

## An educational tool for architectural acoustics

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**ABSTRACT:** With a selection of room geometry and building materials, an architect shapes users' acoustic comfort and audiological safety [1][2]. Technical university education should include building physics issues allowing future engineers to design spaces according to the standards, practice [3][4] and universal access [5]. The *ArAcMultibook* [6] is an innovative teaching and learning tool accessible in four languages meant mainly for architect engineers, but applicable for spatial planners, civil engineers, and interior designers during university and vocational training. An interdisciplinary team of acousticians, engineers, scientists, artists and architects, has developed the multibook [7]. The interactive publication mixes several forms of knowledge transfer: text supplemented with graphics and schemes, video lectures and sound samples with a selection of photographs. The presented study assesses its applicability in the university and professional environment and investigates its influence based on literature, citations, interviews and research data on Internet platforms. The collected data show the positive social impact of the multibook and provide evidence for its suitability as an acoustics educational tool.

### INTRODUCTION

Architectural and building technology changes are quickly forcing university and vocational education to adjust to new realities [8]. Academic graduates must address more issues than ever, like energy efficiency, biodiversity, sustainability, artificial intelligence, augmented reality and climate change. Each of them requires expert knowledge and a deep understanding of the subject matter. Standard engineer design problems also expand especially for building materials, structures, user safety and within that field - acoustics. Fortunately, scientists develop new methods for creating academic curricula [8] and create innovative tools [6][9][10] to strengthen the learning process aiming at its efficiency.

Acoustics, with its physical descriptions of sound phenomena, formulas and building standards, is a complex and broad domain for designers to study. Nevertheless, these designers - engineers-creators decide on a general structure, building compartments, room geometry and materials used inside and outside. Thus, architects, civil engineers and spatial planners create users' acoustic comfort and audiological safety [1][2], providing (or not) universal access [5]. Many projects like houses, offices, schools or hospitals do not legally require engaging an acoustician in the design team, but have to comply with complex regulations regarding acoustics on international [11][12] or national levels [3][4][13]. Academic and vocational education is exceptionally demanding in this regard [3][4].

The article focuses on the evaluation of an innovative tool called *ArAcMultibook* designated to teach acoustics mainly to architects at university and post-graduate levels. Yet the book is useful for civil engineers, spatial and urban planners, interior designers, and all professionals or enthusiasts who deal with sound in the built environment. This solution is publicly accessible and serves academic curricula, self-training or vocational teaching programmes [6].

An interdisciplinary team of acousticians, engineers, scientists, artists and architects from Germany - GFaiTech (executor); Belgium - Khale Acoustics (executor) and KU Leuven (executor); and Poland - KFB Acoustics - Polska (project initiator and leader) and Wrocław University of Science and Technology (executor, tester), supported by technical teams [6][7], developed the multibook, under the European Commission - the Lifelong Learning Programme funding. The developed multibook is an interactive publication that mixes several forms of knowledge transfer: text supplemented with graphics and schemes, video lectures and sound samples with a selection of photographs [14].

The grant implementation during 2013-2015 stimulated many press releases, conferences and scientific publications. Next, the initiators of the *ArAcMultibook* used it as an input in creating an on-line platform with a multimedia course and self-learning materials called *acoucou* [15].

In view of these developments, the article focuses on the influence of the manual on professionals and academics, and its impact on knowledge in the discipline of architecture and urban planning. The presented study evaluates its

applicability in the university and professional environment, and investigates its effect based on literature, citations, conferences and research data on Internet platforms. The article concludes with the so-called influence path and data showing the quantitative and qualitative responses of the university environment to the innovative educational tool. The data show the effect of the ArAcMultibook on the architect's profession.

## METHOD

The investigation was quantitative and qualitative. The latter consisted of harvesting all accessible data concerning the tool's presentation or information publication like:

- Professional and scientific conferences;
- Professional publications;
- Mailing and leaflets;
- Use of knowledge in students' projects (talks, e-mails);
- Use of knowledge in professional projects (talks, interviews and e-mails) [16-18].

Data collection lasted from 2015 until 2023 and was compliant with the so-called product dissemination, obligatory for European grants. This information shows broad-scale promotion and interest of third parties in the ArAcMultibook. However, some disseminated material is available now only in archival form - due to the ephemeral character of posters, announcements or Web site publications. However, several publications are accessible and can still be read on-line [16-18]. They were included in the formulation of the influence path as pointed out in the Summary and Conclusions of this article.

Quantitative data collected from 2015 until 2023 were as listed:

- PDF file of ArAcMultibook downloads;
- Scientific publications based on knowledge from the book;
- Downloads and reads of publications based on knowledge from the book;
- International citations of publications based on knowledge from the book.

The analysis of these data as presented in the article shows the range and impact of the ArAcMultibook on the professional and academic environments, and can be a basis for the elaboration of the influence path presented in the Summary and Conclusions of this article. Both elements serve in the formulation of conclusions to the article using comparative analysis and synthesis. These methods, supplemented with critical evaluation of outcomes, were applied to juxtapose the data included in Table 1 and Table 2. The summary of outcomes is presented in graphical form in Figure 1 to Figure 4.

## THE TOOL

The book consists of six chapters devoted to theory and practice in acoustics. The first one presents the architectural acoustic environment, relations between people and sound, and close links between the professions of architects and acousticians. The second describes crucial notions, their definitions, acoustic wave behaviour and its propagation in space. The chapter's content elaborates also on room acoustics, vibrations and noise barriers. Chapter number three is practical and elaborates on the contemporary measurement method dedicated to buildings and rooms. Information on modelling and simulations required for design is also included.

The next part relates to architectural design and advice on how to program and distribute building functions to gain the best noise-limiting results. The knowledge applies to compartments and partition solving, structure planning and room sound field management. The subchapter titled *Topology of concert halls and opera houses* would be of interest to enthusiasts of advanced acoustic solutions. In chapter five, the reader finds case studies of buildings with exceptional architectural acoustical solutions, while the next chapter presents curiosities. These two parts might interest a broader audience.

The ArAcMultibook manual - the first publication of this type - is an interactive textbook for smartphones and tablets (a computer version in a PDF file was also created) for learning acoustics. This approach was considered innovative in all partner countries, and the book is open access and available in four languages - German, Polish, French and English. The document has a computer version in a PDF file and is available on common platforms: Google Play and iStore. The product was also considered innovative in terms of information technology application as the developed book better explains the relevant issues to the reader, is interactive and addresses the reader's needs. Innovative digital capabilities enabled to combine text with explanatory diagrams, animations, videos and sound samples played at the user's request. This project allowed for knowledge transfer between private companies and public institutions - in this case, higher education schools.

## DISCUSSION

The first investigation considered presentations or informative publications in popular science form. This action related two conferences conducted on 15 April 2015, at the New Horizon cinema in Wrocław, Poland (admission was free) and on 14-17 June 2015 during the 6th International Building Physics Conference, IBPC 2015 in Turin, Italy. The undertaken activities supported publications, such as leaflets and posters on Internet platforms intended for professionals. They aimed

at the product's promotion and presentation of the book's highlights. There were at least seven actions of that type [16-18], which are summarised graphically in Figure 1.

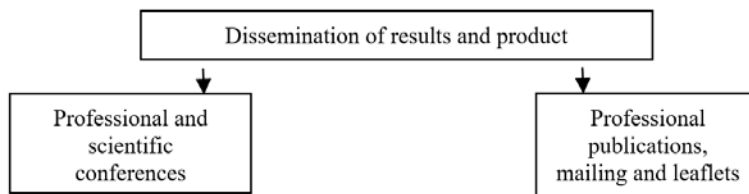


Figure 1: ArAcMultibook - dissemination in popular science form.

The second investigation considered the ArAcMultibook manual's PDF downloads directly from the project Web site between August 2019 to May 2023. During the whole period, the multibook's total downloads reached 6,750, and 4,297 for the English language version, 1,146 for Polish, 628 for German and 679 for French. Table 1 shows the number of downloads sorted by years and language versions. The data allow for the calculation of the average download number for the specified period, and observation of the trend across the considered years. The data included in the bottom row of Table 1 points to a large decline between 2020-2022 and a slight increase in downloads for the year 2023 (Figure 2).

Table 1: Juxtaposition of PDF files of ArAcMultibook's downloads - between August 2019 and May 2023 (authors' own elaboration based on the data delivered by KFB Acoustics - Polska).

Language version	Year 2019 (from August)	Year 2020 (full year)	Year 2021 2021-2021 (full year)	Year 2022 (full year)	Year 2023 until May)
English	635	1,327	1,362	674	299
Polish	123	348	332	229	114
German	63	255	149	109	52
French	86	324	141	100	28
Average downloads/per year	226.75	187.83	165.33	92.67	98.6

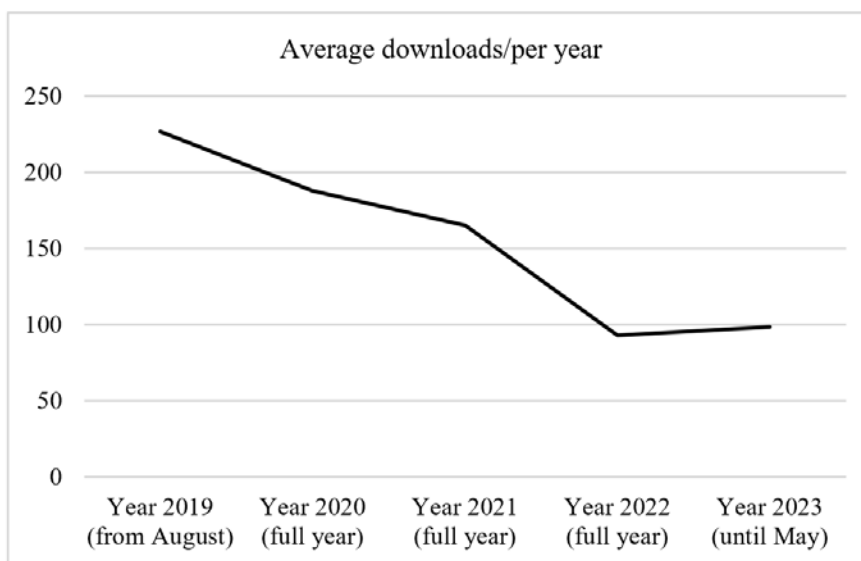


Figure 2: Graphical summary of PDF files of ArAcMultibook's average downloads per year - between August 2019 to May 2023 (authors' own elaboration based on the data delivered by KFB Acoustics - Polska).

The ArAcMultibook's authors and enthusiasts continuously published scientific articles (years 2015-2020) based on the knowledge contained in the manual, referencing it in the literature and bibliographic lists [19][20]. In this regard, especially three publications are of particular interest since they solemnly focused on the ArAcMultibook content or application.

They are as listed: Jaruszewska, K., Melon, M., Dazel., Vorländer, M., Rychtáriková, M., Horvat, M., Wulfrank, T., Herweg, A., Aspöck, L., Sluyt,s Y., Jambrošić, K., Carayol, E., Wojtyła, B, Łuczak, M. and Chmelík, W., *The ACOUCOU platform: online acoustic education developed by an interdisciplinary team*, *J. Acoust. Soc. of America*, 152, **3**, 1922-1931 (2022) [21] - referred to as article 1 in Table 2; Jaruszewska, K., Rychtarikova, M., Wulfrank, T., Jabłońska, J. and Boeck, M., *ArAc - Multibook of architectural acoustics*, *Energy Procedia* 78, 8-12 (2015) [22] - referred to as article 2 in Table 2; Jabłońska, J., Trocka-Leszczynska, E. and Tarczewski, R., *Sound and architecture - mutual influence*, *Energy Procedia* 78, 31-36 (2015) [23] - referred to as article 3. Each chosen article was cited (excluding self-citations) from one to eleven

times by a researcher or researchers not connected in any way to the manual's creation. These citations are a direct proof of the ArAcMultibook's influence on international academics. The juxtaposition of outcomes is presented in Table 2.

Table 2: Juxtaposition of downloads and reads of articles referring to the ArAcMultibook and its quotations (authors' own elaboration based on ResearchGate data [19]).

Article number	Data source	Accesses/reads	Data source	Number of citations
Article 1	ResearchGate	166	ResearchGate	2
Article 2	ResearchGate	1,692	ResearchGate	1
Article 3	ResearchGate	6,316	ResearchGate	11

Researchers and academics downloaded or read articles referring to the ArAcMultibook 8,174 times, which allowed for 14 documented citations on ResearchGate on-line database [19]. This data show the long-lasting interest since 2015 in the tool and proves its effectiveness and applicability (Figure 3).

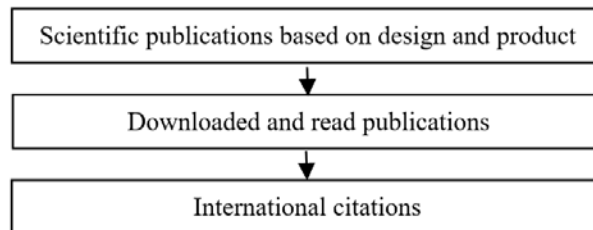


Figure 3: ArAcMultibook's scientific spread.

The ArAcMultibook can be used by professionals and students from the following industries: architecture, acoustics, urban planning, spatial planning, landscape architecture, interior design, artists dealing with acoustic and sound installations, investors, public administration and a wide social group interested in improving the acoustic quality of their environment. Moreover, by being publicly accessible, the publication is designated for broad and international readers - not necessarily engineers. Text, drawings, schemes, videos and lectures guide the reader into the self-solving of basic, yet common problems with excessive noise or elongated reverberation time. The content is useful for the conceptual stage of architectural, urban or building projects in terms of sound management. It allows for a better understanding of various project priorities depending on a space's function and purpose.

In a broader social context, the dissemination of presented knowledge increases users' awareness considering architectural and urban projects. It helps in equipment and interior finishing selection in a flat, office or school aiming at noise reduction in the urban environment and buildings. This is beneficial for the health of children, youth and adults. Ensuring optimal acoustic conditions is a key goal as they positively affect students in schools, workers in offices or industry, people performing basic, everyday activities in residential premises, etc.

A quiet environment helps to lower blood pressure, regulate sleep, increase concentration, keep proper day and night rest and reduce the risk of developing certain diseases, such as those of circulatory tract, heart, nerves, gastrointestinal tract, and can cause hearing loss or damage or raising the threshold of hearing [1-5]. Low background noise favours increased revenues from the private and public sectors. Growth of both income and health in society directly translates into the economic development of towns and villages and tourism expansion. The knowledge and practical examples are adjustable in flats and homes. In light of these arguments the ArAcMultibook's broader impact is as listed:

- social and health - increases the awareness of users of architectural and urban projects; basic knowledge and extended skills in the field of acoustic adjustment in a flat, office and school, allows for reduced noise;
- economical - conducive to increasing work efficiency in industry, administration, offices, primary, secondary and higher education, thus increasing revenues from the private and public sectors;
- technological - i.e. furniture, acoustic screens, suspended ceilings and sound-absorbing islands; opportunity to improve solutions and propose new ones;
- environmental - contributes to increasing the share of flora and fauna.

## SUMMARY AND CONCLUSIONS

Until the creation of the ArAcMutibook, the field of acoustics and architecture lacked publications that would comprehensively and extensively deal with the relationship between these two domains. Acoustics publications based on complex formulas and definitions are too broad for architectural engineering education. On the other hand, books on design and architectural theory reduce the science of sound and its propagation, which is hard to use in practice. Also, the acoustician and the architect need a convenient form of communication for everyday use. Thus, the interdisciplinary team of researchers and experts created the ArAcMutibook tool in 2015 with the support of a European Union grant. The interactive book stimulates learning processes and is appealing to all professionals and enthusiasts, helping to incorporate knowledge quickly and effectively.

This article focuses on the ArAcMultibook's applicability and evaluates its influence on the international arena in professional and academic environments. The conducted comparison of quantitative and qualitative data allows for the formulation of a path of influence showing the effectiveness in both university and professional environment. With the intensive project dissemination through conferences, press releases and pamphlets, followed by scientific articles and their citations, the book's creators have reached a broad audience using their product.

The PDF file manual was directly downloaded over 6,700 times, while articles related to or based on the book have been accessed more than 8,000 with 14 follow-up international citations. This data supported the creation of a graphical representation of the path of influence for the ArAcMultibook. It starts with a grant reception, goes briefly through the product preparation and elaborates on various impacts presented in this article (Figure 4).

To sum up, increasing the awareness and knowledge of industry groups, such as acousticians, architects and urban planners, as well as students of these fields and the recipients of the built environment themselves, i.e. the general public, has a significant impact on increasing the safety of users, their psycho-physical comfort, as well as on their bottom-up activities. Especially valuable in the creation of the ArAcMultibook is the stimulation of new educational initiatives, like *acoucou* on-line courses and materials.

Reducing noise in urban and rural environments, as well as increasing the safety of sound field in schools, hospitals, etc, has an overall positive impact on public health, economic growth, technological development and environment quality. The influence of the ArAcMultibook tool for teaching architectural acoustics is significant in this respect.

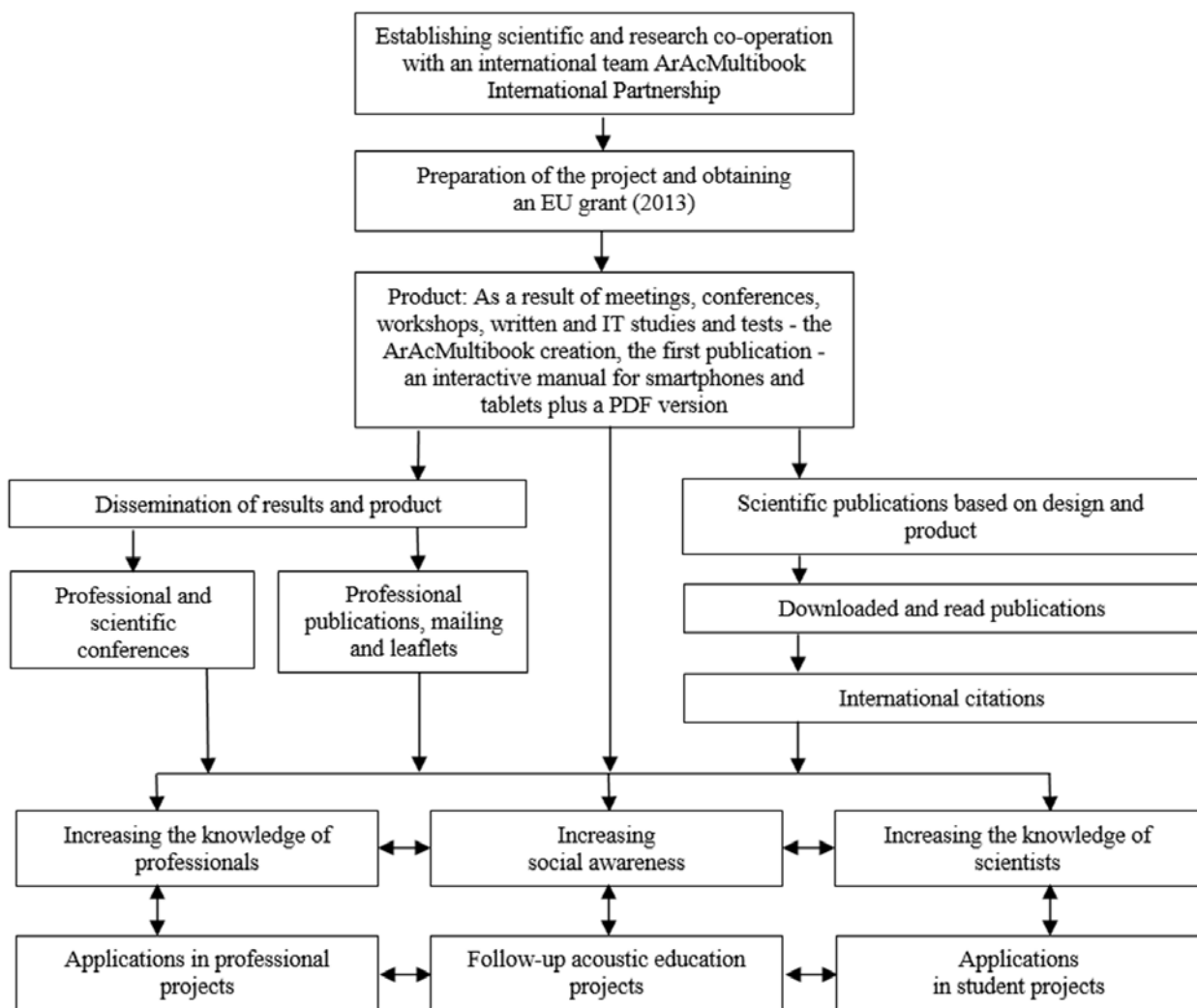


Figure 4: The graphical summary for the ArAcMultibook's path of influence (own elaboration).

#### ACKNOWLEDGEMENTS

The ArAc - Multibook was developed by an interdisciplinary team of acousticians, engineers, scientists, artists and architects from Germany - GFaiTech (executor); Belgium - Khale Acoustics (executor) and KU Leuven (executor); and Poland - KFB Acoustics - Polska (project initiator and leader) and Wrocław University of Science and Technology (executor, tester), supported by technical teams [6][7], under the European Commission - the Lifelong Learning Programme funding (Title: ArAc - Multibook of Architectural Acoustics; Project number: 2013-1-PL1-LEO05-37588; Project type: transfer of innovation).

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