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HISTORY AND ACTIVITIES OF KU LEUVEN LABORATORY OF ACOUSTICS

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ABSTRACT*

The Laboratory of Acoustics at KU Leuven was founded more than 50 years ago. Till today, a variety of acoustics related topics, ranging from physical acoustics, through building and room acoustics up to environmental acoustics and noise related health issues, has been investigated. In the second half of the 20th century, the laboratory was one of the main centers of expertise in acoustics in Belgium, which contributed to consulting and the establishment of legislation in building and environmental acoustics. In the 1990's it also consolidated expertise on the characterization of porous materials and was one of the driving research groups in the field of photoacoustics.
During the past 15 years, additional research directions have been taken thanks to interdisciplinary collaborations, including psychoacoustics, perception of sound, sound quality assessment, archaeo-acoustics, tackling acoustic issues in building retrofit, and characterisation of walls materials in the framework of sustainable development (recycled materials, biomaterials etc.)
This paper first brings a brief historical overview of activities of ATF performed in the past, its involvement in national and international collaborations and its main recent scientific and educational activities.

Keywords: *Physical acoustics, Building and Room Acoustics, Noise control, Psychoacoustics.*

1. EARLY HISTORY OF THE LABORATORY OF ACOUSTICS

The Laboratory of Acoustics has its roots in the Faculty of Sciences of the Catholic University of Leuven (1425-) and the initiative of physics professor Augustin Van Itterbeek (1904-1968), who was leading the Laboratory of Low Temperatures and Technical Physics. The latter had been appointed in 1932 to organize a physics research laboratory for Dutch-speaking students as part of the university's Flemishization. Van Itterbeek initiated a program "ingénieur-physicien" in 1936. Graduated engineers there could receive additional training in scientific research. The program also opened paths to industry for the physicists themselves. In that context, physics research was organized into groups around low temperatures, viscosity, acoustics and nuclear physics. After the university was split in 1968, the Department of Physics was created with seven divisions, including the Acoustics and Thermal Conductivity ("Laboratorium voor Akoestiek en Warmtegeleiding (AW)") division, which was initially led by Prof. Odiel Van Paemel (1911-2006). The other pioneering laboratory members were Prof. Henri Myncke (1921-2001), Prof. André Cops, Paul Jacques and Willy Delvaux. The research part of the department relocated to new built facilities on the Heverlee campus in March 1972 (Fig.1 and 2).

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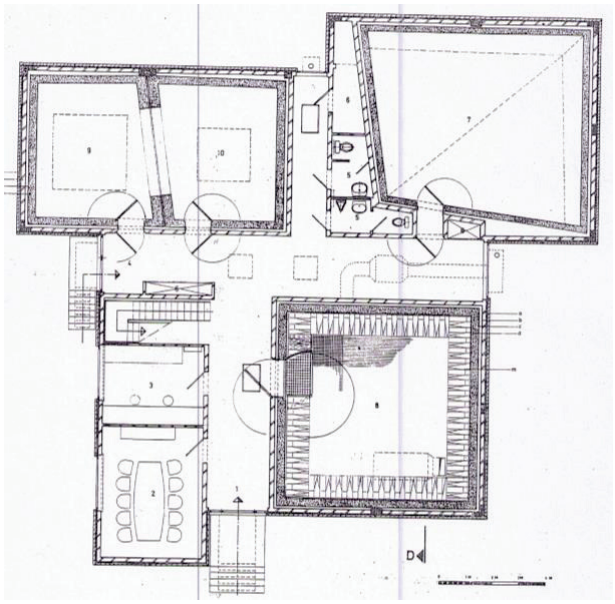

Figure 1. Ground plan of the laboratory (1967)

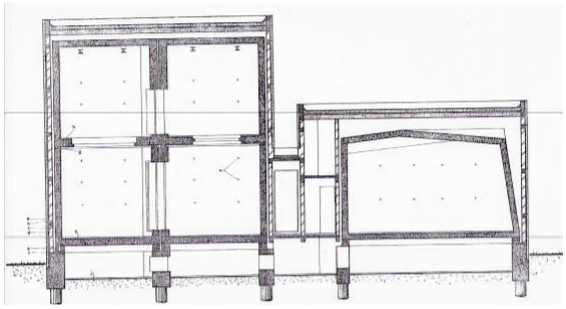

Figure 2. Cross-section of the laboratory, transmission rooms and reverberant room (1967)

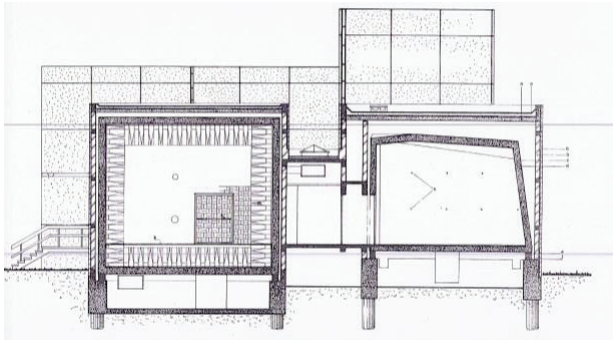

Figure 3. Cross-section of the laboratory, anechoic and reverberant room (1967)

The new acoustics laboratory building, which included an anechoic room, a reverberation room and sound transmission rooms, had already been occupied by then. The acoustic facilities (all built in a robust "box-in-box" approach) as well as setups for determination of thermal conductivity were used for developing measurement methods and performing service measurements for companies.

Among the first environmental acoustics activities were traffic noise measurements (near the newly built E40 highway between Brussels and Liège and near Antwerp), and evaluations of noise disturbance (on the instructions of the Belgian Ministry of Public Health). This venture was undertaken with the help with newly hired members Piet Steenackers, Willy Bruyninckx (1949-2022) and Roger Gambart. In 1986, Prof. Jan Thoen joined the laboratory and became its director in 1988. The laboratory further developed its expertise in building acoustics, room acoustics and environmental acoustics, in particular in many studies and consulting on airport noise. In 1987, Prof. Jan Thoen started also research on photoacoustic and photothermal phenomena. Later on, the expertise was (in collaboration with Prof. Jan Wouters and Prof. Astrid Van Wieringen form audiology department) extended to the-perception acoustics. Around 2000, after a significant expansion of the lab building, the group of Prof. Gerrit Vermeir joined on the building-related acoustic topics throughout the years, several members of the laboratory have taken leading roles in different national and international societies related to acoustics. In particular, Prof. André Cops and Prof. Gerrit Vermeir have chaired the Belgian Acoustical Society (ABAV) and the former one has also been Secretary-General of International Institute of Noise Control Engineering (INCE). In the early 1990s Prof. Jan Thoen served as Secretary General of the Federation of Acoustical Societies of Europe (FASE). Prof. Monika Rychtarikova has chaired the Technical Committee of EAA Room and Building Acoustics (2011-2017). The evolution of the different research, education, dissemination, and consulting activities is sketched in the following thematical overview.

2. THEMATIC OVERVIEW

2.1 Environmental acoustics

Acoustics is one of the scientific disciplines that is connecting research in physics with society. Along with the industrial evolution, the population density growth and the increase of motorized road, railway and airborne traffic, concerns about the impact of noise on health have led to the need for expertise on efficient noise abatement. In view of this, from its early days, the laboratory has been very active

in noise mapping, consultation for developing measures for mitigating noise problems, and developing adequate legislation. Since the foundation of the laboratory, Belgian (Ministry of Public Health) and later on Flemish governmental administrations (subsequently the Administration of Spatial Planning and Environment – AROL, the Administration for Management of Environment, Nature, Land and Water – AMINAL [1] and the Department of Environment, Nature and Energy – LNE [2]) have been consulting its experts (Prof. Henri Myncke and Prof. André Cops, Willy Bruyninckx, Paul Jacques and Prof. Jan Thoen) for advice in general and compiling texts that currently still make part of the Flemish Regulation concerning the Environmental Permit (VLAREM [3]). Essential points of noise regulations, target $L_{A,eq}$ values ("richtwaarden") and limits and permits to install noise producing facilities in Flanders is that these are determined by zones [4], and take into account the original sound $L_{A,95}$-levels. In this context the laboratory executed and coordinated many studies on environmental noise impact for industrial partners and several pilot studies for the Flemish Government (e.g. PESO (1993) and EVA-PESO (1995) on evaluation methods for nature quite areas; EMOLA (1997) on the determination of emission levels to the environment). From the beginning of the 1990s significant contributions were made on the determination and evaluation of aviation noise near the airport of Brussels for RLW (Regie der Luchtwegen) of the Belgian Government and for the Brussels Airport Authority, e.g. in 1989, 1990 and 2014: on noise from airplanes on the ground, from 1997 onwards: scientific support for noise control measures, from 1996 to 2014: calculation and evaluation of noise impact contours. The laboratory made a report on the environmental impact of Brussels Airport (MER-geluid Zaventem 2000). Similar MER reports and noise contour evaluations were also executed (from 1997 to 2022) for three regional airports (Oostende, Antwerpen and Kortrijk-Wevelgem) in Flanders. Throughout the years, also support for noise control measures near the race track of Zolder, motorcross circuits [5] and wind turbines [6] was supplied by ATF.

Via partnership in the European projects ADRIENNE [7] and QUIESST [9], the laboratory has also contributed to the development of European standards for measuring procedures CEN 1793-2 and CEN 1793-5 and 6 for the *in situ* determination of the absorption and isolation of noise barriers [10].

Further in the field of environmental acoustics, together with the Building Physics group (BP) at KU Leuven Department of Civil Engineering, ATF contributed with a new approach to classify soundscapes in the framework of the Belgian project DRUPSSUC [11,12].

2.2 Building acoustics

Where in the early years' attention was focused on the use of the tube method, measurement techniques and in-situ measurements, the facilities of the newly installed laboratory opened many new avenues [13]. From 1969 there was the possibility to make use of transmission rooms, an anechoic room, and a reverberation room. Commissioned work and research clearly got off to a rapid start with reviewed published work. First on a study on sound field diffusivity in the reverberation chamber [14], work on a sound reflection set-up in the anechoic chamber [15] and work on sound transmission. [17].

The nature of the research topics, in particular the properties of building materials and constructions, was also very appropriate within the architectural engineering program of the Faculty of Engineering Sciences. This laid foundations for a solid collaboration on a study of noise transmission in buildings and the use of statistical energy analysis (SEA) [17] which triggered th start of frequent interfaculty master's and PhD work. Different parts of the laboratory infrastructure were used for dedicated goals.

The **transmission chambers** were intensively used for the standardized determination of the airborne sound insulation of walls, floors and later also roof constructions, and for the standardized impact noise testing of floor constructions. Time remained available for in-depth examination and experimental work into sound radiation measurement techniques. Attention was given to the then-new sound intensity measurement technique and research related to the standardization. Also, the sound isolation quality of separation walls, sound propagation by flanking paths, internal damping of walls and floors were highlighted. Recently, a new step was made in the measurement of acoustic sound isolation by using a laser Doppler vibrometer to measure the vibration of a wall of interest and extracting from the deflection shape the sound transmission and isolation spectrum. This method, which was consolidated in the framework of an EU RISE project PAPABUILD [18], has been validated with the classical microphone-based approach for intermediate frequencies. Its main strength is to yield reliable data in the low-frequency range, where the microphone-based method becomes unreliable due to the non-uniformity of the sound pressure level in the measurement rooms, caused by standing wave modes [18-19]. An advanced computational approach of ribbed and stud frame assemblies [20] was successfully compared to laboratory experiments in the work of the team of Prof. Edwin Reynders, successor to Prof. Gerrit Vermeir.

The laboratory also holds a **concrete scale set-up used in the study of flanking transmission [21] and** later converted into a holographic set-up.

2.3 Room acoustics

Research in room acoustic topics has been ongoing in the laboratory since many years, coordinated by Prof. Gerrit Vermeir. In the end of the 20th century, the group belonged to one of the European leaders in this field. In house developed software EPIKUL was one of the leading ray-based software of those times [22]. The group was involved in many projects (both research-wise and consulting-wise), including several in very interesting locations, such as: BOZAR concert hall (Brussels PDS aula (Leuven) [23]. Among the large number of smaller projects and so called second opinion activities, some of the noteworthy are the Elzenveld chapel in Antwerp, AMUZ (Antwerpen), Scheepvaart museum Amsterdam, several projects in Westmalle (Trappistencafé, bbey church, new brewery bottling plant).
Within the laboratory facilities, the reverberation room has been intensively used for standardized sound absorption testing. In the context of ISO standardisation, the laboratory participated in several round-robin tests. The determination of the sound power of various (ventilation) equipment for buildings was also addressed. In terms of research, the influence of edge effects of samples, the diffusivity of the sound field, and the validation of modeling scattering [24] were discussed throughout the history.

Figure 4. Building of the Laboratory of Acoustics (Photo Peter Hanuliak)

In the **anechoic room**, important steps were taken in the measurement techniques concerning reflection, absorption, and diffusion of sound: burst tests [25], over impedance tests [26] to scanning tests [27]. In the reverberation room tests concerning the diffusivity of the sound field, over numerous standardized sound absorption measurements, to set-up and developments on measurement techniques related to the sound reflections. [28]
Recently, room acoustic research has increasingly focused on interdisciplinary collaborations, mainly with KU Leuven research groups in architecture and in audiology. Joint research with experts in architectural history [29] has led to a recently approved ERC Pathfinder project between Oxford University (Prof. Küge) and KU Leuven (Prof. Rychtáriková and Prof. De Jonge). The infrastructure (anechoic room) is being extensively used for the preparation of anechoic recordings for high-level binaural auralisation and for listening test experiments free of background noise and reverberation.

2.4 Psychoacoustics and sound perception

In collaboration with BP - KU Leuven and the KU Leuven laboratory for Experimental Oto-, Rhino-, Laryngology (expORL), the laboratory has put its first steps into the field of psychoacoustics and research on perception of sound in the framework of an FWO-V project ("VIRTAK") on sound source localization, the use of virtual acoustics for testing of speech intelligibility of hearing impaired people [30,31] and echolocation [32,33], by combining binaural impulse response simulations with listening tests with auralized sound. This research was further extended to auralized sound-based recognition of textures of walls. The group also performed listening test-based assessments of wall sound isolation performance in the framework of finding an optimum single number quantity (SNQ) that takes into account the frequency dependence of human hearing. This research was complemented by a proposal for a Loudness calculation-based assessment method of the adequacy of SNQs for sound isolation, which was validated by listening test-based results.

2.5 Physical acoustics

Along with the measurement and evaluation of noise in the living environment, developing and characterizing materials for optimum absorption, isolation or scattering performance in applications, has made an important part of the activities in ATF. In close collaboration with international partners at the universities of Le Mans, Hull, Trondheim, Nevers and others, ATF contributed to the development of dedicated measurement techniques for the key physical parameters that determine the acoustic absorption of porous materials, i.e. the tortuosity, the porosity, the flow resistivity, the thermal characteristic length and the viscous characteristic length [34], and for the macroscopic determination of the sound

reflection. This main driving force behind this research was Prof. Walter Lauriks (1961-2010), in close collaboration with Prof. Jean-Francois Allard and colleagues from Université du Maine (LAUM), France.

Around 1987, a new research direction was opened by Prof. Jan Thoen in the emerging field of photoacoustics, which makes use of the phenomenon where intensity modulated light absorbed by a gas, liquid or solid, through thermal expansion, results in density variations that in turn correspond with sound or ultrasound. This phenomenon was first discovered by Alexander Graham Bell and his assistant Sumner Tainter, and along with the emergence of laser technology, made its way into material science after a publication [35] by Allan Rosencwaig and Allen Gersho in 1980. This approach allows to get combined information on optical absorption properties, thermal properties and mechanical properties of materials and became a unique tool thanks to the versatility of laser light in terms of allowing to generate arbitrary spatial and temporal excitation patterns and remotely detect the resulting thermal expansion and acoustic waves. ATF made substantial contributions to this research field, and was an active player in different European projects. In 1994-95, Prof. Jan Thoen coordinated a large EU Human Capital and Mobility project on "Advanced materials characterization by photoacoustic and photothermal phenomena". Initially research efforts concentrated on thermal properties near phase transitions [36-38] but soon extended to depth profiling [37,38] and acoustic wave generation and detection, in particular in applications of depth profiling [39-43] (EU project HARDPHOTOTEC, grant no. BRRT-CT-5032), non-destructive testing by laser ultrasonics [44-47] (EU-ITN project NDTonAIR [48]. Recently the first footsteps were made in the field of elastic characterization of biological cells and tissue, and photoacoustic imaging [49,50], in a perspective of using this approach for biomedical applications.

A nice synergy between physics and arts was evidenced by the outcome of a collaboration between the laboratory and artist Aernoudt Jacobs, in the form of the artworks Photophone" [51] and "Heliophone" [51,52], in the framework of an IWT CICI-grant (2013-2015).

The multidisciplinary nature of the laboratory is well reflected in the ongoing EU-MSCA doctoral network, Acoustic and Thermal Retrofit of Office Building Stock in EU (ACTAREBUILD) [53], which joins efforts in sustainable development and thermal and acoustic characterisation of green and recycled materials, with special attention to the acoustic perceptive importance of innovative measures in building physics, while training young researchers. Education[1]

2.6 Flanders

In Flanders, members of ATF has contributed to different courses on acoustics listed below:

- Fundamentals of Acoustics (AC, WL, CG), Building Acoustics (GV, AD, ER), Measurement techniques and signal processing (BR) (Hogere Cursus Akoestiek, IENET)
- UIPUOUYAdvanced Acoustics (Master of Physics, KU Leuven: 1987-2021) (JT, WL)
- Environmental Acoustics (Master Environmental Studies, KU Leuven: 1987-2010) (JT, WL)
- Control technique: sound (Environmental coordinator, Syntra West (-2020) (WB, CG)
- Waves and sound (Bachelor Logopedy and Audiology, KU Leuven)
- Introduction to the Physics of Speech and Hearing: Waves and Sound (Bachelor Logopedy and Audiology, KU Leuven)(CG, JW, MM)
- Noise control (Master of Bioscience Engineering: Human Health Engineering, Master Building Engineering, KU Leuven (GV, ER)
- Building acoustics (Master Building Engineering, KU Leuven) (GV, ER)
- Room acoustics and lighting (Master Building Engineering, KU Leuven) (GV, ER)
- ERPhysics: additional topics: sound (Bachelor Architectural Engineering, KU Leuven)(CG),
- Comfort: acoustics (Bachelor Architecture, KU Leuven((MR)

2.7 International level

At international level, ATF has been a collaborator of several EU educational projects, networks and platforms [44], among which the most recent were Erasmus projects (Lifelong Learning Programme)

- Acoustics for Architects (ARAC platform) https://arac-multibook.com/, Programme: Leonardo da Vinci Transfer of Innovation. No. 2013-1-PL1-LEO05-37588. (2013-2015).
- Acoustics for Engineers (ACE) https://ace.acoucou.org/ Programme: ERASMUS+ Strategic Partnerships for vocational education and training. No. 2016-1-PL01-KA202-026719. 2016-2018)
- Acoustics for Industry (ACI) https://aci.acoucou.org/. ERASMUS+ Strategic Partnerships for vocational education and training: No. 2017-1-PL01-KA202-038577. (2017-2019) [54]
- Acoustics Knowledge Alliance (ASKNOW) https://asknow.acoucou.org/. ERASMUS+ Knowledge

Alliances All the activities within the Acoustics Knowledge Alliance (ASKNOW). No. 612425-EPP-1-2019-1-FR-EPPKA2-KA) (2020-2023).

3. DISSEMINATION

Collaborators of ATF has organized or co-organized a high number of national and international events, seminars or conferences. The most important are:

3.1 Conferences

- Chair of Internoise 1981 Amsterdam (AC)
- Chair and proceedings editor of I-INCE 1993, Leuven, Belgium (AC, GV)
- Chair Forum Acusticum 1996, Antwerpen, Belgium (AC) [48]
- Chair Gordon Conference on Photoacoustic and Photothermal Phenomena 2001 (JT, DF) [57]
- Chair 15th International Conference on Photoacoustic and Photothermal Phenomena (ICPPP19) 2009, Leuven, Belgium (CG) [58]
- EAA summer school in Leuven 2019 (MR, AK)

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