scheme. Thus valuation scales can be systematically extracted defined by those who are actually evaluating the product (whether they are experts or not). These valuation scales are formed by independent axes that explain the maximum variability. In short the procedure enables quantification of subjective perceptions and can even establish their impact on the global assessment.

The identification of these independent attributes is very important in order to be able to relate, in a subsequent phase, the perceptions with the physical parameters that determine them. SD is the first step in the Kansei methodology whose ultimate objective is to understand the relationships between the physical variables and perceived acoustic quality. This initial phase is fundamental in the Kansei process as if the evaluation scales are based on attributes that cannot be appreciated by a collective of users, or concepts that manage overlapping information (not independent), it is very difficult to then find statistical evidence of the relationship between certain physical parameters and that collective's perception of acoustic quality.

REFERENCES

[1] Ando Y. Calculation of subjective preference at each seat in a concert hall. J Acoust Soc America 1983;74(3):873e87.

[2] Barron M. Subjective study of British symphony concert halls. Acustica 1988; 66(1):1e14.

[3] Beranek LL. Music, acoustics and architecture. New York: John Wiley and Sons INC; 1962.

[4] Farina A. Acoustic quality of theatres: correlations between experimental measures and subjective evaluations. Appl Acoust 2001;62:889e916.

[5] Fischetti A, Hemim Y, Jouhaneau J. Relations between subjective spatialisation, geometrical parameters and acoustical criteria in concert halls. Appl Acoust 1992;37:233e47.

[6] Hawkes RJ, Douglas H. Subjective acoustic experience in concert auditoria. Acustica 1971;24:235e50.

[7] Hidaka T, Beranek LL. Objective and subjective evaluations of twenty-three opera houses in Europe, Japan, and the Americas. J Acoust Soc America 2000;107(1):368e83.

[8] Semidor C, Barlet A. Objective and subjective surveys of opera house acoustics: example of the Grand Theatre de Bordeaux. J Sound Vibration 2000; 232(1):251e61.

[9] Wilkens H, Lehmann P. The connection between subjective judgements of concert halls and criteria of room acoustics. Acustica 1980;45:256e68.

[10] Sabine WC. Collected papers on acoustics. Harvard University Press; 1922.

[11] Jordan VL. A group of objective acoustical criteria for concert halls. Appl Acoust 1981;14:253e66.

[12] Schroeder MR, Atal BS, Sessler GM, West JE. Acoustical measurements in philharmonic hall (New York). J Acoust Soc America 1966;40:434e40.

[13] Reichardt W, Abel Alim O, Schmidt W. Definition und Messgrunglage eines objectiven Masses zur Ermittlungder Grenze zwischen brauchbarer und unbrauchbarer Dutrchsichtigkeit bei musikdarbietung. Acustica 1975;32:126.

[14] Gilbert Soulodre A, John Bradley S. Subjective evaluation of new room acoustic measures. J Acoust Soc America 1995;98(1):294e9.

[15] Queiroz de Sant'Ana D, Trombetta Zannin PH. Acoustic evaluation of a contemporary church based on in situ measurements of reverberation time, definition, and computer-predicted speech transmission index. Build Environ 2011;46:511e7.

[16] Schroeder MR, Gottlob D, Siebrasse KF. Comparative study of European concert halls: correlation of subjective preference with geometric and acoustic parameters. J Acoust Soc America 1974;56:1195e201.

[17] Chiang W, Wang W. Subjective assessment of broadband background noises in music auditoriums. Appl Acoust 2002;63:103e15.

[18] Brandler S. Differences in mental Abilities between musicians and nonMusicians. Psychol Music 2003;31(2):123e38.

[19] Kim JY, Belkin NJ. Categories of music description and search terms and phrases used by non-music experts. School of Communication, Information and Library Studies. Rutgers University USA; 2002 [IRCAM, Centre Pompidou].

[20] Ohnishi T, Matsuda H, Asada T, Aruga M. Functional anatomy of musical perception in musicians. The psychology of music. 2nd ed. Academic Press; 1999.

[21] Koelsch S, Schröger E, Tervaniemi M. Superior pre-attentive auditory processing in musicians. Neuro-Report 1999;10:1309e13.

[22] Münte TF, Altenmüller E, Jäncke L. The musician's brain as a model of neuroplasticity. Nature Publishing Group. Nat Reviews Neurosci 2002;3:473e8.

[23] Osgood CE, Suci CJ, Tannenbaum PH. The measurement of meaning. Urbana: University of Illinois Press; 1957. pp. 76e124.

[24] Jindo T, Hirasago K. Application studies to car interior of kansei engineering. Int J Ind Ergon 1997;19(1):105e14.

[25] Matsubara Y, Nagamachi M. Hybrid kansei engineering system and design support. Int J Ind Ergon 1997;19(1):81e92.

[26] Llinares C, Page A. Application of product differential semantics to quantify purchaser perceptions in housing assessment. Build Environ 2007;42(7): 2488e97.

[27] Llinares C, Page A. Differential semantics as a kansei engineering tool for analysing the emotional impressions which determine the choice of neighbourhood. The case of Valencia, Spain. Landscape Urban Plann 2008;87: 247e57.

[28] Hsu SH, Chuang MC, Chang CC. A semantic differential study of designers' and Users' product form perception. Int J Ind Ergon 2000;25:375e91.

[29] Kang J, Zhang M. Semantic differential analysis of the soundscape in urban open public spaces. Build Environ 2010;45:150e7.

[30] Nagamachi M. Kansei Engineering: a new ergonomic consumer-oriented technology for product development. Int J Ind Ergon 1995;15:3e11.

[31] Terniko J. Step-By-Step Qfd. Costumer-Driven product design. St. Lucie Press; 1997.

[32] Basilevsky A. Statistical factor analysis and related methods: theory and applications. New York: Wiley; 1994.

[33] Nagamachi M. Kansei engineering. Tokyo: Kaibundo; 1989.

[34] Nagamachi M. Kansei engineering: the framework and methods. In: Kansei engineering 1. Kure: Kaibundo Publishing co. Ltd; 1997.

[35] Schütte Simon TW, Eklund J, Axelsson Jan RC, Nagamachi M. Concepts, methods and tools in kansei engineering. Theory Issues Ergonomic Sci 2004; 5(3):214e31.

[36] Tanoue C, Ishizaka K, Nagamachi M. Kansei engineering: a study on perception of vehicle interior image. Int J Ind Ergon 1997;19(1):115e28.

[37] Chuang MC, Chang CC, Hsu SH. Perceptual factors underlying user preferences toward product form of mobile phones. Int J Ind Ergon 2001;27:247e58.

[38] Jindo T, Hirasago K, Nagamachi M. Development of a design support system for office chairs using 3-D graphics. Int J Ind Ergon 1995;15(1):49e62.

[39] Alcántara E, Artacho MA, González JC, García AC. Application of product semantics to footwear design. Part I e identificction of footwear semantic space applying differential semantics. Int J Ind Ergon 2005;35(8):713e25.

[40] Ishihara S, Ishihara K, Nagamachi M, Matsubara Y. An Automatic Builder for a kansei engineering expert system using Self-Organizing Neural Networks. Int J Ind Ergon 1995;15(1):13e24.

[41] Ishihara S, Tsuchiya T, Nagamachi M, Ishihara K, Nishino T. Conference: Quality Management and Organisational Development. Communication of intention and ideas in collaborative design process-sharing language with Kansei engineering system, 19(26). Sweden: Our Dreams of Excellence, Helsingborg; 2001. 1650e1686.

[42] Kosaka H, Watanabe K. Electronic sound evaluation system based on Kansei (human feeling). Analysis, design and evaluation of Man-Machine Systems. In: A proceedings volume from the 7th IFAC/IFIP/IFORS/IEA symposium, Kyoto, Japan 1999:53e57.

[43] Onishi G, Niizeki M, Kimura I, Yamada H. A Kansei model for musical chords based on the structure of the human auditory system. Int joint conference Neural Networks 2001:1e4. proceedings;1101-6.

[44] Sugihara T, Morimoto K, Kurokawa T. An improved kansei-based music retrieval system with a new distance in a kansei space. RO-MAN 2004:13th IEEE International Workshop on Robot and Human Interactive Communication. Kurashiki, Okayama, Japan 2004;141e146.

[45] Schütte S. Engineering emotional values in product design. Kansei Eng Dev, PhD thesis. Linköping Universitet, Sweden; 2005, p. 4e5

TABLES AND FIGURES

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

Gender			**Age**			**Professional relation with music hall**		
Male	171	59%	<20	15	4.84%	Experts	74	23.87%
Female	139	41%	20–30	58	18.71%	Non-experts	236	76.13%
			31–40	78	25.16%			
			41–50	87	28.07%			
			51–60	43	13.87%			
			61–70	18	5.80%			
			>70	11	3.55%			

Table 2. Concert halls in the stimuli sample.

No.	Concert hall	Data		
1	GRAN TEATRE (Alzira)	Capacity: 896 people Year of construction: 1925 Last restoration: 1989		
2	TEATRE SERRANO (Gandía)	Capacity: 602 people Year of construction: 1960 Last restoration: 2006		
3	CENTRE CULTURAL (Almussafes)	Capacity: 496 people Year of construction: 1984		
4	AUDITORI MUNICIPAL (Aielo de Malferit)	Capacity: 452 people Year of construction: 1996		
5	AUDITORI MOLÍ DE VILA (Quart de Poblet)	Capacity: 475 people Year of construction: 1997		
6	CENTRE CULTURAL "EL OLIVAR" (Alaquàs)	Capacity: 307 people Year of construction: 1989		
7	AUDITORI DE TORRENT (Torrent)	Capacity: 606 people Year of construction: 1997		
8	SALA TÍVOLI (Burjassot)	Capacity: 730 people Year of construction: 1994		
9	GRAN TEATRE (Xàtiva)	Capacity: 765 people Year of construction: 2001		
10	CASA CULTURA (Benifaió)	Capacity: 326 people Year of construction: 1997		
11	CASA CULTURA (La Pobla de Vallbona)	Capacity: 385 people Year of construction: 1997		
12	PALAU DE LA MÚSICA (Valencia)	Capacity: 1790 people Year of construction: 1987		
13	CASA CULTURA (Denia)	Capacity: 300 people Year of construction: 1976		
14	PALAU DE LES ARTS (Altea)	Capacity: 900 people Year of construction: 2001		
15	CASA CULTURA (Alfàs del Pi)	Capacity: 417 people Year of construction: 1991		
16	CENTRE SOCIAL (La Vila Joiosa)	Capacity: 366 people Year of construction: 1992		
17	TEATRO PRINCIPAL (Alicante)	Capacity: 1072 people Year of construction: 1847 Last restoration: 1992		

Table 3. Output of the discriminant analysis between expert and non-expert collectives.

Eigenvalue	0.190
Canonical correlation	0.399
Wilks' Lambda	0.840
Signification Level	<0.001

Table 4. ANOVA for expert and non-expert collectives.

Source	SS	df	MS	F	Sig	Source	SS	df	MS	F	Sig
1. Powerful						5. Dissonant					
Inter-groups	7.717	2	3.859	3.950	0.020	Inter-groups	5.159	2	2.579	3.053	0.049
Intra-groups	294.042	301	0.977			Intra-groups	253.462	300	0.845		
Total	301.760	303				Total	258.620	302			
2 Reverberant						6. Harmonious					
Inter-groups	8.615	2	4.307	4.473	0.012	Inter-groups	5.085	2	2.542	3.301	0.038
Intra-groups	287.928	299	0.963			Intra-groups	230.296	299	0.770		
Total	296.543	301				Total	235.381	301			
3. Resounding						7. No background noise					
Inter-groups	7.576	2	3.788	3.889	0.022	Inter-groups	10.012	2	5.006	3.079	0.047
Intra-groups	294.182	302	0.974			Intra-groups	489.409	301	1.626		
Total	301.757	304				Total	499.421	303			
4. Balanced											
Inter-groups	5.663	2	2.831	3.326	0.037						
Intra-groups	258.793	304	0.851								
Total	264.456	306									

Table 5. Correlation between the 27 acoustic parameters and the global assessment variable.

	Non-experts		Empty Cell		Experts	
Signif. Level	**Correlation coef.**	**Ranking**	**Adjectives**	**Ranking**	**Correlation coef.**	**Signif. Level**
<0.001	0.705	1	Good direct sound	6	0.546	<0.001
<0.001	0.660	2	Clear sound. Sharp. Well-defined	1	0.631	<0.001
<0.001	0.631	3	Good pitch quality	3	0.604	<0.001
<0.001	0.630	4	Balanced	4	0.594	<0.001
<0.001	0.613	5	Harmonious	11	0.482	<0.001
<0.001	0.548	6	Bright. Lively	14	0.443	<0.001
<0.001	0.536	7	Uniform. Homogeneous. Not Focused	12	0.481	<0.001
<0.001	0.528	8	Natural	8	0.519	<0.001
<0.001	0.526	9	Warm	5	0.564	<0.001

Non-experts			Empty Cell	Experts		
Signif. Level	**Correlation coef.**	**Ranking**	**Adjectives**	**Ranking**	**Correlation coef.**	**Signif. Level**
<0.001	0.513	10	Accurate	17	0.333	0.011
<0.001	−0.491	11	Weak. Poor	7	−0.530	<0.001
<0.001	0.488	12	Close	13	0.474	<0.001
<0.001	0.478	13	Powerful	N.S.	0.266	0.043
<0.001	−0.440	14	Dull	2	−0.620	<0.001
<0.001	0.433	15	With texture	9	0.492	<0.001
<0.001	0.415	16	Wide dynamic range	18	0.337	0.01
<0.001	−0.410	17	Booming. Resounding	16	−0.384	0.003
<0.001	0.408	18	Soft	19	0.320	0.014
<0.001	0.406	19	Enveloping sound	20	0.303	0.022
<0.001	−0.405	20	Dissonant	21	−0.248	0.061
<0.001	−0.404	21	Distant	10	−0.490	<0.001
<0.001	0.385	22	Intimate	22	0.214	0.107
<0.001	0.381	23	Without background noise	N.S.	−0.142	0.289
<0.001	0.320	24	Without echo	N.S.	0	1
0.002	−0.207	25	Reverberant	15	−0.437	0.001
0.087	−0.117	N.S.	Enhances bass	23	−0.146	0.277
0.322	0.068	N.S.	Enhances treble	N.S.	0.01	0.941

Note: (N.S: not significant).

Table 6. Range of meaning of kansei factor axes and representative terms for non-experts.

Factor axes (Non-experts)	Correlation with kansei words	Variance explained
1. Fidelity and quality	Accurate (0.759), Wide dynamic range (0.752), Good pitch quality (0.702), Homogeneous (0.672), Harmonious (0.634), With texture (0.627), Balanced (0.606), No background noise (0.583), Bright (0.576), Clear (0.567), Good direct sound (0.543), Warm (0.525), Natural (0.460), Enveloping sound (0.413)	22.45%
2. Power	Powerful (0.504), Weak (−0.819), Distant (−0.792), Dull (−0.734)	14.43%
3. Intimacy	Intimate (0.789), Soft (0.668), Close (0.574)	12.95%
4. Reverberation	Bass enhanced (0.720), Reverberant (0.609), Resounding (0.536), Dissonant (0.517)	6.98%
5. Sound defects	Treble enhanced (0.743), Without echo (−0.512)	4.74%

Table 7. Range of meaning of kansei factor axes and representative terms for experts.

Factor axes (Experts)	Correlation with kansei words	Variance explained
1. Balance and pitch quality	Good direct sound (0.758), Good pitch quality (0.678), Balanced (0.673), Clear (0.661), Warm (0.625), Harmonious (0.568), Close (0.548), Accurate (0.490), Weak (−0.799), Dull (−0.738), Distant (−0.688), Dissonant (−0.650)	24.94%
2. Intimacy and wide dynamic range	Intimate (0.804), Wide dynamic range (0.803), Homogeneous (0.714), With texture (0.575), Natural (0.568)	15.17%
3. Power and brightness	Resounding (0.645), Treble enhanced (0.627), Bright (0.600), Reverberant (0.515), Powerful (0.494)	7.42%
4. Softness	Soft (0.799)	7.14%
5. Bass enhanced	Bass enhanced (0.754), Enveloping sound (0.702)	6.98%
6. Without sound defects	No background noise (0.821), Without echo 0.526)	6.03%

Table 8. Validation results of linear regression models.

Empty Cell		**V1**			**V2**		
		Real value	**Predicted value**	**Deviation**	**Real value**	**Predicted value**	**Deviation**
Global assessment	Non experts	1.58	1.24	−0.34	0.31	0.23	−0.08
	Experts	1	0.96	−0.04	−0.5	−0.35	0.15

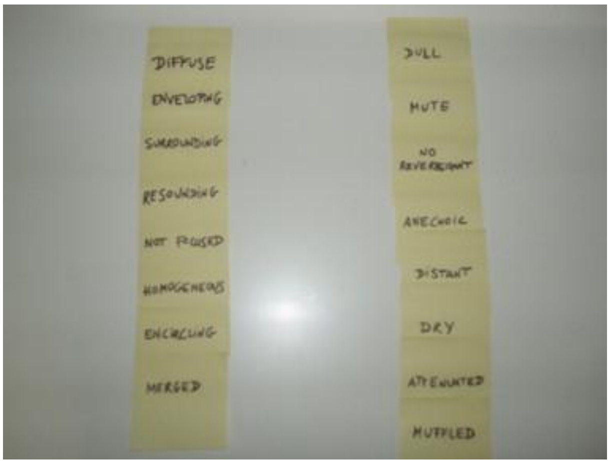

Figure 1. Example of a group of words in the Affinity Diagram.

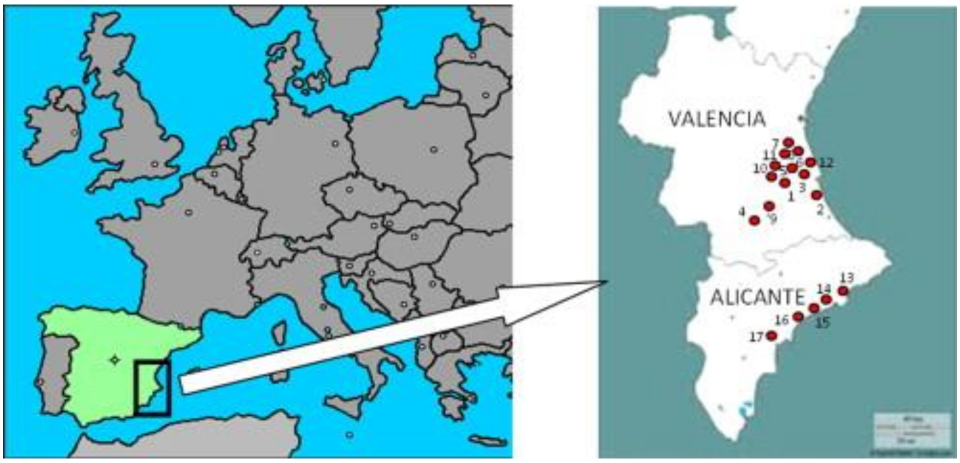

Figure 2. Location of the concert halls in the Valencia region (Spain) VALENCIA: 1- Alzira, 2- Gandía, 3- Almussafes, 4- Aielo de Malferit, 5- Quart de Poblet, 6- Alaquàs, 7- Torrent, 8- Burjassot, 9-Xàtiva, 10- Benifaió, 11- La Pobla de Vallbona and 12- Valencia. ALICANTE: 13- Denia, 14- Altea, 15- Alfàs del Pi, 16- La Vila Joiosa and 17- Alicante.

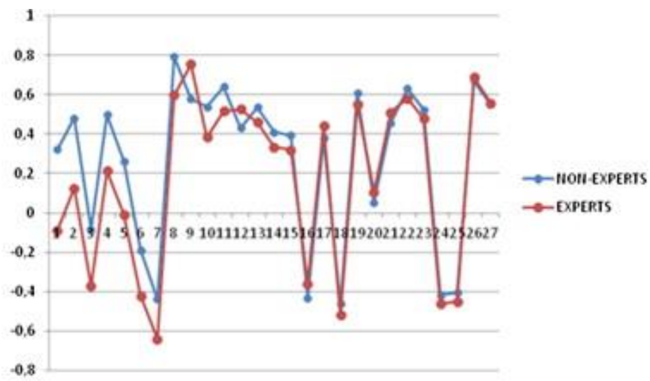

Figure 3. Mean scores for the 27 adjectives for expert and non-expert collectives Adjectives ranked by differences between collectives: 1: no echo; 2: enveloping sound; 3: bass enhanced; 4: powerful; 5: no background noise; 6: reverberant; 7: weak; 8: good direct sound; 9: balanced; 10: homogeneous; 11: harmonious; 12: with texture; 13: bright; 14: intimate; 15: soft; 16: resounding; 17: wide dynamic range; 18: dull; 19: warm; 20: treble enhanced; 21: accurate; 22: good pitch quality; 23: close; 24: distant; 25: dissonant; 26: clear, well-defined; 27: natural.

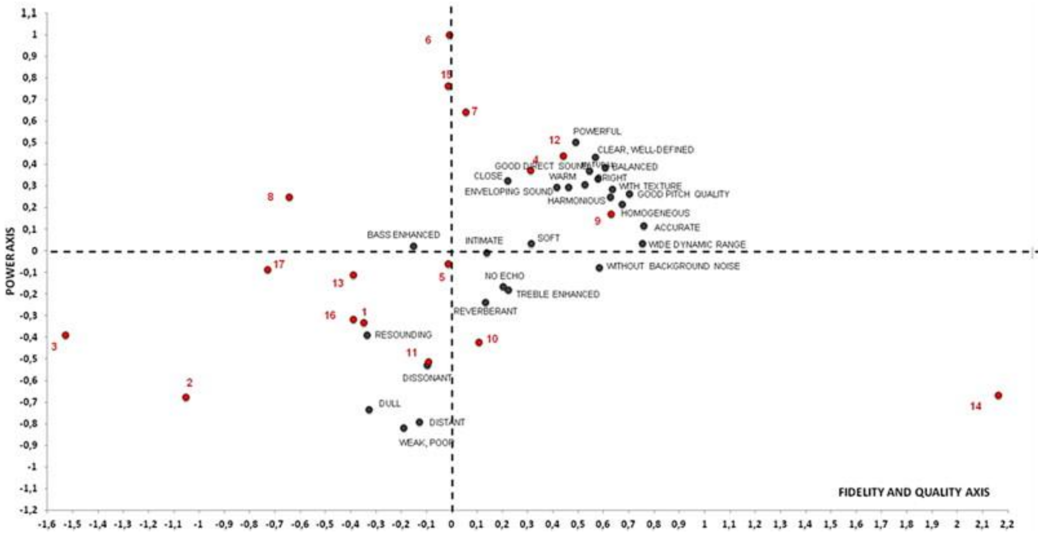

Figure 4. Perceptual space for non-experts, containing expressions (black dots) and numbered sample of stimuli (music halls). The *x*-axis is represented by the factor with the higher load "Fidelity and quality", and the next in importance "power" is represented in the *y*-axis.

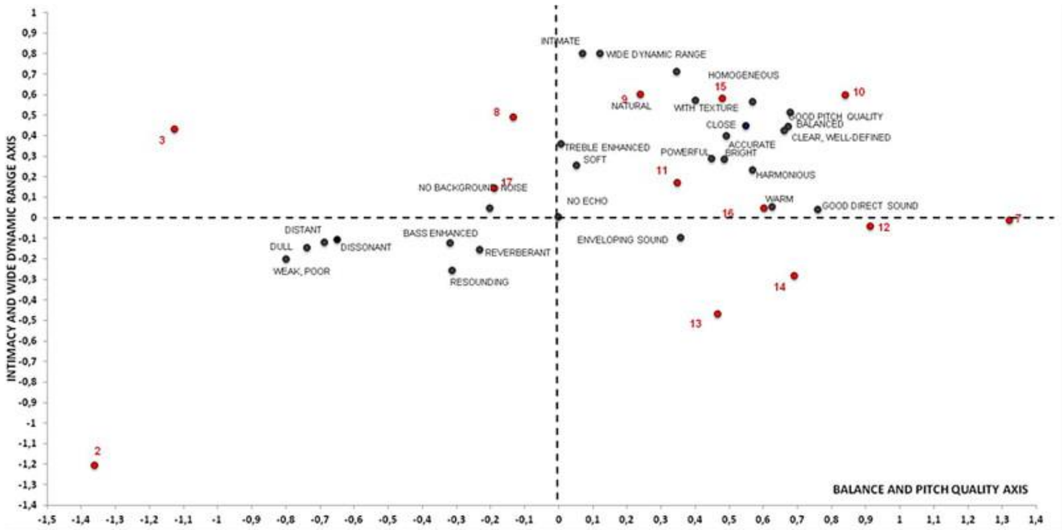

Figure 5. Perceptual space for experts, containing expressions (black dots) and numbered sample of stimuli (music halls). The *x*-axis is represented by the factor with the higher load "Balance and pitch quality", and the next in importance "intimacy and wide dynamic range" is represented in the *y*-axis. Note: some music halls are not depicted in the graph due to a lack of expert data.

Figure 6. Concert halls in the control sample for the validation process.