Final Report

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Abbreviations

Abbreviation	Meaning
ACAI	Associazione Costruttori Acciaio Italiani
AIT	Austrian Institute of Technology (formerly named ARSENAL up to the 31st of December 2011)
AFNOR	Association Française de Normalisation
A-Tech	Acoustic Technologies
BASt	Berichte der Bundesanstalt für Straßenwesen
BEM	Boundary Element Model
CEN	Comité européen de normalisation – European Committee for Standardization
CIDAUT	Fundación CIDAUT
CSTB	Centre Scientifique et Technique du Bâtiment
D	Deliverable
DoW	Description of Work
EC	European Commission
EN	European Norm
ENBF	European Noise Barrier Federation
ERF	European Union Road Federation
EU	European Union
FDTD	Finite Different Time Domain
FP	Framework Programme
IRF	International Road Federation
LRPC	Laboratoire de Recherche des Ponts et Chaussées
M	Month(s)
NF	Norme Française
HOSANNA	Holistic and Sustainable Abatement of Noise by optimized combinations of Natural and Artificial means
NRD	Noise Reducing Device
RWTH	Rheinisch-Westfälische Technische Hochschule Aachen
TLM	Transmission Line Matrix
TNO	Netherlands Organisation for Applied Scientific Research
UNIBRAD	University of Bradford
UNIBO	University of Bologna
WP	Work Package

1 Executive summary

Background

European Commission addresses transport noise through 2002/49 (END): this directive promotes the reduction of the environmental noise. With expected noise reductions of about 10 to 20 dB, no action limited to a single step of the whole process could obtain such targets: one should act (and optimise the means of action) at all the consecutive steps of the whole process (sound - emission, propagation, and reception). Acting on sound propagation, ground transport Noise Reducing Devices (NRD) play an important role in reducing noise: depending on numerous different factors, their global effectiveness can drastically vary. Many efforts had already been done separately on the product side, and on the in-situ side of the NRD performances, while limited research had been done in order to integrate both sides: the final performance clearly depends on both in a true holistic approach.

Objectives

QUIESST merges, within a true holistic approach: the "true" intrinsic products performances, whatever their materials and shapes, together with their extrinsic ones, in order to assess their actual global capacities to reduce the amount of people exposed to noise (END target). It addresses: the near / far field relationship (linking the intrinsic characteristics to their corresponding extrinsic far field effects), the in-situ measurement methods of sound absorption (/reflection) and airborne sound insulation (methods relevant with the actual intended use, also allowing long term performances control), the 1st EU NRD database (listing and comparing both existing and new tests results and providing relevant relationships), the optimisation of the NRD's global performance through a holistic approach (considering acoustic, non-acoustic and global impact optimization, multicriteria optimization strategies, and possible global performance indicators), the sustainability of NRD (defining the relevant generic criteria and developing the first NRD's overall sustainability assessment method). QUIESST outcomes are integrated in the "Guidebook to NRD optimisation".

Work programme

WP1: project administrative, scientific and technical management.
WP2: definition of a far field effect indicator; development and validation of a numerical simulation method converting near field patterns to far field effects; development and validation of an engineering method for the translation of near field measurement data into far field reflection effects.
WP3: new measurement method for sound absorption (/reflection) and airborne sound insulation with regard to sound sources, signals, multiple sensors, signal analysis and the physical representativity; execution of a full inter laboratory (Round Robin) test to assess uncertainty.
WP4: collection and analyse of laboratory and in-situ tests results concerning sound absorption and airborne sound insulation; build-up of a comprehensive database of test results (different EU NRD), establishing the relationship between laboratory and in-situ measurements.
WP5: optimisation strategy for typical roads and railways (urban / rural); application to intrinsic and extrinsic performances, and to holistic optimisation (acoustic, non-acoustic and environmental), database of results from these optimisations; global impact of optimised solutions, case studies.
WP6: assessing the overall NRD's sustainability: defining relevant generic criteria (design, materials, construction technology and practice, maintenance, decommissioning…); establishing relevant assessment method; database of generic relevant criteria and indicators for EU NRD; case studies.
WP7: project dissemination, including the publication of the "Guidebook to NRD optimisation".

Results and achievements

WP1: successfully finalised project, relevant links with NRD stakeholders, special attention to CEN TC226/WG6 and TC256/SC1/WG40 working groups, ready to update standards or start new ones.
WP2: far field low- and high-rise buildings indexes ($DL_{RIff,LR}$, $DL_{RIff,HR}$), database of 1.200 NRD variants, derived and validated engineering method through a user-friendly public Excel sheet.
WP3: 2 new RRT-validated in-situ measurement methods with relevant uncertainty assessments, 2 new draft proposals for CEN 1793-5 and 6, as well as for CEN 16272-5 and 6, ready for WG analysis
WP4: significant database of 1.421 test results on 414 EU NRD corresponding to 25 test laboratories and 9 countries, comprehensive easy-to-use public web database including relevant analysis tools.
WP5: intrinsic, extrinsic and holistic optimisation methods on acoustic, economic and environment factors, optimized NRD database with integrated tool (to be published), 3 global impact case studies.
WP6: assessment method using relevant generic sustainability criteria for NRD sustainability, 2 case studies being useful as models for the stakeholders to amend and tailor their own assessments.
WP7: www.quiesst.eu, relevant participation to major events, 39 papers, 6 publications, 2 workshops, publication of the "Guidebook to NRD optimisation".

2 Project context & objectives

2.1 Background

If we think about how to ensure the sustainability of surface transport, then we definitely need to consider all the possibilities to reduce noise, as well as the sustainability of the associated devices used for noise reduction.
The European Commission clearly addresses transport noise through its 2002/49/EC Directive: its objective is to promote environmental noise reduction, and surface transport is one of the main targets. However, with EC expected impacts of noise reduction of about 10 to 20 dB, it is evident that no action limited to a single step of the whole noise problem could obtain such reduction in noise values: one should act (and optimise the means of action) at all the consecutive steps of the whole process (sound emission, sound propagation, and sound reception).
Acting on sound propagation, ground transport Noise Reducing Devices (NRD) do play an important role in the reduction of noise: depending on numerous different factors, their global effectiveness could be as low as a few decibels (if used inadequately), or reaching up to 20 dB (while using appropriate design).Today, many efforts have been done on both sides of the characteristics leading NRD to be effective: the product side, and the in-situ side. However, too few and limited research has been done yet in order to integrate both sides, while the true final noise reduction clearly depends on both (in a true holistic approach).

The main idea of QUIESST is to optimise the knowledge, the methods, the use and the GLOBAL effectiveness of the ground transport NRD, in order to allow a durable and sustainable development of transport.

2.2 Overall concept and objectives

The global NRD performance depends on:

- the initial intrinsic acoustic characteristics of the industrial products used, and their sustainability;
- their relevant design (intrinsic acoustic performances, flat /non flat - homogeneous / heterogeneous devices, dimensions and location) in function of the vehicles, the infrastructure and the concerned environment;
- the whole sound propagation process: intrinsic performances which directly affect the near field propagation could affect the far field performances in a complete different way (remember that END can lead to more stringent noise reduction criteria, leading to more and more distant affected areas).

The concept of QUIESST is to merge, for the very first time, the consideration of the “true” intrinsic acoustic characteristics of NRD, together with their extrinsic acoustic characteristics, and their sustainability in a holistic way, in order to control the actual global effectiveness to reduce ground transport noise, to minimise the number of exposed people to noise and reduce the level of noise exposure and to make NRD more sustainable long term.
QUIESST aims to control all those important factors through a true holistic approach.
The main deliverable of QUIESST is a comprehensive reference guidebook about NRD holistic optimisation (referring to associated databases, simulation methods, measurement methods and recommendations: all these are also QUIESST deliverables).

QUIESST addresses: the near field / far field relationship, in-situ measurement of “true” sound absorption and airborne sound insulation, the comparison of the existing laboratory tests results of European NRD with the corresponding in-situ measurement test results, the holistic approach of NRD optimisation, and sustainability.

2.3 Detailed concept and objectives

To achieve its objectives, QUIESST clearly identified the following topics:

2.3.1 The near field / far field relationship

After more than 30 years using NRD alongside roads and railways, no definitive survey has been done yet in order to clearly demonstrate the global effect of specifically designed NRD. In short, shape and sound absorptive materials are tools for achieving better noise reduction but, at present, it is impossible to properly simulate non flat and / or sound absorptive NRD effect in the far field: mastering the NRD performance, whatever their sound absorptive characteristics and / or shape in the near *and* in the far field is the QUIESST's 1st objective.

The main steps to achieve this objective were:

- to develop a numerical simulation method for the conversion of near-field sound reflection patterns to far field effects with NRD of different sound absorptions and / or shapes;
- to validate the numerical simulation method against measured data acquired in near and far field;
- to develop an (analytical) engineering computation method for the translation of near field measurement data into far field reflection effects to validate the engineering method against the results of the numerical simulation method and the available measurement data;
- to define an appropriate indicator for the rating of the NRD sound reflecting characteristics based on the far field effect.

The verifiable result is the validated engineering computation method, drafted with user friendly instructions for data processing and the corresponding far field indicator derivation.

2.3.2 In-situ measurement method of NRD intrinsic "true" sound absorption and airborne sound insulation

Since too long, one characterizes NRD intrinsic acoustic performances in close field and / or reverberant laboratories as if they were products to be used inside buildings (EN 1793-1 and EN 1793-2): this is inadequate relatively to their intended use, i.e. in open spaces. Moreover, this way does not allow an easy control of the NRD long term acoustic performances years after years, in facts a real need in order to assess NRD sustainability.
For in-situ measurements, the tentative CEN/TS 1793-5 is currently used by several Member States but has serious problems while characterizing / comparing flat and non flat products: as it stands, CEN/TS 1793-5 has been rejected as an harmonised EN standard.
Today, the need to characterize NRD in-situ is more than ever a *priority* if one wishes to master the NRD "true" intrinsic characteristics: addressing this is the QUIESST's 2nd objective.

The main steps to achieve this objective were:

- to develop a new measurement method for sound absorption/reflection and airborne sound insulation of NRD with regard to: choice of sound sources and signals, use of multiple sensors, signal analysis and the essential physical representativity (near field/far field, whatever the shape of the NRD);
- to assess the uncertainty of this new method (through a full Round Robin Test –RRT).

The verifiable results are the 2 new measurement methods and their uncertainty (assessment of accuracy).

2.3.3 Comparison between the laboratory and the corresponding in-situ tests results of existing NRD

The EU NRD market offers many already approved products (often tested under different methods), while many new ones are appearing. However, even if the European product standard EN 14388 is published since 2005, no comprehensive database of the NRD acoustic performances does exist yet. On the other hand, facing the expected coexistence of laboratory and in-situ tests results, the stakeholders strongly need to understand the possible relationships, if existing between in-situ test results and existing laboratory results.
Addressing both needs, the QUIESST 3rd objective was to build a relevant database comparing the European NRD intrinsic performances according to the different test methods, and to establish the relationships between the different results.

The main steps to achieve this objective were:

- to collect and analyze laboratory and in-situ tests results concerning sound absorption and airborne sound insulation (EN 1793-1/2, TS 1793-5, and the new QUIESST methods);
- to build a comprehensive database of test results, taking into account different EU NRD;
- to establish the relationships between laboratory and in-situ results and to supply data for a fair comparison of the two methods in terms of applicability;

The verifiable result is the database itself: a very significant one, including 1.421 test results on 414 EU NRD and corresponding to 25 test laboratories and 9 countries, this is presented under a comprehensive, easy-to-use, public web database including relevant analysis tools.

2.3.4 The holistic approach of how to optimise the use of NRD

Whatever the numerous existing “comprehensive” guides about NRD of these last 30 years, no one has yet included the holistic approach, i.e.: starting from the “true” intrinsic performances, considering the optimised combination of their acoustic characteristics and design shapes, considering the best situation in order not only to reduce noise, but also the amount of people exposed to noise, without forgetting the cost / benefit ratio and the sustainability…
QUIESST’s 4th objective is to develop a comprehensive strategy on how to optimise NRD within a true holistic approach: this part of the project merges the results of the other parts (near/far field, “true” intrinsic performances, sustainability) together with all the other acoustic and non-acoustic considerations at global scale (road/rail, close/far field, urban/rural sites).

The main steps to achieve this objective were:

- to develop an optimisation strategy adapted to typical road and railway traffic noise configurations where both urban and rural areas are addressed;
- to apply this methodology to intrinsic performances, considering NRD shapes and surface impedances;
- to apply this methodology to extrinsic and holistic NRD optimisation, considering acoustic, non-acoustic and environmental (site) parameters, building a database of the results;
- to provide the expected global impact of optimised noise abatement solutions in terms of reduced number of exposed people in typical urban and rural situations (3 case studies: Belgium, the Netherlands and Germany);
- to merge the main outcomes from all the other parts of the project into a comprehensive final report of all the results issued in the project and giving recommendations and guidelines through good practices.

The verifiable result stands in the optimisation methods presented in the guidebook about NRD holistic optimisation (referring to associated databases, simulation methods, and measurement and assessment methods); moreover, a database of optimized NRD, with integrated tool helping the approach, will also be published.

2.3.5 Sustainability

Sustainability of surface transport is a key objective of the White Paper on European Transport Policy: it includes not only the vehicles and their infrastructure but also the numerous adverse effects they can have on the environment, noise being a major one. One then clearly understands the high interest to master all the systems which are able to reduce the number of affected people.
Optimised and sustainable NRD can play a very important part in this achievement towards a more sustainable ground transport. Furthermore, one also has to consider NRD as an integral part of the whole transport system, and their sustainability is equally important.
At present, there is no method allowing the assessment of NRD sustainability: QUIESST's 5th objective is to provide a relevant method for assessing the overall sustainability of ground transport noise reducing devices.

The main steps to achieve this objective were:

- to define the relevant generic sustainability criteria for NRD:
  - ✓ sustainable design criteria, sustainable materials and their carbon footprint;
  - ✓ sustainable construction technology and practice and their carbon footprint;
  - ✓ sustainable maintenance; sustainable decommissioning;
  - ✓ future sustainable solutions…
- to research relevant methods for assessing the overall sustainability of NRD;
- to build a database of those generic relevant criteria and indicators for existing European NRD;
- to apply the method(s) on existing NRD in order to compare and rank them from the point of view of their overall sustainability: this has been done through 2 cases studies (Italy and Spain);
- to present the methods and outcomes within the final report on NRD sustainability.

The verifiable result is the comprehensive report about NRD sustainability (referring to relevant parameters and generic sustainability criteria and associated assessment method): this report is also presented in the "Guidebook to NRD optimisation".

2.3.6 Dissemination

All the project results and outcomes have been distributed in the most transparent and effective way. Dissemination was a major part of QUIESST project as it ensured that the objectives and results of the projects were brought to the attention of targeted groups through appropriate dissemination channels.

The main steps to achieve this objective were:

- to exploit as much as possible the project's potential through a comprehensive review of previous and existing initiatives and potential target groups as well as a continuous clustering effort with all interested parties;
- to ensure that the objectives and results of the project are brought to the attention of these groups through appropriate dissemination channels (web site, articles and trainings);
- to confront the QUIESST expectations and conclusions with the needs expressed by the end users through dedicated workshops and by participating in major European and international events dealing with noise issue.

The verifiable results are: the QUIESST website (www.quiesst.eu), the relevant participation to major events, 398 papers, 6 publications, 2 workshops, and the publication of the "Guidebook to NRD optimisation".

3 Main Scientific & Technical results / foregrounds

3.1 WP2 "Near field - far field" relationship for sound reflectivity

Shape and sound absorptive materials are tools for achieving better noise reduction but, at present, it is impossible to properly simulate non-flat and / or sound absorptive NRD effects in the far field: mastering the NRD performance, whatever their sound absorptive characteristics and / or shape in the near *and* in the far field is the QUIESST's 1st objective.

3.1.1 The engineering extrapolation method: the final WP2's outcome

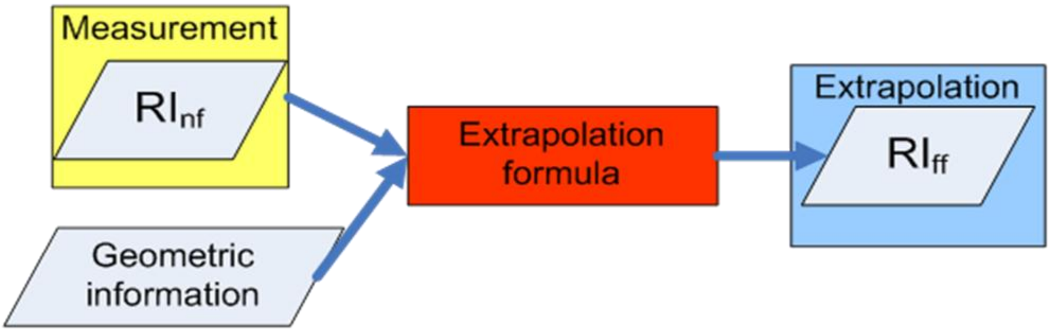


Figure 1: principles of the QUIESST engineering extrapolation method

The final outcome of WP2 is an engineering computation method that gives the values of 2 far field performance indicators (for high- and low-rise buildings as in Figure 2) for different NRD.

As shown in Figure 1, the method uses, as inputs, the results of the new WP 3 near field reflection test method: the ⅓rd octave band values of the averaged Reflection Index (RI_{nf}) are used. The barrier type and the geometrical shape parameters are also relevant inputs.
The output is an estimated contribution of the reflected sound to the sound level in the far field, expressed as the single number rating for the far field reflection index: $DL_{RI,ff}$.

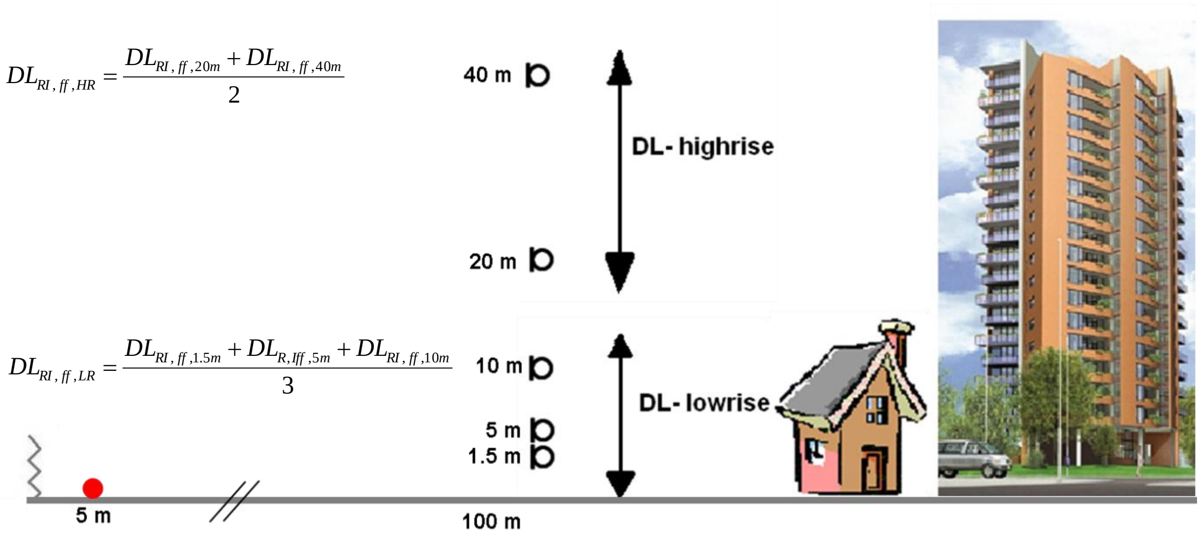


Figure 2: locations that are considered for the sound source, the NRD and the receivers definitions of $DL_{RI,ff,HR}$ and $DL_{RI,ff,LR}$

This single number rating, expressed in dB(A), is computed at five different receiver positions: at a distance of 100 m from the NRD, and at heights of 1.5, 5, 10, 20 and 40 m above the ground (see Figure 2).

The far field reflection index RI_{ff} is defined as the ratio between the amount of energy which is reflected by the device and the energy that would be reflected by a *reference* barrier (as a reference, a flat rigid vertical barrier of the same height as the test sample -usually 4 m - is chosen).

In order to obtain a compact description of the reflection effects in the far field the single number ratings at the five positions are then clustered and averaged in two groups (see Figure 2): the average of the single number ratings of the three lowest positions $DL_{RI,ff.LR}$ is considered to be representative for low rise buildings and the average of the single number ratings of the highest two $DL_{RI,ff,HR}$ is considered representative for high rise buildings.

In this way, those two far field indicators characterise the far field reflectivity of NRD.

3.1.2 Basis of the engineering extrapolation method

The basis for the method is formed by the use of two data bases filled with results of numerical simulations.

Near field data base

The first database consists of results of simulations under the near field reflection tests conditions for different NRD variants representing the majority of the European NRD market. Five different NRD families were selected (see Figure 3).

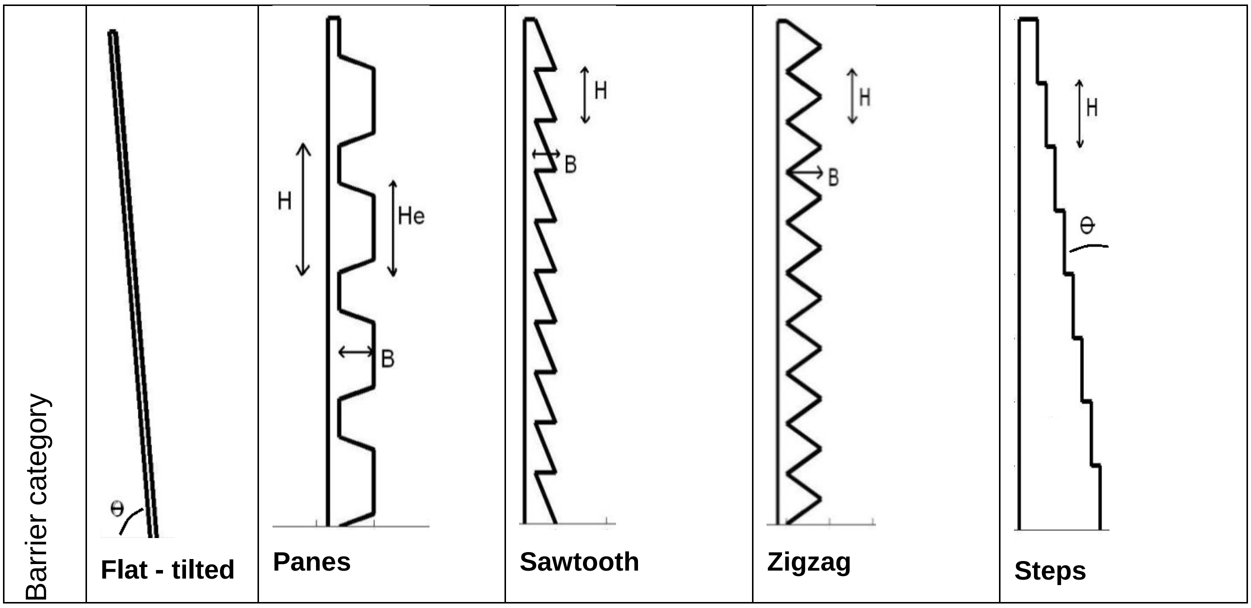


***Figure 3**: NRD families*

For each NRD type, 3 different types of *absorptive material* were applied:

1. Rigid: all materials with an acoustically hard surface (100 % reflective; 1 variant)
2. Porous concrete (6 variants)
3. Perforated metallic or plastic cassettes filled with mineral wool (6 variants)

The total number of variants in the near field data base is 1196. For each variant, the spectral values of RI_{nf} (near field Reflection Index) and the corresponding single number rating $DL_{RI\ nf}$, averaged over three receiver positions are stored in combination with the material and geometrical parameter values.

Far field database

The second database contains the results of Boundary Element Model (BEM) simulations of the far field reflection index RI_{ff} values, for the same series of NRD variants as for the near field data. In this case, the values were computed for the five different receiver positions in the far field (Figure 2). For each receiving position, the far field single number indicators $DL_{RI,ff}$ have been also computed.

Step-wise extrapolation

The extrapolation is carried out in a two-step approach:

1. the result of a near field reflection test is matched to the best fitting simulated variant in the database, following a 2 steps matching procedure;
2. then, the *material parameters* (type of absorption material, flow resistivity and porous layer thickness) are used as input data for the computation of an estimate of the far field effects of the NRD: this estimate is computed with a polynomial approximation of the contents of the far field database. This enables a fast computation with the possibility to interpolate between the simulated variants.
   The *geometrical shape parameters* are also used as input and these values can be interpolated between the values of the originally simulated variants in the database.

The final outputs of this far field extrapolation method are the two far field indicators $DL_{RI,ff,LR}$ and $DL_{RI,ff,HR}$.

3.1.3 Uncertainty of the method

The engineering extrapolation method is a heuristic method, based on an approximation of the data that were computed with numerical simulation models for 1196 barrier variants: the approximations can deviate, to a certain extent, from the original simulated data.

Within the first step of the approximation process, the matching of the near field test results to the best fitting simulated variant was tested against the results of the WP 3 Round Robin Test: the differences between the single number ratings of the tests and the single number ratings of the fitted variants were always smaller than 1 dB, except for one very unusual design (absorbing zigzag - see Figure 4).

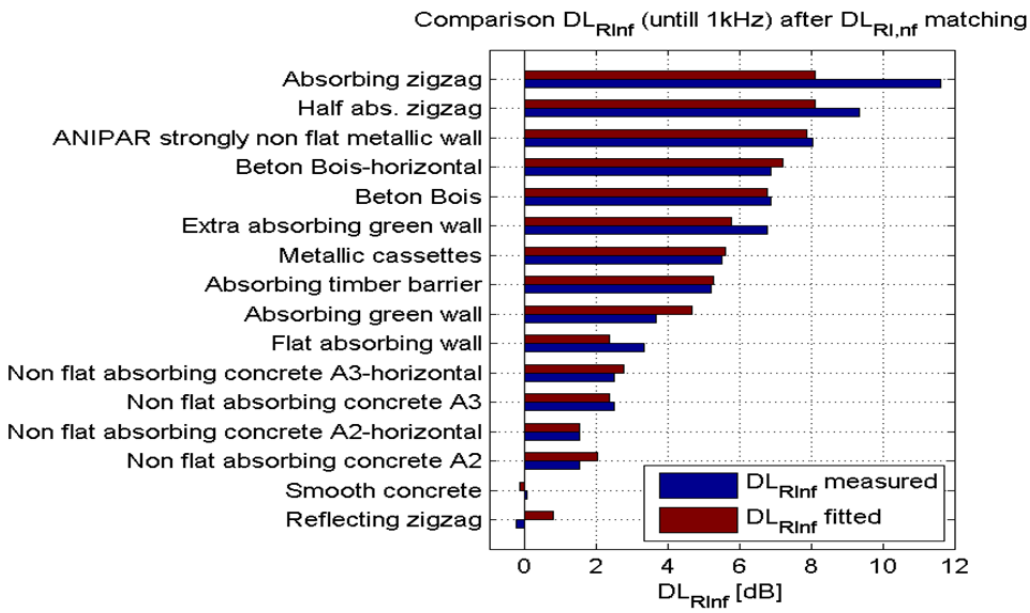
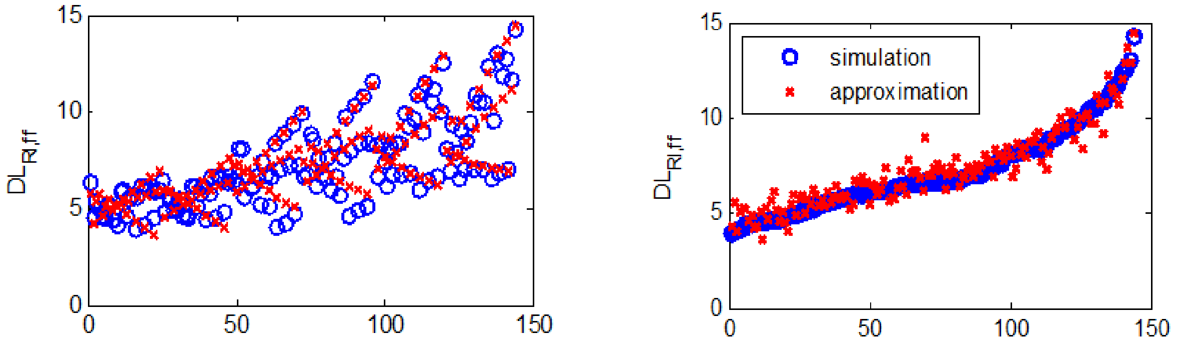


Figure 4: Comparison between Round Robin Test results and best fitting simulated variants (based on near field single number rating $DL_{RI,nf}$ in the frequency range 125 - 1000 Hz)

The second step estimates the far field reflection contribution for the best fitting simulated variant. It uses the material parameters of this best fitting variant and the barrier type and geometrical shape data. The basis of this estimation is a polynomial approximation of the far field simulation results that were computed with the BEM model. The estimated values have been compared with the original simulated values for all 1196 barrier variants and the 5 receiver positions. Figure 5 shows a graph of the comparison for one of the barrier types.



Results of polynomial approximation sorted in order of geometric variation

Results of polynomial approximation sorted in order of $DL_{RI,ff}$

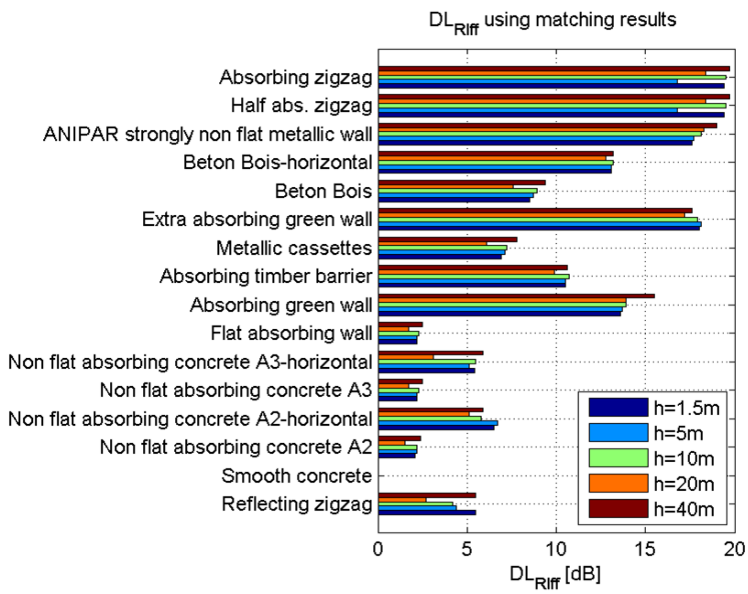
Figure 5: Example of fitting performance - porous concrete ZZ type, at 5m receiver height

88 % of all the approximated data were within 1 dB of the original simulated values and 99 % were within 2 dB: it may be concluded that both steps of the method have an uncertainty margin of approximately ±1 dB compared to the measured / simulated values. The combined uncertainty of the extrapolation method may then be estimated at ±1,4 dB.

In this assessment of the estimation uncertainty the far field effects simulated with the BEM model are considered to be the “true” values: based on experiences in other studies there is a well-founded confidence in the reliability of the BEM simulation method, if it is used for modelling of sound propagation over relatively short distances.

The engineering extrapolation method derived from the BEM simulation results is presented with confidence and the uncertainty values specified above are seen as realistic estimates.

3.1.4 Examples of far field reflection effects computed with the engineering method



Near field
$DL_{RI,nf}$
14,5
9,3
8,2
7,9
7,9
7,0
6,4
5,2
3,3
3,8
3,5
3,5
2,5
2,5
0
-0,7

Figure 6: Example of the results of the engineering extrapolation method

As an example, the data of the samples used for the WP3 Round Robin Test have been used here as input to the engineering method: both steps of the method (near field matching and far field extrapolation) were applied. In Figure 6, the extrapolated results for each of the receiving heights are shown as a far field $DL_{RI,\ ff}$, the table beside the figure shows the corresponding near field $DL_{RI,\ nf}$ from the reflection tests.
From those results, it can be seen that the far field effect does not always follow closely the near field reflection index values. This is logic and expected: if the barrier sample has a surface shape with large dimensions in vertical and horizontal directions, the far field effects of this surface design may be substantial and can enhance the reduction of reflections due to the absorption characteristics of the material.
In many cases the surface shape effects are also dependent of the receiver height.

3.1.5 Scope and availability of the engineering extrapolation method

The goal of the method is to give an *indication of the far field reflection effects* that can be achieved with a specific NRD design.

The scope of the method is *limited to the NRD types and geometries considered in the database*: if a specific design does not fall within that range, it cannot be assessed with the engineering method and new BEM simulations have to be carried out in order to obtain a reliable estimate of its reflectivity effects. The execution of a dedicated BEM simulation is also advisable if an assessment of the far field effects of a specific barrier design with less uncertainty is targeted.

The complete extrapolation method is described in a separate document in the format of a draft for an informative annex to the future revised standard for in situ testing of the reflectivity of noise barriers (EN 1793-5). For an easy use of the method, it is also implemented in a pre-programmed Excel spread sheet (Figure 7) that is available to public through the QUIESST website (www.quiesst.eu).

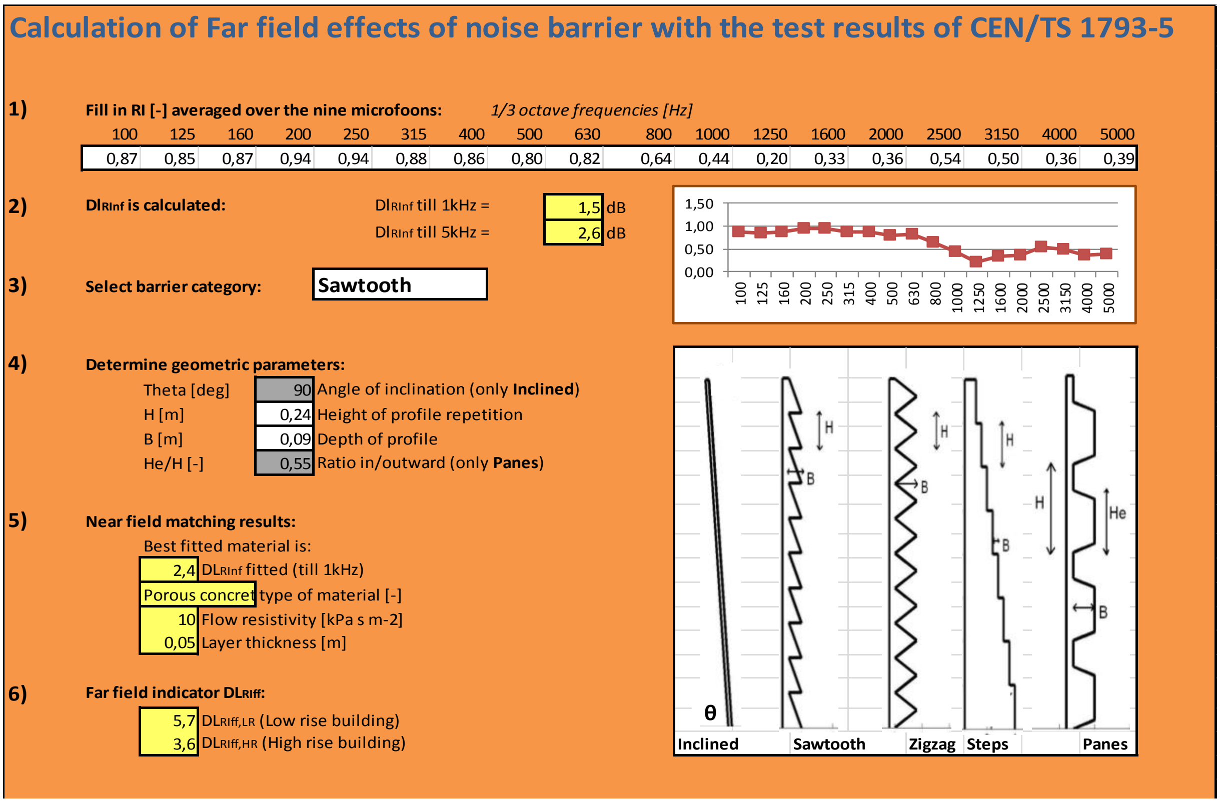


Figure 7: the QUIESST spread sheet for an easy use of the engineering extrapolation method

3.2 WP3 Improvement of the in-situ methods for sound absorption and insulation measurement

3.2.1 Objectives of the new methods

The objectives were:

1. to develop new robust in situ measurement methods in order to assess the sound absorption/reflection and airborne sound insulation characteristics of NRD,
2. to assess the accuracy of those new methods.

The first objective implied that the new methods must be applicable on the site where the NRD are installed, without removing or altering them in any way and in presence of an unpredictable background noise, variations of meteorological conditions, traffic flows, etc. It should be kept in mind that the new methods are not intended to qualify NRD to be installed in almost “diffuse sound field” conditions, e.g. inside tunnels or deep trenches: in those cases, the traditional laboratory methods supply the necessary information.

The second objective has been achieved by assessing the so called ”uncertainty” of the measurements by means of an inter-laboratory test (or Round Robin Test, RRT). In this context, the word “uncertainty” means a quantitative evaluation of the reliability of the results; it should be noted that it doesn’t mean “error” or “wrong result”: on the contrary, the declaration of the uncertainty is the best way, according to the recommendations of all international standard organizations (ISO, CEN, OIML, etc.), to assess the accuracy of a measurement.

Some more technical data are given in 3.5.3; the full description of the inter-laboratory test and its outcomes are given in the QUIESST deliverable D3.5.

3.2.2 Outline of the new in situ measurement method

In situ sound reflection measurement

An artificial sound source (loudspeaker) and a square array of 9 microphones (0,80 x 0,80 m) are used (Figure 8 andFigure 10). Multichannel acquisition can be exploited. The array is placed between the loudspeaker and the device under test. The sound source emits transient sound waves that travel through the microphone array to the device and then reflects on it.

The microphones receive both the direct sound travelling from the sound source to the device under test and the reflected sound (including scattering).

A free-field measurement, taken for each microphone with the same source and microphone configuration but far away from any reflecting object, is then subtracted from the previous one in order to isolate the reflected component.

Several technical improvements (specifications for analysis windows application, a new algorithm for signal subtraction, a quantitative criterion for measuring the quality of the subtraction, etc.) have been developed in order to assure accurate results, even in difficult conditions (Figure 11).

From the ratio of the acoustic power of the direct and the reflected components, averaged on the nine microphones, a characteristic quantity is calculated: the sound reflection index RI. It is a dimensionless quantity, presented as a function of frequency in the ⅓rd octave bands between 100 Hz and 5 kHz. From those frequency dependent values, a single-number rating can be calculated, called DL_{RI} and expressed in decibels.

In this formulation three newly defined *“corrective factors”* are included to master all the details of the measurement: a geometrical *divergence correction factor* taking into account the path length difference between the direct and reflected waves, a *directivity correction factor* taking into account the sound source directivity, and a *gain correction factor* used to compensate any gain mismatch (if any) of the amplification settings between the “free-field” and “barrier” measurements.

All this gives *RI* values physically meaningful and independent of the sound source used.

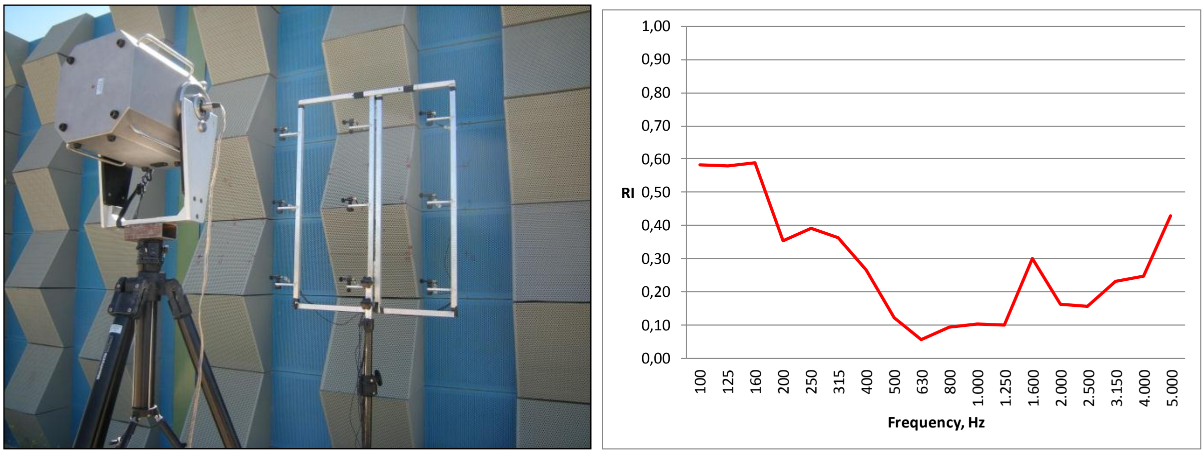


Figure 8: Left: sound reflection measurement in situ
Right: measurement results in ⅓rd octave bands. DL_{RI} = 8 dB

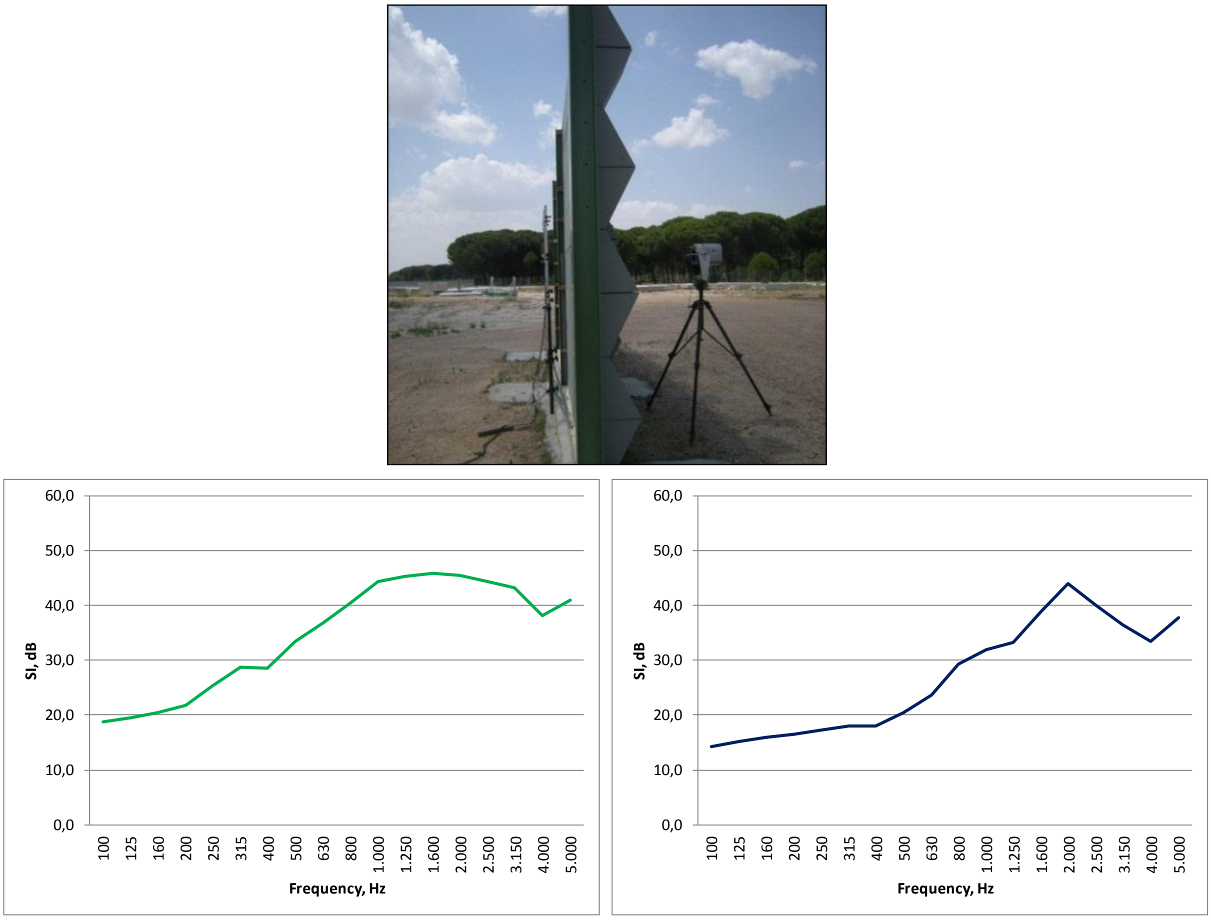


Figure 9: Top: airborne sound insulation measurement in situ
Left: measurement results for the acoustic elements in ⅓rd octave bands $DL_{SI,EL}$ = 33 dB
Right: measurement results across posts in ⅓rd octave bands $DL_{SI,P}$ = 24 dB

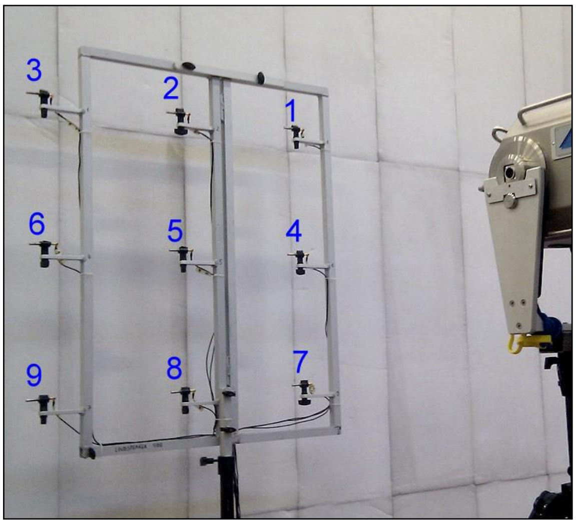


Figure 10: Sound reflection index measurements:
sound source and microphone array in front of a sample noise barrier

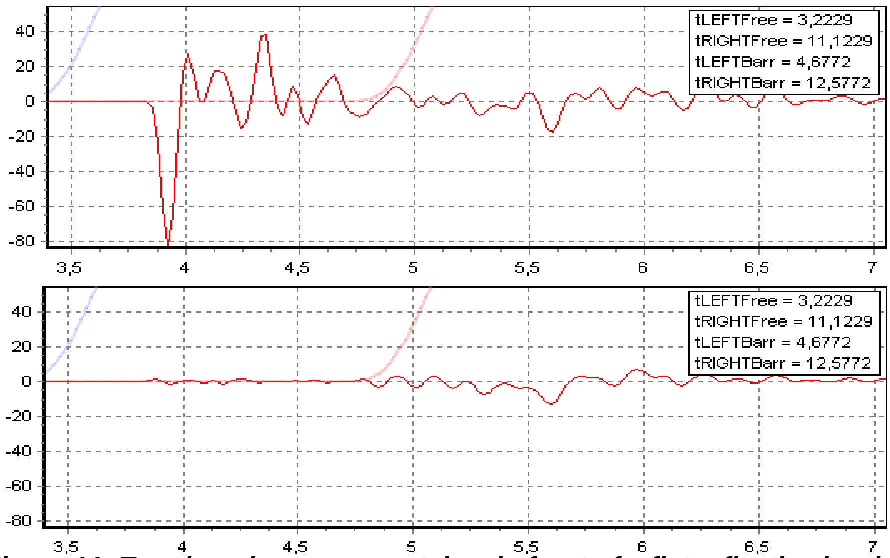


Figure 11: Top: impulse response taken in front of a flat reflective barrier
Bottom: the same impulse response after the signal subtraction
(X axis: signal strength in dB, Y axis: time in ms)

In situ airborne sound insulation measurement

The sound source emits a transient sound wave that travels toward the device under test and is: partly reflected, partly transmitted and partly diffracted by it. The microphone array placed on the other side of the device under test receives both the transmitted sound pressure wave travelling from the sound source through the device under test, and the sound pressure wave diffracted by the top edge of the device under test (Figure 12).

If the measurement is repeated without the device under test between the loudspeaker and the microphone, the direct free-field wave can be acquired.

From the ratio of the acoustic power of the direct and the transmitted components, energetically averaged on the nine microphones, a characteristic quantity is calculated: the sound insulation index *SI*. It is a dimensionless quantity, expressed in dB and presented as a function of frequency in the ⅓rd octave bands between 100 Hz and 5 kHz. From the frequency dependent values a single-number rating can be calculated, called DL_{SI} and expressed in decibels.

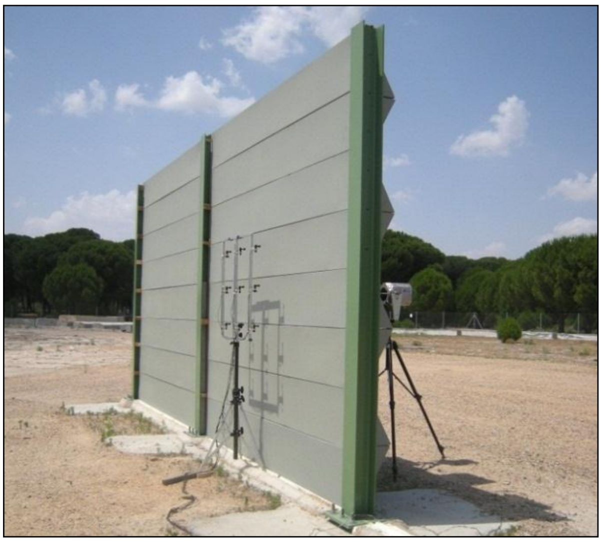


Figure 12: Sound insulation index measurements: sound source and microphone array near a sample noise barrier, in front of the acoustic elements

Repeatability and reproducibility

The above outlined methods have been verified by 8 independent laboratories on 13 samples installed on 2 test sites in Grenoble (France, Figure 13) and Valladolid (Spain, Figure 14).

Overall, the test has been carried out following the procedure for an inter-laboratory test (also called Round Robin Test, or RRT) in order to be able to get both the repeatability and the reproducibility of the method.

Figure 13: the Grenoble test site (France)

Figure 14: the Valladolid test site (Spain)

The repeatability is the random variation of the measurement result under constant measurement conditions, while the reproducibility is the random variation of the measurement result under changed conditions of measurement.

The reproducibility is directly used to declare the reliability of the method according to the ISO guide on uncertainty in measurement. In other words, if *M* is the value of a single measurement and *R* is its reproducibility, there is a probability of 95% that the true value of a single measurement lies in the interval [*M* – *R*; *M* + *R*].

Both the repeatability and the reproducibility are different for each ⅓ rd frequency band; their trends as a function of frequency are shown in Figures 30 and 31 that summarize the results of the Round Robin Test.

It is worth noting that these results have been achieved on real-life samples, built as in practice with irregularities and sound leaks due to average workmanship; in other words, these samples were not fully homogenous “laboratory samples”. Thus, the final repeatability and reproducibility values do include the effect of sample irregularities.

In this regard, the final values obtained, already satisfying as they are, may be considered a worst-case estimate.

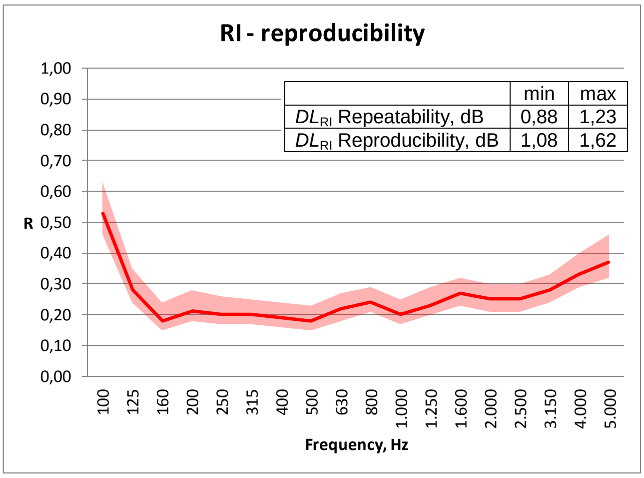


Figure 15: Reproducibility of the sound Reflection Index measurement method in ⅓rd octave
Thick red line: median value, Light red area: range between min. and max. values
Table of the 95% credible intervals for reproducibility and repeatability
of the single-number rating of the sound reflection index DL_{RI} in dB

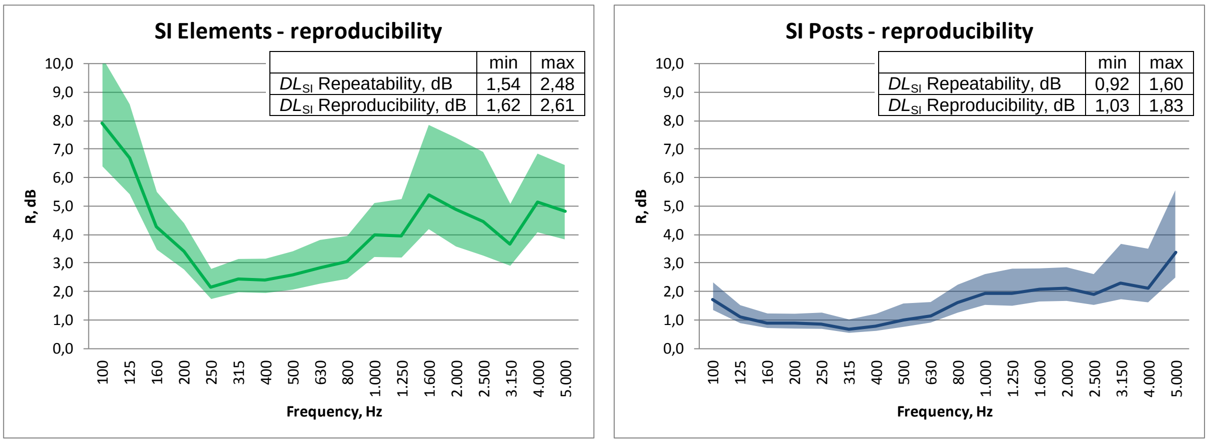


Figure 16: Reproducibility of the Sound insulation Index measurement method for the acoustic elements and at post in ⅓rd octave
Thick green/blue lines: median value, Light green/blue areas: range between min. and max.
Tables of the 95% credible intervals for reproducibility and repeatability of the single-number rating of the sound insulation index for the acoustic elements and at posts DL_{SI} in dB

3.3 WP4 Database of Acoustic performance of the European NRD

3.3.1 Overview of the Database Content

The NRD database contains data obtained with the different methods presenting single number rating and ⅓rd octave band spectra for different NRD families. The database contains 414 different NRD produced by 40 noise barrier manufacturers, and more than 1421 different measurement results, from tests performed by 25 different laboratories from 9 European countries (see Figure 17).

More than 400 test results are on in-situ sound reflection, around 120 are on sound absorption measured in the laboratory, while 250 test results are concerning in-situ sound insulation and 100 sound insulation measured in the laboratory (see Figure 18).

The measurement methods currently covered in the database are the following:

- Laboratory measurements for sound absorption and sound insulation according to EN 1793-1 and EN 1793-2,
- The so-called "Adrienne" in-situ method for sound absorption and airborne sound insulation according to CEN/TS 1793-5, and prEN 1793-6
- The newly developed QUIESST method for measurements of sound reflection,
- French in-situ method for sound absorption and airborne sound insulation NFS 31089.

Entry type	Number of entries
NRD	414
Tests	1421
Manufacturers	40
Laboratories	25
Countries	9

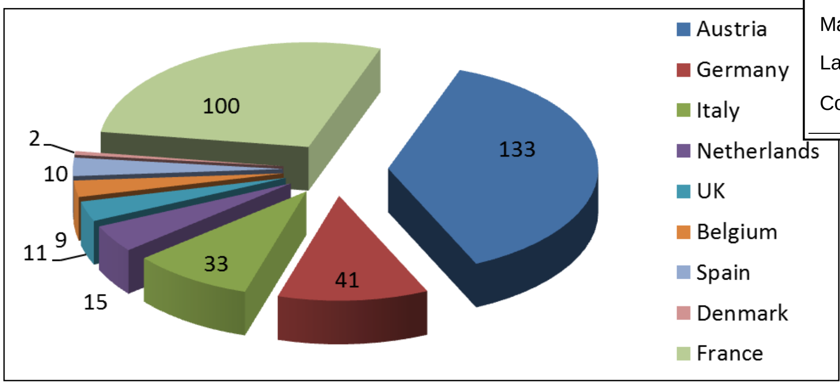


Figure 17: Geographical distribution of the Noise Reducing Devices present in the database and European countries represented

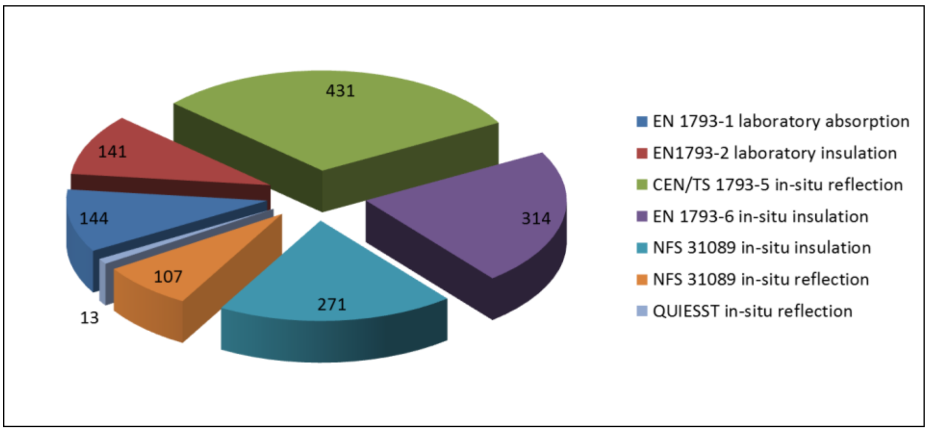


Figure 18: Amount of data collected following the test method

The collected data represents the EU market distribution fairly well: most of the available data come from wood-fibre concrete, metallic cassettes and timber barriers, while transparent materials, photovoltaic barriers, added devices and green walls are less represented in the database (see Figure 34).Table 1 lists the different categories of NRD that have been considered (for details, see the QUIESST deliverable D4.3.).

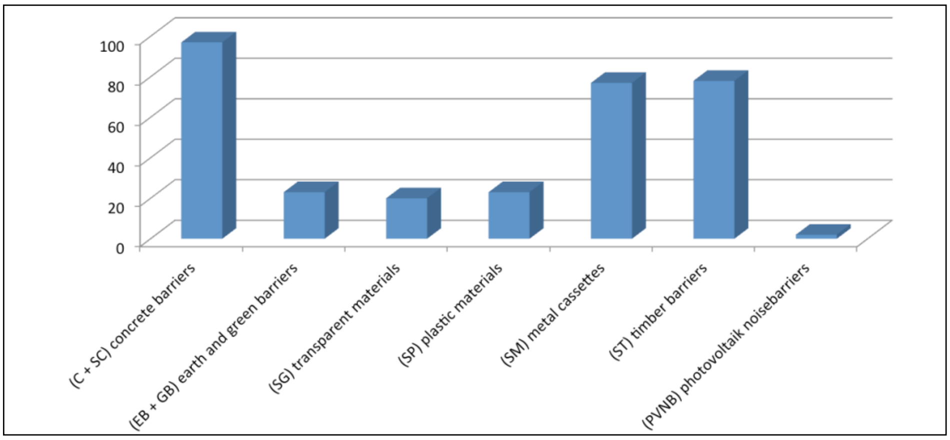


Figure 19: NRD material types contained in the database

Table 1 - Definition of the different NRD categories in the database

Barrier Type	Description
SM – Steel supporting structure + Metallic panels	Most steel supporting structures have a H-shaped appearance. At least the surface layer consists of metallic material
SC – Steel supporting structure + concrete panels	Structure of posts like in SM. At least the surface layer consists of concrete. Wood-fiber concrete barriers can also be assigned to this family.
ST – Steel supporting structure + Timber panels	Structure of posts like in SM. At least the surface layer consists of timber.
SG – Steel supporting structure + Transparent panels	Structure of posts like in SM. It is very highly probably that the noise barrier consists of only one transparent layer (e.g. acrylic glass)
C – Self-supporting concrete or brick system	NRD made of self-supporting construction. An example would be brick wall.
SP – Steel supporting structure + plastic panels	Structure of posts like in SM. At least the surface layer consists of plastic material
CT – Tunnel-concrete structure	Tunnel-structure, which surrounds the entire road to provide full noise screening. May be constructed self-supporting or with concrete beams supported by concrete pillars.
Stu – Tunnel steel structure	Tunnel-structure, which surrounds the entire road to provide full noise screening. Consists of steel supporting structure and metallic cassettes.
GT – Tunnel with transparent panels	Tunnel-structure, which surrounds the entire road to provide full noise screening. Consists of steel supporting structure and transparent panels
GB – Green barrier	NRD type, which obtains its acoustic properties of soil with vegetation. A classic example would be a concrete structure with containers, filled with earth and plantings.
GA – Gabion with stones	NRD made of a gabion framework (solid metallic grid) filled with stones.
EB – Earth barrier	Artificial or natural earth wall – can be planted or unplanted
PVNB – Photovoltaic noise barrier	Usually a conventional noise barrier with added photovoltaic elements.

3.3.2 The “internal” database

The database serves two different objectives: the first one is to perform an *in depth* statistical analysis of the current and historic data, the second one is to provide information about NRD for the general public, and especially for road and railways administrations. However, this leads to the major issue of confidentiality. On the one hand, there was a need to collect as many data from the manufacturers as possible to perform the analysis, while not all manufacturers and research institutions want to share this detailed information with the public and especially their competitors. For this reason, the detailed content of the so-called *internal database* will not be accessible to the public. Because of this, a second version of the database has been developed using only anonymous data and statistical information about the different NRD classes. Infrastructure administrations can check the currently possible performance of different classes while the manufacturers test reports and confidential information will not be publically available.

3.3.3 Examples of case Studies from the “internal” database

Metallic barrier: Figure 20 shows the ⅓[rd] octave band results according to EN 1793-1, EN 1793-2, CEN/TS 1793-5 and prEN 1793-6.

Figure 20: Test results of a metallic barrier according to the different standards

The lower right plot presents sound insulations results at post and at the acoustic element.

Timber barrier:

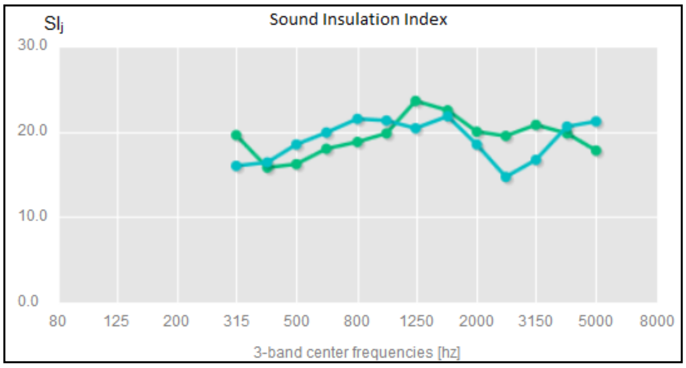
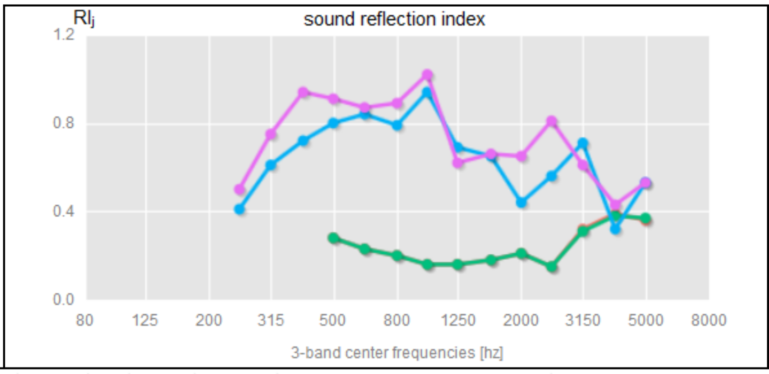


Figure 21: ⅓[rd] octave band results of element and post of a timber barrier

Wood-fibre concrete barrier: Figure 22 illustrates a big discrepancy in DLRI between the tests with different cut-off frequencies due to the small height of the tested barrier.



		Method	Property	Type	Class	Value	Measured	Organisation	Remark	Actions
☑		Adrienne	Reflection	AVERAGE		DLRI: 7.0	2005-05-23		(3/AV/500Hz); Meas.location on highway A9 at km 154.2 at a parking area; DLRI is average value of meas.points located on the acoustic element; cutoff-frequency at 500Hz	
☑		Adrienne	Reflection	AVERAGE		DLRI: 1.5	2005-06-22		(1/AV/250Hz); Meas.location on highway A9 at km 154.2 at a parking area; DLRI is average value of meas.points located on the acoustic element; cutoff-frequency at 250Hz	
☑		Adrienne	Reflection	AVERAGE		DLRI: 1.1	2005-06-22		(2/AV/250Hz); Meas.location on highway A9 at km 154.2 at a parking area; DLRI is average value of meas.points located on the post; cutoff-frequency at 250Hz	

Figure 22: ⅓rd octave band results of sound reflection index according to CEN/TS 1793-5 The frequency in the remark field indicates the used lower cut-off frequency for the test

3.3.4 The "public" database

The public database is the main output of WP4: it is directly accessible for all the stakeholders from the QUIESST website. The public database is based on the analyses performed with all the data collected during the project. For confidentiality reasons only an overview of the data and the results of the analyses can be presented to the public and not the data itself, which are present only in the internal database. Here are some "menus":

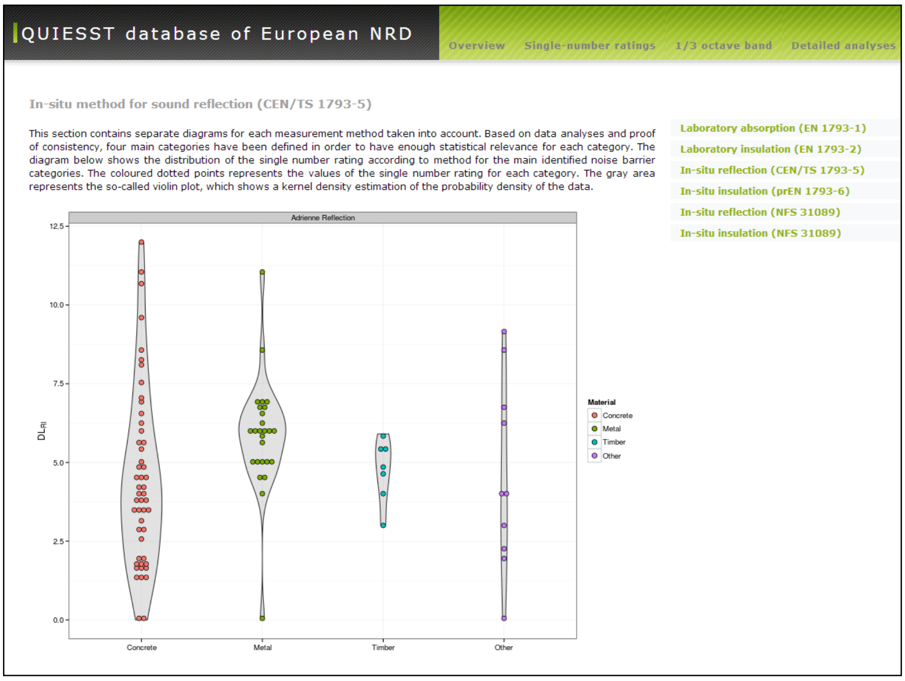


Figure 23: Overall values according to the different measurement methods: distribution of all the NRD single number ratings according to the in-situ method

Menu "single-number ratings"

Figure 23 shows the single number rating distribution of all the NRD present in the database.

Menu "Detailed analysis"

In addition to the overview of the single number ratings and the frequency spectra, more detailed analyses and comparisons between the different methods have been performed. In this section, the following analyses and comparisons are presented:

- Correlation between laboratory and in-situ method for sound insulation over all barrier types (EN 1793-2 & prEN 1793-6)
- Correlation between laboratory and in-situ method for sound insulation for each material where sufficient data were available (EN 1793-2 & prEN 1793-6)
- Correlation between laboratory and in-situ method for sound absorption/reflection over all barrier types (EN 1793-1 & CEN/TS 1793-5)
- Correlation between laboratory and in-situ method for sound absorption/reflection for each material where sufficient data were available (EN 1793-1 & CEN/TS 1793-5)
- Comparison between in-situ sound insulation measurements performed in front of a post and measurements performed in front of a noise barrier element over all barrier types (prEN 1793-6)
- Comparison between in-situ sound insulation measurements performed in front of a post and measurements performed in front of a noise barrier element for each material where sufficient data were available (prEN 1793-6)
- Comparison between different methods for in-situ sound reflection, where sufficient data were available (CEN/TS 1793-5 and NFS 31089)
- Comparison between different methods for in-situ sound insulation, where sufficient data were available (prEN 1793-6 and NFS 31089)
- Cluster analysis of the collected results for each measurement method separately in order to identify NRD families based on the frequency spectra

Figure 24 show an example of the analysis that can be found under "Detailed analysis".

Based on the huge amount of data collected, it will be possible to perform many other analyses in follow-up research.

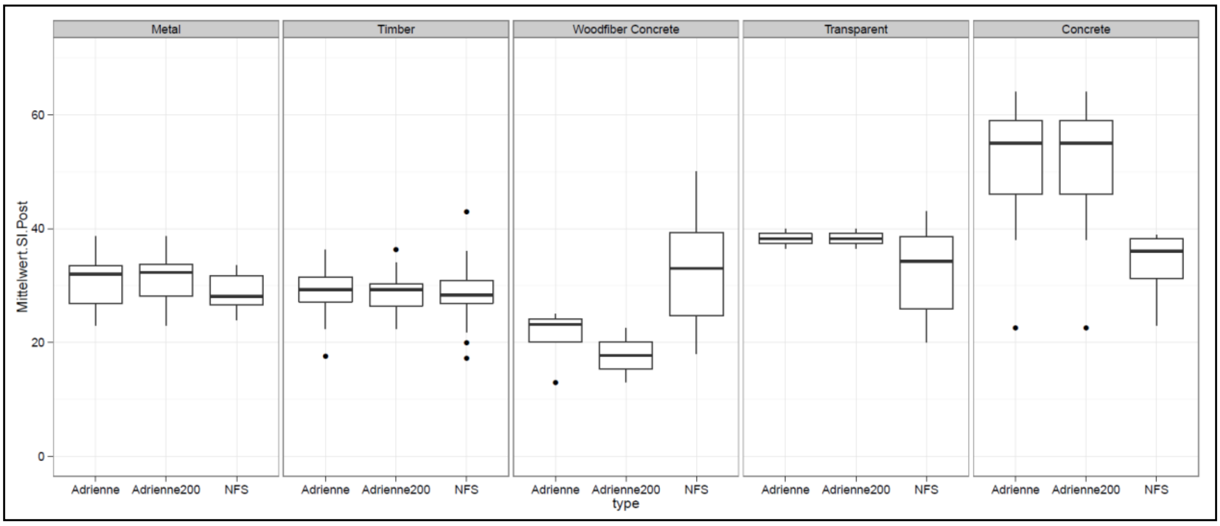


Figure 24: in-situ measurements of sound insulation at post: Comparison between French NFS method, CEN/TS 1793-5 (Adrienne) and CEN/TS 1793-5 (Adrienne) restricted to the 200Hz to 5 kHz frequency range

3.4 WP5 Holistic optimisation of NRD

The main challenge of this Work Package was to develop an original optimisation methodology dedicated to complex shape NRD, taking into account acoustic and non-acoustic parameters simultaneously through global performance indicators.

The goal was not to produce the "best optimised NRD", but instead to give the opportunity to engineers as well as manufacturers to re-use this approach for their own research.

3.4.1 Choice of best practice models

Sound propagation models

Four main 2D sound prediction models were selected to be the most pertinent for the purpose of accurately predicting complex shape NRD performances:

- The BEM (Boundary Element Method), very flexible to model noise barriers of complex shape including impedance jumps and curved surfaces. On the other hand, BEM ignores the effects of atmospheric gradients due to meteorological effects and should be used for predictions not too far from the NRD (100 m propagation max);
- The FDTD (Finite-Difference Time-Domain) model considering atmospheric refraction and therefore useful to include meteorological conditions in the optimization of barrier shapes. However, FDTD is a bit less flexible than BEM for modelling complex shapes;
- The TLM (Transfer Line Matrix) offering flexibility in the description of the geometry of the boundaries with atmospheric refraction taken into account;
- The TMM (Transfer Matrix Method) dedicated to the prediction of sound transmission and absorption through a multi-layered noise barrier.

We also suggest using hybrid models such as the FDTD-PE and BEM-PE (PE for Parabolic Equation model) for NRD effects at long ranges taking into account meteorological effects.

A 3D asymptotic model such as the Ray method is recommended when studying the global impact of NRD on realistic large built areas (see 3.4.4 hereafter).Then the model should be adapted to complex situations by including results from BEM, FDTD, TLM and TMM.

Optimisation models

As regards with selection of best optimisation models, our recommendations are:

- Concerning mono-objective optimizations the evolutionary strategy is the most relevant, since many parameters have to be simultaneously optimized;
- Concerning multiple-objective optimization, both approaches by aggregated methods and Pareto methods are advised;
- The construction feasibility of the optimized NRD should be taken into account in order to avoid unfeasible noise abatement solutions.

3.4.2 Acoustic and non-acoustic optimisation indicators

Acoustic indicators

Intrinsic optimisation means that one evaluates any acoustic performance in the vicinity of the noise barrier, ignoring its own environment and considering a point noise source. The performance indicators we used were those calculated in the relevant EN 1793 standards: the reflection index DL_{RI}, the transmission index DL_{SI} and the diffraction index $DL_{\Delta DI}$.

Extrinsic optimisations are achieved considering the NRD in its environment: real sound sources, infrastructure heights, topography and, eventually, buildings. We calculated the sound level difference ΔIL as the acoustic indicator, for receivers located on both sides of the infrastructure. ΔIL represents the acoustic gain obtained with an optimized NRD compared to the reference concrete barrier.

Environmental indicators

As a result of a specific Life-Cycle Assessment (LCA), a set of environmental indicators was proposed. Among them we recommend to utilize the four ones used in QUIESST: Energy, GWP (Global Warming Potential), Waste (non-hazardous and inert) and Water consumption. These environmental indicators were evaluated for a set of 8 common materials used in NRD engineering (wood concrete, timber…) on a basis of a common functional unit, chosen here to be the production of 1000 kg of material and its transport over 100 km. We also took into account the reference service life of each material exploited. Recommended values are available. We finally used the ratio of the indicator value to the one of the reference barrier.

Cost indicators

In our approach, the cost indicator was the sum of three parameters: construction, maintenance and demolition costs. Demolition costs included transportation but did not consider material re-use. Applicable values have been proposed. As previously, we used the ratio of the indicator value to the one of the reference barrier.

3.4.3 Holistic optimisation methodology

Description of the methodology

The different steps of this new holistic optimisation methodology are shown in Figure 25.

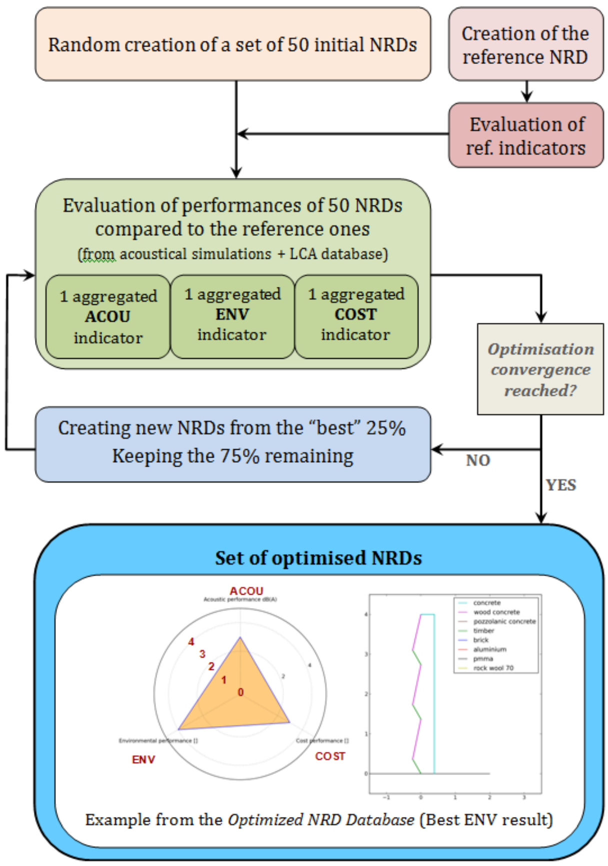


Figure 25: General flowchart of the holistic optimisation methodology

Starting with the random creation of a set of 50 different NRD within fixed NRD family and environmental situation (source/area/topography), an evaluation of the acoustic, environmental and cost indicators is achieved, and a linear averaging is done to obtain 3 *aggregated indicators*: *ACOU*, *ENV* and *COST*. All these indicators are compared to those obtained for the reference NRD: a straight, rigid concrete barrier. Then 12 new NRD (25% of 50) are created with limited changes (in shape and material) from the 12 "best" NRD they finally replace. Hence a new set of 50 NRD is revaluated. This process ends when the highest values of all indicators vary by less than 5% from an evaluation step to another.

Application to typical NRD families

This holistic optimisation methodology has been applied to acoustic and non-acoustic performances of 4 generic NRD families (Figure 26) in different environmental situations including road and railway sources, rural (absorbing ground) and urban (rigid ground) areas, as well as flat, embanked (+5 m) and depressed (-5 m) topographies.

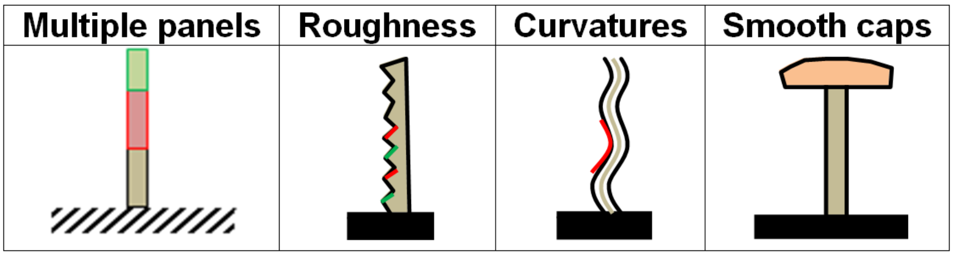


Figure 26: generic NRD families considered for the holistic approach

A grading system [12] has been applied to the 3 aggregated indicators in order to express them on a dimensionless scale ranging from 0 (bad) to 4 (very good). A radar plot display is recommended to present these 3 global NRD performance indicators.

Optimized NRD database

All extrinsic NRD optimisation results were recorded in a database that can be queried through a simple tool. The 1st step consists in selecting the type of source as well as the environmental configuration, the infrastructure topography and the NRD family (Figure 27).

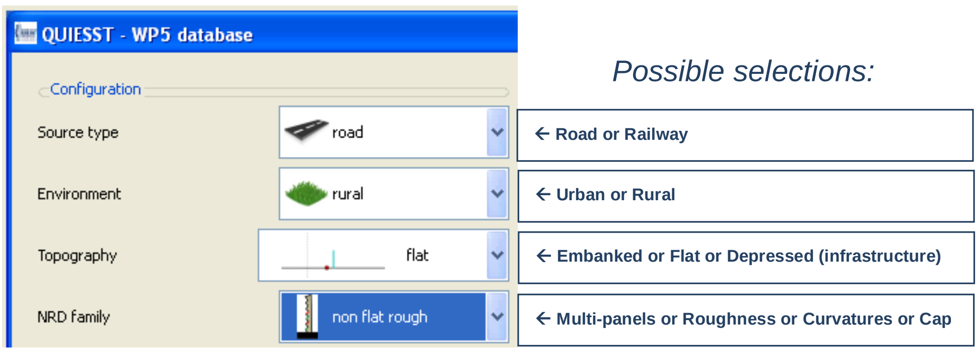


Figure 27: Query parameters of the Optimized NRD database

One also may select one of 3 following configurations for calculation of the *ACOU* indicator: receiver at the source side only (sound reflection), receiver at the receiver side only (sound diffraction), or receivers on both sides.

Then, the user has to select one optimized solution among the set of final optimized NRD obtained at the end of the optimization process described in Figure 25. To do so, the user should tune the three aggregated indicators *ACOU*, *ENV* and *COST* to the desired weights (in percentage), 0%, 50% and 100% meaning minimum, medium and highest importance, respectively (Figure 28).

In order to select the solution corresponding to the best *ACOU* aggregated indicator (whatever the *ENV* and *COST* indicators), one has to tune as follows: *ACOU*=100, *ENV*=0, *COST*=0. One can also display all results one by one, using the function “individuals”.

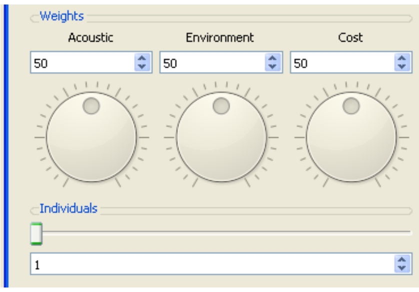


Figure 28: Weighting the 3 aggregated indicators ACOU, ENV and COST

Finally, the selected optimized solution is displayed, as shown in Figure 29, giving:

- The *general* shape of the optimized NRD in a vertical section,
- Materials used and their location on the NRD surface,
- The NRD optimization shape parameters (width, tilting, roughness size, etc.)
- The corresponding values of *ACOU*, *ENV* and *COST*

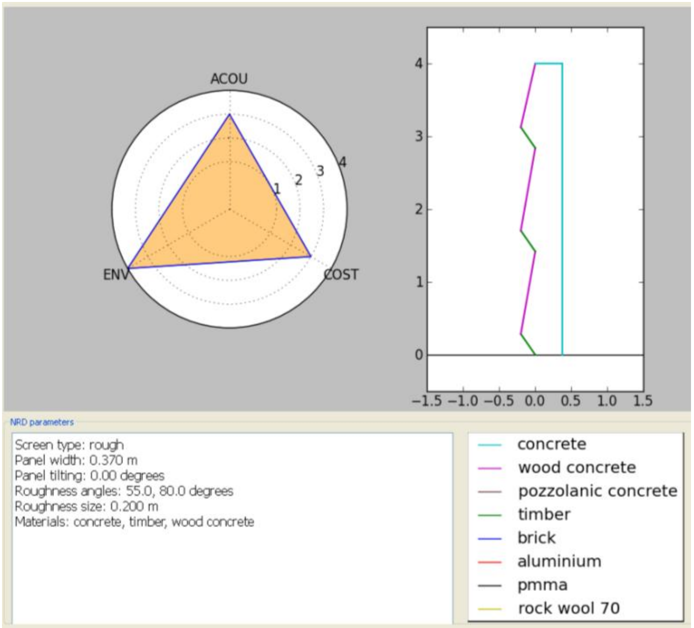


Figure 29: Example of result displayed by the Optimized NRD database tool

Example of use of the Optimized NRD database

An example of typical results one can get from the database is presented hereafter.

Considering the case of a strongly non-flat barrier along a motorway on a flat, rural terrain with the receiver at the source side only (sound reflection), we extracted three solutions optimised in priority for ACOU, ENV and COST (Figure 30), whatever the values of the two other aggregated indicators: one may note the great diversity in shapes and materials used depending of the choice of the indicators’ weightings.

The database could be re-used and adapted at the upstream phase of future traffic noise impact projects in order to globally assess the potential acoustic gain that may be obtained by optimising (in shape and in material type) a conventional noise barrier taking also into account both the environmental impacts and the cost efficiency.

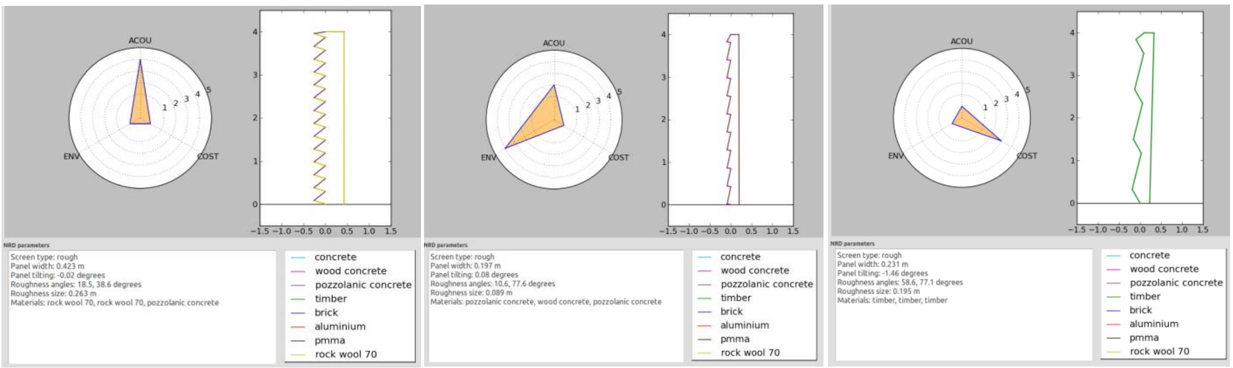


Figure 30: Results from the Optimized NRD database for a high ACOU, ENV, or COST values

3.4.4 Global impact

We also aimed at using the previously optimized NRD and placing them in a realistic 3D built environments. With the use of a sophisticated multidimensional interpolation model and a ray tracing method OASIS developed at CSTB (Figure 31), we showed the ability to determine how much these optimized NRD could reduce the amount of people exposed to high noise levels.

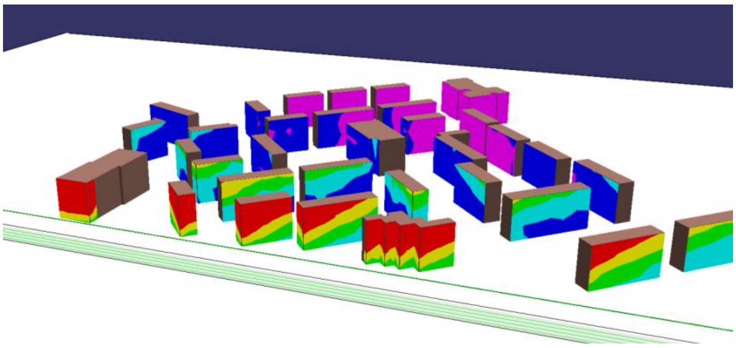


Figure 31: View of OASIS software integrating optimized NRD with facades noise maps

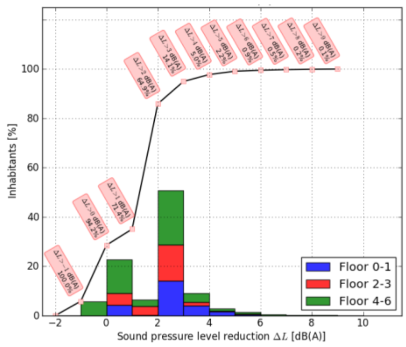


Figure 32: Example of sound level reduction histogram

Application

3 different types of dwellings were considered: collective (21 mH), semi-collective (9 mH) and individual. Different optimised NRD were tested. Final results were given through histograms showing for each of the studied cases (depending on type of optimized barrier, type of dwelling, road infrastructure) the proportion of inhabitants subject to a sound level abatement (ΔL) by step of 1 dB(A) (Figure 32). In this approach, we distinguished people living at lower, intermediate and upper floors.

We also calculated the *population exposure indicator* difference $\Delta L_{den,pop}$ that represents the difference between the $L_{den,pop}$ obtained with the reference NRD and the $L_{den,pop}$ obtained with the optimised NRD in terms of global sum of noise level of all residents on the most exposed facades: values of ΔL ranged from 0 to 8 dB(A), when average values on all receivers $\Delta L_{den,pop}$ were from 0 to 5 dB. The highest values of ΔL were obtained for the lower (ground and first) floors of the semi-collective housing, the 2nd and 3rd floors of the individual houses, and the upper floors of the collective housing.

Another way of presenting global results is to give for a specific case the proportion of population benefiting from a noise abatement of at least 3 dB(A): in this research, depending upon the type of optimised barrier and type of dwellings considered, the proportion varied from 1% to 70%, pointing out that *NRD optimization should be realised for very specific noise situations (sources/environment/receivers location).*

3.5 Sustainability

Assessing sustainability involves measuring and evaluating many and conflicting attributes in an unbiased way. In order to assist the relevant stakeholders to assess the sustainability of NRD projects with the view to complying with and supporting the transport and overall global sustainability agenda, the following key novel QUIESST outcomes are presented hereafter.

The result of the present research work will assist the relevant stakeholders to show a demonstrable commitment to achieving sustainability related objectives with respect to NRD.

During the research, we concentrated our analysis on 13 main NRD types as listed in table 2:

Table 2 - Main NRD Types considered for sustainability

No.	Key	Noise Barrier
1	SM	Steel supporting structure + Metal panels
2	SC	Steel support structure + Concrete panels
3	ST	Steel supporting structure + Timber panels
4	SG	Steel supporting structure + Transparent modules
5	C	Self-supporting concrete or brick system
6	SP	Steel supporting structure with plastic panels
7	CT	Tunnel-concrete structure
8	STu	Tunnel-steel structure
9	GT	Tunnel with transparent panels
10	GB	Green barrier
11	GA	Gabion with stones
12	EB	Earth barrier(earth berm)
13	PVNB	PVNB (photovoltaic noise barrier)

3.5.1 Defining 'Sustainability' for NRD

NRD sustainability has been defined as the following: *'The optimal consideration of technical, environmental, economic and social factors during the design, construction, maintenance and repair, and removal/demolition stages of NRD projects'.*

Figure 33 illustrates how sustainability factors should be incorporated throughout the lifecycle of NRD.

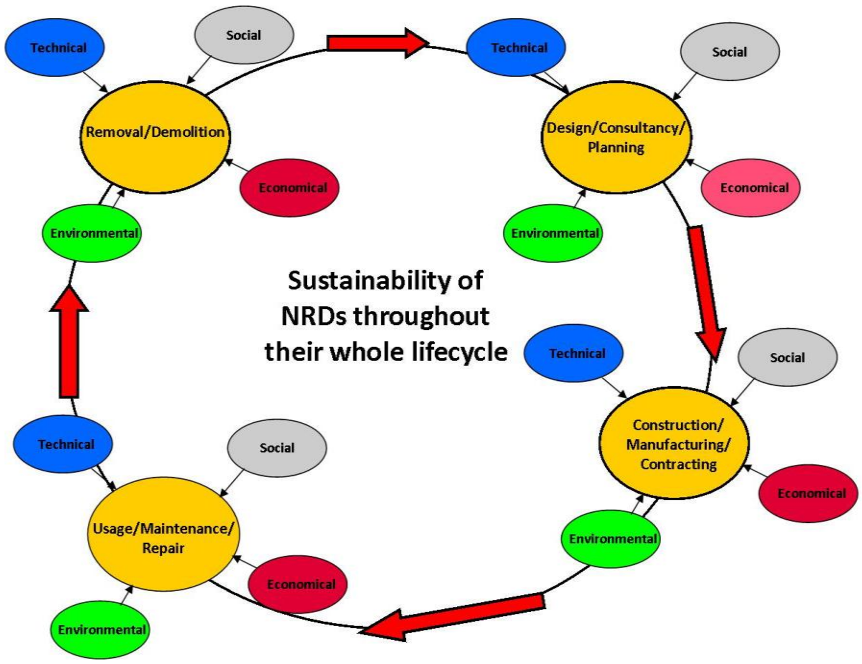


Figure 33: ***Sustainability factors to consider throughout the whole lifecycle of NRD***

3.5.2 Sustainability Key Performance Indicators for NRD projects

The Sustainability Key Performance Indicators (KPIs) are essential components in the overall assessment of progress towards sustainable development. They are useful for monitoring and measuring the sustainability state of a NRD project by considering a manageable number of variables considered critical to sustainability. Table 3 shows the subsequent generic set of sustainability KPIs for NRD projects.

Table 3 - Generic set of sustainability KPIs for NRD projects

KPI n° per Sustainability Factor	NRD Sustainability Assessment Criteria	Key Performance Indicator (possible way of measurement)	Benchmark to Improve Sustainability Performance
Social	**Acoustic comfort**	No. of complaints from residents	Reduce
	Work related sicknesses and Injuries	No. of reported health incidents/work related injuries due to working conditions	Reduce
	Vulnerability of the barrier to vandalism	No. of reported acts of vandalism to the NRD (includes graffiti)	Reduce
	Glare control for road users	No. of reported road accidents due to the glare from the noise barrier to the emergency services	Reduce
	Crossing facilities such as footbridges/ underpasses	No. of complaints from the impacted community due to the lack of adequate crossing facilities	Reduce
	Acceptance of the architectural design of the NRD	No. of complaints due to the architectural design of the NRD	Reduce
	Loss of view for residents and road users	No. of complaints from residents and road users due to loss of views	Reduce
	Barrier design/type via public consultation	No. of projects that included (and implemented) a stakeholder engagement plan	Increase
	Use of local companies and labour	No. of local companies employed/No. of local labour opportunities realised	Increase
	Social acceptability of the NRD	No. of complaints from residents	Reduce
Technical	**Use of new materials**	% new(virgin)material content/m3 or m² or m	Reduce
	Use of recycled materials	% recycled material content/m3 or m² or m	Increase
	Local materials	% local material content/m3 or m² or m	Increase
	Whole barrier service life	Years	Increase or maintain
	Acoustic durability in-situ	years (yrs.) until acoustic performance drops below the accepted level	Increase or maintain
	Buildability/constructability of the noise barrier	square meter/day to build the noise barrier system	Increase
	Durability	No. of years the NRD system can be used in comparison to its design life	Increase
Environmental	**Loss of land**	'Footprint' (m²) of the NRD/m or total length	Reduce
	Overall waste production	kg/m²	Reduce
	Materials used for energy recovery at the end of its life	% material recoverable for energy/m²	Increase
	Recyclability potential	% recyclable /m²	Increase
	Re-use potential	% re-usable/m²	Increase
	Carbon footprint (global warning potential)	kg CO2equivalent/m²	Reduce
	Water footprint	litre/m²	Reduce
	Embodied energy content (Use of primary energy resources/consumption)	MJ/m²	Reduce
	Renewable energy production (Photovoltaic/small scale wind turbines)	MJ/m²	Increase
Economic	**Capital costs**	Euro/ m²	Reduce
	Maintenance and repair costs	Euro/ m²	Reduce
	Removal/replacement costs	Euro/ m²	Reduce
	Income generation	Euro/ m²	Increase

No research informed set of sustainability key performances indicators specifically for NRD projects existed. The use of the set of industry and project specific sustainability KPIs developed in QUIESST will now allow the relevant stakeholders to measure, monitor, benchmark, and report on key sustainability related issues for NRD.

3.5.3 Relevant Generic Sustainability Criteria for Assessing the Sustainability of NRD

Sustainability criteria highlight issues that are important for sustainability assessment. Primary criteria are not usually measurable, and will typically have a set of secondary criteria which define the primary criteria. Secondary criteria underpin the primary. These are measured through the use of indicators that are the ‘Unit of measurement’ for secondary criteria which may be either quantitative or qualitative. In some cases, secondary criteria may have further attributes/tertiary criteria that define them further and are measured through the use indicators, too.

A ‘Top-Down-Bottom-Up (TDBU)’ research strategy was developed and implemented to create and validate the relevant generic set of sustainability criteria for NRD projects. This mainly involved gathering expert opinion from the relevant stakeholders through a series of workshops, questionnaires and interviews. Table 4 shows the resulting 22 sustainability primary criteria defined for NRD. These ‘22 primary criteria’ highlight all the major issues to consider, and assess across each sustainability factor. In total, 141 criteria form the complete sustainability hierarchy for NRD, of which, 92 are directly measurable.

Table 4 - Summary of sustainability factors and primary criteria ranked in order of importance

Sustainability Factor	Primary Criteria
Technical	-Material selection -Buildability/constructability -Flexibility and adaptability
Environmental	-Energy -Land use -Air quality and climate change -Flora and fauna -Water -Waste
Economic	-Life cycle cost -Green value - Financial sources -Compensation cost -Affect on local residential/commercial property prices -Contractual and procurement type
Social	-Safety and security -Health and well-being -Severance/separation -Social acceptance -Architectural design and local context -Community engagement -Local employment and engagement with local business

However, it should be noted that optimising a particular criterion in isolation, e.g. cost and technical performance, does not necessary increase the sustainability of NRD projects.

Indeed, it is the combination of the outcome of *all* measured criteria in relation to each other in an equitable way within the defined sustainability framework which shows the relative sustainability of the project as a whole. Multi Criteria Analysis (MCA) tools offer one viable approach to assessing multiple NRD sustainability criteria in conjunction with each other in an unbiased way to generate an index value to denote overall sustainability performance.

3.5.4 Generic database of sustainability criteria per main NRD type

Using the generic set of NRD sustainability criteria previously established, research was carried out to generate and collect indicative sustainability criteria values for the 13 main NRD types. Results have been tabulated into a database (see Figure 34) so that the sustainability performances of the 13 NRD types can be viewed and compared to either:

1. benchmark the sustainability performance of a given NRD type with respect to the average/generic data provided in the database for the NRD type in question, or
2. use the generic data in place of collecting site/system specific data when it is considered impractical (or in some cases not necessary) to conduct the sustainability assessment, and so reduce significant analysis time and costs.

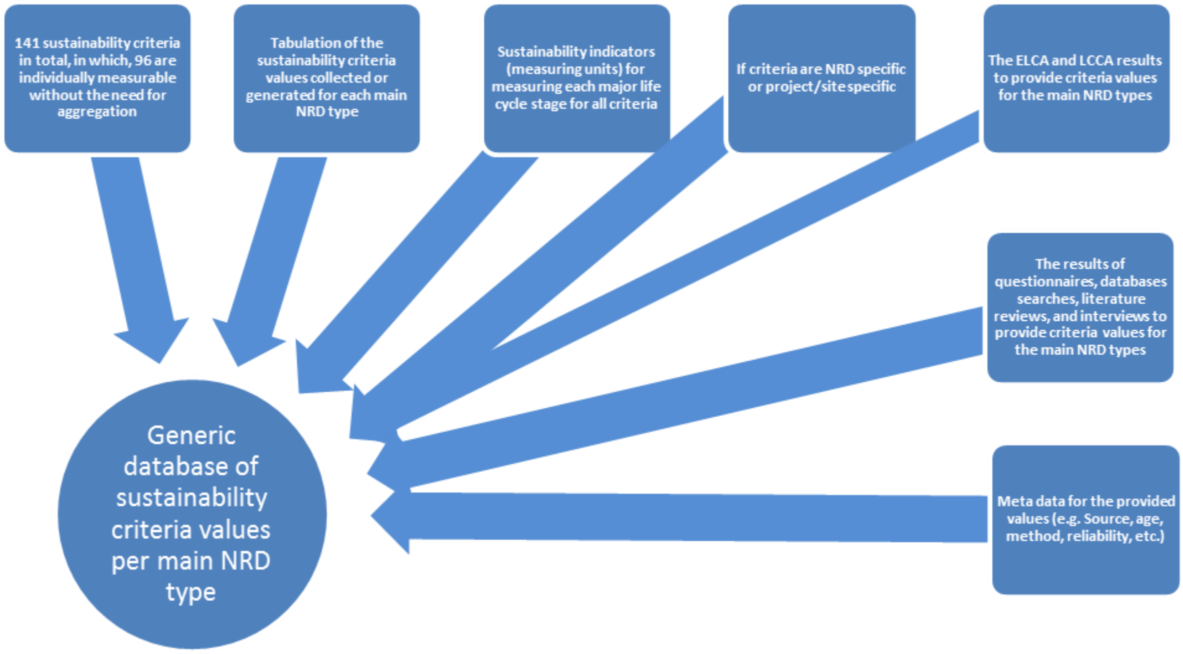


Figure 34: Key highlights of the generic database of sustainability criteria values

3.5.5 Stages for Assessing the Sustainability of NRD via Multi Criteria Analysis Approaches (MCA)

The assessment of the sustainability of NRD is a multi-criteria analysis (MCA) problem as it involves selecting and assessing multiple conflicting NRD sustainability criteria. Figure 35 shows the main stages for assessing the sustainability of NRD via MCA approaches.

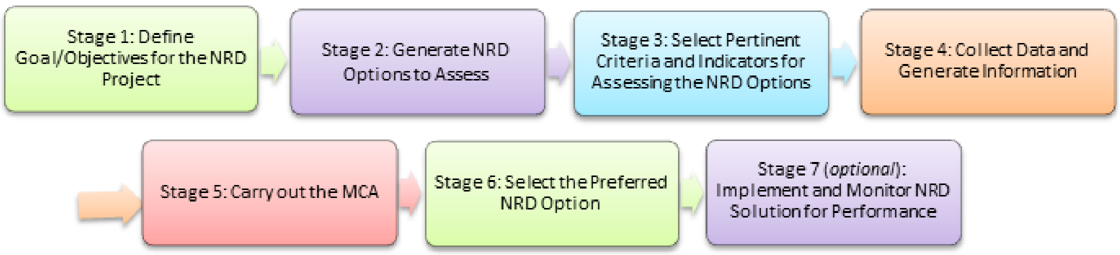


Figure 35: Stages for assessing the sustainability of NRD projects

Any MCA tools are able to generate a sustainability assessment index score in the range 0 to 1 or -1 to 1 for potential design and build NRD solutions, or built and operating NRD projects, relative to either the set of alternatives considered, or to a user defined baseline.

3.5.6 An Example Analysis of Assessing the Sustainability of NRD

An example of assessing the sustainability of a given NRD type (a steel noise barrier) using a small set of selected criteria and generic NRD sustainability performance data is given below. It should be noted that the assessment of sustainability is always a relative concept.

There are principally two relative assessment approaches:

1. The sustainability assessment is relative to the set of alternatives (or options) being considered, or
2. The sustainability assessment is relative to an absolute state/user defined baseline.

Approach 1 is well-suited for design/planning/procuring selection problems, and approach 2 is well-suited for determining the absolute sustainability of a single existing built NRD project, i.e. the assessment is not relative to any other built project.

The steel noise barrier type in this example will be assessed relative to the OHIS (approach 2) in order to assess its sustainability in absolute terms.

The SAW, PROMETHEE, and ELECTRE 3 MCA tools have been used to assess the sustainability of ten selected criteria for the steel noise barrier example.

Table 4 presents the relevant overall index values/preference scores generated by SAW, PROMETHEE, and ELECTRE 3 to denote the overall sustainability performance of the assessed noise barrier.

Table 5 - NRD sustainability preference index scores generated by the SAW, PROMETHEE, and ELECTRE 3 multi criteria sustainability analysis for the steel noise barrier type example

	NRD Sustainability Overall Preference/Index Scores for the Steel Noise Barrier Example	
	OHIS	**Steel Noise Barrier Type**
SAW	1	0.36
PROMETHEE	n/a	-1
ELECTRE 3	n/a	0.12

Whilst a conclusion cannot be drawn based on ten sustainability criteria, only the results of the analysis for the Steel Noise Barrier presented in Table 5 show a relative low level of sustainability for all three MCA methods used.

3.5.7 Overall Benefits of the NRD Sustainability Research and Contribution to the State of the Art for the NRD Industry

NRD Industrial Associations have been directly involved in this research both at national and European level and relevant benefits are expected from a common approach in sustainability evaluation and assessment.

NRD manufacturers have always shown a great interest in sustainability assessment due to its construction products being developed due to the environmental need of reducing noise disturbance in residential areas.

Sustainability assessment method developed during this research for NRD may also help the NRD Industry in the future to face new challenges regarding product qualification and testing against legislation and standards. With respect to the previous Construction Product Directive (89/106/EEC - CPD) some relevant new challenging requirements have been included.

Sustainability has been specifically addressed with the new 7^{th} basic requirement.

NRD considered among “road equipment’s” are already covered by approved harmonized standard referring to EN 14388. Updating of the existing standard is then foreseen and the method developed within this research project will be an essential aid to define evaluation procedures to meet sustainability as the 7^{th} basic requirement. NRD industry can then benefit for coming first on the market with a full set of standards.

4 Impacts

4.1 Potential impacts

The first major impact of QUIESST will be the direct consideration of its outcomes at the coming meetings of the CEN TC226/WG6 (road NRD) and CEN TC256/SC1/WG40 (railway noise barriers): those meetings will be held on the 8th, 9th and 10th of April 2013 in Paris.

Those working groups are drafting the EU / CEN standards for the NRD products and use: they reply to the Construction Product Directive (CPD), the new Construction Product Regulation (CPR) and the Directive on Interoperability of transports.

Thanks to the (strongly expected) results of QUIESST, the following points will be considered by the working groups' experts:

1. submission of a new topic / new standard item on Far Field effects in the road and railway standards for NRD (WP2);
2. (re)drafting the EN1793-5 and 6 (roads) and corresponding EN 16272-5 and 6 (rail) with the new QUIESST methods in order to reach consensus toward true harmonized standards (WP3);
3. submission a new topic on Sustainability in the road and railway standards for NRD (WP6).

Of course, this will also be the perfect place to distribute the Guidebook to all the stakeholders present: manufacturers, authorities, road / railway companies, experts… The results of the 1st EU NRD database (WP4) and the optimization methodologies described in WP5 are also of main interest for all.

The standardization working groups are the best to value the outcomes of QUIESST: this will be assured by Jean-Pierre Clairbois, who is the convenor of TC226/WG6, and Massimo Garai, the TC256/SC1/WG40's convenor.

4.1.1 Holistic noise abatement

Acting on sound propagation, NRD's global performances can vary from a few decibels (if use in an inappropriate manner – what is unfortunately too often the case), or reaching up to 20 dB (while using appropriate design, materials and infrastructure integration). Facing this huge scale of performances, one clearly understands the QUIESST objectives, that is to optimize NRD global performance thanks to: product characterization relevant of the actual intended use, understanding how the relevant "true" intrinsic performances can act in the far field, a better and fairly balanced knowledge of EU NRD product market, and optimization strategies that really consider noise propagation in a holistic approach.

By optimizing all the knowledge, the methods, the use and the global performance of NRD to reduce noise, QUIESST (WP2, 3, 4, 5 and 6) strongly contributes to improve ground transport noise abatement.

4.1.2 Reducing the amount of people exposed to noise

Reducing environmental noise of ground transport by 10 to 20 dB is a challenging objective; however, it is meaningless if it does not correspond to a relevant reduction of the amount of people exposed to noise, which is the target objective of the 2002/49/EC END Directive.

QUIESST not only addresses a more relevant characterization of NRD, whatever their materials, shape and design, but also the global NRD capability to reduce environmental noise at all the steps of the process, i.e.: from the vehicles to the finally exposed habited areas: by improving the knowledge about the near / far field relationship and by improving NRD with adapted method of characterizing their acoustic performances, a new NRD should give either a better noise reduction, or should be able to give similar performances to existing ones, but in such a way that some gain is found (lower height, design more integrated to the landscape, better sustainability)

NRD ability to reduce the amount of people exposed to noise is a key impact, more specifically addressed within WP5.

4.1.3 Increasing NRD sustainability

Only optimizing noise reduction properties of NRD (without considering their sustainability and, in particular, their impact on the environment AND on natural resources and the social consequences that NRD can bring in the human environment) is the worst mistake done up to now.

More optimal NRD as a result of research carried out in WP2, 3, 4 and 5 will impact less on the environment and contribute less to climate change; it will be less costly as well.

On the other hand, the "intrinsic" NRD sustainability is a characteristic which was not yet defined, and needed to be. WP6 provides a relevant method for assessing the sustainability of NRD at all stages in the life of a NRD (design, construction, maintenance and repair and decommissioning), including their carbon footprint.

Through WP6, QUIESST contributes to the reduction of the impact on climate change when using NRD, and should reduce the use of natural resources through more sustainable materials and the usage of recycled ones.

4.1.4 Economic impacts

By delivering optimization strategies to all the relevant stakeholders, QUIESST helps to improve the costs / benefits ratio of NRD global performance, what will finally benefit to the whole Community.

On the other hand, QUIESST will have a very important impact on promoting European NRD Industry and also the European experts abroad. It could be relevant to mention how important it is that QUIESST helps European NRD Industry to improve their products design and promote them abroad.

In order to guarantee that those economic impacts will be achieved, relevant representatives of European road and rail infrastructures / authorities, European NRD Industry, as well as consulting companies were involved in the project and the future use will be continued within the CEN TC226/WG6 and CEN TC256/SC1/WG40 working groups. The public character of all the QUIESST results and outcomes has been also decided in order to reach all the concerned professionals, even not working on standards.

4.1.5 Policy concerns

QUIESST replies to European policies requirements: the whole project clearly targets the achievement of the END Directive main objectives, i.e.: not only noise reduction, but also the reduced amount of people exposed to noise.

On the other hand, the project clearly addresses the Construction Product Directive (CPD) and the new Construction Product Regulation (CPR) as well as the Directivity on the Interoperability of transports., i.e.: the requirements to place products on the market only if they are fit for their intended use (WP2 to 4), and doing so in an economically reasonable working life (WP3 to 6), providing (methods) standards about essential characteristics that qualify products in a common, fair and relevant manner (WP 3).

Finally, QUIESST replies to the strategy on sustainability drafted within the EU White Paper on Transport Policy, through its exhaustive analysis of the sustainability aspects within WP6.

4.2 Dissemination and exploitation of project results

In order to increase the awareness of research, industry, users and public authorities of the developed solution and the project in general, a broad range of dissemination activities has been provided in QUIESST (in line with the tasks envisaged as part of this strategy):

- Production of a Guidebook at the end of the project;
- A dedicated website;
- Leaflets distributed by the partners and diffused during relevant events;
- Contributions to technical literature, research journal papers, articles in newspapers (science and technology section);
- Organization of two open workshops for selected attendants (amongst which different stakeholders);
- Participation on international workshops and conferences and submission of abstracts if adequate.

Throughout the project, the project partners participated in specialized conferences, events, etc. to present the initiative or to focus on specific aspects of the project.

The QUIESST partners also liaised with HOSANNAH project partners.

(Note: the HOSANNA project was different from QUIESST, but the topic stays common, i.e. the noise reduction. HOSANNA considered how to optimize green areas, green surfaces and other natural elements in combination with artificial elements in order to reduce the noise impact, while QUIESST targeted the manufactured NRD, and the extrinsic effect of their intrinsic acoustic performances in near and far field, while considering sustainability of NRD all along their lifetime).

Evident events like the annual INTER NOISE congress, as well as EURO NOISE congresses were considered: successful specific sessions dedicated to QUIESST have been organized . International road Congress like the International Road Federation Meeting (IRF) to which ERF is directly linked have been also attended.

Not less than 39 papers and 6 publications derived from the QUIESST research (see list hereafter).

Interaction with the European Noise Barrier was also direct, thanks to common participants: this independent platform animates the dialogue between noise barriers manufacturers, European Institutions and other different stakeholders (infrastructure operators, etc…).

Exploitation is directly accessible to public, as almost all the deliverables are public; for instance, the “Guidebook to NRD optimization” sums up all the work done, including: the WP2 engineering method for the near field / far field relationship, the new measurement method resulting from WP3, the European database of the acoustic properties of manufactured NRD from WP4, the holistic approach from WP5 and the sustainability conclusions from WP6 . this Guidebook targets to be reference tool for the industrials and all the stakeholders.

Finally, QUIESST outcomes are to be directly considered at the coming CEN TC226/WG6 (road NRD) and CEN TC256/SC1/WG40 (railway noise barriers) meetings.

Those working groups will guarantee the continuous exploitation of the QUIESST results.

At the following pages, we present a list of the papers, the publications and the relevant events at which the QUIESST results have been disseminated.

CONFERENCES & PAPERS

No less than 39 papers have been presented at major events as scientific congress, workshops and professional expo, those papers are directly downloadable on the QUIESST website:

1. **Fusco I., Clairbois J-P., De Roo F., Garai M., Conter M., Defrance J., Oltean-Dumbrava C.** **"***Quietening European roads"* IRF World Meeting 2010, Lisbon, Portugal, 25-28 May 2010
2. **Clairbois J-P., De Roo F., Garai M., Conter M., Defrance J., Oltean-Dumbrava C., Fusco I.** **"***QUIESST: toward a better knowledge and understanding of how efficient noise barriers could actually be",* Noise in the built environment Conference, University of Ghent, Belgium 29-30 April 2010
3. **Brero G.** *"Nowe trendy I projekty rpzwiazan technicznych ekranow w Europie ze szczegolnym uwzglednieniem Wloch I Szwajcarii, a takze rola I cele"*, European Noise Barrier Federation, Krakow, Poland, 24-25 May 2010
4. **Clairbois J-P., De Roo F., Garai M., Conter M., Defrance J., Oltean-Dumbrava C., Fusco I.** **"***QUIESST: toward a better knowledge and understanding of how efficient noise barriers could actually be"*, INTERNOISE 2010, Lisbon, Portugal 15-16 June 2010
5. **Garai M., Guidorzi P.** *"Effect of slit-shaped leaks on airborne sound insulation of noise barriers"*, INTERNOISE 2010, Lisbon, Portugal 15-16 June 2010
6. **Aretz M., Dietrich P., Behler G.,** *"Comparison of in situ measuring methods for absorption and surface impedances"*, INTERNOISE 2010, Lisbon, Portugal 15-16 June 2010
7. **Oltean-Dumbrava C., Watts G., Miah A.** *"Review of the sustainability of noise reducing devices for EU project QUIESST"*, International Symposium on Sustainability in Acoustics, ISSA 2010, Auckland, New Zealand, 29-31 August 2010
8. **Clairbois J-P., De Roo F., Garai M., Conter M., Defrance J., Oltean-Dumbrava C., Fusco I.** **"***QUIESST: toward a better knowledge and understanding of how efficient noise barriers could actually be",* 1st Mediterranean Congress on Acoustics, Rabat-Salé, Morocco 28-30 October 2010
9. **Lutgendorf D., de Roo F., van der Eerden F., Jean P., Ecotière D., Dutilleux G.** *"Numerical simulation of the sound reflection effects of noise barriers in near and far field",* FORUM ACUSTICUM 2011, Aalborg, Denmark, 27 June - 1 July 2011
10. **Clairbois J-P., De Roo F., Garai M., Conter M., Defrance J., Oltean-Dumbrava C., Fusco I.** *"QUIESST: mid-term report"*, INTERNOISE 2011, Osaka, Japan. 4-7 September 2011
11. **van der Eerden F., Lutgendorf D., de Roo F.** *"Simulating complex noise barrier reflections",* INTERNOISE 2011, Osaka, Japan.4-7 September 2011
12. **P. Guidorzi, M. Garai "***Reflection index measurement on noise barriers with the Adrienne method: source directivity investigation and microphone grid implementation*", INTERNOISE 2011, Osaka, Japan. 4-7 September 2011
13. **Oltean-Dumbrava C., Watts G., Miah A.** *"Primary sustainability criteria for assessing the sustainability of noise reducing devices for EU Project QUIESST"*, INTERNOISE 2011, Osaka, Japan.4-7 September 2011
14. **Leissing T., Grannec F., Defrance J., Jean P., Lutgendorf D., Heinkele C., Clairbois J-P.,** *"Holistic optimisation of noise reducing devices"*, Acoustics 2012, Nantes, France, 23-27 April 2012
15. **Conter M., Wehr R., Haider M., Gasparoni S.,** *"Influence of ground reflections and loudspeaker directivity on measurements of in-situ sound absorption"*, Acoustics 2012, Nantes, France, 23-27 April 2012

16. **Glorieux C., Rychtáriková M.,** *"Self-calibrating method for sound reflection index measurements"*, Acoustics 2012, Nantes, France, 23-27 April 2012

17. **Leissing T., Defrance J., Jean P., Guigou-Carter C., Clairbois J-P.,** *"Optimization of noise reducing device intrinsic performances",* Acoustics 2012, Hong-Kong, 13-18 May 2012

18. **Brero G., Fusco I.** *"Barriere antirumore per la mitigazione del rumore delle infrastrutture di trasporto"*, Strade&Autostrade 6-2010

19. **Clairbois J-P., De Roo F., Garai M., Conter M., Defrance J., Oltean-Dumbrava C., Fusco I.** *"QUIESST: third-term progress report"*, EURONOISE 2012, Prague, Czech Republic, 10-13 June 2012

20. **Lutgendorf D., Wessels P.W., van der Eerden F., de Roo F.** *"Reflection performance of noise barriers in the far field"*, EURONOISE 2012, Prague, Czech Republic, 10-13 June 2012

21. **Guidorzi P., Klepáček J., Garai M.**, *"On the repeatability of reflection index measurements on noise barriers"* EURONOISE 2012, Prague, Czech Republic, 10-13 June 2012

22. **Wehr R., Conter M., Haider M., Gasparoni S., "***Far-Field Measurements of the Acoustic properties of Noise Barriers"* EURONOISE 2012, Prague, Czech Republic, 10-13 June 2012

23. **Oltean-Dumbrava C., Watts G., Miah A.** "*Defining sustainability key performance indicators for measuring, monitoring, and reporting the sustainability performances of noise reducing devices for EU project QUIESST"*, EURONOISE 2012, Prague, 10-13 June 2012

24. **Clairbois J-P., De Roo F., Garai M., Conter M., Defrance J., Oltean-Dumbrava C., Fusco I.** *"QUIESST: third-term progress report"*, INTERNOISE 2012, New York, USA, 19-22 August 2012

25. **Garai M., Guidorzi P., Barbaresi L.,** *"Progress in sound reflection measurements on noise barriers in situ"* INTERNOISE 2012, New York, USA, 19-22 August 2012

26. **Conter M., Haider M., Breuss S. , Czuka M.,** *"Structure and Use of a new Database for the acoustic Performance of Noise Barriers in Europe"*, INTERNOISE 2012, New York, USA 19-22 August 2012

27. **Wehr R., Conter M., Haider M.,** *"Investigations on the Influence of Source Directivity for Measurements of in-situ Sound Absorption"*, INTERNOISE 2012, New York, USA 19-22 August 2012

28. **Defrance J., Leissing T., Grannec F., Jean P., Lutgendorf D., Heinkele C., Clairbois J-P.,** *"Holistic optimization of noise barriers from acoustical and non-acoustical parameters"*, INTERNOISE 2012, New York, USA, 19-22 August 2012

29. **Oltean-Dumbrava C., Watts G., Miah A.** "*Generic database of sustainability criteria values per main noise reducing device type for EU project QUIESST"*, INTERNOISE 2012, New York, USA 19-22 August 2012

30. **Behler G., Dietrich P., Vorlander M.** *"Multi-Channel Measurements for the Qualification of Noise Barriers In Situ, Discussion of Uncertainty Factors"*, INTERNOISE 2012, New York, USA 19-22 August 2012

31. **Rychtáriková M., Roozen N.B., Chmelík V., Geentjens G., Bruyninckx W., Wursten E., Frederickx R., Glorieux C.,** *"Determination of the sound reflection index of noise barriers: guidelines to improve the measurement accuracy"*, INTERNOISE 2012, New York, USA 19-22 August 2012

32. **Brero G., Durso C.** *"Noise Measures ERF",* Serbian Noise Congress, Belgrade, Serbia, 7 November 2012

33. **Garai M., Guidorzi P., Schoen E.,** *"Assessing the repeatability and reproducibility of in situ measurements of sound reflection and airborne sound insulation index of noise barriers"* Atti AIA-DAGA 2013, Merano, Italy,18-22 March 2013

34. **Conter M., Czuka M., Breuss S., Haider M.:** *"European Database of Noise Reducing Devices"* AIA-DAGA 2013 Conference on Acoustics EAA Euroregio, Merano, Italy, 18-22 March 2013

35. **Garai M., Guidorzi P.,** *"In-situ measurements of sound reflection and sound insulation of noise barriers: validation by means of signal-to-noise ratio calculations"* ICA 2013, Montreal, Canada 2-7 June 2013

36. **de Roo F.,** *"Assessment of reflectivity of noise barriers in the far field – QUIESST method compared to traditional approach*", INTERNOISE 2013, 15-18 September 2013, Innsbruck, Austria

37. **Garai M., Guidorzi P.,** *"On the declaration of the measurement uncertainty of airborne sound insulation of noise barriers*", INTERNOISE 2013, 15-18 September 2013, Innsbruck, Austria

38. **Conter M.,** *"QUIESST Database on intrinsic acoustic performances of European Noise Reducing Devices*", INTERNOISE 2013, 15-18 September 2013, Innsbruck, Austria

39. **Oltean-Dumbrava C., Watts G., Miah A.,** *"The sustainability assessment of noise barriers for EU project QUIESST: A case study*", INTERNOISE 2013, 15-18 September 2013, Innsbruck, Austria

PUBLICATIONS

4 publications are already available while 2 other ones are under review:

40. **Oltean-Dumbrava C., Watts G., Miah A.,** *"Procurement of Sustainable Noise-Reducing Devices: State-of-the-Art Review from EU Project QUIESST"* Journal of Management in Engineering", Vol. 28(3) (2012) pp.324–329

41. **Oltean-Dumbrava C., Watts G., Miah A.** *"Transport Infrastructure: making more sustainable decisions for noise reduction"*, ELSEVIER Journal of Cleaner Production, Vol. 42 (2013) pp. 58 – 68

42. **Brero G., Oltean-Dumbrava C., Perazzi M.** *"Infrastrutture di trasporto sostenibili: il caso delle barriere antirumore"*, Costruzioni Metalliche (Professional Journal), Vol. 6, Nov Dic 2012, pp. 62 – 65

43. **J-P. Clairbois, F. de Roo, M. Garai, M. Conter, J. Defrance, C. A. Oltean-Dumbrava, C. Durso,** *"Guidebook to Noise Reducing Devices optimisation",* QUIESST Project, European Community's 7th FWP (FP7/2007-2013), Grant agreement n°SCP8-GA-2009-233730, 10 December 2012

44. **Oltean-Dumbrava C. Watts G., Miah A.** *"Determining the relevant primary sustainability criteria for assessing the sustainability of noise reducing devices for EU Project QUIESST",* submitted to the International Journal of Sustainable Transportation October 2011, pending review.

45. **Oltean-Dumbrava C., Watts G., Miah A.** *"Expounding the 'Top-Down-Bottom-Up' Methodology for Eliciting Bespoke Sets of Sustainability Assessment Criteria for Unique Civil Engineering/Infrastructure Projects"* submitted to the ASCE Journal of Management in Engineering, 2012, pending review.

LIST OF DISSEMINATION ACTIVITIES

The list is presented at the following page.

5 QUIESST public website

The QUIESSY dedicated public website is: http://www.quiesst.eu/

LIST OF DISSEMINATION ACTIVITIES

	type of activity	participants	title	date/period	place	type of audience	size of audience	Countries addressed
1	CEN Working Group Meeting	Clairbois J.-P.	TC 226/WG6	17-18/02/ 2010	Brussels	Experts	25	European Countries
2	CEN Working Group Meeting	Garai M.	TC 256/SC1 / WG40	19/02/2010	Brussels	Experts	20	European Countries
3	Conference	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava	Noise in the built environment	29-30/04/2010	Ghent University, Belgium	Scientific Community	100	European Countries
4	Conference	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava C.	IRF 2010 World Meeting	25-28/05/2010	Lisbon, Portugal	Industry	1500	Worldwide
5	Presentation	Brero G.	European Noise Barrier Federation Meeting	24-25/05/2010	Krakow Poland	Industry	30	European Countries
6	Conference	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava C.	INTERNOISE 2010	15-16/06/2010	Lisbon, Portugal	Scientific Community Industry	1200	European Countries
7	Symposium	Oltean-Dumbrava C., Watts G., Behler G.	International Symposium on Sustainability in Acoustics	29-31/08/2010	Auckland, New Zealand	Scientific Community Industry	500	Worldwide
8	CEN Working Group Meeting	Garai M.	TC 256/ SC1 / WG40	4/10/2010	Tenerife, Spain	Experts	12	European Countries
9	CEN Working Group Meeting	Clairbois J.-P.	TC226 / WG6	5-6/10/2010	Tenerife, Spain	Experts	20	European Countries
10	Congress	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava C.	1st Mediterranean Congress on Acoustics	28-30/10/2010	Rabat-Salé Morocco	Scientific Community	60	Mediterranean Countries
11	Workshop	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava C	1st QUIESST Publlic Workshop	11-12/11/2010	Dortmund Germany	Scientific Community		European Countries
12	Conference	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava C	Lärmschutz 2010	11-12/11/2010	Dortmund Germany	Scientific Community Industry	40	European Countries
13	CEN Working Group Meeting	Garai M.	TC 256/ SC1 / WG40	8/02/2011	Luxembourg	Experts	15	European Countries
14	CEN Working Group Meeting	Clairbois J.-P.	TC 226 / WG6	9/02/2011	Luxembourg	Experts	20	European Countries
15	Worldwide Event on Sustainability	Clairbois J.-P. Cordero R.	Challenge Bibendum 2011	18-22/05/2011	Berlin, Germany	Scientific Community	7200	Worldwide
16	Conference	Lutgendorf D., de Roo F., Garai M., Conter M;, Defrance J., Oltean-Dumbrava C.,Fusco I.	FORUM ACUSTICUM 2011	27/06/2011– 1/07/2011	Aalborg Denmark	Scientific Community	600	European Countries
17	Conference	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava C.	INTERNOISE 2011	4-7/09/2011	Osaka Japan	Scientific Community	900	Worldwide
18	CEN Working Group Meeting	Clairbois J.-P.	TC 226 / WG6	5-6/10/2011	Milan, Italy	Experts	25	European Countries
19	CEN Working Group Meeting	Garai M.	TC 256/ SC1 / WG40	7/10/2011	Milan, Italy	Experts	18	European Countries
20	Conference	Leissing T., Grannec F., Defrance J., Jean P., Lutgendorf D., Heinkele C., Clairbois J-P.	ACOUSTICS 2012	23-27/04/2012	Nantes France	Scientific Community	1050	European Countries
21	Article	Brero G., Fusco I	Barriere antirumore per la mitigazione del rumore dellle infrastrutture di trasporto	06-2010	Strade&Autostrade	Industry		Italy
17	CEN Working Group Meeting	Clairbois J.-P.	TC 226 / WG6	28-29/02/2012	Krakow Poland	Experts	25	European Countries
18	CEN Working Group Meeting	Garai M.	TC 256/ SC1 / WG40	1/03/2012	Krakow Poland	Experts	16	European Countries
19	Conference	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava C.	EURONOISE 2012	10-13/06/2012	Prague Czech Republic	Scientific Community	250	European Countries
20	Conference	Clairbois J-P.,Conter M.,Defrance J., De Roo F., Fusco I., Garai M., Olteana-Dumbrava C.	INTERNOISE 2012	19-22/08/2012	New York USA	Scientific Community	1500	Worldwide
21	CEN Working Group Meeting	Clairbois J.-P.	TC 226 / WG6	8-9/10/2012	Leipzig Germany	Experts	20	European Countries
22	CEN Working Group Meeting	Garai M.	TC 256/ SC1 / WG40	10/10/2012	Leipzig Germany	Experts	18	European Countries
23	Congress	Brero G., Durso C.	Serbian Noise Congress	7/11/2012	Belgrade Serbia	Industry	75	Balkan countries
24	Conference	Conter M., Czuka M., Breuss S., Haider M., Garai. M., Guidorzi P., Schoen E.	AIA-DAGA 2013	18-22/03/2013	Merano Italy	Scientific Community	1200	European Countries
25	Conference	Garai M., Guidorzi P.	ICA 2013	2-7/06/2013	Montreal Canada	Scientific Community		Worldwide
26	Conference	De Roo F., Garai M., Guidorzi P., Conter M., Oltean-Dumbrova C., Watts G., Miah A.	INTERNOISE 2013	15-18/09/2013	Innsbruck Austria	Scientific Community		Worldwide