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AUTOMATED EN 12354 CALCULATIONS OF ENTIRE BUILDINGS: SONARCHITECT ISO

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Abstract

Building designers are currently subjected to strict requirements on acoustic insulation. These requirements usually stem from local Building Codes. A traditional approach to the assessment of the acoustic insulation compliance of a building is to assume that a few pairs of rooms can be located that represent the worst performance in the building. The selection of the critical pairs usually relies on the acoustic expertise of the designer. Then, typically, software tools that analyze the behavior of a pair of rooms according to a set of more or less flexible typologies are used to assess the acoustic performance of the selected pairs, which acts then as an indicator of the compliance of the entire building. This is far from trivial, and complex geometries are often encountered which hinder the intuition of the designer, and also the reliability of conventional tools. Moreover, the critical pairs, if correctly chosen and modeled, could suffice to assess the compliance of the building, but do not provide information on the overall acoustic performance of the building. We present a new design tool allowing the computation of EN 12354 in the entire building, taking into account every room in the building, allowing any regular geometry, and reporting the acoustic performance of the entire building. This tool helps to allocate those critical rooms, so it also helps with the acoustic measurements needed to verify the legal requirements. Besides, it opens the way for a sound insulation quality classification scheme for entire buildings.

Keywords: EN 12354, acoustic insulation prediction, acoustic quality.

1 Introduction

In the last decade, new building regulations have been specified throughout Europe to ensure a better acoustical comfort in dwellings. To achieve that, regulations specify sound insulation requirements that should be fulfilled from building design, according to the EN ISO 12354 family [7], to prospective measurements. As stated by Rasmussen [3], “to meet specific sound insulation requirements efficiently and effectively, appropriate design tools are important, and there should be a high correlation between construction data, the predicted sound (designed) sound insulation, the measured sound insulation in the finished building and the occupants' evaluation".

The correlation between measurements and the subjective evaluation of sound insulation has been thoroughly analysed in an study carried out in 1998/99 at the Technical University of Denmark [12, 13]. The study found a good correlation between measured A-weighted level and perceived loudness. The annoyance slope ranged from 4% to 6% per dB(A) depending on the type of noise, resulting in a mean slope of approximately 4% per dB(A) in the middle part of the regression line [8].

The correlation between predicted and measured sound insulation has led to a heated debate in the community, divided between the need for accuracy and the urgent necessity of a method to compute sound insulation in buildings. Statistical energy analysis (SEA), which is under the EN ISO 12354 specification, provides simple algebraic relations that enable us to compute sound insulation. However, besides the fact that SEA, in its present form, is applicable only to weakly coupled systems, the uncertainty in the coupling loss factor (CLF) of the elements in actual buildings (which are rarely homogeneous and isotropic) may lead to important divergences. It seems unlikely that a solution will arise soon that will convince everyone, whether it comes from an improvement of the current SEA or, maybe, from numerical computation of the entire building.

However there is still work to do in the mere application of EN ISO 12354 to real buildings, regarding the need of appropriate design tools noticed by Rasmusen [3].

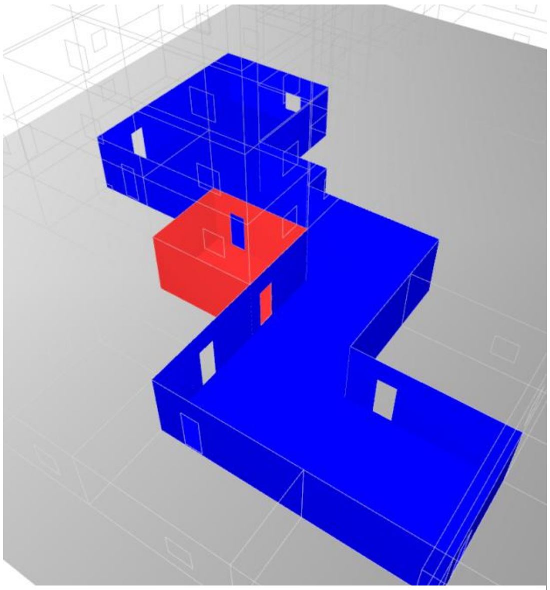

Figure 1 Geometry of a pair of rooms in a real building from SONarchitect ISO software

Consider the geometry shown in Figure 1: Two rooms with two separating walls. With conventional tools both rooms must be approximated through rectangular boxes and it must be assumed that the two separating walls are just one. This assumption implies important deviations in the computation of the structural reverberation time of the separating elements T_{situ} and of the equivalent absorption length,

$$a_{situ} = \frac{2.2\,\pi^2 S}{c_0\,T_S}\sqrt{\frac{f_{ref}}{f}}, \qquad (1)$$

needed to obtain the in situ values. In addition the rectangular box approximation will need of special care to preserve the area of the modified flanking walls, floor, and ceiling, in order to keep unaltered their respective in situ sound reduction index. In the case of U-shaped or L-shaped vertical enclosures, the rectangular box assumption is simply not possible. It must be remarked that these are not limitations of the EN ISO 12354 standard, which is clear about how to compute the flanking transmission whatever the number of flanks, but of the geometrical limitations of the usual tools, constrained to a rectangular box approximation.

Another common source of error came from the impracticability of computing each and every pair of rooms in a building. In Figure 2, a 3D model of an actual hospital (with 1 256 enclosures) built in Bilbao (Spain) is shown. To fully compute the sound insulation between every pair of rooms, 5 209 computations of airborne sound insulation and 6 035 computations of impact sound insulation are needed. This is beyond the capabilities of conventional tools, and, as a consequence, the acoustic consultants were forced to choose pairs of rooms supposed to represent the 'worst cases'.

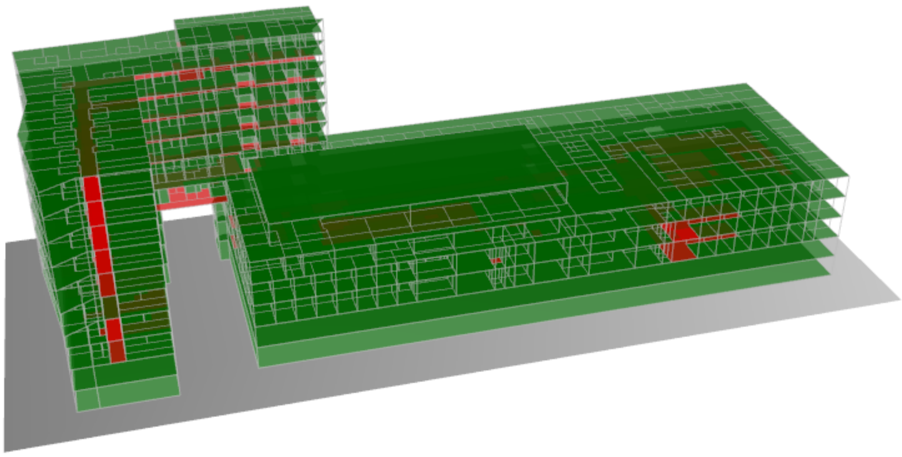

Figure 2 - 3D model of a hospital in Bilbao, as modelled by SONarchitect ISO

However this task is far from evident, due to the huge variability in volumes, shapes, encounters, uses, and materials.

Rules of thumb such as "the smaller the volume, the worse" are not always safe, since the flanking transmission spreads the sound insulation result, leading to wide probability density functions and fuzzy limits. In Figure 3 the sound insulation histograms of Bilbao's hospital are shown, for the apparent sound reduction index (R'_w) and the normalized impact noise pressure level ($L'_{nT,w}$).

Even though the materials used in all rooms are nearly the same, the sparsity shown by the results in Figure 3 is notable. The airborne results show a clear bimodal density function, born from the different acoustic performance of vertical (from 54 dB to 68 dB) and horizontal (from 73 dB to 85 dB) separating elements. The impact sound results present a single mode, but with much greater deviation, ranging from 13 dB to 54 dB[1]. The 'worst cases' are those in the extreme bars of the airborne/impact histograms, 14 and 6 respectively. This yields 20 'worst cases' to verify against two requirements.

[1] Such high insulation values, such as R'_w=58 dB or $L'_{nT,w}$=13 dB, should not impress the reader, since acoustic insulation was computed for all separating walls and slabs, including those with very small area.

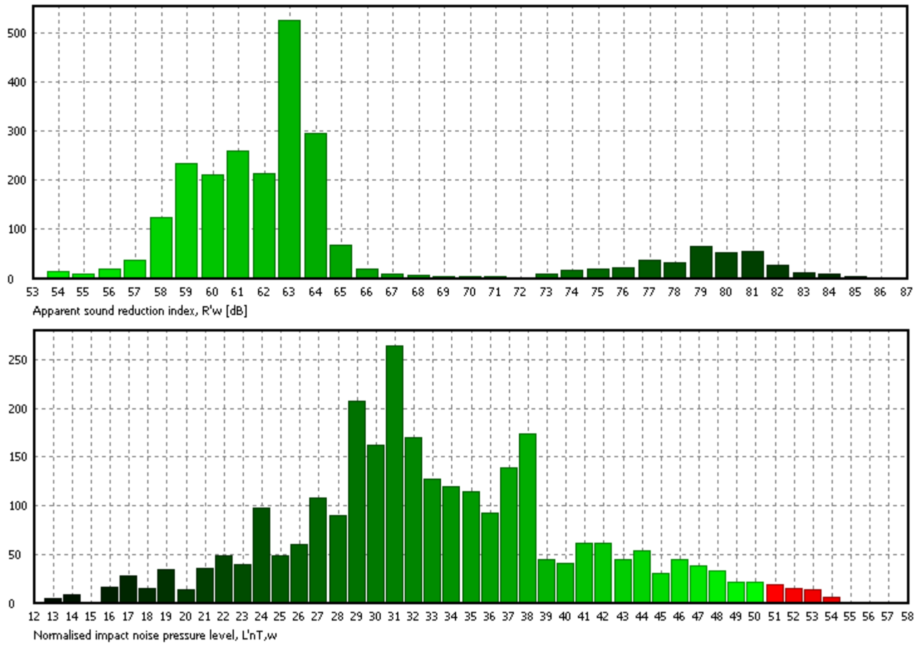

Figure 3 – Histograms of the insulation results of hospital in Bilbao, computed with SONarchitect ISO software

If more than two requirements must be checked (which is usually the case in European building codes) the number of 'worst cases' is multiplied, growing to 132 in the case of the Spanish regulation. In addition, if the cases in the adjacent bar were also checked, the number of 'worst cases' would grow up to several hundreds.

Of course, stepping from 11 244 cases down to 132 cases means a useful and appreciable simplification that a reliable acoustic consultant could perhaps provide, but, even then, there will never be guarantee that no one is missed, unless each and every case is computed.

In October 2009, a new design tool, SONarchitect ISO, was presented [14], enabling the computation of EN ISO 12354 in entire buildings, with no geometric restrictions, automatically checking the 100% of the pairs in the building. Validation studies were carried out, both in real buildings and against EN ISO 12354 examples, showing very good agreement. The computing time, in the order of seconds[2], makes it possible to optimise the design, increasing both the quality and the throughput, boosting the productivity, and establishing a new work flow for building acoustics consultancies or acoustic design studios.

In this paper, some features of this tool are reviewed, and new capabilities are presented, such as the built-in implementation of the classification schemes of Denmark, Finland, Iceland, Norway, Sweden, France, Germany, Lithuania, and The Netherlands, as well as an auralisation tool for subjective evaluation of the acoustic design of buildings, that will ease the understanding of some acoustic concepts by architects, civil engineers, and end users. The definition of an acoustic label is proposed, and the need of classification of entire dwellings is stressed. Classification of the whole building is also discussed.

[2] Computation time of Bilbao's hospital (11 244 cases) was 4.37 seconds in an Intel Core 2 Duo CPU E8200 @ 2.66 GHz machine with 2 GB RAM.

2 Automated computation of ISO12354: General Review

Sonarchitect ISO provides automatic computation of the sound insulation in a whole building for airborne and noise impact, outdoor noise, noise emission, and reverberation time, according to EN ISO 12354 parts 1, 2, 3, 4, and 6. Calculations are performed on plans with no geometric restrictions. The vibration reduction indices K_{ij} are automatically chosen according to the junction configuration and the element material. Results are provided in one-third octave values, and configurable requirements are automatically checked. Results can be inspected in the whole 3D building, enabling the optimization of the design, or printed together with the statistics of the whole building for submitting to the local authorities.

Metzen analyzes in [6] the impact on EN ISO 12354 calculations of the assumptions that an operator must make during the modeling process. As already stated, one of the main problems related to the use of traditional design tools was the difficulty to deal with complex geometries. The user was forced to approximate all geometries in a building by rectangular box shaped rooms, resulting in errors in the reverberation time computation T_{situ} and in the equivalent absorption length a_{situ}, when two or more separating elements exist between the pair of rooms. She was also forced to define and compute "equivalent rooms" taking special care of the modified flanking walls, floor and ceiling, to preserve their area and, thus, keep unaltered their respective in situ flanking sound reduction index $R_{ij,situ}$.

Some geometries, such as those shown in Figure 4, cannot be directly approximated through the rectangular box assumption. And even if a safe approximation is achieved through an equivalent pair of rectangular rooms, the computation of the equivalent areas will make that task extenuating.

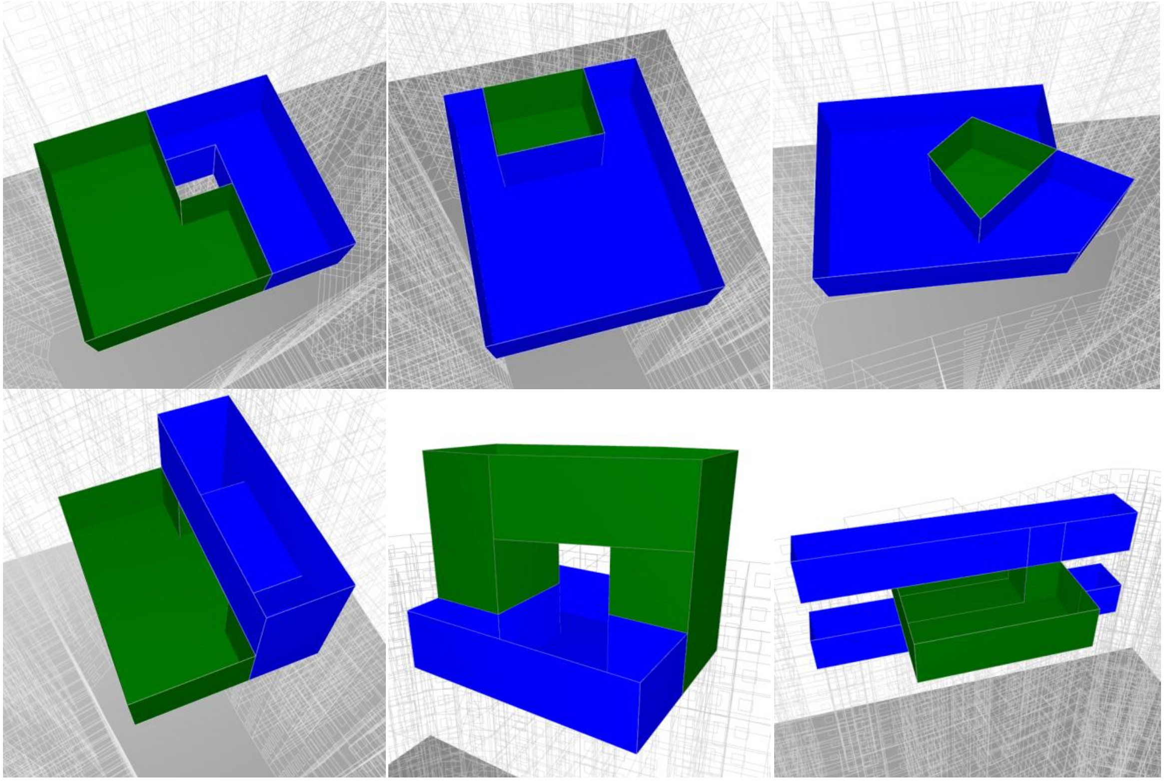

Figure 4 – Examples of cases which cannot be approximated through rectangular box shaped rooms

SONarchitect ISO computes the sound transmission through every separating element and pair of flanking elements, whatever they are, performing the summations of all transmissions coefficients from source to receiver.

The program includes basic drawing tools which allow inserting the geometry of the whole building. Tracing plans can be imported as ".dxf" files (drawing exchange format), see Figure 5, enabling to stick the drawn lines to the imported lines.

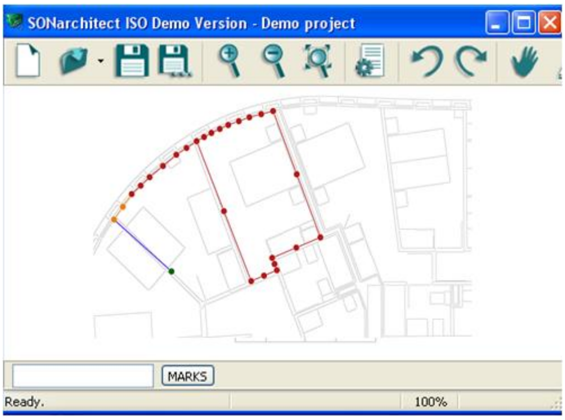

Figure 5 – Drawing process in SONarchitect ISO over the tracing plan

Using powerful geometric parsing technology, the enclosed volumes are automatically recognized, intersections detected, and encounters between floors resolved. The building definition can be done without any geometric restriction. 100% of the adjacency relations are solved at high speed.

The **Smart-2DJ ©** technology enables SONarchitect to automatically process the junction geometry and to select the appropriate vibration reduction index K_{ij} for each junction in the building. Contrary to conventional tools, in SONarchitect there is no need of specifying whether a junction is "T", "L", or "X-shaped", whether the elements are "light" or "solid", or whether the junction corresponds to a "light façade". All this information is already implicit in the geometry and the material specification, and Smart-2DJ technology is able to compute it for any junction geometry without user intervention. Some extensions of the model [10] are used for junctions which are not included in the EN ISO 12354-1 Appendix E, such as heavy double walls. New improved expressions are currently being developed using FEM calculations [11].

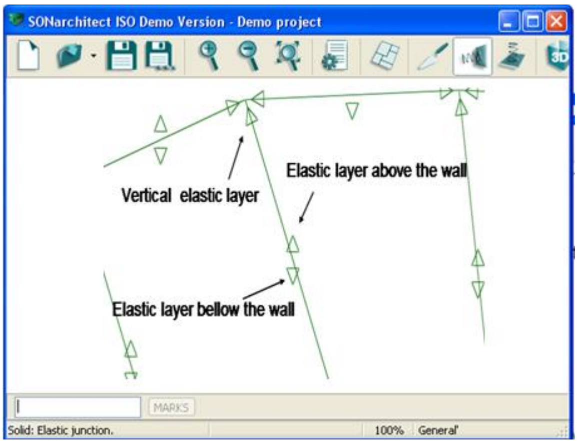

Figure 6 – JLANv1 interface implementation

In addition, if the user wants to place a resilient inter-layer between two elements, this can be easily done through the elastic junction configuration mode, see Figure 6, which implements the **JLAN** interface. New improvements are scheduled to be released in summer 2010, which will enable the definition of rigid connections between double walls in the special cases where it may be required.

Building materials are selected from a database, see Figure 7, with over 500 solutions from different European countries, manufacturers and classical references in the literature. The user can add new materials and custom solutions. Several tools are built in to help the user to define new customized materials, using the predicting formulas in Appendix B of EN ISO 12354-1, Appendix C of EN ISO 12354-2, and several mass laws such as Cremer's, London's, Josse-Lamure's, Price-Crocker's, Sewell's, Brekke's, and Arau's. The impedance method for multilayer media is also implemented.

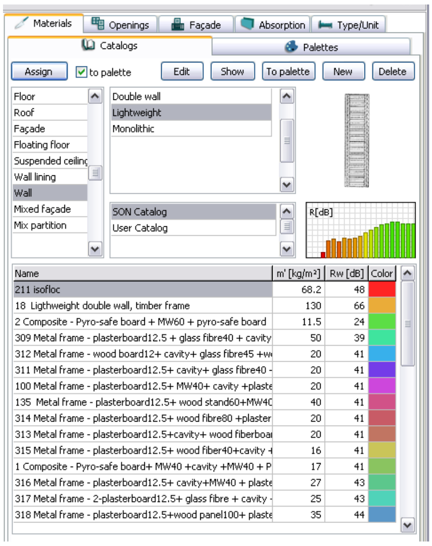

Figure 7 – SONarchitect database

Results are presented through a result tree, see Figure 8, showing at the same time the results in one-third octave bands and the location of the pair of rooms in the building. Every result in the tree, from the performance of each separating element to the contribution of each flanking path, can be conveniently examined. For each result, a record can be printed in pdf format.

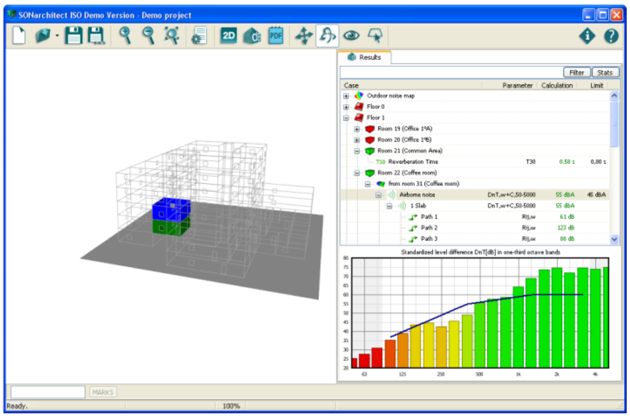

Figure 8 – SONarchitect 3D results inspection

Those pairs of rooms which do not fulfill the customizable requirements are represented in red. The program automatically detects which are the predominant transmission paths and marks them in red, if only one exists, or orange, if more than one is responsible of decreasing the acoustic insulation between the pair of rooms. Thus, the weakest path can be easily identified and acted upon.

The A-weighted sound pressure level noise map is calculated around the building according to EN ISO 12354-4 (see Figure 9), if the indoor sound pressure levels in the noisy rooms are specified. The total acoustic power radiated by each element (façade, slab, or cover) can be examined and reported.

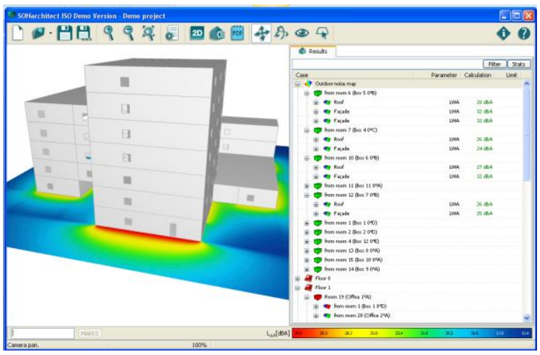

Figure 9 – Outdoor noise map according EN ISO12354-4:2000

Results are summarized in a configurable report, containing building statistics, histograms, selected requirements, a collection of calculation records, shown in Figure 10 (a customized selection or an automatic selection of the worst cases), the bill of quantities, and a compliance statement for the local authorities.

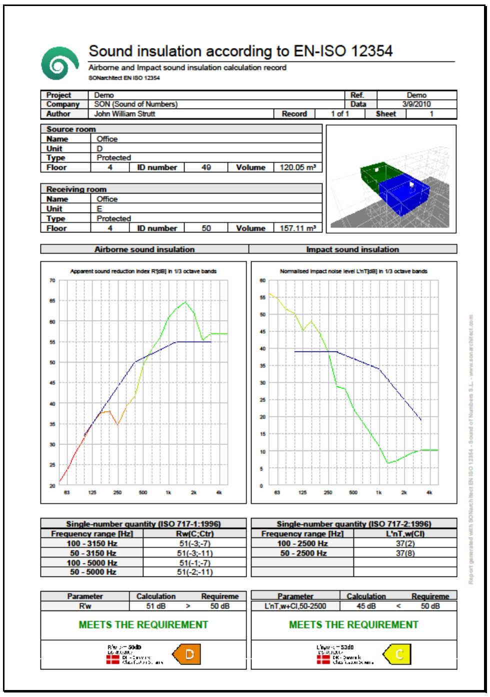

Figure 10 – Calculation Record

A new feature, available from release v1.0.58, is the auralisation of sound insulation results. This auralisation technique enables subjective evaluation of the acoustic design, as well as a better translation of the acoustic quantities to people less acquainted with acoustics such as architects, civil engineers, or building end users. Several sound files are provided to let the user evaluate the acoustic insulation experience with different types of noise sources.

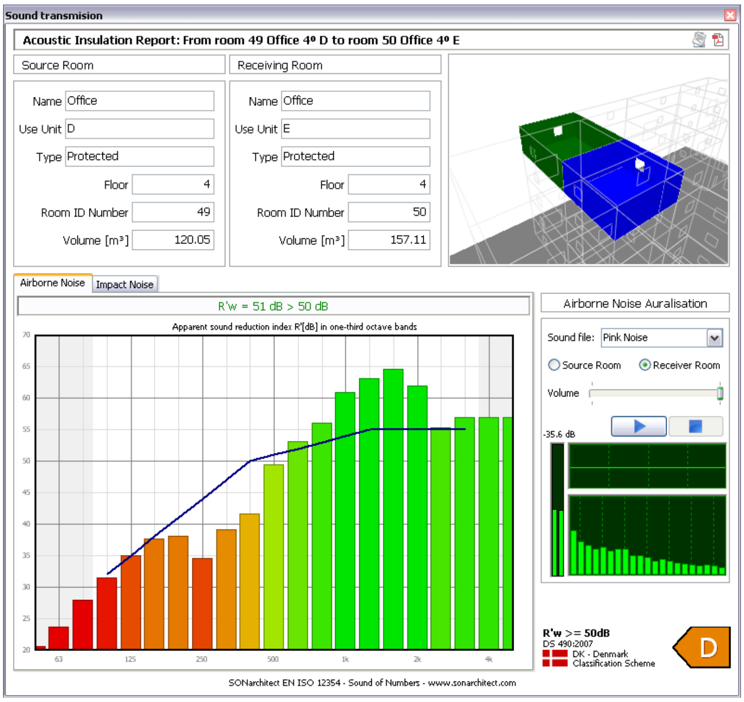

Figure 11 – Inspection of Results including the new features in v.1.0.58: acoustic label and auralisation interface.

3 Towards a general classification of buildings

Two main works [8,13] have contributed to the derivation of the dose-response functions, resulting in a mean slope of approximately 4% per dB(A), between 20% and 80% of annoyed persons. The laboratory experiment performed at the Technical University of Denmark [13] confirmed this quantity, although some variation was observed depending on the type of noise: CD music through a wall (airborne), a male walker (impact), and children playing (impact).

In our opinion, the slope of annoyance would present stronger variations if other types of common domestic noises were included in the evaluation, such as: bathroom noises, tonal noises from installations, instrument playing by beginners (instead of commercial music), or some kinds of impact sound produced in bedrooms. Even if those sounds are not present in all rooms of the dwelling, our subjectivity to them is so high that their mere presence could devaluate the acoustic comfort of the whole dwelling. Hence, for a better consecution of acoustic comfort, they should be constrained by stricter requirements, and managed from the early design stage. This has been already done indirectly in most building codes, by allowing less restrictive requirements between rooms of the same dwellings, or by increasing the requirements for sound insulation from installations room.

For the moment, typical requirements for acoustic insulation give satisfactory conditions for approximately 40 % of people [2], which means that national building regulations guarantee, at least, a minimum degree of acoustic comfort. But minimum is not enough.

By August 2009, nine European countries have already developed a sound classification scheme [3, 4]. They arose as a tool for increasing the acoustic comfort of dwellings, but also for optimization, since the same level of comfort can be provided at all the rooms in the same dwellings. In addition, many of the schemes are linked with building regulations, providing that the building code refers directly to a specific class in the scheme. This link simplifies considerably the application of the Building Code and powers the quality concept born from the classification scheme. In accordance with the results provided in[13], in some of them, the higher classes take into account the performance at low frequencies, using the spectral adaptation terms with extended frequency range down to 50 Hz.

Classification schemes do apply on pair of rooms. The problem of going from the small to the large still remains. How to classify rooms? How to classify dwellings or even buildings? Is there any interest for doing that?

Acoustic classification schemes are useful as a simplification for the public. We can see the successful implementation of a similar scheme in the energy efficiency classification scheme. Everybody understands that class A is better than class B, and that the leap from B to A must be relatively equal to the leap from C to B, without getting into the electrical details. It means also a significant simplification for regulators, which can settle the requirements in terms of a more abstract concept such as “class”. Therefore, classification is interesting indeed, because final users are more comfortable with concepts such as “this room is class A” or “this dwelling is class B” than with acoustic quantities. Hence, user-wise, we should take the classification up to dwelling level.

The question of building classification, on the other hand, is not that important for final users, but for the building contractor or, may be, for regulators. It does not seem incompatible to have in the same buildings dwellings belonging to different classes, as it is likely that some users may be willing to pay a little more than others for a better acoustic comfort.

In quality assessment, the quality of the weakest link defines the quality of the entire chain. Thus, the class of a room must be defined by the minimum insulation result from all adjacent rooms. Regardless of whether a given room belongs to class A against the 90% of the adjacent rooms, the user will be equally annoyed if just one of the results is class D. Analogously, the class of the dwelling must also be defined by the class of the weakest room. Another question, still to be addressed is the different human subjectivity to different kinds of noise, which will need, perhaps, of redefining the classes in terms of the use of the source room.

But if a room belongs to a given class, should it mean that all rooms in the dwelling belong to the same class? In addition, all dwellings in a building will belong to the same class, just if one of them belongs to a given class? These questions are partially answered by the histogram shown in Figure 3. The sparsity in the results reveals that little extrapolation can be made, and hence, for correct classification, all pairs must be analyzed. Of course, if all floors in a building are identical the results could be extrapolated, but there will be still three floors that must be totally computed: the first (just on top of the lower floor), the last (just below the roof), and the inner floor. If there are variations between floors (not matching plans), or in the case of considering a different incident noise to the façade, all floors must be computed.

For a better translation of the results of the acoustic classification scheme, an acoustic label is proposed, mirroring the energy efficiency labels (see Figure 12).

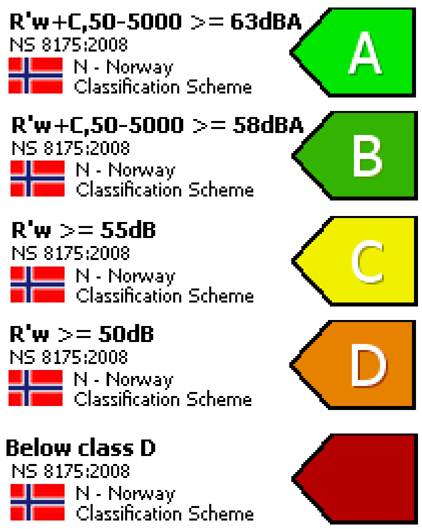

Figure 12 – Acoustic label proposal

The label contains the result of the classification scheme, in the same fashion as in energy efficiency labels, together with the acoustic requirement fulfilled and the identification of the national classification scheme, since no harmonized scheme exists yet.

The acoustic labels mean a comprehensible way of transmitting what level of acoustic comfort the user would expect from his dwelling. Each room may have an acoustic label, as well as each dwelling. The classification may be performed even backwards, labeling the building materials which, for given geometric and construction conditions, resulted in a certain sound insulation class. This will enable to label the whole process of building, from the materials, to the acoustic design, and in-situ measurement, enhancing the quality chain of the building process.

4 Conclusions

Some features of SONarchitect ISO have been reviewed, and new capabilities presented, such as the implementation of the classification schemes or the auralisation tool for subjective evaluation of the sound insulation. Some aspects about the sound classification of rooms, dwellings, and buildings have been discussed. The definition of an acoustic label was proposed to enhance the quality control of the building process, from manufacturer to final user.

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