Noise control by design: A tool intended for architectural use

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ABSTRACT

This study aims to present a building elements selection tool, which has been generated to assist architects with determination of acoustically appropriate assemblies at the preliminary design stage. In order to succeed, practicality, easy usage and reliability are considered essential for every step. In this context a catalogue and a calculator are generated as components of the tool.

The catalogue constitutes a database in which building elements are subcategorized according to their constructional and acoustical characteristics. Acoustical measurement results of 587 different assemblies are collected from relevant literature and their technical drawings are prepared in order to provide easy selection. The calculator serves to simplify the calculations by giving the sound insulation requirement according to outdoor noise levels and acceptable background noise levels. The calculator also determines composite (average) sound insulation value of building elements composed of multiple components. Background noise criteria and data from the catalogue are predefined in the calculator, simplifying data insertion and parallel usage of the catalogue and the calculator.

In order to prove efficiency and practicality of the building elements selection tool, its usability by architects is tested on subjects with a sample design problem and outcomes are discussed.

Keywords: Building, Elements, Noise   I-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

Architects are responsible for creating livable environments and among many other aspects, they also need to consider acoustical environment that they are offering the users. By using correct design strategies and careful selection of building elements at the preliminary design stage, it is possible to obtain efficient results in acoustical design. However, noise control is a subprocess of design that is generally left unnoticed. Main reason is that the design process has a complicated nature with many inputs and usually it is restricted by time and budget limits. This circumstance underlines the need for simple design methods to facilitate integration of acoustical theory into design routines. For this purpose a building elements selection tool is prepared to encourage consideration of acoustical design in the preliminary design stage and to enable easy selection of acoustically appropriate building elements. The building elements selection tool consists of a catalogue and a calculator (1).

The catalogue is prepared in order to give easy access to acoustical data of typical assemblies and to make comparisons among each other. By using the catalogue an architect is expected to select assemblies that may satisfy the sound insulation requirement. However it is only possible if the sound insulation requirement is already known. Therefore a calculator is prepared in order to facilitate calculations that may be necessary while designing a building. The calculator is primarily designed to give sound insulation requirements of building elements and secondly, it is used to calculate the composite sound insulation values of building elements that consist of different components (e.g. a wall containing a window).

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2. METHODOLOGY

2.1 Catalogue

In order to prepare a catalogue relevant literature is reviewed and similar studies are analyzed. A classification system is found necessary in order to divide the data in groups and enable easier selection. Existing classification systems for building elements and their compatibilities with alteration of acoustical properties are analyzed. The classification system of the catalogue needs to represent both constructional and acoustical characteristics of building elements and collect the ones with similar characteristics under the same group.

Secondly, acoustical measurement results for various assemblies and materials are derived from relevant resources. Literature, online sources and different laboratory test results are selected predominantly from 1994–2011. A couple of selected literature which contains large variety of sound insulation data is given in the reference list (2-8). For all accessed sources, verifiability and sufficiency of definition are sought. The amount of provided information about assembly details and material features affects the accuracy of the numerical data representing the sound insulation. Therefore results are eliminated if explanatory data are found insufficient. The catalogue is meant to be neutral, so acoustical measurement results offered by specific companies or those of a specific product are excluded if they are not required for the integrity of the catalogue. Acoustical data that are derived from calculations instead of acoustical measurements are also left outside of this study.

Thirdly, compiling such data requires a new catalogue format. For this purpose, the existing studies are examined. Similar catalogue studies can usually be found as singular chapters in several books. Many of these are formatted as lists of verbal definitions of building elements and corresponding numerical values while some others are designed to serve practical use by involving technical drawings and only single number ratings of assemblies. For the new catalogue, usage of both systematic approaches is aimed in order to attain more comprehensiveness and intelligibility.

2.2 Calculator

The calculator is expected to give sound insulation requirements and average insulation values for building elements with different components. Existing programs and studies for sound insulation calculations are researched and their usability by architects is evaluated. Main consideration has been to simplify and facilitate the calculation process for architects.

For settling the criteria for acceptable background noise levels, noise rating systems and criteria curves are researched. Background noise criteria curves and their accepted values for different space functions are collected from relevant literature.

For the calculations, methods proposed in ISO 717-1 (9) and EN-12354-3 (10) are followed. R_w single number rating system is used as the main evaluation criteria and C, C_{tr} values are also calculated. The calculations are made in 1/1 octave frequency band.

2.3 Application

In order to prove efficiency and practicality, the building elements selection tool is tested on architects. The experimental setup is built in accordance with the design process monitoring methods explained by Yeomans (11). The experiment consists of monitoring of architects solving a design problem in using the building elements selection tool. The results are evaluated in the light of surveys, records, and solutions of the design problem offered by each subject.

3. THE BUILDING ELEMENTS SELECTION TOOL

3.1 Catalogue

The catalogue involves 587 different building elements' acoustical measurement results derived from various resources. These data required division into categories according to a classification system in order to facilitate selection. Before building a classification system, another catalogue study from California Department of Health Services is examined (4). Similar to this study, a hierarchical classification system is planned considering building elements constructional characteristics that also determine their acoustical characteristics. Building elements are divided in groups in 4 steps. They are primarily categorized according to their function and later subcategorized according to their construction type, core material and structural continuity (Fig.1).

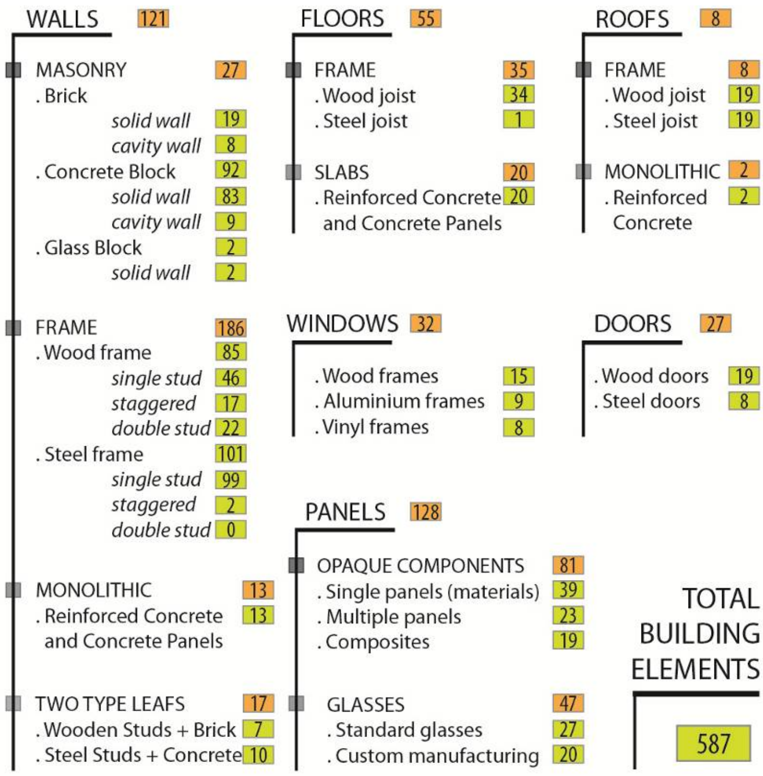
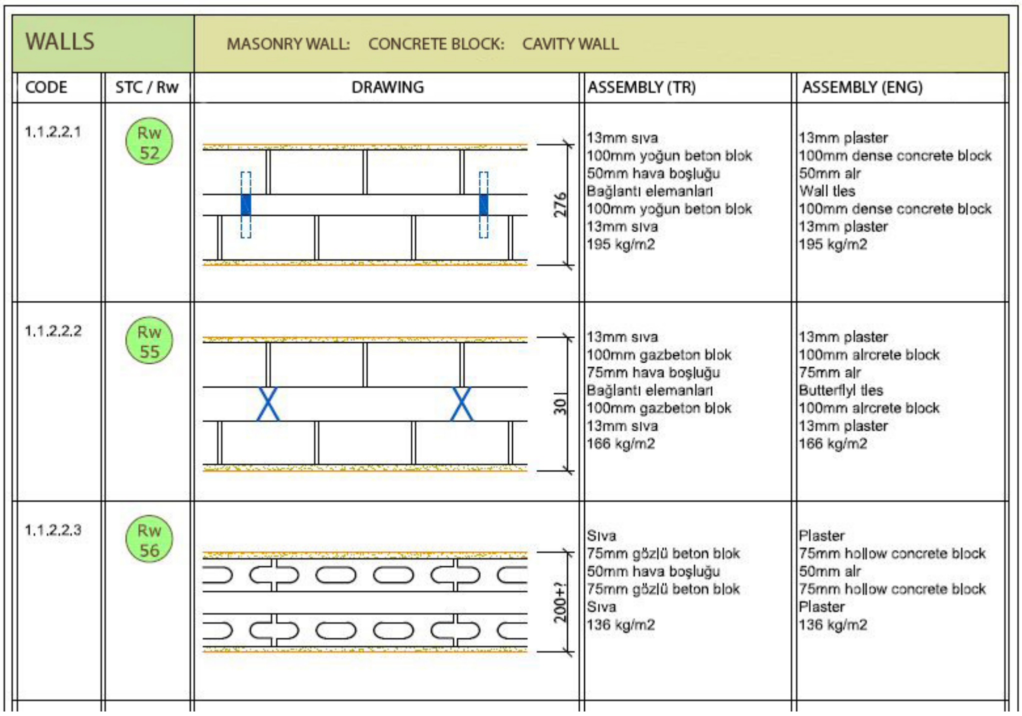


Figure 1 – The classification system and the distribution of the assemblies according to categories.

The catalogue consists of 2 parts. In the first part acoustical data are given only in single number ratings and they are accompanied by explanatory technical drawings (Fig.2). The technical drawings are prepared following the verbal expressions of assemblies or by reformatting the existing drawings if available. The first part format is kept simple to provide speed and practicality.



WALLS		MASONRY WALL: CONCRETE BLOCK: CAVITY WALL		
CODE	STC / Rw	DRAWING	ASSEMBLY (TR)	ASSEMBLY (ENG)
1.1.2.2.1	Rw 52	276	13mm sıva 100mm yoğun beton blok 50mm hava boşluğu Bağlantı elemanları 100mm yoğun beton blok 13mm sıva 195 kg/m2	13mm plaster 100mm dense concrete block 50mm air Wall ties 100mm dense concrete block 13mm plaster 195 kg/m2
1.1.2.2.2	Rw 55	301	13mm sıva 100mm gazbeton blok 75mm hava boşluğu Bağlantı elemanları 100mm gazbeton blok 13mm sıva 166 kg/m2	13mm plaster 100mm aircrete block 75mm air Butterfly ties 100mm aircrete block 13mm plaster 166 kg/m2
1.1.2.2.3	Rw 56	200+?	Sıva 75mm gözlü beton blok 50mm hava boşluğu 75mm gözlü beton blok Sıva 136 kg/m2	Plaster 75mm hollow concrete block 50mm air 75mm hollow concrete block Plaster 136 kg/m2

Figure 2 – First part of the catalogue which contains drawings.

The second part contains explanations about assemblies, the acoustical data in 1/3 octave band frequencies, single number ratings and laboratory names (Fig.3). Some original resources used STC values to express building elements acoustical performance while some others used R_w. To enable

CODE NUMBER
ASSEMBLY (TR)
ASSEMBLY (ENG)
VALUES FROM THE RESOURCE
VALUES DERIVED FROM CALCULATIONS
VALUES FROM THE RESOURCE
REFERENCES
LABORATORY

1	DUVARLAR	WALLS																											
1.1	ÖRME DUVARLAR	MASONRY WALLS																											
1.1.1	o Tuğla duvarlar	o Brick walls																											
1.1.1.1	• Tek gövdeli duvarlar	• Solid walls																											
			STC	Rw	STC hesap	Rw 1/3 oktav	Rw 1/1 oktav	(C,Ctr) 1/3 oktav	(C,Ctr) 1/1 oktav	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	8 kHz	Ref.	Lab
1.1.1.1	Standart UK tuğlası (102.5 x 65 x 215 mm)	Standard house brick unrendered	28		-	-	-	-	-																			[95]	
1.1.1.2	90mm boşluklu tuğla, bir tarafta sıva ile, 75 kg/m2	90mm hollow clay blocks, plaster one side, 75kg/m2		35	-	-	35	-	(-1,-2)		30			33			32			33			37			41		[9]	
1.1.1.3	90mm tuğla	90mm terracotta		35	-	-	35	-	(-1,-3)		26			26			30			35			40			41		[9]	
1.1.1.4	89 x 122 x294 mm taşıyıcı tuğla, 109 kg/m2	4-in. Structural Clay Tile dimensions: 3-9/16 by 4-7/8 by 11-3/4 in Wall thickness: 3-9/16 in. Average weight: 22.3 psf	39		39	39	39	(-1,-4)	(-1,-4)	28	27	28	30	31	31	31	34	36	38	39	40	43	48	51	53	52	50	[92]	RAL
1.1.1.5	114mm duvar: her iki yüzeyi sıva kaplanmış tuğla (12+90+12mm)	terracotta plastered both sides (114mm)		39	-	-	39	-	(-1,-3)		32			30			33			40			49			54		[9]	
1.1.1.6	89 x 122 x294 mm taşıyıcı tuğla, bir tarafında 15mm alçı sıva, 124 kg/m2	4 in. Structural Clay Tile Wall, with 5/8-in. plaster one face dimensions: 3-9/16 by 4-7/8 by 11-3/4 in. Wall thickness: 4-3/16 in. Average weight: 25.3 psf	41		41	41	41	(-1,-3)	(-1,-3)	30	31	30	32	32	33	34	36	38	41	42	43	45	49	52	54	53	51	[92] [91]	RAL
1.1.1.7	191 x 122 x 294 mm taşıyıcı tuğla, 199 kg/m2	8-in. Structural Clay Tile Wall dimensions: 7-5/8 by 4-7/8 by 11-3/4 in. Wall thickness: 7-5/8 in. Average weight: 40.6 psf	45		45	45	45	(-1,-4)	(-1,-4)	33	33	32	33	37	36	38	39	43	44	45	47	49	52	55	53	50	55	[92] [91]	RAL
1.1.1.8	56 x 94 x 206 mm cephe tuğlası, 189 kg/m2	4-in. Face Brick Wall dimensions: 2-1/4 by 3-3/4 by 8-1/4 in. Wall thickness: 3-3/4 in. Average weight: 38.7 psf	45		45	45	45	(-2,-5)	(-1,-5)	32	32	31	32	34	35	37	40	43	45	47	49	53	55	57	59	61	63	[92] [91] [9]	RAL

Figure 3 – Second part of the catalogue which is in table format.

selection according to different criteria the single number ratings (STC, R_w, C, C_{tr} values) are calculated for those building elements whose sound insulation values were also given in 1/1 octave frequency band. The calculations are made in accordance with ISO 717-1 (9) and ASTM 413-10 (12). The second part is more concerned with the verbal definitions and acoustical data. Detailed explanations that can't be illustrated in the first part are to be found in the second part of the catalogue.

In both parts, assemblies are defined both in Turkish and in English as well as dimensions are given in both metric and imperial units to avoid fallaciousness resulting from translation and interpretation. Due to its graphical expressions the first part of the catalogue enables practical search of appropriate building elements and comparison of different assemblies. On the other hand, the second part of the catalogue which is in table format should be preferred for examination of further explanations about characteristics including detailed acoustical data. Label numbers assigned to each assembly facilitates use of two parts in unison.

It is also possible to quest information by using the digital catalogue. In order to facilitate quest by different characteristics, filtering options are offered in a spread sheet. Here, building elements' constructional and acoustical characteristics are divided into columns. 16 filtering options are as it follows: *total thickness (mm), building elements function, construction type, core material, structural continuity, core thickness (mm), aperture between studs (mm), width of airspace (mm), presence of insulation (yes/no), insulation thickness (mm), presence of resilient connection (yes/no), number of plates (single/multiple), number of plates at 1st side, number of plates at 2nd side, symmetry (symmetrical/asymmetrical), surface density (kg/m2), STC derived from resource, Rw derived from resource, STC calculated, R_w calculated at 1/3 octave band, R_w calculated at 1/1 octave band, C / C_{tr} calculated at 1/3 octave band, C / C_{tr} calculated at 1/1 octave band.*

3.2 Calculator

Calculations required to determine the sound insulation requirement are too complicated for architects to involve in the design. In order to bring practicality to these calculations a calculator is prepared as the second stage of the building elements selection tool. Various macros are prepared in order to get results from Excel spread sheet.

The calculator's primary tab serves to give the sound insulation requirement by comparing the outdoor noise levels and acceptable background noise levels (Fig.4). Acceptable background noise levels are predefined in the calculator as NCB, NC, NR and RC curves. The R_w and C, C_{tr} results are given by extraction of values at 1/1 octave band frequencies.

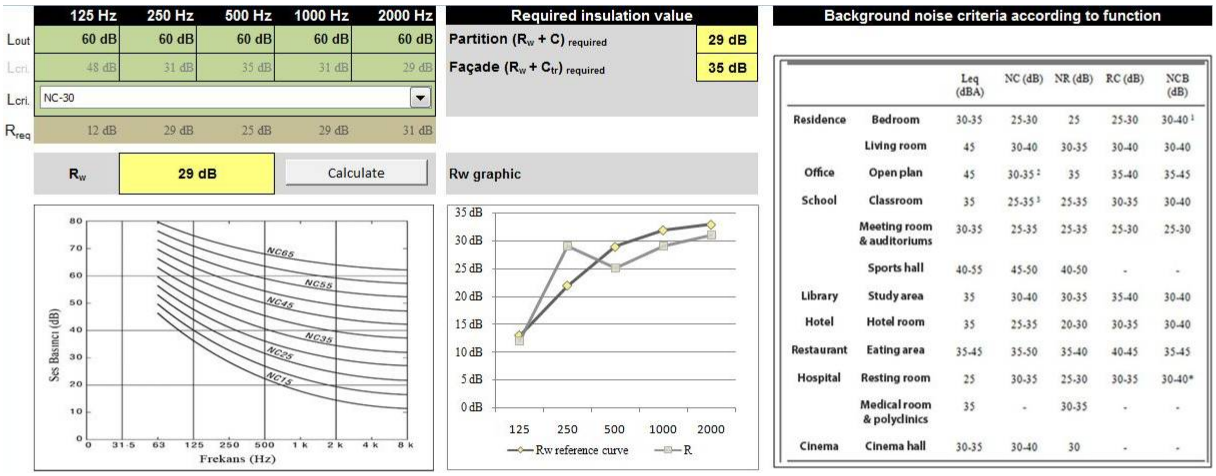


Figure 4 – First tab of the calculator is used for determining sound insulation requirement.

If the building element consists of more than one component its composite sound insulation value needs to be calculated. The calculator's second tab serves to calculate composite R_w and C, C_{tr} values for building elements that consists of up to 5 different components (Fig.5). The data from catalogue are predefined in the calculator so it allows selection of different wall, window and door assemblies from menu. The classification system is also applied to calculator in order to facilitate selection from menu. Selection steps are as it follows: *building element's function, construction type, core material, core number.* If the components sound insulation values at 5 frequencies are known by the user, it is possible entering the data directly in relevant fields. The results are automatically compared with the required sound insulation values calculated in the first tab; and user is informed if the selection is satisfactory.

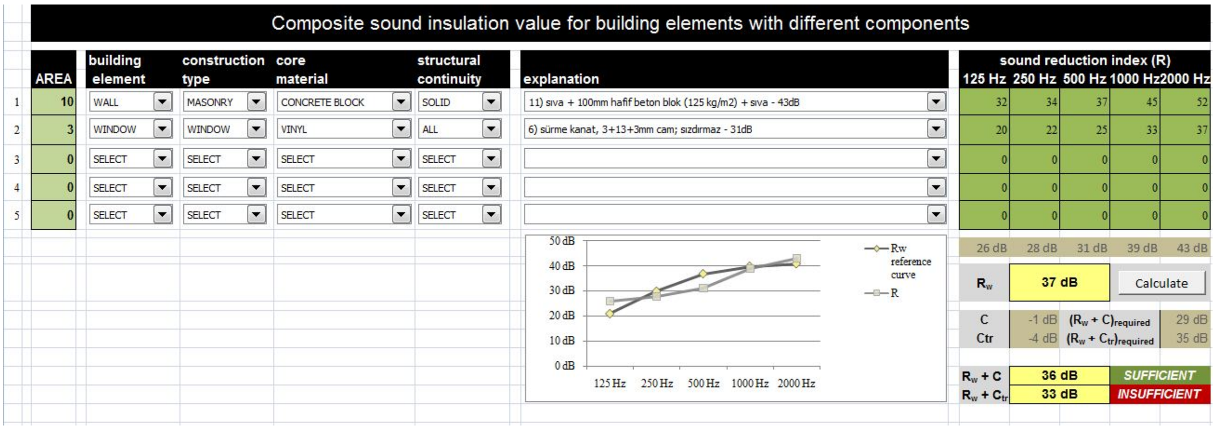


Figure 5 – Second tab of the calculator is used for determining composite sound insulation value.

4. APPLICATION OF THE TOOL

4.1 The experimental process

The usability of the building elements selection tool is tested on 5 subjects. The subjects are introduced with a sample design problem and they are expected to solve it by using the tool.

Initially, a design problem is settled and the documents are prepared to present to the subjects during the test. The design problem is selected as a hotel room façade, facing a main street with dense traffic. The noise levels of the site and dimensions for wall and window of a typical room are given in a flyer along with some other explanatory drawings (Fig.6).

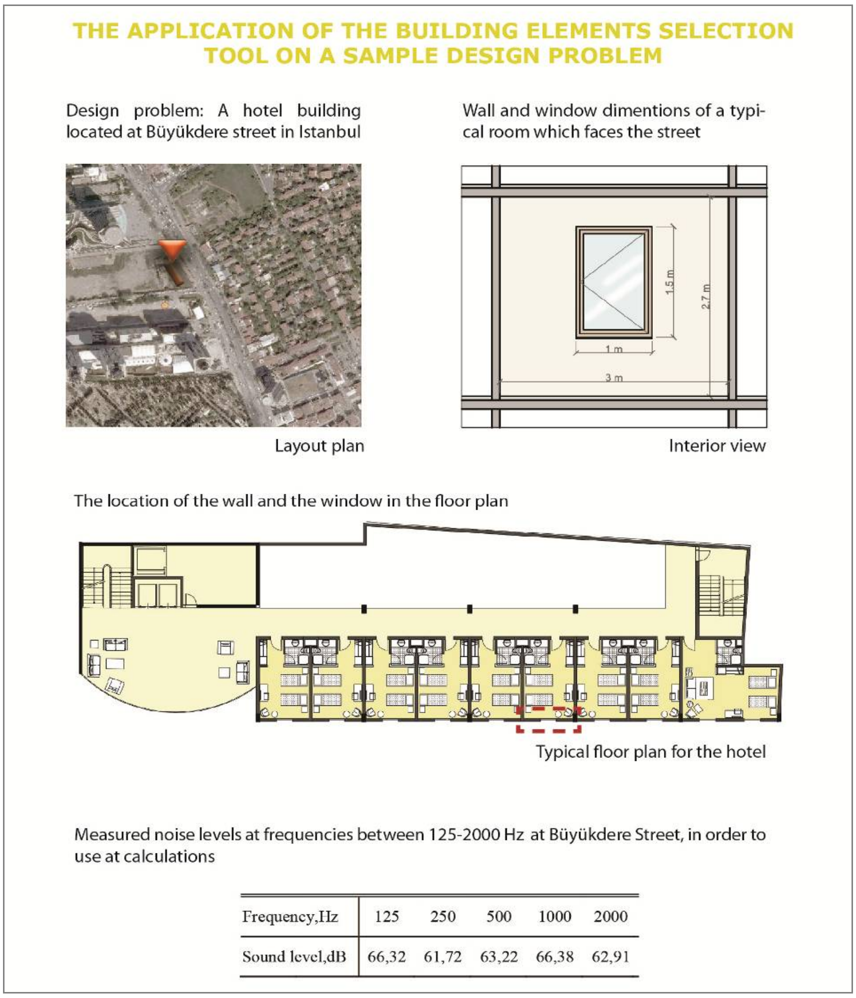


Figure 6 – The flyer introducing the design problem.

A brochure is prepared in which, the design steps are defined first, and followed by necessary explanations for the use of the calculator and the catalogue (Fig.7). The brochure is kept concise in particular and limited to 3 pages. Lastly, a survey is prepared to analyze architects prospects about the test process, the building elements selection tool and its application.

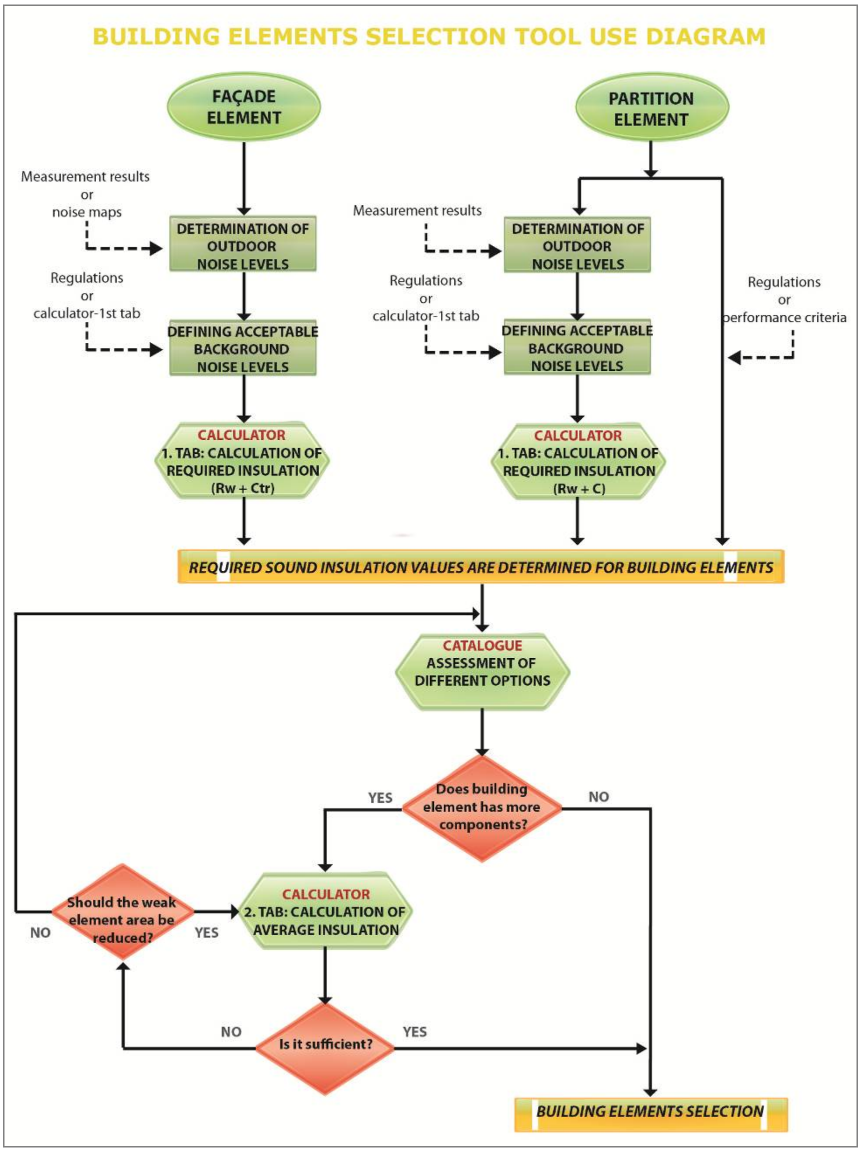


Figure 7 – The design steps, presented in the brochure.

Variables are minimized by selecting subjects with similar backgrounds and realizing the tests in similar environments. All of the subjects are graduated with a bachelor's degree in architecture and they have not completed any post graduate studies. The subjects have 3 to 4 years of architectural office experience and all of them have worked both in concept projects and construction projects. The subjects have little or no experience in acoustical design.

Before they start, the subjects are informed briefly about the purpose of the study, design problem, design steps and the interface of the calculator. The subjects are asked to select a wall and a window assembly by using the building elements selection tool and to meet the sound insulation requirement for the hotel room. The brochure is handed to them containing design steps they must follow. They are asked to read the brochure and later follow the design steps. They are advised from the start to either change the window or the wall selection, or to reduce the surface area of the window, hence to improve the composite sound insulation value if the composite R_w+C_{tr} value stays below the sound insulation requirement.

The experiments are realized in office environment. The test processes are sound recorded. Upon finalizing, the subjects are asked to fill the survey.

4.2 Results

All subjects have failed to meet NCB 35 with their first choices. Their first treatments have been to improve the window, and if not yet accomplished, they have also improved the wall. All subjects have determined final assemblies in 3 or less trials except for one who had set lower criteria for background noise levels (NCB30). In that case the subject has also reduced the window area and has met the criteria at 6 trials. Subjects have made their first choices on architectural preferences but upon failure they have also earned acoustical concern and analyzed assemblies more carefully with this aspect. Each experiment has taken approximately 15 minutes to complete; 5 minutes for oral explanation and reading, 10 minutes for application. It has been observed that subjects have wasted more time on understanding how to use the calculator, but once it has been understood, they have been able to use it with more practicality.

The surveys have shown that while the building elements selection tool has been found very useful and practical, intelligibility has slightly dropped in use of the calculator. Some subjects have suggested that the intelligibility can be raised by improving the interface. The catalogue has been found comprehensive and intelligible, and the selections that had been made with the aid of the tool have been found more reliable than intuitive selections of building elements.

On the other hand, when the subjects have been asked if they consider acoustics on daily life projects, some of the answers have shown that mostly standard details are being used for any type of building and no further discussions are made on acoustics. Later, they have been questioned about how they would solve this design problem without the tool and 3 of them have responded that an acoustical consultant would be necessary while 2 others responded that they would try to determine it by calculations or with pre-teachings yet they would doubt the results.

The tests have shown that the sample hotel room façade would not block the street noise if the assemblies had been selected without acoustical consideration. This clearly indicates the importance of architects' awareness on acoustics. It is observed in the tests that subjects pay more attention on acoustical characteristics of assemblies after realizing that their first selections are unfavorable. Besides improving the design, using this kind of design aid can also be beneficial for raising architects' awareness on the subject. The time required for application of the building elements selection tool was short (approx. 10 min.) even though most of the time was spent on comprehending the calculator. Thus, the application is expected to be even faster in second and later uses. The handicaps of the calculator interface are determined and further studies will be realized for increasing its intelligibility.

As also observed in the test results, most of the architects leave acoustics out of the design process and they believe that acoustical consultant is the answer when the subject gets inevitable. However, the architects must be conscious of that they must also play an active role on acoustical design by analyzing the environmental factors and user requirements carefully and by supporting it with their design decisions starting from early stages of the project.

5. CONCLUSIONS

Noise control should be supported by building design to obtain more efficient results in meeting user requirements. This requires architects sensibility and acousticians hard work to search for a common language. A building elements selection tool is generated with this intend, in order to support selection of building elements which meet the acoustical requirements. Since the tool addresses architects at the preliminary design stage; easy usage, intelligibility and practicality are aimed. A catalogue and a calculator constitute the building elements selection tool. The catalogue provides easy access to acoustical data and enables easy comprehension of the assembly by offering technical drawings. The calculator, on the other hand, gives the sound insulation requirement in its first tab and composite sound insulation value in its second tab. Input entry is reduced by predetermining necessary information in the calculator. The catalogue data are also introduced in the calculator and this provides parallel usage of two outcomes of this study.

The building elements selection tool is tested on 5 architects and the results are discussed. Experiments have shown that the architects can obtain results from the tool in a fairly short time despite their hesitation while using the program for the first time. The subjects have found the tool beneficial and practical, yet they also advised some improvements on calculators interface in order to increase its intelligibility. Further studies will be conducted to analyze and improve the usability of the building elements selection tool.

In response to the importance of architectural engineering, this study suggests that noise can be controlled to an acceptable level, before the acoustician's intervention, if it is included in the design strategy. Using this type of design tools can accelerate adaptation of noise control in the project and it can raise awareness among architects.

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