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Educating of Architectural Students in Acoustics as an Answer to the Reverberant Noise Standard

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Abstract Implementation of the new standard PN-B-02151-4 – Building Acoustics – Protection against Noise in Buildings, Part 4: Requirements for Reverberation Conditions and Indoor Speech Intelligibility and Testing Guidelines imposes on architects an obligation to design interiors in compliance with acoustic requirements. The above regulations give rise to the need to educate future architects so that the standard can be practically employed in their professional career. The aim of the article is to describe a teaching method tailored for students of architectural design compliant with the standard requirements without using specialized software programmes. The paper presents two types of design tasks that form a basis for teaching students within the framework of design practice in building physics – acoustics. The article shows how to teach students to facilitate full acquisition of the rules governing interior design compliant with reverberation parameters suitable for the assumed function, and to enable thorough comprehension of interior design.

Keywords: education, architectural acoustics, reverberant noise, reverberation time, designing

1. Introduction

The new Polish PN-B-02151-4 standard - Building Acoustics – Protection against Noise in Buildings, Part 4: Requirements for Reverberation Conditions and Indoor Speech Intelligibility and Testing Guidelines was introduced in 2015 [1]. Since 2018, the new standard has been mandatory. The introduction to the standard says that the observing the rules of the standard will "*reduce the level of noise in an interior through reduction of one of its components, i.e. reverberant noise*" and that it will *"ensure speech intelligibility in order to provide adequate conditions for the use of interiors dedicated to speech purposes*". The standard applies to the so-called interiors with non-qualified acoustics, i.e. interiors where acoustics are not the key function. The document gives recommendations for reverberation time *RT* values and speech transmission index *STI* for interiors designed for speech. Requirements applicable to the remaining interiors are *RT* reverberation time and sound absorption.

The abovementioned legal regulations stipulate that acoustic requirements should be taken into consideration in architectural design. A designer's primary goal is to prevent occurrence of reverberant noise in interiors. Hence, the ability to deploy the reverberation time formula is a must in design practice. For architects who have not been taught architectural acoustics as part of their university course, training courses are organised. Therefore, an important aspect of educating future architects is to ensure such professional training in order that the graduates do not have to look for it later on in their career.

It has been evident for many years that architects need to be educated in architectural acoustics [2]. The need to educate architects and civil engineers on acoustics is discussed – the area that still craves for commitment and development [3]. New ways of education regarding architectural acoustics are searched for [4]. Analyses of current teaching programmes in acoustics at faculties of architecture are carried out [5]. The practical aspect is emphasised with respect to imparting acoustic knowledge to future architects [6,7,8,9,10].

In the case of non-qualified interiors, an architect can successfully design an interior in most situations regarding acoustics without the assistance of an acoustician. Moreover, typical cases can be acoustically designed without specialised software. The aim of the paper is to present a teaching method of acoustic design principles while taking into consideration standard requirements for reverberant noise.

2. Methodology

The guidelines specified in the standard render it possible to estimate reverberation in an interior with the use of the RT formula, as well as to implement acoustic treatment through selecting the appropriate amount of sound-absorptive materials. However, the formula only helps estimate reverberation time in an interior, while acoustics are also influenced by the arrangement of materials and shape of the interior. This is, naturally, what cannot be computed based on the RT formula given in the Standard. Hence, knowledge on how to arrange sound-absorptive materials and how to shape the interior is crucial.

The aim of the design tasks implemented within the framework of the subject called "building physics – acoustics" should be to teach architectural design inclusive of the acoustic aspect. The diagram depicting the teaching process is presented in Figure 1. Before proper teaching acoustic guidelines for architectural design begins, students should understand what reverberant noise is. Once they learn to what extent this acoustic defect translates to non-functional and problematic interiors, they will be keen to study the principles of correct acoustic design. This can be achieved by introducing students to sound samples that illustrate how the reverberation time affects music and speech perception. Also, one of the first exercises is a visit to a room with significant reverberant noise. Next, the students learn how to use the reverberation time formula. The rules of the calculations are explained on a simple example. Thus prepared students can use the formula in practice in order to, on the one hand, learn to carry out acoustic treatment in a problematic interior, and, on the other hand, independently design a room without acoustic defects.

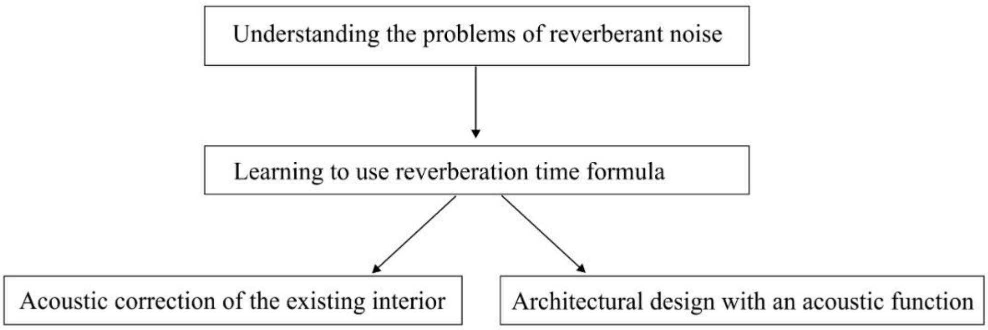

Fig. 1. Diagram depicting the process of teaching design compliant with standard requirements related to reverberant noise.

The teaching process is shown on the example of two design tasks. The first task is to correct an existing interior whose acoustic parameters have been determined in result of acoustic tests. The second task consists in designing an interior taking account of its acoustic function. Both design tasks do not require the use of specialized software, which is particularly important because most graduates will not have access to acoustic programmes.

3. Tasks

3.1. Acoustic correction of an existing hall

The first design task involves carrying out treatment of an interior of a large internal volume with reverberant noise. Students work in pairs, and each pair receives its own design topic. The sample tasks presented in this paper refer to the design of acoustic treatment for two churches in Poznań: St. Lawrence Church and the Sacred Heart of Jesus Church. Acoustic measurements carried out earlier by the author provided information on the actual reverberation time in the interiors [11]. The design of the acoustic treatment consisted of two stages. The first stage consisted in making an inventory of the existing finishes whose acoustic properties, based on the formula (1), enable computational recreation of the current reverberation time.

Reverberation Time of given premises can be calculated from Sabine's formula (1):

$$RT = \frac{0.161V}{A}, \tag{1}$$

where: RT is the reverberation time [s], V is the volume of room, [m^3], A is the total absorption of room, metric sabins.

It can be concluded from the formula above that reverberation time is affected by the internal volume of an interior and the applied finishes. Reverberation time is proportionate to the volume, i.e. the larger the volume, the longer reverberation time. The influence of the finishes is related to sound absorption coefficient α. When α =0, absorption is equal to 0, when α =1, the incident wave is fully absorbed. For a given material, sound absorption coefficient α depends on sound frequency - the values are typically given for octave bands equal to 125, 250, 500, 1000, 2000 and 4000 Hz . The Sabine equation is most accurate in a live room where the average sound absorption coefficient is less than 0.25 [12]. For more absorptive room the Eyring equation (2) is useful:

$$RT = \frac{0,161V}{-S\ln(1-\alpha_{\text{average}})}, \tag{2}$$

where: RT is the reverberation time [s], V is the volume of room [m^3], S is the total surface area of room [m^2], α_{average} is the average sound absorption coefficient .

The second stage involved such correction of the set of those materials as to obtain the desired change of reverberation time. It is obvious that architectural and fire protection requirements, market availability of materials and the investor's financial capabilities are taken into account.

St Lawrence Church (internal volume = 7500 m^3, RT = 5.5 s) has much too long reverberation time due to its reinforced concrete structure and sound reflective finishes (see Fig.2). Thus, reverberant noise in the interior is audible. In order to correct the acoustics, the proposal of acoustic treatment involved placement of glass wool secured to minimise release of dust, with sound absorption coefficient α = 0.6, in coffers 1.7 m deep. It was assumed that such a modification would be unnoticeable due to the depth of the coffers. Acoustic plaster with sound absorption coefficient of α = 0.8 was used on the walls and the balcony. Additionally, an absorptive material was adopted for the wooden pews. In order to obtain such a high value of the sound absorption coefficient, the adaptation assumed covering the whole pews and kneelers with upholstery, which is atypical of solutions applied in Poland. Therefore, sound absorption coefficient α = 0.5 was adopted. As a result of the applied treatment, it was possible to achieve the expected reduction of the RT reverberation time from 5.5 s to 2.6 s.

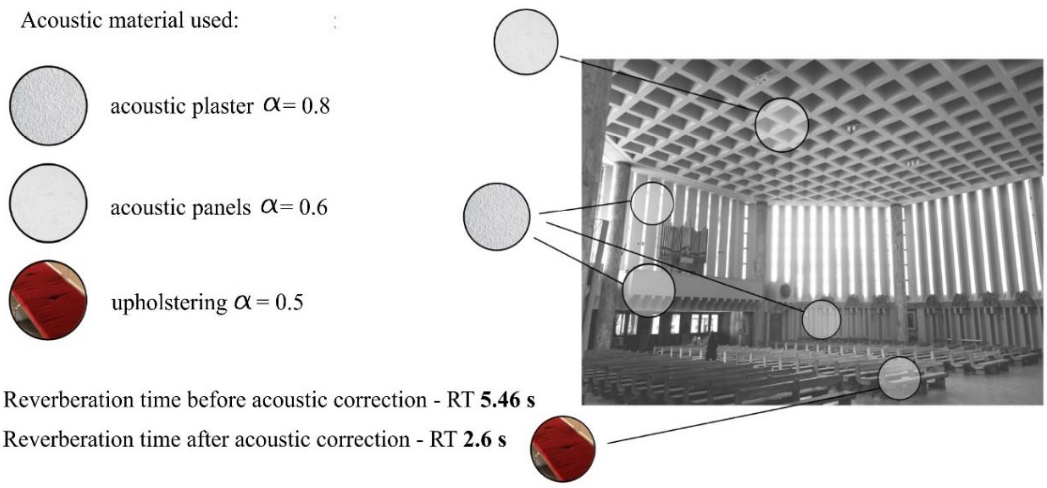

Fig.2. Proposal of acoustic treatment of St Lawrence Church – fragment of a board developed by students: Katarzyna Ciesielska and Sebastian Skrzydliński under the supervision of the author, within the framework of classes in building physics – acoustics.

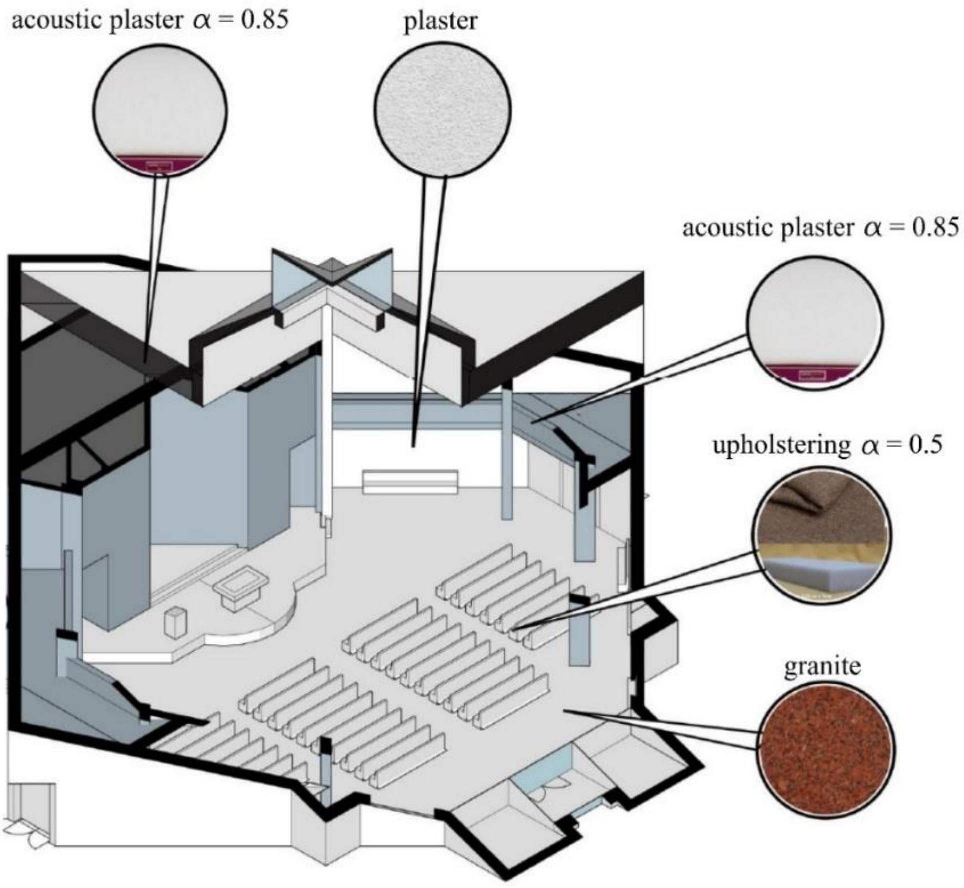

Fig. 3. Proposal of acoustic treatment of the Sacred Heart of Jesus Church – fragment of a board developed by students: Sebastian Gajewski and Paweł Szott under the supervision of the author, within the framework of classes in building physics – acoustics.

The Sacred Heart of Jesus Church has reverberation time RT = 5.9 s with an internal volume of 5410 m^3 (see Fig. 3). The church is built of reinforced concrete, and its interior is finished with plaster. In order to reduce the reverberation time, the proposed treatment involved covering the ceiling and the balustrades of the choir with acoustic plaster with sound absorption coefficient α = 0.85, as well as increasing the extent of upholstery on the pews so that the pews reach α = 0.5. As a result of the adaptations, the reverberation time after the acoustic treatment reached RT = 1.8 s.

3.2. Architectural design with an acoustic function

The second task is to develop an architectural and acoustic design for a public utility room. Students use their own designs, previously made within other subjects, or prepare new ones. The interior is characterised by non-qualified acoustics and should have a considerable volume. It is important for such an interior to be of a relatively considerable volume because problems related to reverberant noise increase along with the increase in the interior volume.

In the initial stage, students look for examples of architectural and acoustic solutions for rooms with a similar function. They select three examples; next, they analyse the solutions adopted in the examples. The focus is on the type of materials; their acoustic properties, interior design, and colour solutions. Such analyses inspire students' own design choices. Then, the acoustic properties planned for the designed room are determined together with the required reverberation time. Based on the formula (1), reverberation time for the room is calculated before acoustic treatment is applied. The calculations assume typical materials used in construction which usually have low sound absorptive properties.

Then, the students work on a design that assumes an approach consisting in parallel, twofold combination of architecture and acoustics. An addition of sound absorptive materials that are stylistically unrelated to the designed interior is unacceptable. Yet, this commonly happens when final decisions are made without an architect's contribution and when visually unfavourable solutions are applied to improve acoustic properties of the interior. The final design must constitute a comprehensive solution which ensures that the acoustic treatment is coherent with and inseparable from the architecture. The design is carried out together with monitoring the obtained reverberation time, which in the final stage should assume the value consistent with the previous assumption. Figure 4 shows the design of a dining hall, while Figure 5 shows an entrance hall. The design works on both the interiors were constantly focused on maintaining harmony and unity of the proposed solutions and the style of the interior. It was important to ensure that, from the visual point of view, the adopted solutions were not perceived as acoustic treatment but as a complement to the designed architecture.

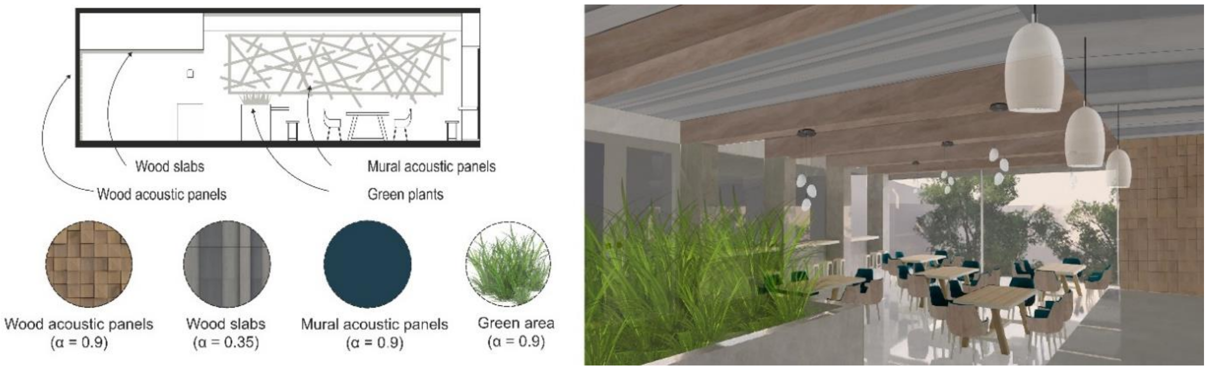

Fig.4. Acoustic design of a dining hall – fragment of a design board developed by Johann Mansuy under the supervision of the author within the framework of classes in building physics – acoustics.

A dining hall is a space used by many people at the same time and can quickly become very noisy. As the hall is designed for ski factory workers, it will serve not only as a dining area but also as a relaxation space. Therefore, it is essential to ensure peace and quiet as well as conditions for effective communication. Before acoustic treatment was applied, reverberation time RT = 2.3 s was calculated, which is definitely too long for an interior with such a function. Sound absorptive materials were used, such as acoustic panels with sound absorption coefficient α = 0.9 or greenery so selected as to absorb sounds as much as possible. The applied acoustic solutions rendered it possible to obtain reverberation time RT = 1.0 s.

In the entrance hall, 9 m high and with an internal volume of V = 7933 m^3, acoustic solutions were absent before the treatment. Large surfaces were made of concrete and glass. The reverberation time was RT = 6.4 s. Such long reverberation time causes reverberant noise. In addition, extensive glass surfaces will produce an echo. The basic acoustic solution was to use acoustic plaster with sound absorption coefficient α = 0.85. Most acoustic plasters are not particularly resistant to mechanical damage (such as a person leaning against a plastered wall). The plaster-covered surfaces are applied mainly in places where the plaster is not exposed to such damage. Also, wooden strips were applied where it could be damaged, which additionally enhances sound diffusion favourable for acoustic conditions. To further reduce the reverberation time, grooved acoustic wood panels with stripe perforation with sound absorption coefficient α = 0.6 and plants with planting substrate coated with granular gravelite substrate with sound absorption coefficient α = 0.4 were used. The reverberation time obtained after the use of the acoustic materials was RT = 1.0 s. Such reverberation time ensures great acoustic comfort in the designed interior.

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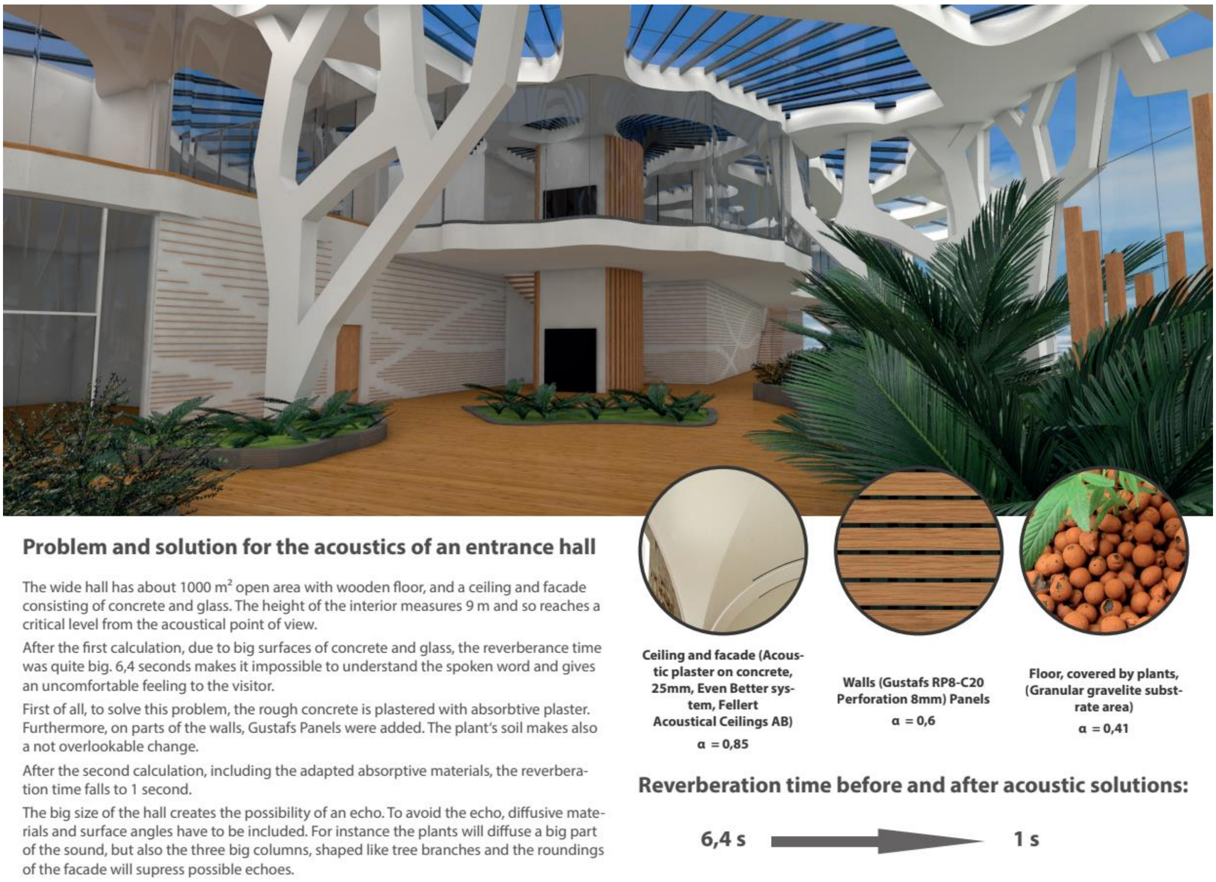

Fig. 5. An acoustic design of an entrance hall – fragment of a board developed by student Clemens Albert under the supervision of the author within the framework of classes in building physics – acoustics.

4. Discussion

Through the implementation of the presented tasks, students acquire a number of skills. Both the tasks allow them not only to learn about the noise standard but also to use it practically in design. Design classes are complemented by lectures covering theoretical knowledge of reverberation issues. Such a combination enables the students to carry out design tasks consciously, which is confirmed by authors [3], who have observed that it is of utmost importance that practical methods be reinforced by theoretical foundations. However, the main goal of the course in building physics-acoustics is to impart practical knowledge and teach practical skills. Acoustics is under threat of being limited to theory devoid of the practical aspect, in effect of which the students will not know how to put the theory into practice [4]. Certainly, the support that relevant literature provides in the teaching process cannot be discounted. The essential book on acoustics recommended in teaching architects is "*Akustyka sal-zalecenia projektowe dla architektów*" by Andrzej Kulowski, which takes into account the specificity of the profession and expectations of designers [13].

The first design task renders it possible to confront acoustic measurements of the interior with the subjective perception of acoustic conditions. Students gain experience because they can see that long reverberation time makes an interior noisier and reduces speech intelligibility. Another practical skill involves learning about acoustic materials as well as learning to use the data provided in manufacturers' catalogues. A selection of materials for an acoustically treated interior is carried out with due respect for the existing architecture.

The second task prepares students to develop an architectural design coherent with an acoustic design. The applied solutions, apart from bringing out an acoustic impact, are to match the interior harmoniously. The combination of the acoustic design with the interior design allows the students to fully comprehend the rules of how to use the reverberation time formula, and teaches them to think about interior design holistically. Students realize that their architectural decisions shape the acoustic conditions. A holistic approach to design allows them to avoid the use of acoustic solutions as peculiarly autonomous elements attached to the interior without any reference to its style.

The literature also discusses the issue of raising students' interest in architectural acoustics [5]. Introduction of sound as a new dimension of architectural design constitutes an attractive supplement to teaching. Also, students become more involved when they learn that an architect's decisions on design translate to acoustic quality of interiors. In addition, "(…) the instructor's ability to listen and understand the questions from the students (…)"[7] is a crucial component of a successfully conducted course in building physics – acoustics. The assumed formula of active individual consultations enables the instructor to accompany and support the students throughout the whole design process.

5. Conclusions

Acoustic issues in architectural design are gaining in importance, which is highlighted by implementation of standard PN-B-02151-4 – Building Acoustics – Protection against Noise in Buildings, Part 4: Requirements for Reverberation Conditions and Indoor Speech Intelligibility and Testing Guidelines. The standard provides for requirements related to reverberation time or acoustic absorption according to the functions, and for requirements regarding speech intelligibility for interiors designed for speech purposes. The most vital requirement defined in the standard is the skill to apply a formula for reverberation time in design practice. Teaching to use the RT formula based only on a sample calculation without student's active participation in design will not yield satisfactory results.

Two types of design tasks were presented. Task 1 assumes treatment of an existing interior whose acoustic parameters were determined on the basis of acoustic investigations. Task 2 consists in designing an interior following acoustic requirements on the basis of the student's own design developed in other design classes.

Incorporation of architectural acoustics into the curriculum at faculties of architecture is crucial due to legal regulations directly related to the architectural sector. It is absolutely necessary to ensure that architecture graduates are prepared to design in accordance with the extended acoustic requirements so that they do not need to look for additional training courses in this respect. The curriculum should be carefully adjusted to the practical aspect of acoustic design in order to meet architects' needs.

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