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ASSESSMENT OF RELIABILITY PREDICTIONS OF THE REVERBERATION TIME BY USING THE ARCHITECTONIC SOFTWARE PACKAGE ECOTECT

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Abstract. *Contemporary architectonic design mostly relies on the software tools which enable the engineers to analyze multiple factors affecting a space, and to timely detect and correct certain errors in designing, resulting from attempting to satisfy certain aspects of a space at the expense of others. Those tools which apart from architecture itself also consider other fields of science, depending on the function of these areas are important; thus in the lecture halls designing process, adequate software for analysis is used. In addition to a number of acoustic parameters characterizing the acoustic response of a room, in terms of design, one of the most important factors affecting the acoustics of the indoor areas is reverberation time, which is characterized by the architectonic parameters: room volume (dimensions), shape (form) and materialization (finish material). In this paper, for the purposes of acoustic analysis of the A amphitheater, the parametric values obtained in two ways, by experimental measuring and by software - Autodesk Ecotect and Autodesk Revit Architecture are compared. The software is increasingly used in contemporary architectonic software because of the option to analyze acoustics of indoor space, so there is a need to analyzed the values provided by the software and compare them with actually measured reverberation time.*

Key words: *room design, acoustic analysis, software, reverberation time, measuring*

1. INTRODUCTION

Contemporary technology of software engineering makes rapid advances and public space designing is based nowadays on numerically verifiable values. Such case is prominent in those areas where an architect must take into consideration other sciences

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whose research subject impacts the purpose of the area being designed. Otherwise, the space designed may turn out beautiful but non-functional. This paper analyzes successfulness of experimental measuring o reverberation time and that performed using software tools when designing lecture halls. Nowadays, when designing is required to be extremely precise and fast, software tools are very convenient especially when they can demonstrate the quality of space earmarked for a specific function based on a large number of influential factors. One of such tools is *Autodesk Ecotect* software which belongs to the group of software intended for the engineering profession (Autodesk AutoCAD, Autodesk Revit). Simultaneously, Autodesk software is mutually compatible and they are increasingly used in the architectonic trade, which makes the research subject of the software package *Autodesk Ecotect* particularly important. *Ecotect* and *Revit* are intended for modeling based on numerical information (Binary Information Modeling) which starts from the specific demands of the designer. One of the criteria is that space meets acoustic criteria, primarily the reverberation time criterion.

Time of reverberations is on characteristic criteria when designing lecture halls, because it can be an adversary, but also a valuable ally in achieving intelligibility of speech. The goal is analysis of the mentioned software from the aspect of architectonic designing in terms of acoustic quality of lecture halls (amphitheaters, in the specific case). The most direct way of checking the successfulness of acoustic software analyses is comparison of the obtained results with the parameters obtained by the experimental measurement.

In the domain of indoor acoustics it is known that there is no good alternative for a poorly designed reverberation time in lecture halls [1]. Too short reverberation time in large rooms can lead to undesirable effects in large rooms, because direct sound in them can have insufficient intensity to reach from the lecturer to the remotest listeners in time. For that reason there is a need that reverberation is such that it contributes in such a way that the direct sound reaches every listener with the highest possible intensity. In lecture halls, the range of reverberation time where sound can be heard well is 1 - 1,5s.

From this it is clear that adequate acoustic design can attain a certain value of reverberation, so that the sound reaching each listener has minimally reduced intensity. In this way, the decrease of sound intensity is not accompanied with large distortions (e.g. echo and noise occurrence).

2. ANALYSES AND CALCULATION OF REVERBERATION TIME BY SOFTWARE

2.1. Autodesk Ecotect software

In *Autodesk Ecotect* software, it is possible to perform several analyses of various characteristics of buildings related to the domain of building physics. In addition to the main window displaying data on the project currently worked on by a designer, there is a widow for a wire model of the structure, in which every individual architectonic element can be singled out, and its impact on the physics of the structure can be analyzed. In this window, the structure can be viewed through the layout and different view, but it retains the wire structure. In addition to this wind, there is yet the visualization window for checking whether the 3D model of the structure is fully enclosed by physical structures of architectonic elements. There is also a window containing the commands for various

kinds of physical analyses, one of the being the reverberation time readout (Fig. 1). Due to good compatibility of two software packages, the models for the *Autodesk Revit* software are used, in which a models is designed and its materials are defined. Both software packages possess their own material databases, which are very poorly supplied with certain contemporary and technologically advanced materials.

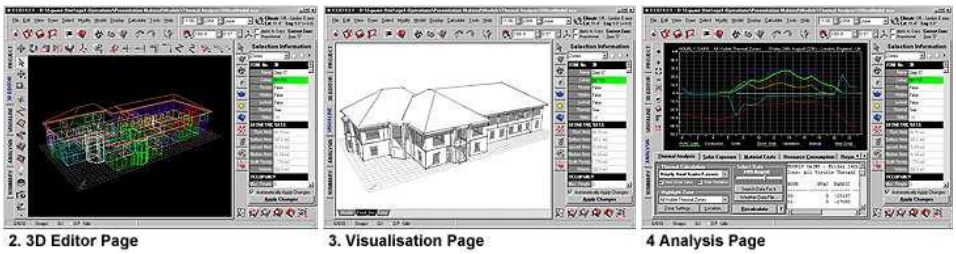

Fig. 1 Different views of a structure in its physical characteristics.

Such fact is the consequence of the fact that companies dealing with the production of building materials often do not provide full specifications, thus protecting their manufacturing technology and the market. The *Autodesk Ecotect* software is primarily intended for the architects, and in essence it is compatible with the models of structures made in other software by Autodesk (such as AutoCAD, which is most often used by architects and other engineering.).

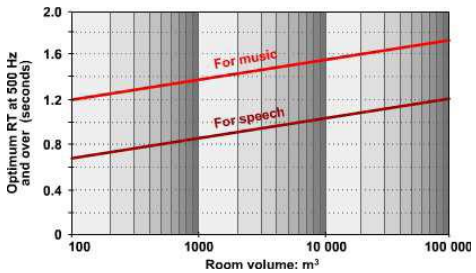

Fig. 2 Optimum reverberation time on the room volume in the Ecotect software

As already said, in the *Autodesk Ecotect* software, it is possible to measure reverberation time. In the Ecotect software, the optimum reverberation time (Optimum RT) at 500Hz was directly related to the room volume (Room volume). One of conditions used to establish this relation is that the room is empty, i.e. without people in it. In addition, there are options for separate reverberation analyses in cases when the room is used for speech or for music according to the diagram (Fig. 2).

2.2. Calculation of reverberation time in the Ecotect software

The first method of measuring the reverberation time in the *Ecotect* software uses the standard Sabin formula (1). Along with the results obtained by the Sabine formula are presented all the results obtained according to the Norris-Eyring formula (2), and according

to the Millington-Sette formula (3), which uses the Neper logarithm *ln*, where V – is volume, a – is average absorption coefficient of all surfaces in a room, S – is total surface area of the entire envelope of a room, a_i – is absorption coefficient of individual surfaces of a room, A – is total absorption surface area:

$$RT = \frac{0{,}161V}{A} \tag{1}$$

$$RT = \frac{0{,}161V}{-S \times \ln(1-a)} \tag{2}$$

$$RT = \frac{0{,}161V}{\sum -Si \times \ln(1-a)} \tag{3}$$

These formulae are provided in order to compare them with the Sabine formula, whereby a designer adapts the model in order to obtain as close values of the three formulae as possible. One must emphasize that, according to Parkin-Humphreys, all patterns for reverberation time contain a premise that sound energy is evenly distributed across all surfaces of a room, which is a rare occurrence in practice [3]. Such assumption is often a basic reason why the time calculated at lower frequencies often does not match the actual time. It is however clear, that the given formulae are, by nature, are intended for the statistics of behavior of rooms of various volumes, by negating their form (geometry), usage of reflective or absorbent materials (nature of materials) and usage of special acoustic absorbing means. It is necessary to indicate that Millington-Sette formula is most often used for measuring of reverberation time of a very large hall. When measuring reverberation time one may observe considerable discrepancy in the obtained results. Such reverberation deviations in the obtained graphs cannot be avoided. The window showing the results according to three given formulae simultaneously recommends the one formula considered by the software as the most relevant in case of the observed room (Fig. 3-left). The window for calculation of reverberation time contains commands for calculation and graphic presentation in the form of reverberation time statistics diagram for the octaves: 63Hz, 125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, 8000Hz, 16000Hz.

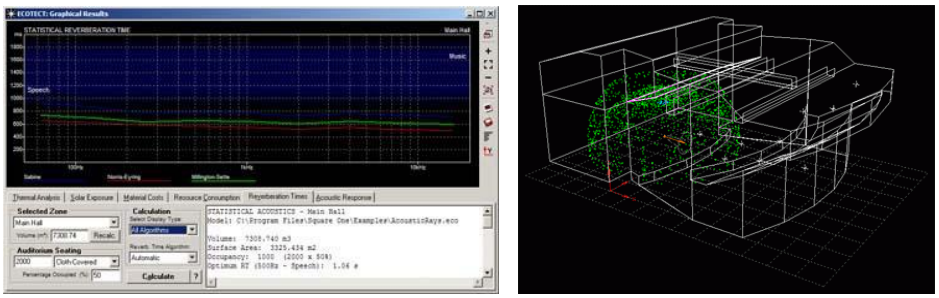

Fig. 3 Window for calculation and display of reverberation time diagram in the Autodesk Ecotect software (left) and structural model with the marked out sound source (right)

2.3. Implementation of the Autodesk Ecotect software in the reverberation time analyses of lecture halls

Regarding the data set by a designer, the closest attention is paid to the model imported into the *Autodesk Ecotect* software, because it provides the volume of the indoor space of the hall (Fig. 3-right). On the basis of this model *Autodesk Ecotect* is able to visualize propagation of sound via the sound rays (or waves) and to calculate reverberation time. The analysis of these factors in acoustics is initiated using *Statistical Reverberation* command in *Calculate* tab *(*Fig. 4).

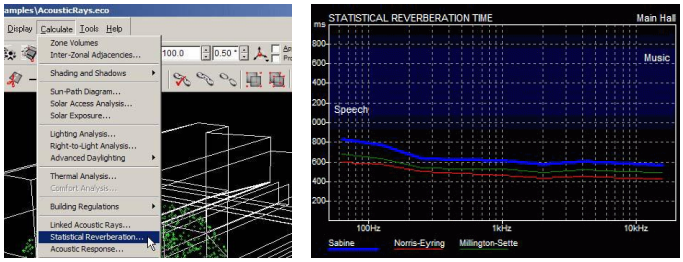

Fig. 4 Initiation of Reverberation time in the Autodesk Ecotect software

The space for the room volume parameter is interactive, so a designer can write some alternative volume value over it. It cannot affect the model, and thus the actual volume of the designed room, but manipulation of this value provides a good estimation of the required value of the volume required to achieve optimum reverberation time. The controlled manipulation of volume value is thus useful for the conceptual phase of the work on a lecture hall design. A designer can specify with how many seats a room has, of what material they are made (hardwood, leather or cloth upholstered (Fig. 5), what is the seat occupancy in percents.

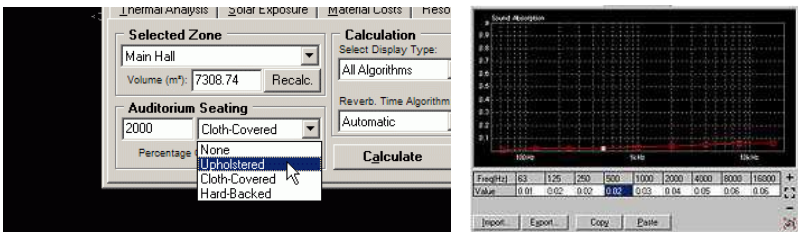

Fig. 5 Fundamental variables in the Ecotect algorithm: Volume (Volume), Number of seats (Auditorium seating), seat material (Upholstered, Cloth/leather-covered or hardwood), as well as the occupancy percentage (Percentage) and window for defining the values of the absorption capacity of materials

The number of seats in a hall affects the calculation of volume per a seat, which can be compared to a recommended optimum range. Seat occupancy percentage will affect the diagram, since high occupancy will reduce reverberation time, while emptier lecture halls space will reverberate more.

After each change, it is possible to perform recalculation by pressing the button of the same name, which makes the software interactive. In the white section of the window, there are displayed results as texts, and tables of reverberation time values for the selected room. In order to be able to further use the information the *Autodesk Ecotect* software has the option of selecting and copying them to another application of the Windows.

Therefore, reverberation time is defined in the *Autodesk Ecotect* software through several factors: volume, material of the surfaces the room is clad with and those on the furniture, and by the number of persons in the room. By varying any of these factors in the *Autodesk Ecotect* software, it is possible to monitor their impact on the characteristic reverberation time of a given room in an interactive way and even consider some changes in design from the architectonic viewpoint, in order to provide as good reverberation time in the room as possible (i.e. in accordance with those recommended by the software). This further implies that it is the best to use the *Autodesk Ecotect* software in the conceptual phase of the work on the design, so that one could timely improve the reverberation time of the rooms for special purposes and of large volumes, and by this the perception of sound of listeners. Large lecture halls are particularly sensitive sot such variations.

Particularly in the case of large rooms, it is difficult to find the spaces which are ideal in terms of reverberation time and for delivering speeches and for musical performances, unless they are not flexible in terms the volume and material used for cladding the interior surfaces. The rooms, according to the note in the manufacturer's Tutorials are made so that one of these uses is preferred, unless additional electronic devices are constantly used, and normally those are rooms intended for delivering speeches [11].

3. MEASUREMENT OF REVERBERATION TIME OF THE AMPHITHEATER - A (GAF AND MF)

Here will be mentioned the "architectonic" data which were considered in the design of amphitheater, and which are also related to reverberation time, but also to the general principles of room designing with the goal of achieving good acoustic qualities. Dependence of these dimensional relations can be presented via the equation (4), where *S* – is the distance of the ultimate row of seats form the sound source, *H* – is the how height the source is above the heads, and *r* – spacing between the rows, while the free height is the height of a listener's head in the ultimate row h [2].

$$h_n = h_{n-1} + h - \frac{r \times (H - h_{n-1})}{S + (n-1) \times r} \tag{4}$$

$$h_n = 1{,}035 + 0{,}115 - \frac{0{,}807 \times (1{,}30 - 1{,}035)}{2 + (10-1) \times 0{,}807} \tag{5}$$

Where h_1, h_2, h_3,…,h_n is the elevation of first, second, third, ..., n-th row, and S represents a distance from the first row (or the last row in the line of those which are situated in the horizontally lowest part of the hall) from the sound source, according to figure 6.

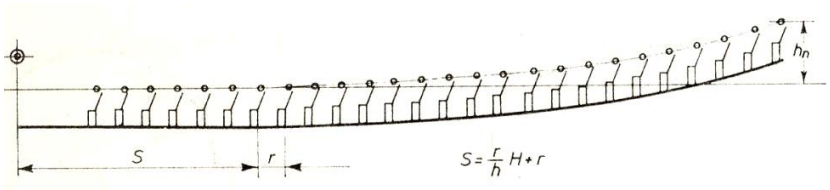

Fig. 6 Gradually elevated rows of seats offer good acoustic characteristics of the lecture halls in terms of the direct sound, which is very important when the back rows the halls are concerned

The ideal height of the ultimate row should be h_n = 1,17m in respect to the top of the head of the listener in the first row. The actual height (measured on the A amphitheatre cross section) is 1,15m, which is a very low deviation. This also holds for the actual elevation rise of the rows (11,5cm) in comparison to the optimum (12cm).

The volume of the **A** amphitheatre interior space is V=853.69m^3, so according to the Harrison-Knudsen graph, the optimum reverberation time is 0,78s. In the *Autodesk Ecotect* software, the measure of 200 planned seats is entered, which yields the unit volume result of 4,268m^3 per seat. It was already mentioned that the range of these values of lecture halls should be from 2,8m^3 to 4,2m^3.

Fig.7 Interior surfaces finish materials of A amphitheatre

The materialization of the interior surfaces of the A amphitheater (Fig.7). has the following composition: CEILING - GK ceiling plasterboard, imperforated dp = 12.5mm;

FLOOR - Tarket Tapiflex vinyl floor; UNCOATED WALLS - plastered and coated with acrylic paint; BACK WALL of the amphitheater - wall wooden covering; SIDE WALLS - wooden slopes with air space between them and the wall surface, FURNITURE (doors, tables and chairs) - wood, chipboard; SCHOOL BOARD – blackboard [6].

Measurements of reverberation time of the **A** amphitheatre of the faculty of Civil Engineering and Architecture of Niš was performed according to standardized methods by measuring reverberation time on site using; building acoustic analyzer B&K 4418, sound source B&K 4224, ½ inch microphone type B&K 4166 plus microphone preamplifier type B&K 2639 and microphone boom B&K 3923 (Fig. 8).

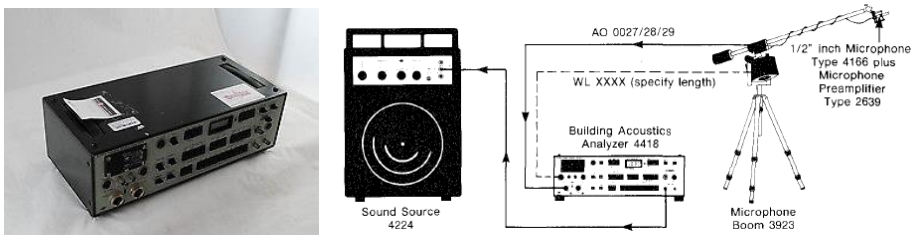

Fig. 8 Equipment used during the reverberation time measurements

On the occasion of measuring on site, in the A amphitheatre of the Faculty of Civil Engineering of Niš, was implemented the sound source method. Measuring is performed in the position usually occupied by a standing lecturer in the mentioned room. A decrease of 20dB is defined (irrespective of the selected decrease, reverberation time will be the same – it can be a decrease of 60dB which defines reverberation time, but any other, as well). Measuring is repeated three times for each frequency, and the values are measured in thirds from 100Hz to 5000Hz. The obtained values are as follows:

Table 1 Measured values of reverberation time TR (s) for various frequencies f (Hz)

f (Hz)	100	125	160	200	250	315	400	500	630
TR (s)	**1.90**	**2.17**	**2.12**	**2.17**	**2.09**	**2.59**	**2.34**	**2.49**	**3.07**

f (Hz)	800	1000	1250	1600	2000	2500	3150	4000	5000
TR (s)	**3.31**	**2.81**	**2.94**	**2.74**	**2.43**	**2.37**	**2.28**	**2.02**	**1.72**

According to the results obtained by the measuring in an empty amphitheatre, it can be concluded that there is a high value of reverberation time which starts to decrease beyond the frequency of 800Hz. The measured values are shown on the graph (Fig.10) with thick dotted lines.

According to literature [2] where the percentage of intelligibility of syllables is correlated to the room value and reverberation time, this value would slightly exceed 80%. The best results of reverberation time, that is, of its compliance with the optimum range of lecture halls (1-1,5s) are achieved in cases when the amphitheatre is fully occupied and the seats are upholstered.

Calculated reverberation time, obtained using the *Autodesk Ecotect* software in case when the amphitheatre is empty is also presented on the following graph (Fig.10). The software adopted the Sabine equation as the most suitable one, whose graph of function is more prominent. In the text below are marked the values for all three graphs of function. It is evident that the closest values to the values measured on site are those obtained with the equation favored by the software – the Sabine one. On the graph is also labeled (grayed area) the reverberation time range that enters the range close to the optimal reverberation time for speech in the case of a given room.

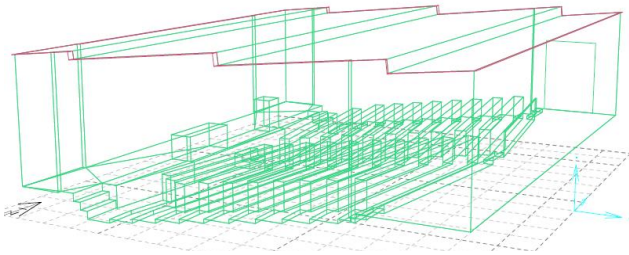

Fig. 9 Wire model A amphitheatre adapted to the Autodesk Ecotect software for physical analyses

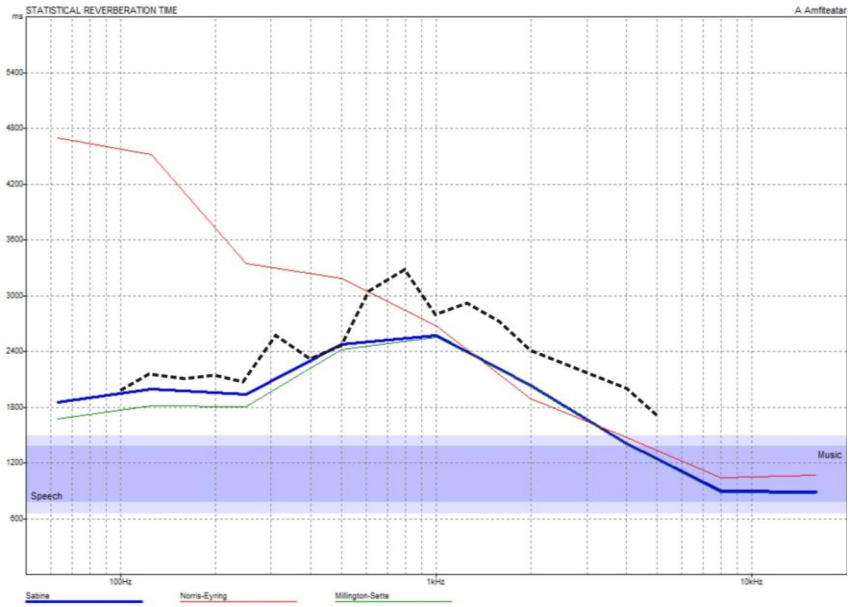

Fig. 10 Comparison of the graphs obtained by measuring (dotted lines) and the graph obtained by the Autodesk Ecotect software (thick line marks the function graph obtained by the Sabine equation)

4. DISCUSSION OF THE RESULTS

Autodesk Ecotect represents such software, which is, as already mentioned, intended for the architects, for their analysis of the impact of the designed structure on the environment, according to the lighting, thermal and acoustic criteria. In the environmental terms, therefore, this software is related to many interesting issues which can be influenced by the architects. Accordingly, it is important for the architects, especially in educational terms, to identify software which is relatively easy to master and which would provide sufficiently accurate results on whose bases designers could become aware of the impact of design of their structures on the environment. Precisely for that reason this software is intended for early phases of designing – conceptual designing. The interactive approach BIM (Binary information model) of the software such as *Autodesk Ecotect*, makes work and decision making easier for various issues, especially in case of the structures which are complex in terms of geometry.

However, the *Autodesk Ecotect* software has its limitations. The model entered into the analysis software would be better modeled in some other BIM software, because Ecotect is not sufficiently precise yet. The model presented here is modeled in the Autodesk Revit software (Fig. 9), which is of BIM kind, which means that in it, materials and thickness of layers constituting certain architectonic elements can be defined. A part of the space analyzed (in this case the amphitheatre interior) must be a fully enclosed 3D area, which means it must not have any air bridges with the environment of the observed space.

In terms of *reverberation time analysis the Autodesk Ecotect* software exhibits satisfactory results. The software shows decrease of sound beyond 500Hz. Although the measurement on site show that the sound decreased beyond 800Hz, this is somewhat acceptable difference, because the comparatively similar results were obtained in the USA [4]. With the deviation of 0,2-0,6s the accuracy can be observed as approximately accurate. The deviations occur due to the details in the furniture (writing tables of the desks, cassettes for bags in them, ventilation openings etc.) which can be modeled separately, and for them one must have special absorption coefficients at various frequencies, which are very difficult to attain (furniture and ventilation equipment manufacturers for amphitheatres rarely present (or consider) information on absorption capacity in terms of acoustics, especially when these values are observed at various frequencies), unless special measurements are done for each architectonic element.

Another advantage of *Autodesk Ecotect* software is that in terms of analysis of reverberation time in lecture halls, on the basis of input parameter variations, it is possible to suggest subsequent acoustic adaptations of already designed spaces whose characteristics are not adequate. This particularly refers to reverberation time of medium and large lecture halls (such as amphitheatres, as we demonstrated). By varying several parameters, we demonstrated how somewhat better acoustic characteristics could be obtained, but we were also able to simultaneously affect the values of reverberation time in cases of a certain percent of amphitheatre occupancy rate. It is an additional quality of the interactive approach to designing of this software, especially when the use of the rooms in question requires good acoustic characteristics such as reverberation time.

5. CONCLUSIONS

It is evident from the mentioned facts that acoustic designs must achieve certain value of reverberation, i.e. that its value must be harmonized as a constant in the entire range of audible frequencies, so that the sound can reach every listener with the least muffled intensity possible, and that the decrease of the sound occurs with no major distortions.

The *Autodesk Ecotect* software is capable of detecting frequencies on the octave degrees. For that reason the higher deviation of reverberation time on the values of frequencies in the thirds must be understood. Yet, the highest deviations of the *Autodesk Ecotect* software on the example of A amphitheatre occur at frequencies of 1000Hz (considered by octaves). These deviations are of the order 0,20-0,60s. They are not of much importance for the needs of architectonic modeling, because with such range of discrepancy of parameters, acoustic response of the room can be finely tune using specific architectonic intervention. If the range of parameter discrepancy were larger, the software itself would be insufficiently reliable, which is not the case.

The reason for deviation of the measured results from those analyzed in software is the fact that the amphitheater has certain architectonic elements, for which it is currently difficult to obtain absorption capacity result at different frequencies. It is however clear that in the observed amphitheater reverberation time at medium frequencies can according to the measurements reach the value of 3,31s (at the frequency of 800Hz) when the room is empty. This time is shorter when the amphitheater is full (because of absorption of human bodies, clothing, bags and backpacks, etc.`), and the analysis in the *Autodesk Ecotect* software demonstrated that the particularly speech intelligibility would be close to optimum if the seats were upholstered. According to the graph for such possibility, reverberation time would be longer than the range close to optimum only in case of low frequencies, which in case of the speech (i.e. lecturing) need not be specifically taken into account. What was observed in the course of varying the material in the interactive software *Autodesk Ecotect* is that the walls plastered and coated with acrylic paint, cause long reverberation time, and this also holds for the ceiling and the cladding of the back wall, for which it would be recommendable to have a high degree of absorption. In general, majority of used materials for this amphitheater in the current status has a low absorption coefficient. Such reverberation time effects are particularly observable by the students sitting in the back rows of amphitheatre. Finally, taking into account all potential shortcomings, the analysis carried out in this paper suggests that the *Autodesc Ecotect* software can be successfully used as a prediction tool in the auditorium and speech rooms design.

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PROCENA POUZDANOSTI PREDIKCIJE VREMENA REVERBERACIJE KORIŠĆENJEM ARHITEKTONSKOG SOFTVERSKOG PAKETA ECOTECT

Savremeno arhitektonsko projektovanje se u najvećoj meri oslanja na softverske alate koji inženjerima omogućavaju analizu više faktora koji utiču na jedan prostor. Ovo pre svega ima za cilj da izvesne greške u projektovanju, koje su posledica zadovoljavanja jednog aspekta prostora i narušavanja drugog, budu na vreme uočene i ispravljene. Od značaja su oni alati koji pored same arhitekture razmatraju i druge oblasti, u zavisnosti od funkcije samih prostora, pa se u projektovanju prostorija za držanje govora primenjuju i adekvatni softveri za analizu. U ovom radu je za potrebe analize akustičkog kvaliteta amfiteatra A, izvršeno poređenje vrednosti dobijenih na dva načina, eksperimentalnim merenjem i softverski, putem programa Autodesk Ecotect i Autodesk Revit Architecture. Ovi programi su sve češći u savremenom arhitektonskom projektovanju zbog mogućnosti predikcione analize akustike zatvorenih prostora, pa postoji potreba za analizu pouzdanosti vrednosti koje se dobijaju njihovim korišćenjem u odnosu na realno izmerene vrednosti vremena reverbaracije.

Ključne reči: *projektovanje prostorija, akustička analiza, softver, vreme reverberacije, merenje*