SUBJECTIVE EXALUATION OF ACOUSTICS IN JAZZ CLUBS

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1. INTRODUCTION

Research in acoustics during the last three decades has been focused on the formulation of design principles for auditoria for classical music. The latest electronic atonal music has also been studied and lead to specific design proposals for the interior architecture of auditoriums for this music genre (Stockhausen, 1958). On what concerns contemporary music genres, acousticians were not interested in most of the music genres of the 20th century (pop, rock, jazz) until very recently. It has been observed that the design of auditoria for all music genres is based solely on the principles of classical music thus follows empirical rules.

Jazz music which is the subject of the current study, is one of the music genres, the beginning of which was accompanied by great prejudice concerning its social roots. Today no prejudice exists due to the worldwide popularity of Jazz music. We talk about a type of music which isn't addressed to big crowds as does classical music and neither does to listeners who have the energy and the characteristics of pop or rock music. It could be said that in terms of audience size, jazz music is similar to chamber music.

The current study aims to attain a thorough understanding of the elements that affect both the acoustics of spaces designed for this music genre and its perception by the listeners. On site measurements of objective parameters of sound followed by subjective evaluation experiments carried out in two case studies, allow us to draw valuable conclusions as to the factors that affect the acoustic performance of jazz clubs. The latter intends to contribute to the evolution of the technical know how on the construction of jazz auditoria.

2. LITERATURE REVIEW

2.1 Auditorium Acoustics

The current scientific knowledge on the construction of auditoria is focused on classical music and is summarized by the existing literature about the proposed design principles and techniques. Extensive research on classical music and sound in general (Beranek L.1962, Marshall H.,1967) has established some criteria (Table 1,) which have the form of suggested value ranges for the objective parameters of sound, namely the reverberation time, the early decay time, the clarity index, the early lateral fraction and the sound pressure level. On what concerns contemporary music, recent studies have focused on objective parameters' measurements within existing spaces for popular music. The scope was the formulation of design principles for this music genre (Larsen W.N, 2004).

Organ music	>2.5
Romantic classical music	1.8–2.2
Early classical music	1.6–1.8
Opera	1.3–1.8
Chamber music	1.4–1.7
Drama theatre	0.7–1.0

Table1 Recommended occupied RT values

In terms of subjective acoustic evaluations, the introduction of binaural recordings (1975) in actual concert halls demonstrated the priorities for concert hall listening (Cremer and Müller, 1982). Additionally, the role of the orchestration, the musicians and the audience on the quality of sound inside an auditorium, has been the subject of

early (Hawkes R., Douglas H. 1971) and more recent studies (Dammerud and Barron M. 2008, Yong Hee K.,2007) offering further insight into the parameters that affect the quality of sound.

All the conclusions of the previous studies have been carefully considered on the analysis of the obtained physical measurements and on the design of our experimental study.

2.2 Physical criteria of sound

Extensive research since the 1900 (Sabine, 1900) has identified the parameters that are considered to play a vital role to the control of the acoustic performance of a space (Beranek L, 1962). Nine studies sum up the early scientific research on the objective measures of acoustics. We talk about (Sabine (1900), Thiele (1953), Beranek (1960), Shroeder (1965), Marshall (1967), Hawkes &Douglas (1971), Reichardt et al (1974), Cremer &Muller (1982).

All the above mentioned studies share the notion that the control of five objective measures is most important for the design of concert halls, namely the clarity index (C80, dB), the Early Decay Time (EDT, sec) the sound pressure level (SPL), the early lateral fraction (L_f) and the reverberation time (RT, sec). Each of these measures is quantified through functions introduced by, Sabine (1900), Reichardt et al (1975) and Barron and Marshall (1981) respectively. It has been understood that auditoria for classical music since 1985 have been constructed using as a reference successful precedents. However as far as contemporary popular music is concerned, no design principles have been formulated up to now in a way that could offer criteria values for all the above mentioned objective measures.

2.3 Acoustic perception of audience

Audience's perception of music, especially classical one, has been explored in order to achieve a further understanding of all the parameters that determine the acoustics of a space. The already known criteria for optimum acoustics in auditoria for classical music, have emanated from experiments based on interviews with musicians who evaluated the acoustics in 54 auditoria. Other studies applied semantic differentials, thus required from audiences to evaluate several live concerts through questionnaires (Beranek L., 1962, Hawkes R.J, Douglas H. 1971, Barron M., 1988). According to Barron M. (2009) it was widely admitted that the previously mentioned objective measures affected various subjective measures of sound. The results are illustrated on Table 2. A qualitative and summarized interpretation of the correlations of these criteria with the physical criteria of sound, which incorporates the findings of other studies (Sotiropoulou A, Flemming D.B, 1995), is illustrated on Table 3.

Subjective quality	Objective measure
Clarity	Clarity index (C_{80})
Reverberance	Early decay time (EDT)
Intimacy	Sound strength (level)
Source broadening	Early lateral fraction and strength
Loudness	Sound strength and source-receiver distance

Table 2 Important subjective qualities and objective measures related to them (Barron M., 2009)

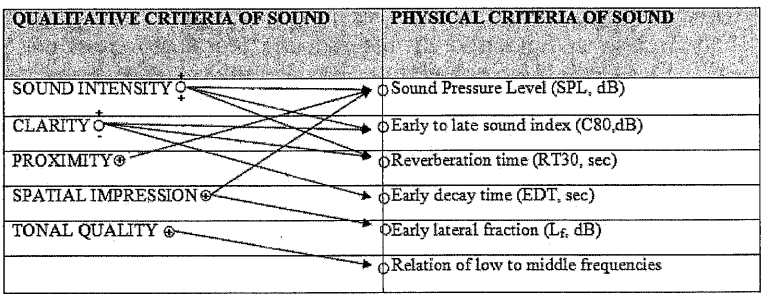


Table 3. Correlation of qualitative with physical criteria of sound as were obtained via subjective experiments. (Sotiropoulou A. 1996 cited Barron M. 1993, Sotiropoulou A. and Flemming D.B, 1995, Barron M. 1988, Lehman and Wilkens1980)

Overall the idea that the 'clarity' of sound, the 'sound intensity', the 'tonal quality', the 'spatial impression' and the 'proximity' are the basic parameters that influence the quality of music heard inside a concert hall, was a common conclusion in all the above subjective experiments.

As far as the acoustic experience of Jazz auditoria is concerned, the first completed experiment has implemented audience that evaluated recorded jazz music (Sotiropoulou A., Karagiannis G., Poulakos G., 2007). This study, has underlined the most important criteria for the perception of this music genre, namely 'Tonal quality', 'Clarity', 'Body' and 'Proximity'.

2.3 Other subjective experiments

The understanding of human perception has been studied in the past and was usually approached through the use questionnaires filled by the participants of each experiment (Cattell R.B, 1966, Darlington R.B, 2005 cited Rubenstein 1986, Spearman C, 1971).The processing of the obtained data has been made through factor analysis. The first of those experiments (Spearman C. 1970) aimed at attaining an understanding of people's dexterities in math, vocabulary and art. Other similar experiments looked at the function of the automatic nervous system and of the feelings (Cattell R.B, 1957). Under this perspective, Rubenstein in 1986 (Rubenstein, 1986) studied man's curiosity, utilizing as a sample several high school students. The suitability of the factor analysis as a method for the processing of the collected data from the above experiments has been tested since its introduction to the social sciences by Charles Spearman, Cattell (Kaiser H., 1958 and 1970), Cattell R.B, 1966) and Bartlett. They have introduced several criteria for the tests made within factor analysis, in order to ensure the validity of the results based on the size of the sample.

3. AIMS OF STUDY

3.1 Wider Study

The present experiments and measurements are parts of a wider study which has anticipates, the proposal of design principles for a Jazz club through a scientific methodology. The overall study includes on site measurements of acoustic parameters in selected jazz clubs (ongoing process), subjective evaluation experiments implementing different audiences in jazz clubs (completed process) and a comparison of the results from both studies (completed process).

3.2 Current study

3.2.1 Physical measurements

The principal aim of the comparison through on site measurements of two spaces designed for the same type of music with similar occupant densities and patterns was to investigate the possibility, that a set of parameters (e.g. materials, geometry, sizing of the various building elements) affects the acoustics of these auditoria. At a second stage the interpretation of possible similarities and/or differences and an attempt to indentify their source, was expected to provide us with valuable conclusions in terms of the choice of materials and/or geometry of both spaces.

3.2.2 Subjective evaluation experiment

The subjective evaluation experiment at a first stage seeked the parameters that affect jazz audiences' perception and at a second stage the extraction of a smaller number of factors which could interpret the relations between those parameters. We aimed for an accurate approximation of the studied variables by the obtained factors in order for the factor analysis results to be reliable. A comparison of our results with those from past researches was pursued, in order for useful conclusions to be made for the perception of jazz music.

4. CASE STUDIES

For this study two spaces were chosen: the "**Half Note Jazz Club** " in Athens and "**The Forge**" which is a part of the multipurpose space '**Caponata**' and is located in Camden Town in London. Tables 4 and 5 present the characteristics of these auditoria.

The subjective evaluation experiment was completed with the participation of audiences of different cultural backgrounds which evaluated one concert in each of those spaces (56 people in Half Note Jazz Club and 21 in the Forge).

Half Note Jazz Club	
Use of space	Jazz music concerts
Construction	Result of a conversion of an older house in 1990 (Architectural study: G. Tsokas)
Physical characteristics	**Surface area F**=76.5 m^2, **volume V**= 382m^3, capacity 180 people Indicative reverberation time values **RT_{500} = 0.67sec, RT_{1000} = 0.72sec** No acoustic design principles have been applied

Table 4 Technical characteristics of 'Half Note Jazz Club'

The Forge	
Use of space	Jazz, pop and ethnic music concerts
Construction	Part of the multipurpose space of Caponata which is an all day coffee-bar restaurant (Architectural study: Burd Haward Architects, Max Fordham, Arup)
Physical characteristics	**Surface F**=84 m^2, **volume V**= 530m^3, capacity 160 people Indicative reverberation time values **RT_{500} = 1.11sec, RT_{1000} = 1.16sec** Adequate acoustic design which took into account the basic design principles of auditoria. For the Forge, an environmental design of high standards has been made. The aim has been the construction of the first naturally ventilated auditorium.

Table 5 Technical characteristics of 'The Forge'

5.METHODOLOGY

5.1 Literature review

The first stage of this study was the completion of a literature review as it has been outlined in section 2. At a next stage a selection of case studies was made with the criterion that they host a

big proportion of the jazz gigs organized in each city. The architectural studies of both spaces along with their design briefs have been thoroughly examined. In addition, personal communication with the sound engineers and part of the design teams of both spaces, contributed to the understanding of the basic aims of each space. At this point we were familiarized with the level of acoustic design that has been applied in these spaces.

5.2 Physical measurements

The room acoustic parameters which have been measured at 14 locations inside Half Note Jazz Club, and 13 positions inside The Forge. were: the reverberation time T30 (sec), the Early Decay Time, the Early to late sound index (C80 in dB), the Early to total sound index (D50 in dB). The procedure and the equipment that have been used in both cases, complied with the requirements of ISO 3382. Suitable equipment from Brüel and Krueger (images 6, 7) and software DIRAC and WinMLS have been used for the measurements and the analysis of results.

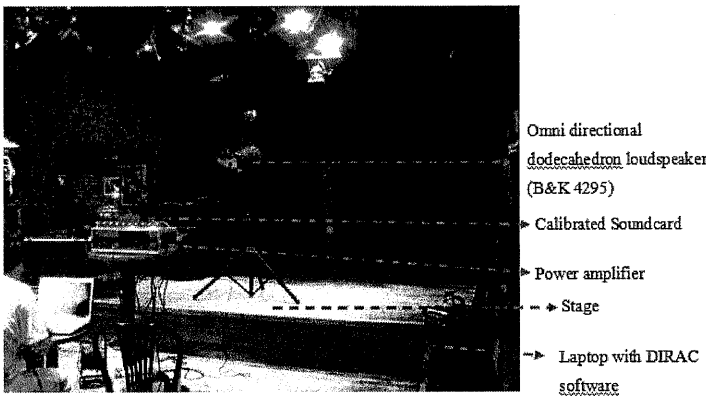


Image 6 Configuration of measurements equipment for Half Note Jazz Club

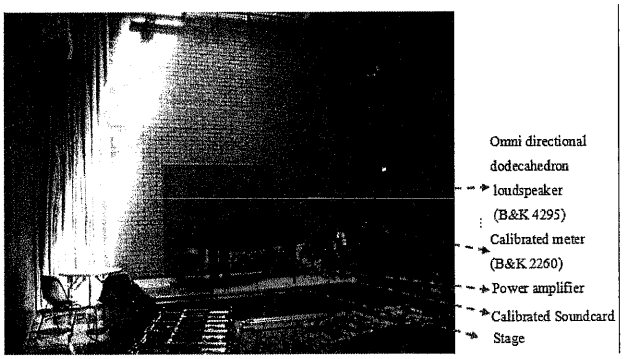


Image 7 Configuration of measurements equipment for The Forge

At the next step, a mathematical analysis of the results obtained via DIRAC software aimed at identifying possible issues that the design of those spaces failed to address. Valuable conclusions were made regarding the acoustic quality of the case studies and the spatial characteristics that could affect it based on the qualitative criteria of sound and their proven correlations with physical criteria, as they were defined in the literature review (Table 3).

5.3 Subjective experiment

The subjective evaluation experiment was completed in the following stages:

I. Synthesis of questionnaires from rating scales that have been selected with the criterion of showing high scores to the extracted factors at the experiment that was conducted for the recorded jazz music (Sotiropoulou A. , Karagiannis G., Poulakos G., 2007).

II. Distribution of the questionnaires to the audience

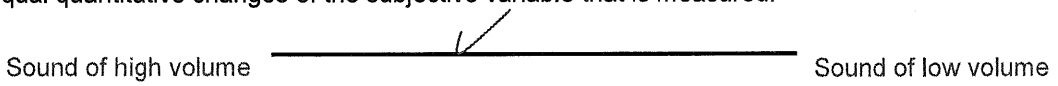
III. Factor analysis of the obtained data

IV. One way Analysis of Variance, in order to test whether the different seat of each listener had a statistically significant impact on the factors

V. Evaluation of the results and extraction of conclusions

5.3.1 Synthesis of questionnaires

As it has been realized through the literature review, studies preoccupied with the understanding of perception have been implementing the semantic differential method according to which, perception is measured via semantic rating scales. For our experiment we applied the above mentioned method. The rating scales were continuous and bipolar of the form shown on shape 1. The line represents a continuous evolution form one pole to the other. These poles are named after different adjectives which describe the same variable. Equal distances on this continuous line represent equal quantitative changes of the subjective variable that is measured.



Shape 1 Bipolar semantic rating scale

Each of the listeners was expected to place a mark on those bipolar scales at any distance from the poles. This mark would represent his/her evaluation of the quality of the sound that was heard. At a next stage those scales were numbered from 0 to 1 and thus all the answers were translated into numerical data. The questionnaires included questions regarding the age, sex, seat and familiarity of each listener with the specific music genre.

5.3.2 Processing of data

The processing of the data that were obtained from the questionnaires was made with factor analysis and the use of SPSS software. The number of factors that best describe our data was based on the criterion of 'Scree' test' as it was formulated by Raymond Cattell (Darlington R., 2005). In order to achieve a better approximation and interpretation of our data from the extracted factors, we made a varimax rotation of the original table of factors that was obtained via factor analysis.

At a next stage in order to ascertain whether the different seat of each listener affected our results, we completed a one way Analysis of Variance. In that way we checked the following two hypotheses:

H_0: the seat of each listener affects the extracted factor

H_1: the different seat of each listener doesn't have an impact on the extracted factor

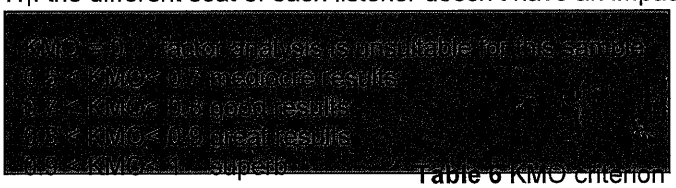


Table 6 KMO criterion

Finally in order to confirm the suitability of factor analysis as a method for the processing of the data, we relied on the Kaiser-Meyer-Olkin criterion (Table 6).

6. RESULTS- DISCUSSION

6.1 Physical measurements

The results of the on site measurements inside the two case studies are summarized in Table 7 and are organized in three frequency ranges, low (63-125Hz), middle (500Hz-1kHz) and high (2-4kHz).

	Physical measurements											
	T30(sec)			EDT(sec)			C80(dB)			D50(dB)		
	Frequency											
Half Note Jazz Club	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
	0.62	0.69	0.68	0.71	0.7	0.68	6.36	5.49	6.32	0.64	0.61	0.64
The Forge	0.86	1.13	1.07	0.84	1.21	1.12	4.05	2.65	2.46	0.5	0.49	0.46

Table 7 T30, EDT, C80, D50 values as they were measured inside the two case studies

6.2 Subjective evaluation experiment

Factor analysis has been conducted separately for each case study. After the varimax rotation of the initial table of factors, each of the bipolar rating scales- variables appeared with high score on one single factor, as it is shown on tables 8, 9. The latter lead to a better interpretation of the results. Values of factor scores that equal the standard error are excluded from the tables.

Factors	Associated scales	Factor loadings	%of Variance
1. PROXIMITY	Live-Dead	0.82	23.7
	Near-Remote	0.79	
	Near-Distant	0.77	
	Brilliant-Dim	0.74	
	Poor-Rich	-0.63	
2 CLARITY	Clear-Noisy	0.81	22.12
	Clear-Dull	0.75	
	Preffered- Not preffered	0.74	
	Clear-Blurred	0.74	
	Dark-Bright	-0.70	
	Colored-Dark	0.67	
	Fullbodied-Thin	0.58	
3.TONAL QUALITY	Smooth-Harsh	0.83	19.99
	Gentle-Harsh	0.81	
	Harsh-Velvety	-0.78	
	Smooth-Rough	0.72	
	Smooth-Sharp	0.67	
	Loud-Silent	-0.63	
	Cool-Warm	-0.57	

Table 8 Obtained factors at Half Note Jazz Club

Factors	Associated scales	Factor loadings	%of Variance
1. TONAL QUALITY	Smooth-Harsh	0.95	32.01
	Harsh- Velvety	-0.95	
	Gentle- Harsh	0.86	
	Smooth-Rough	0.81	
	Clear- Noisy	0.79	
	Smooth- Sharp	0.72	
	Colored-Dark	0.65	
	Full Bodied- Thin	0.58	
2 CLARITY	Colored-Dark	0.58	30.50
	Clear-Dull	0.93	
	Brilliant- Dim	0.88	
	Near-Remote	0.84	
	Dark- Bright	-0.72	
	Clear- Blurred	0.72	
	Live-Dead	0.71	
	Preferred- Not preferred	0.57	

Table 9 Obtained factors at The Forge

Taking into account the qualitative characteristics of the bipolar rating scales included in each factor, we labeled the three factors. They are:

1. Clarity, **2.** Tonal quality and **3.** Proximity

After realizing that common factors have been extracted in both subjective experiments, we decided to combine the data and conduct a new factor analysis. The results after the varimax rotation of the initial table of factors are illustrated on table 10.

1 CLARITY	Dark- Bright	-0.80	35.34	35.14
	Clear-Dull	0.78		
	Clear- Blurred	0.78		
	Colored-Dark	0.78		
	Preferred- Not preferred	0.74		
2 TONAL QUALITY	Clear- Noisy	0.70	17.1	52.44
	Full Bodied- Thin	0.65		
	Smooth-Harsh	0.85		
	Gentle- Harsh	0.83		
	Harsh- Velvety	-0.83		
	Smooth- Sharp	0.73		
	Smooth-Rough	0.71		
	Cool - Warm	-0.52		
3 PROXIMITY	Near-Distant	0.84	8.55	60.96
	Near-Remote	0.83		
	Live-Dead	0.83		
	Brilliant- Dim	0.67		

Table 10 Obtained factors with an increased sample including data by both auditoria

The one way ANOVA lead to the results shown on table 11. At the last column we can notice that for each factor the significance value is greater than 0.05. Therefore we can accept the null hypothesis H_0, reject H_1 and conclude that the different seat of each listener doesn't have a statistically important impact on any of the three independent factors

REGR factor score 1 for analysis 1	Between Groups				
	Within Groups		.946		
	Total				
REGR factor score 2 for analysis 1	Between Groups			.870	.589
	Within Groups				
	Total				
REGR factor score 3 for analysis 1	Between Groups				
	Within Groups		1.086		
	Total				

Table 11 One way ANOVA results

The test according to Kaiser-Meyer-Olkin criterion, lead to the results shown on Table 12.

	Approx.	890.114
		190
	Sig.	.000

Table 12 Value of the index Kaiser-Meyer-Olkin for the whole sample of the subjective evaluation experiment

According to this criterion (Table 6) and based on the value of KMO that was obtained (Table 12), the results of the factor analysis are 'good' and the implemented method of factor analysis was appropriate for the purpose of this study.

6.3 Discussion

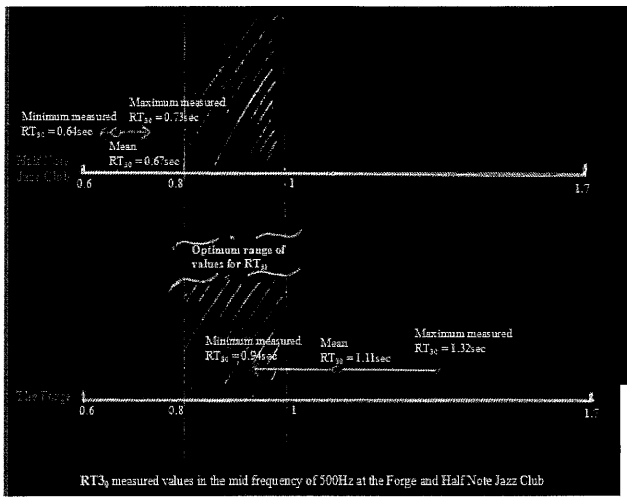
6.3.1 Physical measurements

The analysis that follows is based on the proven correlations between the qualitative criteria of sound and the physical acoustic ones as where identified through the literature review (Table 3). The criteria for the evaluation of the obtained results, are the following: **i)** 0.8<RT (frequency averaged)<1sec (Larsen N.W, 2004), **ii)** D50=0.5dB (Barron M., 1993), **iii)** Bass ratio< 1sec is not a disadvantage (Larsen N.W, 2004)

As it can be seen in Table 7 and figure 4 the average values of each parameter in every frequency range meets the above mentioned criteria for the listening of popular (incl. Jazz) music. A through study of the results, has showed that these criteria were also met individually in almost all chosen locations within our spaces. Whenever this wasn't the case it is expected that the presence of audience during concerts, which offers a high level of absorption, will mitigate the higher values at the level of criterion i. In both case studies the higher T30 values on the middle and high frequencies (500Hz-4kHz) (Table 7) lead us to say that it is possible that these spaces will be perceived as 'harsh' and 'glassy' in tone (Brooks, 2003).

Our evaluation on the obtained C80 values (Table 7), has been based on criteria suggested by Campanella,(1995) and Noack,(2005). C80 is a measure of the degree to which the individual sounds stand apart from one another. Furthermore it has been established that high positive values mean the space is non reverberant, therefore the music is expected to be heard clearly. On what concerns the early to total arriving sound energy ratio (D50) although it is employed to explore clarity of speech in this case (Table 7, figure 5) the obtained values for both the studied spaces, are close to the optimum value of 0.5. The large positive values of both parameters suggest that a big

portion of the direct sound's energy will arrive at the audience within the first 50ms. The latter is rational since in both our case studies reflective surfaces are close to the seating area.



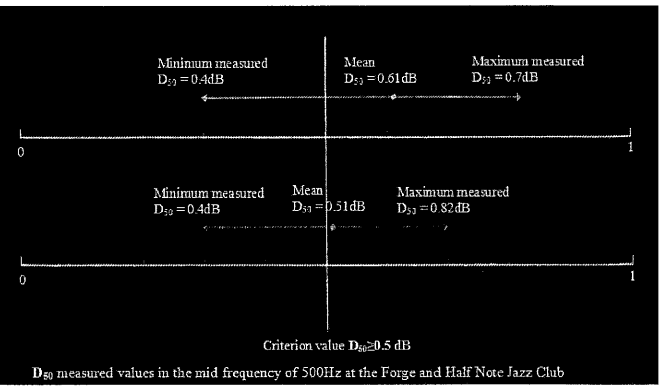


Figure 5 Graphic representation of the obtained values of D50 in relation with the criterion of the optimum values

Figure 4 Graphic representation of the obtained values of RT_{30} inside our case studies in relation with the criterion for the optimum values

6.3.2 Subjective evaluation experiment

With the completion of the subjective evaluation experiments in both auditoria we can conclude that identical factors have been extracted. This outcome is positive especially since the two spaces had different reverberation time values and the audiences had a different cultural background. The fact that in the case of The Forge, the factor 'Proximity' was not extracted is explained by the higher volume and dimensions of the space, which caused an absence of the feeling of proximity. The presence of the bipolar scale 'colored –dark' in both factors extracted at the Forge, indicates that some people interpreted the sound they heard as one 'absent of darkness' and thus as a clear sound and some along 'tonal quality'. As far as the qualitative characteristics of the extracted factors are concerned, we can advocate that both audiences interpreted 'tonal quality' as a measure of smoothness of sound, 'clarity' as a measure of fullness and 'proximity' as a measure of liveness of sound. The 60.98% of the variation that is explained by the three independent factors (table 10) that were extracted at the final stage, is a positive result since in the case of categorical data, as those of our study, a percentage greater than 50% is regarded as good. This means that the three independent factors are important in perception, a conclusion which is very useful to engineers since they design spaces based on the public opinion.

At this point it is crucial to state that although there were differences in the measured values of objective parameters, subjectively they were not identified by the audiences. Assuming that the factor 'tonal quality' is associated with the spectral balance of RT (EDT) and given that the latter varies between the two auditoria, one would expect a significant difference in this factor in terms of the resulting sign of factor scores of the associated rating scales. However the results don't confirm this. Finally as the correlation of subjective 'clarity' with C80 has been established (Table 3), we can conclude that the indication of 'harshness' that the measured C80 values provided, was confirmed by the fact that the perception of clarity of sound in both auditoria was profound and perceived as a harsh sound. The extraction of factor 'clarity' confirms the latter.

7. Conclusions

With the completion of the first set of measurements and both the subjective evaluation experiments we can affirm that live and recorded classical and jazz music, are perceived in common ways. The indications about the acoustic qualities of the selected spaces, as they were given by the results of on site measurements, are confirmed by the qualitative interpretation of the associated scales to the three independent factors. In addition the extraction of the factors 'clarity, 'tonal quality, 'proximity' supports the view that there are common subjective acoustic factors for jazz listeners who belong to distinct cultural backgrounds (that is 'British', 'Greek').The latter permits engineers to look for universal design principles for Jazz clubs.

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