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INFLUENCE OF TRANSPARENT ROOFING SYSTEMS ON ROOM ACOUSTIC PROPERTIES OF LARGE ATRIA

VPLYV TRANSPARENTNÝCH ZASTREŠOVACÍCH SYSTÉMOV NA PRIESTOROVÚ AKUSTIKU VEĽKÝCH ÁTRIÍ

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Abstract: *This paper investigates the influence of roofing systems based on structural skins such as an ETFE cushion systems, textile membranes, micro-perforated foils and polycarbonate sheets, on the room acoustic quality of large halls. In situ acoustic measurements in three large atria covered by ETFE were performed and compared in terms of their reverberation time, overall sound absorption and sound pressure level due to indoor noise. Several alternatives based on different roofing systems are suggested in the three atria and simulated by a ray-based algorithm, in order to assess the influence of the ceiling surface on the acoustic quality in large halls.*

Keywords: *room acoustics, indoor comfort, atria, structural skins, ETFE cushions*

1. INTRODUCTION

Architectural design of atria requires integration of many aspects that relate not only to structural stability [1], energy performance [2], monument protection [3] or sustainability [4], but also to several comfort issues such as thermal [6], day-light [7, 8], ventilation, air quality and acoustics. Unless acoustic treatment is implemented, covering of atria by transparent roof structures made of a hard material such as glass leads to a long sound reverberation and an uncomfortable indoor soundscape. In order to improve the acoustic quality, reduction of the reverberation time is often achieved by sound absorbing elements mounted under the ceiling.

Sound absorption structures under the ceiling can however change the daylight comfort and architectural view. The choice of a convenient structural membrane integrated in the roofing system and/or placement of transparent absorptive foils on carefully chosen positions in the hall can avoid many problems and discussions [9 – 14].

Typically, high background noise levels in atria are either caused by external noise entering via natural ventilation systems or by noise produced by interior sound sources, which are amplified due to multiple reflections by hard surfaces. In large halls, different resonances and sound effects occur. Although these are often out of assessed frequency range of

1. ÚVOD

Architektonický návrh átrií vyžaduje integráciu mnohých aspektov, ktoré sa nespájajú iba so statickým návrhom [1], energetickou náročnosťou [2], ochranou pamiatok [3] a udržateľným rozvojom [4], ale tiež s parametrami zohľadňujúcimi komfort v priestore ako sú tepelná pohoda [6], denné osvetlenie [7, 8], vetranie, kvalita vzduchu a v neposlednom rade akustická pohoda. Napriek návrhu akustických opatrení v priestore, zastrešením átrií transparentnou konštrukciou z tvrdých materiálov ako je sklo atď. docielime predĺženiu času dozvuku čo vedie k zníženiu komfortu tzv. interiérovej zvukosféry. Tento problém sa často rieši ďalšími dodatočnými akustickými opatreniami ako je zavesenie pohltivých prvkov pod zastrešením.

Zvukovo pohltivé prvky však môžu zmeniť požadovaný komfort z hľadiska denného osvetlenia (nežiadúce tienenie) ako aj celkový architektonický vzhľad. Výberom vhodného integrovaného membránového konštrukčného systému v zastrešení a/ alebo návrhom zvukovo pohltivých fólií v správne zvolených miestach priestoru dokážeme predísť mnohým diskutovaným problémom [9 – 14].

Zvyčajne vysoká hladina hluku pozadia v átriách je spôsobené zvukom šíriacim sa z exteriéru vetracími prvkami v prípade prirodzeného vetrania a hlukom generovaným zdrojmi v interiéri, ktorý je umocnený zvyčajne násobnými odrazmi od tvrdých povrchov. V priestoroch s veľkým objemom dochádza k rôznym zvukovým efektom a rezonanciám. Aj keď actual norms and standards, they do cause discomfort, indicating the requirement for revision of standards.

The aim of this work was to get further insight in the influence of roof materials on room acoustic parameters, by comparing the numerically simulated acoustic performance of three atria with different roof cladding systems.

ich výskyt je väčšinou mimo štandardne posudzovaného frekvenčného spektra uvádzaného v technických normách, môžu spôsobovať akustickú nepohodu čo vedie k diskusii o revízií niektorých noriem.

Cieľom tejto práce bolo sledovať vplyvu rôznych transparentných materiálov zastrešenia na vlastnosti priestorovej akustiky troch átrií za použitia numerických simulácií.

2. CASE STUDIES

Three halls covered by ETFE were chosen for this article: (1) the Atrium at Berufsbildende Schule (BBS) in Oldenburg, (2) the Atrium of Kapuzinergraben in Aachen and (3) the Atrium of DomAquaree in Berlin. These atria are covered by ETFE based roof cladding systems.

2. PRÍPADOVÉ ŠTÚDIE

Pre účel tejto publikácie boli vybrané tri átriá zastrešené ETFE vankúšovým systémom. Vybrané átriá boli: (1) Átrium odbornej školy (BBS) v Oldenburgu, (2) Átrium Kapuzinergraben v Aachen a (3) Átrium DomAquaree v Berlíne.

Fig. 1: (a) Oldenburg atrium , (b) Aachen atrium, (c) Berlin atrium

Obr. 1: (a) Átrium v Oldenburgu, (b) Átrium v Aachen, (c) Átrium v Berline

Atrium Oldenburg
The BBS atrium in Oldenburg is covered by a Texlon® ETFE cushion system (Fig.1a). The volume of embedded space is approximately 8900 m^3 (with ceiling height of about 16,5 m). The total interior surface area is 4570 m^2, which is mainly consisting of ETFE, glass, absorptive walls, ceilings and rigid walls with brick based linings.

Atrium Aachen
The atrium investigated in Aachen has a trapezoidal shape with niches in two corners (Fig.1b). The volume is ca 7030 m^3 and the area of the interior surfaces is about 3500 m^2. Like in the case of the BBS in Oldenburg, the space is covered by a Texlon® ETFE cushion system. The dominant materials used on the atrium interior surfaces are the ETFE roofing, grouting brick walls, a stone floor, and glazing in the atrium space. The ceiling height is ca 15.5 m.

Atrium Berlin
The dominant building material used in the rather high (27m) atrium investigated in Berlin, is glass (Fig. 1c). It is used for the wall claddings, as well as for interior structures, such as elevator walls, as well as interior walls. The atrium has a volume of 30 500 m^3 and the interior surfaces are 10 300 m^2.

Atrium v Oldenburgu
BBS átrium v Oldenburgu je zastrešené Texlon® ETFE vankúšovým systémom (Obr.1a). Celkový objem priestoru je cca 8900 m^3 (so zastrešením vo výške cca 16,5 m) a celková plocha interiéru je 4570 m^2. Interiérové povrchy sú prevažne tvorené ETFE fóliou, sklom, pohltivými stenami a podhľadmi a stenami s keramickým obkladom.

Átrium v Aachen
Analyzované átrium v Aachen je trapézového pôdorysného tvaru s výklenkami vo dvoch rohoch (Obr. 1b). Objem je cca 7030 m^3 a celková povrchová plocha interiéru je cca 3500 m^2. Priestor je taktiež zastrešený vankúšovým systémom Texlon®, ako v prípade átria v Oldenburgu. Dominantným materiálom použitým v interiéri je ETFE zastrešenie, steny so škárovanou tehlou, kamenná podlaha a zasklenie priestorov presvetľovaných cez átrium. Svetlá výška zastrešenia je cca 15,5 m.

Átrium v Berlíne
Dominantný použitý stavebný materiál v posudzovanom átriu v Berlíne svetlej výšky 27 m je sklo (Obr. 1c). Na báze skla sú tvorené všetky povrchy ako obklady stien, interiérové konštrukcie, výťahy atď. Podlaha je kamenná a zastrešenie ETFE. Objem átria je 30 500 m^3 a celkový povrch interiéru átria je 10 300 m^2.

3. MEASUREMENTS AND SIMULATIONS

Standardized room impulse response measurements were performed according to ISO 3382-1 and ISO 18233.

Next, simulations were performed in CATT Acoustic v. 9. The models were calibrated, based on the measured average reverberation time. Several alternatives have been simulated based on variations of roofing material (ETFE, glass, polycarbonate, textile membrane and micro-perforated foil). A summary of the sound absorbing materials and their properties, as used in the simulations, are given in the Tab.1.

The surface area of ceiling is different in each atrium. The fraction of ceiling surface with respect to the total surface was 8.8%, 12.6% and 13.7% in the Oldenburg, Aachen and Berlin atrium respectively.

3. MERANIA A SIMULÁCIE

Merania vlastností priestorovej akustiky posudzovaných priestorov použitím metódy integrovanej impulzovej odozvy boli vykonané v súlade s platnými technickými normami ISO 3382-1 a ISO 18233.

Následné simulácie boli vykonané použitím programu CATT Acoustic v. 9. Simulačné modely boli kalibrované na základe zmeraného priemerného času dozvuku v jednotlivých átriách. V modeloch bolo požitých niekoľko alternatív zastrešenia (ETFE–kalibrácia, sklo, polykarbonát, textilná membrána a mikroperforovaná fólia). Prehľad pohltivých materiálov použitých v simuláciách je v Tab. 1.

Podiel povrchu zastrešenia v jednotlivých átriách bol rôzny. V percentuálnom vyjadrení v závislosti k celkovému povrchu interiéru bol 8,8%, 12,6% a 13,7% v Oldenburgu, Aachen a Berlíne.

Name	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Textile membrane	0.15	0.40	0.75	0.85	0.65	0.65
Glass	0.15	0.05	0.03	0.03	*0.02*	*0.02*
Micro-Perforated foil	*0.33*	*0.29*	*0.37*	*0.48*	*0.57*	*0.47*
Polycarbonate	*0.08*	*0.04*	*0.03*	*0.03*	*0.02*	*0.02*
3 layer ETFE cushion system	*0.41*	*0.21*	*0.26*	*0.17*	*0.08*	*0.02*

Tab. 1: Overview of sound absorption coefficients of the materials that were varied in the simulations

Názov	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Textilná membrána	0.15	0.40	0.75	0.85	0.65	0.65
Sklo	0.15	0.05	0.03	0.03	*0.02*	*0.02*
Mikroperforovaná fólia	*0.33*	*0.29*	*0.37*	*0.48*	*0.57*	*0.47*
Polykarbonát	*0.08*	*0.04*	*0.03*	*0.03*	*0.02*	*0.02*
ETFE vankúšový systém	*0.41*	*0.21*	*0.26*	*0.17*	*0.08*	*0.02*

Tab. 1: Prehľad činiteľa zvukovej pohltivosti materiálov zastrešenia použitých v simuláciách

4. RESULTS AND DISCUSSION

The sound absorption of glass and polycarbonate sheet is much lower than the one of ETFE cushions and of the other simulated materials (Fig.2-4): the former 2 materials reflect about 35% more energy back into the room, resulting in substantial differences between the acoustic performances of the respective atria with an ETFE cushion system, perforated foil, textile membrane, polycarbonate sheet and glass roofing (Fig. 2-4).

4. VÝSLEDKY A DISKUSIA

Zvuková pohltivosť skla a polyarbonátových dosiek je výrazne nižšia v porovnaní s ETFE vankúšovým systémom a ďalšími membránovými konštrukciami: spomínané 2 materiály odrážajú približne o 35% zvukovej energie viac naspäť do priestoru v porovnaní s membránami, čoho dôsledkom je výrazný rozdiel výsledných parametrov pohltivosti priestoru s použitím ETFE, perforovanej fólie, textilnej membrány a polykarbonátových dosiek resp. zastrešenia sklom (Obr. 2 – 4).

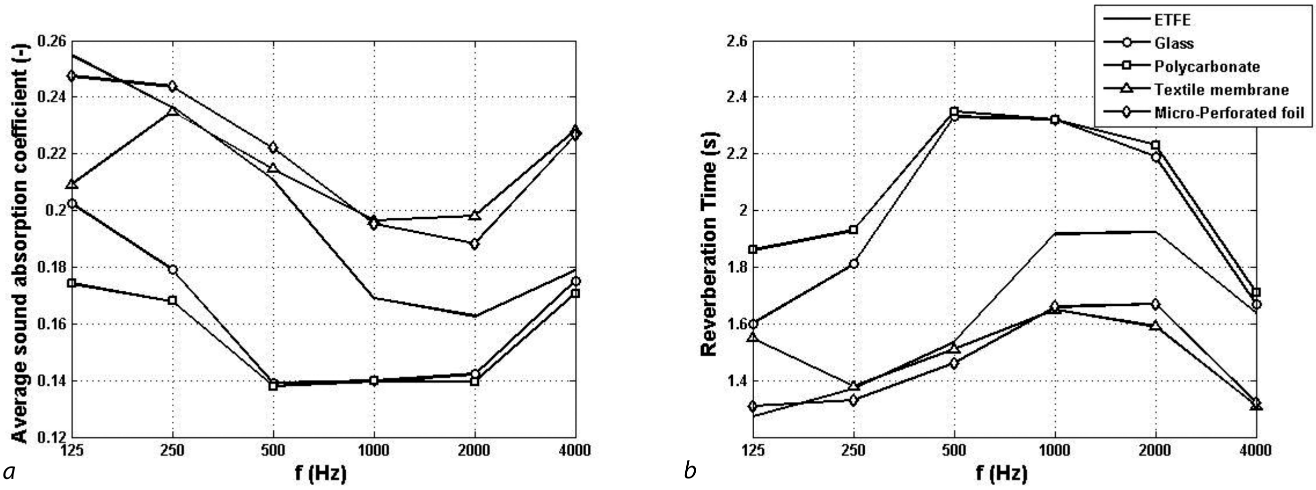

Fig. 2: a) Average sound absorption coefficient α (-) (Oldenburg); b) Measured and calculated reverberation time T_{30} (s)

Obr. 2: a) Priemerný činiteľ zvukovej pohltivosti α (-) (Oldenburg); b) Meraný a simulvaný čas dozvuku T_{30} (s) (Oldenburg)

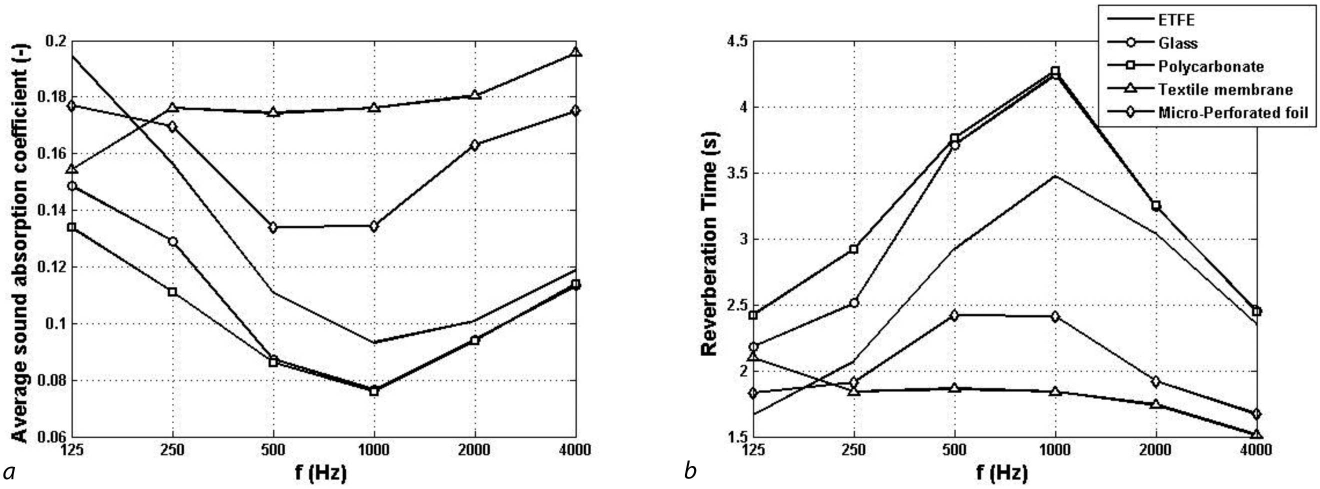

Fig. 3: a) Average sound absorption coefficient α (-) (Aachen); b) Measured and calculated reverberation time T_{30} (s)

Obr. 3: a) Priemerný činiteľ zvukovej pohltivosti α (-) (Aachen); b) Meraný a simulovaný čas dozvuku T_{30} (s) (Aachen)

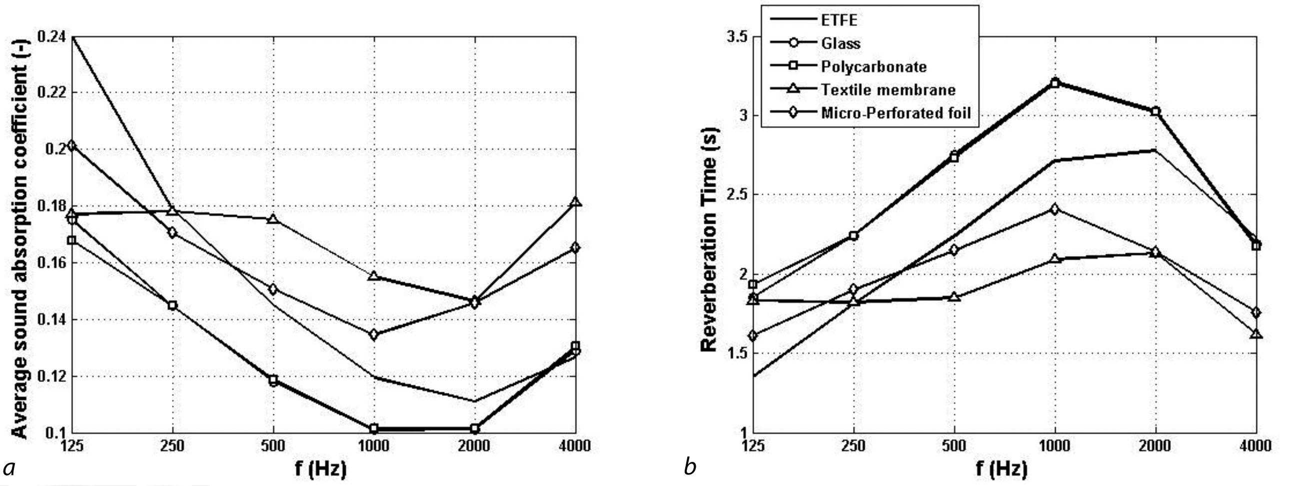

Fig. 4: a) Average sound absorption coefficient α (-) (Berlin); b) Measured and calculated reverberation time T_{30} (s)

Obr. 4: a) Priemerný činiteľ zvukovej pohltivosti α (-) (Berlin); b) Meraný a simulovaný čas dozvuku T_{30} (s) (Berlin)

5. CONCLUSIONS

The results confirm expectations that, by virtue of their higher acoustic absorption, ETFE systems help to improve the acoustic quality in large halls such as atria. In comparison with glass or polycarbonate, rooms covered by structural skins such as ETFE have a shorter reverberation time, particularly in low and middle frequencies. However, the acoustic comfort in large halls cannot be fully reached by roofing structure only because of the surface of the roof only covers a limited fraction of the overall surface. In order to achieve optimum acoustic comfort, also the atrium walls need to be treated.

One should also take into account that, although typical membrane structures have higher sound absorbing properties than hard materials such as glass (the use of materials such as glass and polycarbonate where ca. 35% more energy is reflected back to the room, in comparison with foil or textile membranes), they typically have poorer sound insolation (is mainly determined by mass). This can result in an increase of background noise levels in the hall if the building is located in a noisy outdoor environment.

5. ZÁVERY

Výsledky potvrdili očakávania, vďaka vyššej zvukovej pohltivosti, použitie ETFE systému dopomôže k výraznému zlepšeniu priestorovej akustiky priestorov veľkého objemu ako sú átriá. V porovnaní s materiálmi ako sklo a polykarbonát, priestory zastrešené membránovými konštrukciami ako napr. ETFE majú kratší čas dozvuku v nízkych a stredných kmitočtoch. Avšak zvukovú pohodu v átriách nedosiahneme iba zvolením správneho typu zastrešenia nakoľko povrch strešného systému tvorí vždy iba časť celkového interiéru. V dôvodu docielenia optimálnych akustických parametrov projektant musí brať do úvahy vplyv odrazov od stien átria.

Nesmieme zabúdať na to, že i keď typické membránové konštrukcie majú vyššiu zvukovú pohltivosť ako tvrdé materiály ako je napríklad sklo, majú zväčša oveľa nižšiu zvukovú izoláciu. To sa výsledne prejavuje ako zvýšená hladina hluku pozadia v átriách situovaných v hlučných lokalitách.

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POĎAKOVANIE

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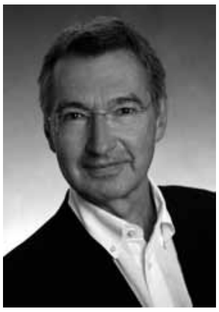
Lukáš Zelem *was born in 1989, in Bardejov, Slovakia. In 2008, he joined the Faculty of Civil Engineering at The Slovak University of Technology, in Bratislava. He graduated with a Bachelor's Degree in the field of Civil Engineering & Architecture in 2012. In 2014, he earned a Master's Degree in the field of Architectural Construction & Engineering. He is presently working toward his PhD at The Slovak University of Technology, which includes working on research projects in the field of room acoustics and psychoacoustics (i.e. The assessment and prediction of acoustic conditions in restaurants).*



Carl Maywald *has entered the company 9 years ago and as head of R & D department has been assigned to extend the scientific and technical lead of Vector Foiltec. Working closely with VF's engineering department Dr. Maywald has advanced expertise regarding novel structural skins, particularly thermal and optical properties, as well as ETFE technology in areas of material and system development, analytical processes and quality control management, holding patents on thermal insulation as well as roof surveillance and controll concepts. Much emphasis has been put on proving the outstanding environmental benefits of the Texlon ETFE system by publishing the first environmental product declaration (EPD) for transparent building cladding systems worldwide, the Texlon® EPD. Dr. Maywald has analyzed the acoustic properties of lightweight membranes for roof as well as façade applications. Besides being member of the European Norm Committee for membranes, today Dr. Maywald is a resource to the engineering team on complex projects while pushing a detailed research agenda.*

Christ Glorieux *born July 12, 1965, in Kuurne, Belgium, studied physics at the Katholieke Universiteit Leuven (K.U. Leuven), Belgium, and graduated in 1987 with a thesis on "Investigation of the structure of amorphous silicon by electron spin resonance and electrical conductivity measurements." He obtained his Ph.D. degree in 1994 on the topic "Depth profiling of inhomogeneous materials and study of the critical behavior of gadolinium by photoacoustic and related techniques," in the Laboratorium voor Akoestiek en Thermische Fysica (ATF) at the Physics and Astronomy Department of K.U. Leuven. After working one year as an R&D engineer in an industrial company he continued his research into thermo-elastic properties of soft condensed matter by photoacoustic and photothermal techniques in ATF, with a postdoctoral visit at the Department of Chemistry of the Massachusetts Institute of Technology, Cambridge, USA in 1999 and 2000. Now he is an Associate Professor at the Laboratory of Soft Matter and Biophysics, and is active in research and teaching physics and sounds and waves, general physics, and experimental physics to undergraduate and graduate students. He is leading a research group of typically 5 to 10 young researchers in the field of photothermal applications and laser ultrasonics for the fundamental study of the thermophysical properties of complex soft and heterogeneous matter, the development of measurement techniques for characterization and depth profiling of thin (sub-micron) layered structures, and non-destructive evaluation. He is also leading a research division with consulting activities in physical acoustics, room acoustics, building acoustics and environmental acoustics. In 2009, he organized the 15th International Conference on Photoacoustic and Photothermal Phenomena (ICPPP15). In March 2017 he had 200 articles published in international peer reviewed journals (h-index 27).*

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During her research stays, she has visited different universities such as TU Wien, TU Delft, RWTH Aachen, TU Zagreb. Since 2002, she has been active in different fields of building physics in general and building and room acoustics, environmental and virtual acoustics and perception of sound in particular. She has contributed to 8 monographies, 3 course text books, over 17 papers in peer reviewed international journals (CC), and over 160 scientific articles. She has given more than 80 talks at conferences and presentation at TEDx Bratislava. She has been involved in around 60 acoustical consultancy projects 4 windcomfort studies and 7 architectural projects. Recently, she is active as an associated profesor at KU Leuven (Faculty of Architecture) and as a profesor at STU Bratislava (Faculty of Civil Engineering).