Does Architecture affect Acoustic perception in music halls?

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Abstract: Acoustics and architecture are two of the main parameters that influence the quality of a music hall. However, does the user perceive these two factors independently? A good architectural design may affect the perceived acoustic quality and vice-versa?

In this line, the present work aims to determine the conceptual structure employed by the users when evaluating a music hall. This study also pursued analyzing whether architectural variables have an influence on the perceived acoustic quality and vice-versa.

To achieve these goals, a previous research was conducted in 17 venues of the Valencian Region using Semantic Differential within the frame of Kansei Engineering. A sample of 221 users classified as "non-experts" (neither musicians, nor acousticians or architects, nor people related professionally to concert halls) participated in this experience evaluating the architectural and acoustic quality of these venues.

Results showed that, from a conceptual perspective, the users clearly differentiated the acoustic variables from the architectural ones. Nevertheless, it was observed that architecture influenced the perceived acoustic quality and vice-versa. Thus, regression models were obtained and tested to measure the perception of acoustic and architecture quality. These results may be interesting to enable optimization of design features of future music halls.

Keywords: music hall, acoustics, architecture, perception, non-experts.

1. INTRODUCTION

The 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 since many years ago. Physical parameters which determine the acoustic quality of these venues wanted to be identified and measured. Thus, in the early 20's, Sabine research pointed out that reverberation time was the only parameter that represented the acoustic quality of a music hall (Sabine, W. C., 1922). However, later on, researchers realized there were some other parameters which influenced the acoustic perception: Early Decay Time (EDT) (Jordan, V. L.,1981), Initial Time Delay Gap (ITDG) (Beranek, L.L., 1962), Spatial Impression (Schroeder, M.,R., Atal, B., S., Sessler, G., M. & West, J., E., 1966), Clarity Factor C_{50}, C_{80} (Reichardt, W., Abel Alim, O. & Schmidt, W., 1975), Gain Factor (G) (Gilbert Soulodre, A. & John Bradley, S., 1995), Interaural Cross-Correlation (IACC) (Ando, Y., 1983) ... among others.

All this knowledge resulted in a new branch of acoustics: psychoacoustics. This discipline studies the relation between all these physical parameters and the subjective evaluation that they evoke on the listener (intimacy, enveloping sound, clarity, loudness, balance, warmth, etc...). In fact many authors have conducted researches in this field; though particularly important was Leo Beranek (Beranek, L.L., 1962). He highlighted the importance of the feeling of intimacy in a music hall and its influence over the global assessment. After him, many other authors studied and quantified the influence of other acoustic parameters on the listener's perception: influence of Lateral Energy Fraction (LF) on the perception of enveloping sound (Barron, M., 1988); influence of the Clarity Factor C_{80} on the subjective clarity perceived (Fischetti, A., Hemim, Y. & Jouhaneau, J., 1992); influence of the Gain Factor G(A) on the loudness (Gilbert Soulodre, A. & John Bradley, S., 1995); influence of the IACC on the diffusion of sound (Hidaka, T. & Beranek, L.L., 2000); influence of the Speech Transmission Index (STI) on the intelligibility of sound (Farina, A. 2001; Fischetti, A., Hemim, Y. & Jouhaneau, J., 1992; Gilbert Soulodre, A. & John Bradley, S. 1995; Semidor, C. & Barlet, A. 2000), reverberation (Barron, M. 1988; Kürer, R. & Kurze, U. 1968; Sabine, W. C. 1922; Seraphin, H. P. 1958); intimacy (Ando, Y. 1983; Beranek, L.L. 1962; Farina, A. 2001; Hawkes, R.J., Douglas, H. 1971); power (Gilbert Soulodre, A. & John Bradley, S. 1995; Hidaka, T. & Beranek, L.L. 2000; Schroeder, M.R., Gottlob, D. & Siebrasse, K.F. 1974; Wilkens, H. & Lehmann, P. 1980), etc.

All these studies have a common link: listeners' impressions were evaluated through questionnaires and tests. The sample of listeners was composed of experts in some studies (musicians, acousticians, conductors, etc...) (Barron, M. 1988; Beranek, L.L. 1962; Farina, A. 2001; Hidaka, T. & Beranek, L.L. 2000); and non-experts in others (students or usual listeners) (Hawkes, R.J., Douglas, H., 1971; Semidor, C. & Barlet, A. 2000; Wieihwa Chiang & Weichung Wang 2002). However, in all cases the concepts and attributes to evaluate had been set by experts (professional musicians, conductors, acousticians). That is, the mental scheme of non-experts was not taken into account to build the questionnaires. This could led to wrong results since non-experts may misunderstand some of the concept set by the experts, and moreover, as experts filter the information to assess, some of the parameters appreciated by non-experts may not be never evaluated. Besides, several studies have shown that the brain of professional musicians work in a different way from that of the non-musicians (Brandler, S. 2003; Ja-Young Kim & Nicholas J. Belkin 2002; Ohnishi, T., Matsuda, H., Asada, T., Aruga M. 1999; Stefan Koelsch, Eric Schröger & Mari Tervaniemi 1999; Thomas F. Münte, Eckart Altenmüller & Lutz Jäncke 2002).

On the other hand, it is well known that Kansei Engineering is a technique that allows studying the perception of a product based from the user point of view since it may be different from that of experts (Nagamachi, M. 1989; Nagamachi, M. 1997; Schütte Simon, T. W., Eklund, J., Axelsson Jan, R. C. & Nagamachi, M. 2004). There are many studies which have used this technique to analyse this perception over multitude of products: automotive industry (Jindo, T. & Hirasago, K. 1997; Tanoue, C., Ishizaka, K. & Nagamachi, M. 1997); mobile phones (Chuang, M. C, Chang, C. C. & Hsu, S. H. 2001; Hsu, S.H., Chuang, M.C. & Chang, C.C. 2000); shoes (Alcántara, E., Artacho, M. A., González, J. C. & García, A. C. 2005; Ishihara, S., Ishihara, K., Nagamachi, M. & Matsubara, Y. 1995); beer cans (Ishihara, S., Tsuchiya, T., Nagamachi, M., Ishihara, K. & Nishino, T. 2007); building sector (Llinares, C., Page, A. (2007), etc... and it has been proved that non-experts and experts work with different mental schemes.

Taking all this information as a basis, the authors carried out a previous research in the field of music hall acoustics, using the technique of Differential Semantics (DS) (Osgood, C.E., Suci, C.J. & Tannenbaum, P.H.,1957) within the context of Kansei Engineering (KE), (Galiana, M., Llinares, C., Page A. 2012a; Galiana, M., Llinares, C., Page A. 2012b). Results showed that non-expert users of music halls have a different conceptual structure than expert users, what means that both groups use different cognitive factors to assess music hall acoustics; and therefore their perception is different. Thus, both collectives should be studied in a separate way since the perceptual scheme of one group may be not valid for the other and vice versa.

This led the authors to continue studying in depth the collective of non-experts users, in this case in the area of architectural perception in music halls. Since they are massive users of these venues, more information about this collective wanted to be gathered and analyzed. Thus, the present research proposes to implement KE in the context of music halls as a useful tool to include the "voice" of the user in the whole process from the beginning.

On the other hand, as it has been commented before, music halls have been traditionally studied from the acoustic point of view. Few works have taken into account some architectural parameters (Beranek, L.L. 1962; Hawkes, R.J., Douglas, H. 1971; Semidor, C. & Barlet, A. 2000). However, in no case these parameters have been related in a quantitative way to acoustics perception or connected in a particular way to subjective evaluation of these venues.

In this paper several variables related to the architecture of music halls have been studied, as well as their interaction with acoustics perception. The objective is to analyze and quantify the influence of architecture on the acoustic perception and vice-versa, for non-expert users.

2. MATERIALS AND METHODS

As in the previous research (Galiana, M., Llinares, C., Page A. 2012b), materials and methods follow the same structure: firstly, select a representative sample of subjects composed by non expert users of music halls (neither musicians, nor acousticians, nor professionals related to music halls). Secondly, select a sample of music halls and auditoria across the Comunitat Valenciana (Spain) to be assessed by the subjects according to a set of acoustic and architectural parameters.

2.1. Subjects

Non-expert users of concert halls in different towns and cities of the Comunitat Valenciana were chosen in order to collect a representative sample of subjects. The technique was simple random sampling and users were contacted before the performance at the music hall. Finally, a sample of 221 participants was collected, which had to reply a questionnaire in order to asses a set of subjective parameters related to the acoustics and architecture of the music hall.

2.2. Questionnaire

Three blocks composed each questionnaire. The first block gathered objective information about the subject (gender, age, concerts attended per year, kind of music mostly listened at the music hall and usual location in the venue). The second block contained subjective information about acoustics parameters perception, and the third block the same about architecture. These parameters were expressed by means of 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 (Schütte Simon, T. W., Eklund, J., Axelsson Jan, R. C. & Nagamachi, M. 2004). 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 much 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 Simon, T. W., Eklund, J., Axelsson Jan, R. C. & Nagamachi, M. 2004), 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 was composed by 162 acoustic adjectives and 259 adjectives related to architecture. However this is a number of words 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 with this purpose (Schütte, S. 2005). In this study the *Affinity Diagram* was used, which groups the semantic descriptions according to their affinity (Terniko, J., 1997). 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 into 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 represent all the kansei words in the group. The set of expressions finally obtained formed the *reduced semantic universe*, which was composed of 27 adjectives related to acoustics and 26 architectural expressions. These were evaluated by means of a 5 point Likert scale ranging from: totally disagree, disagree, neutral, agree, totally agree.

Additionally, two new variables were included to show the global user opinion from the expression “Considering the whole set of features I think this is a good music hall from the architectural point of view” and idem about acoustics. These parameters were also evaluated through the former 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) located in two regions of the Comunitat Valenciana (Spain) with a long musical tradition: Valencia and Alicante. These music halls were selected so as to have a variety of them: large music halls in big cities like Valencia, Alicante, Xàtiva or Gandía and other modest auditoria in smaller towns. In order to increase the variety of the sample of stimuli we also chose music halls of new construction or recently restored and others with long tradition.

These stimuli were: Gran Teatre (Alzira), Teatre Serrano (Gandía), Centre Cultural (Almussafes), Auditori Municipal (Aielo de Malferit), Casa Cultura (Denia), Auditori Molí de Vila (Quart de Poblet), Centre Cultural “El Olivar” (Alaquàs), Auditori de Torrent (Torrente), Casa Cultura (Alfàs del Pi), Sala Tívoli (Burjassot), Gran Teatre (Xàtiva), Casa Cultura (Benifaió), Palau de la Música (Valencia), Palau de les Arts (Altea), Casa Cultura de La Pobla de Vallbona, Centre Social (La Vila

Joiosa) and Teatro Principal (Alicante).

The subjects had to evaluate the acoustics and architecture of the music hall *in situ*, so that they were “immersed” into the stimulus. It was decided to undertake the field study under these conditions instead of doing it in the laboratory because lab conditions cannot represent with 100% reliability the real settings.

Figure 1 shows an example of an auditorium participating in the field study. The most relevant data of each venue was collected:

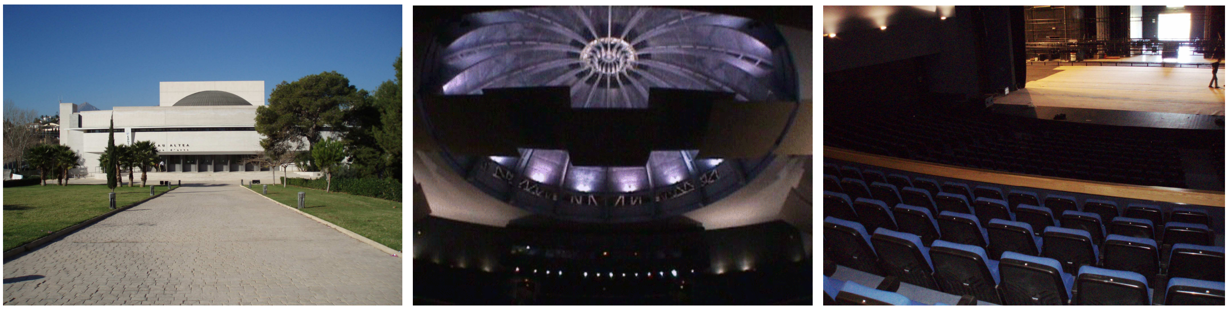

Figure 1: Example of concert hall of the stimuli sample: Palau de les Arts de Altea (Alicante). Capacity: 900 people. Year of construction: 2001.

2.4. Development of the field study

The field study was developed as follows: the subjects participating in the experience were handed a questionnaire before the performance took place. Subjects were informed of the objectives of the study but the questionnaire also included instructions to fulfil it in the correct way. 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 and truly impressions. Finally, responded questionnaires were gathered all together. Fulfilling the questionnaires took an average time of 15 minutes which was considered a reasonable interval to answer the questions before losing interest.

2.5. Data processing

Data base of answers was statistically processed with specific software: SPSS. 16.0. Then, the following data processing procedure was applied:

In a first step, to determine whether non-experts collective is able to clearly differentiate in their mental scheme the acoustic parameters from architectural ones, a factor analysis was made using the whole set of parameters:

1- Identifying semantic axes. It was necessary to reduce the amount of information to handle, 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 concrete product; a music hall in this study. A combination of adjectives of the original set (acoustic + architecture) composes each axis in a way that these attributes present significant correlations in the users’ responses. The technique used to identify and extract the semantic axes was principal components factor analysis (Basilevsky, A., 1994). Only principal components with eigenvalues greater than one were selected. Then, Varimax rotation was applied to obtain the semantic axes factors.

In the next step, the purpose is to determine whether architectural factors have influence on the acoustics subjective assessment and whether the acoustic factors influence the evaluation of the architecture of the music hall. Thus, it was necessary to calculate two linear regression models.

2- Ranking semantic axes. It was essential to analyse the influence of each axis on the global assessment (acoustics and architecture) 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 and the same for architecture. Therefore, in order to quantify the influence of each axis, linear regression analysis was applied and nonparametric Spearman correlation coefficient between the factor scores and the overall opinion about acoustics and architecture were used to get this ranking.

3. RESULTS

3.1. Identifying semantic axes

At this point the amount of information to handle was still quite large, so it was necessary to condense it. Therefore, the original set of 53 adjectives (27 acoustic + 26 architecture) was reduced by means of factor analysis to 9 uncorrelated factors which explained 61,92% of the variance in the original variables. Table 1 shows these factors, their correlations with the original adjectives and their Cronbach's Alpha coefficient (α), (Cronbach, L. J. 1951). This parameter ensures the internal consistency of the axes for values $\alpha \geq 0.6$.

Table 1: Range of meaning of kansei factor axes and representative terms for non-experts users, with their Cronbach's Alpha coefficient (α)

FACTOR AXES	CORRELATION WITH KANSEI WORDS	VARIANCE EXPLAINED
1- Acoustic quality *(α = 0.91)*	Harmonious (0.827), Good pitch quality (0.816), Good direct sound (0.777), Balanced (0.743), Clear sound (0.736), Warm (0.714), Homogeneous (0.708), Powerful (0.683), Bright (0.673), With texture (0.668), Wide dynamic range (0.657), Faithful sound (0.638), Natural (0.614), Close (0.602), Enveloping sound (0.449), Dull (-0.577), Weak (-0.556), Distant (-0.477), Resounding (-0.46)	19.09%
2- Architectural quality *(α = 0.90)*	Well-proportioned (0.742), Practical distribution (0.694), Organized (0.681), Quiet-peaceful (0.635), Wide (0.620), Versatile (0.619), Quality materials (0.581), Good view of stage (0.564), Warm-friendly (0.559), Comfortable (0.486), Light-filled (0.466), Stylish (0.460), Good interior organisation (0.450)	11.81%
3- Original, emblematic *(α = 0.86)*	Original-different (0.795), Emblematic-prestigious (0.750), Luxurious (0.678), Elegant (0.652), Innovative (0.643), Lively (0.443)	8.94%

4- Good interior organisation *(α = 0.62)*	Good interior circulation (0.712), No background noise perceived (0.534), Formal (0.517)	4.45%
5- "Sad" architecture *(α = 0.72)*	Dark-sad architecture (0.691), Poor (0.532), Dull (0.469),	3.94%
6- Acoustic intimacy *(α = 0.63)*	Intimate sound (0.668), Soft (0.585)	3.80%
7- Classic vs. Modern style *(α = 0.61)*	Classic architecture (0.787), Excessively ornate-baroque (0.548), Modern style (-0.516)	3.74%
8- Bass enhanced *(α = 0.63)*	Bass enhanced (0.799), Resounding (0.428), Dissonant (0.426), Reverberant (0.419)	3.25%
9- Good view of stage *(α = 0.60)*	Good view of stage (0.570), Incomparable framework (0.476)	2.90%

As it can be seen from Table 1:

- 1st axis: it presents a strong correlation with the adjectives: Harmonious (0.827), Good pitch quality (0.816), Good direct sound (0.777), Balanced (0.743), Clear sound (0.736), Warm (0.714), Homogeneous (0.708), Powerful (0.683), Bright (0.673), With texture (0.668), Wide dynamic range (0.657), Faithful sound (0.638), Natural (0.614), Close (0.602), Enveloping sound (0.449); and negative correlation with: Dull (-0.577), Weak (-0.556), Distant (-0.477), Resounding (-0.46). All items included in this factor refer to acoustic features. It has been interpreted as the dimension "*Acoustic quality"* and it is the main axis since it explains 19.09% of the sample variance. Therefore, it is the first attribute identified by the non-experts to discriminate between different music halls.
- 2nd axis: it represents the dimension *"Architectural quality"* and gathers a whole set of attributes related to the architecture of the venues. It shows high positive correlation with the items: Well-proportioned (0.742), Practical distribution (0.694), Organized (0.681), Quiet-peaceful (0.635), Wide (0.620), Versatile (0.619), Quality materials (0.581), Good view of stage (0.564), Warm-friendly (0.559), Comfortable (0.486), Light-filled (0.466), Stylish (0.460) and Good interior organisation (0.450). It explains 11.81% of the variance so it is the second axis in importance to discriminate between different music venues.
- 3rd axis: it also groups adjectives related to architecture: Original-different (0.795), Emblematic-prestigious (0.750), Luxurious (0.678), Elegant (0.652), Innovative (0.643), Lively (0.443). This axis has been interpreted as the dimension *"Original, emblematic"* and explains 8.94% of the sample variability. This may lead to think that users appreciate music halls with some singular features that make it unique and different from the rest of venues.
- 4th axis: it includes the attributes Good interior circulation (0.712), No background noise perceived (0.534) and Formal (0.517). This set of adjectives may be related since if the interior circulation of the venue is well organized, this can reduce the sensation of

background noise, and therefore the architecture is perceived as formal (well-designed). It reflects the dimension *“Good interior organisation”* and explains 4.45% of the variance.

- 5th axis: it represents the dimension *“Sad” architecture* and shows positive correlation with some adjectives with negative meaning: Dark-sad architecture (0.691), Poor (0.532) and Dull (0.469). These are non-desired attributes and this axis explains 3.94% of the sample variance.
- 6th axis: *“Acoustic intimacy”.* It groups two adjectives related to acoustics: Intimate sound (0.668) and Soft (0.585). This factor explains 3.80% of the sample variability and reflects the sensation of the user that the performance takes place in a cosy, intimate place.
- 7th axis: *“Classic vs. Modern style”.* This factor includes the items: Classic architecture (0.787), Excessively ornate-baroque (0.548), Modern style (-0.516) and it explains 3.74% of the sample variability.
- 8th axis: it presents a positive correlation with several adjectives related to acoustics: Bass enhanced (0.799), Resounding (0.428), Dissonant (0.426), Reverberant (0.419). It has been interpreted as the dimension *“Bass enhanced”* and explains 3.25% of the variance. This may lead to think that non-expert users do not appreciate music halls that present this feature due to the negative connotation of some items.
- 9th axis: it is correlated to two architectural attributes: Good view of stage (0.570), Incomparable framework (0.476); both associated to good visual impression. This axis has been interpreted as the dimension *“Good view of stage”* and explains 2.90% of the sample variability.

These 9 factors represent the semantic space for non-expert users, associated to music hall acoustics and architecture; and they are able to explain almost 62% of the variance in the original variables. This may become a useful tool for quantifying perceived differences among different music halls.

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

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 architectural evaluation. Therefore, the axes obtained previously, were analysed in order to quantify their influence on the overall evaluation. Hence, two linear regression models were obtained for the sample of subjects and the influence of the axes on the overall opinion could be quantified.

3.2.1. Linear regression model for acoustics global assessment

In order to obtain this model, the variable “acoustics global assessment” was taken as the dependent one, while the nine 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 axes “*Acoustic quality*” and *“Architectural quality”* mainly determined the overall evaluation with high positive correlations: 0.750 and 0.329 respectively. Next in importance appeared the axis *“Acoustic intimacy”* with a correlation of 0.199; followed by the axis “*Good interior organisation”* with a load of 0.128. Last, the axis *“Original, emblematic”* contributed with a correlation of 0.100. This analysis showed a high linear correlation coefficient (0.804) which confirmed the power of the model:

{1} *Acoustics Global Assessment = 0.603 + 0.750 (Acoustic quality) + 0.329 (Architectural quality) + 0.199 (Acoustic intimacy) + 0.128 (Good interior organization) + 0.100 (Original, emblematic)*

Observing model {1} it can be noticed that acoustic and architectural factors are taken into account by the non-experts when evaluating the acoustics of a music hall. Logically, the factor with the higher load is related to acoustic quality. However, the influence of architectural factors is not negligible since three out of five factors in the model are related to architecture: *Architectural quality, Good interior organization, Original-emblematic*.

3.2.2. Linear regression model for architectural global assessment

In this case, the variable "architectural global assessment" was taken as the dependent one, and the nine axes worked as independent variables. The linear regression model showed 7 significant factors (s.l.<0.05) while the rest were excluded. This analysis showed a high linear correlation coefficient (0.814) which confirmed the power of the model:

{2} *Architectural Global Assessment = 0.429 + 0.660 (Architectural quality) + 0.343 (Original, emblematic) + 0.337 (Acoustic quality) + 0.192 (Good interior organization) + 0.140 (Good view of stage) + 0.136 (Acoustic intimacy) – 0.107 ("Sad" architecture)*

As it can be seen in model {2}, the factors with higher impact on the assessment of the architecture are: *Architectural quality, Original-emblematic* and *Acoustic quality*, with high positive loads: 0.660, 0.343, 0.337, respectively. It is remarkable that an acoustic factor is the third in importance. Next, it appears the axis "*Good interior organization"* with a correlation of 0.192, followed by "*Good view of stage"* (0.140). Then, another acoustic factor "*Acoustic intimacy"* influences the architectural assessment with a load of 0.136. Last, the axis *"Sad architecture"* contributed with a small negative correlation of -0.107. The negative sign reveals that the absence of this factor was positively appreciated by the collective of non-experts.

4. DISCUSSION OF RESULTS

This paper has attempted to analyze the listener's (non-expert) emotional response to music hall acoustics and architecture. Besides, the purpose was to study the interaction between acoustic and architectural parameters and their influence on the global assessment.

Firstly, the possibility of defining a set of variables which captures non-expert user's perception of music hall acoustics and architecture in his own words was verified using Differential Semantics (DS). Hence, this perception can be expressed through 9 uncorrelated factors obtained by factor analysis; which explained 62% of the variability. These factors (Table 1) are by order of explained variance: 1st *"Acoustic quality"* (19.09%); 2nd *"Architectural quality"* (11.81%); 3rd *"Original, emblematic"* (8.94%); 4th *"Good interior organisation"* (4.45%); 5th *"Sad architecture"* (3.94%), 6th *"Acoustic intimacy"* (3.80%), 7th *"Classic vs. Modern style"* (3.74%), 8th *"Bass enhanced"* (3.25%), 9th *"Good view of stage"* (2.90%). Internal consistency of these axes was ensured by means of Alpha Cronbach coefficient ($\alpha \geq 0.6$). Moreover it was observed that, in general, each factor gathered items related either to acoustics or architecture. This means that the sample of subjects was able to separate in their mental scheme the concepts related to both fields.

On the other hand, the order of these factors gives information about the parameters that this collective use to differentiate one music hall from another. It can be seen form Table 1 that the 1st, 2nd and 3rd axes altogether are able to explain almost 40% of the variability. This means that these are the attributes that non-experts appreciate most to discriminate between different music venues.

Secondly, the influence of architectural parameters on the acoustic assessment and the influence of acoustic parameters on the architectural evaluation wanted to be analyzed. Thus, factors were ordered depending on their influence on the corresponding assessment variable. Two linear regression analysis determined the following results giving the load of each factor (β):

{1}: Factors influencing Acoustics Global Assessment: 1st "*Acoustic quality*" (β:0.750); 2nd *"Architectural quality"* (β:0.329); 3rd *"Acoustic intimacy"* (β:0.199), 4th *"Good interior organization"* (β:0.128) and 5th *"Original, emblematic"* (β:0.100).

{2}: Factors influencing Architectural Global Assessment: 1st "*Architectural quality*" (β:0.660); 2nd *"Original, emblematic"* (β:0.343); 3rd *"Acoustic quality"* (β:0.337), 4th *"Good interior organization"* (β:0.192), 5th *"Good view of the stage"* (β: 0.140), 6th *"Acoustic intimacy"* (β:0.136) and 7th *"Sad architecture"* (β: -0.107). The negative sign means that the absence of this factor was positively appreciated.

The linear correlation coefficients of these models was high (>0.8) which confirmed its power.

It is noteworthy that, in both models, acoustic and architectural factors are present. This means that not only architecture influences the acoustic perception, but also acoustics influences the perception of architecture. Besides, this influence was quantified thanks to the previous models by means of the weights of each factor.

In model {1} it can be seen that two acoustic parameters contribute to the rating of the acoustics (*Acoustic quality* (β:0.750) *and Acoustic intimacy* (β:0.199)*)*. However, a non-expert listener will increase in a positive way his acoustic perception if he/she perceives the music hall as a venue with architectural quality (β:0.329), with a good interior organization (β:0.128), original and emblematic (β:0.100). Therefore, equation {1} shows the importance of this architectural axes and their influence on the acoustics assessment since their weights are relevant for this evaluation. So, if acoustic satisfaction of the users is to be increased, the perception of these architectural factors should be also improved since this will result in a better rating of the overall acoustic impression of the venue.

On the other hand, model {2} shows that several architectural axes contribute to architectural global assessment: "*Architectural quality*" (β:0.660); 2nd *"Original, emblematic"* (β:0.343); 4th *"Good interior organization"* (β: 0.192), 5th *"Good view of the stage"* (β:0.140), 6th and 7th *"Sad architecture"* (β: -0.107). Nevertheless, two factors related to acoustics also influences this perception: *Acoustic quality* (β:0.337) *and Acoustic intimacy* (β:0.136). Therefore, if the user perceives a good acoustic quality and intimate sound sensation, this will have a positive impact on the architectural perception.

Comparing these results with those obtained in previous studies, it can be observed that music hall acoustics have been traditionally rated depending on acoustic parameters exclusively. We can find many studies related to the influence of *"Intimacy"* and *"Power"* on the acoustics evaluation. Beranek, L. (Beranek, L.L. 1962), concluded that *"Intimacy"* contributed up to a 40% of the perceived quality of a music hall. In his study made with expert subjects, the weight of this attribute on the overall assessment was 3 times bigger than the rest of attributes. On the other hand, the present study corroborates that *"Acoustic intimacy"* is also an important factor for non-expert users to evaluate acoustics and architecture, since this axis is present in both regression models. It is the 3rd in importance for its influence on the acoustics assessment (β:0.199) and the 6th in importance on the architectural global assessment (β:0.136). These results confirm that intimacy is a significant factor for non-expert users but not the main factor as Beranek stated using a sample of experts. Something similar happens with the parameter *"Power"*. This factor, understood as loudness and power of sound, has been considered of great importance for many authors in their research (Gilbert Soulodre, A. & John Bradley, S. 1995; Hidaka, T. & Beranek, L.L. 2000; Schroeder, M.R., Gottlob, D. & Siebrasse, K.F. 1974; Wilkens, H. & Lehmann, P. 1980). Results achieved in the present study show that for non-expert users this is an important item but as a component of a bigger axis, not as a factor itself. It is part of the factor *"Acoustic quality";* 1st in importance on the acoustics assessment and 3rd over the architectural global evaluation.

On the other hand, according to several studies (Barron, M. 1988; Beranek, L.L. 1962; Kürer, R. & Kurze, U. 1968; Sabine, W. C. 1922; Seraphin, H. P. 1958), *"Reverberation"* is the "key factor" for acoustic quality in music halls. However, in the present study this item was part of the factor *"Bass enhanced"* which was excluded from both regression models since it did not have a significant influence on the global assessment (s.l.<0.05), neither acoustics nor architecture. This result is particularly important because it shows that mental scheme of expert and non-expert users are different, since the present study analyzed non-expert users' response while the cited works gathered opinions from expert subjects.

Besides the acoustic aspect, few studies have compiled data related to music halls architecture and its relation to perception has not been quantified or determined in a specific way. Beranek (Beranek, L.L. 1962), gathered a lot of information about materials, decoration, seats, carpets, curtains and main dimensions of different music halls. These parameters were evaluated by him to classify the venues depending on their quality. Later on, Hawkes & Douglas (Hawkes, R.J., Douglas, H., 1971), affirmed that acoustic perception could be influenced by other aspects such as: illumination of the hall, temperature, comfort of the seats and "enjoyment" of the performance. In no case these parameters were quantified, and their influence on the global assessment was neither measured. Another research carried out by Semidor & Barlet (Semidor, C. & Barlet, A. 2000) at the Grand Theatre de Bordeaux analyzed acoustic parameters and the influence of other parameters such as view of the stage, temperature of the hall, space between seats and other aesthetic aspects of the lounge. They concluded that after a good acoustics, the most appreciated parameter was a good view of the stage.

In summary, these works dealt with attributes related to music halls architecture; although they present some drawbacks: the parameters to be studied were exclusively set from an expert point of view, so the user's opinion was removed from the beginning of the process. In addition, architectural attributes were considered as a complementary data to the acoustic information, not giving them a specific importance. Finally, the impact of these architectural parameters on the acoustic assessment was not measured.

On the contrary, results of the present paper show the importance of quantifying the influence of architectural attributes in the acoustic perception as well as consider the influence of acoustics on the architectural assessment. This has been studied in the scope of non-experts users. It must be taken into account that this collective are massive users of music halls; therefore these evaluations and opinions are essential for acousticians, architects and designers since they make it possible to compare a music hall with its competitor; identifying weak and strong points. This is fundamental when defining a future design or restoring strategies for this kind of venues.

5. CONCLUSIONS

In a previous study (Galiana, M., Llinares, C., Page A., 2012a) it was already confirmed that expert and non-expert collectives use different cognitive factors to assess music hall acoustics and therefore their perception is different. In addition, results achieved in this study show some significant implications: at a theoretical level it can be concluded that non-expert users of music halls are likely to have a different mental structure than expert users when evaluating music halls architecture, so its impact on acoustics perception may be different. Thus, both collectives should be studied in a separate way since the perceptual scheme of one group may be not valid for the other and vice versa. Hence, it is essential the fact that the parameters which have been traditionally used to evaluate acoustic and architectural quality of a music hall from an expert point of view (reverberation, intimacy, power, lighting, comfort, etc…), are not perceived in the same way by non-expert users. Thus, it is necessary to implement techniques such as Kansei Engineering in this field so that the “voice” of the user is included in the whole process from the beginning. This make it possible to take into account the acoustic and architectural parameters of his own mental scheme, as a truly and potential variables to be improved.

From the methodological point of view, it is remarkable the application of Differential Semantics (in the context of Kansei Engineering) to evaluate music hall acoustics and architecture through a set of adjectives and expressions provided by non-expert users. Thus, SD is a verbal measurement instrument capable of measuring the subjective component of the emotional state which this collective is able to recognize.

Another significant result has been confirmed: in the context of non-expert users of music halls, architectural parameters have an influence on the acoustic perception and acoustic parameters influence the evaluation of architecture. In addition, these factors have been identified and its contribution to acoustic and architectural assessment has been quantified.

Regarding to limitations, it must be said that the sample of stimuli used in the present study was chosen in order to have a wide range of combination of design elements: large and small concert halls, new and traditional, located in big cities and small towns, etc… However, the sample of stimuli consisted of real music halls so the combination of design elements of each venue was fixed. It represents a limitation since the possible combination of design elements that may influence the acoustics and architecture perception was given by the availability of those combinations in the real “product”.

As a final remark, obtaining and analyzing non-experts’ affective dimensions which influence the global assessment of music hall acoustics and architecture, is the first phase of Kansei Engineering. With these results, it would be very interesting to identify what design elements in a music hall cause them. This is established for further research. On the other hand, the authors studied in previous research the differences of acoustic perception between expert and non-expert users in music halls (Galiana, M., Llinares, C., Page A. 2012a; Galiana, M., Llinares, C., Page A. 2012b). Following this line of work it would be also interesting to analyze the perception of expert users in the context of music halls architecture, and determine the differences between both collectives.

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