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## REVIEW OF THE DOCTORAL DISSERTATION

Candidate's Name: Bethalihem Samuel, M.Sc.

Title of the doctoral dissertation:

Acoustic Properties of Weave Structure Depending on Their Internal Geometry

Supervisor: Dr hab. Eng. Marcin Barburski, Prof. PŁ

Reviewer: Dr hab. Eng. Katarzyna Majchrzycka, Prof. CIOP-PIB

Basis for the preparation of the review:

Letter No. W/Z111/2023 of the Council for Scientific Degrees of the Lodz University of Technology in the disciplines of Mechanical Engineering, Materials Engineering, dated June 7, 2023.

### 1. Scientific Value of the Dissertation

#### 1.1 Relevance of the Research Topic and Originality

The doctoral dissertation encompasses research topics in the design and manufacturing of textile porous sound-absorbing systems. These materials are used for covering sound-reflecting obstacles (including walls and ceilings) to enhance the acoustic absorption of a space and eliminate sound reflections from the obstacles.

Creating conditions for expanding the range of materials designed to counteract excessive noise remains an ongoing challenge, as the threat of noise increases with societal development and human occupational activities. Excessive noise levels can cause stress, sleep disturbances, hearing damage, and other health issues, making effective noise reduction conducive to improving public health.

When considering comprehensive approaches to noise reduction, it is important to mention other methods and technical solutions as well. These include noise source attenuation, acoustic-urban measures (such as green belts, earthen berms, and sound barriers), as well as architectural solutions involving sound scattering on building facades or the use of soundproof windows. However, in enclosed spaces, the predominant and relatively cost-effective method for shaping the acoustic climate is the application of textile sound-absorbing materials.

The effectiveness of reducing noise through the application of sound-absorbing materials to sound-reflecting obstacles, aiming to increase the acoustic absorption of a room and eliminate sound reflections, is estimated to be in the range of 3 to 7 dB. This applies to spaces with initially low absorption levels. In this context, improving the effectiveness of sound-absorbing structures, particularly by ensuring efficiency across a wide frequency spectrum, is an important aspect. In this regard, the primary research challenge faced by the doctoral candidate has been to shape the acoustic properties of textile materials towards absorbing low-frequency sounds, followed by the construction of multilayer systems that provide high absorption capabilities for both low and high-frequency sounds.

The doctoral candidate has taken on a new technological and research challenge. Until now, there has been a lack of textile materials that provide effective sound absorption across a wide frequency spectrum. This work aligns with the current trend in the development of textiles used to improve human safety in work and living environments. The knowledge gained from modelling the geometry of porous sound-absorbing structures, particularly fabrics, will contribute to enhancing the effectiveness of sound-reflecting obstacles used in public utility and production spaces. Moreover, thanks to new design possibilities, it can be utilized in the design of textiles for residential, tourist, and business facilities. Considering the demand from interior designers and architects for new multifunctional materials, and especially due to the importance of research aimed at improving the acoustic climate and protecting individuals from excessive noise exposure, the choice of research area made by the doctoral candidate is validated. The doctoral dissertation has a scientific character with significant implementation potential.

## 1.2 Scientific Value of the Chapters

The doctoral dissertation consists of six chapters, each contributing to the overall scientific value of the research. The following is an evaluation of the scientific value of the individual chapters:

In the first chapter, the doctoral candidate presented the rationale for addressing the research problem and formulated the research objectives and hypotheses based on that. The second chapter contains an extensive literature review related to the topic.

In the third chapter, the candidate presented the materials used for the research, along with a detailed description of fabric sample preparation. Additionally, the chapter presented the results of the acoustic insulation of fabrics obtained from anechoic chamber testing, along with a discussion on the relationship between acoustic insulation and the physical properties of the fabric and yarn.

The fourth chapter discussed the verification of the sound absorption properties of the fabric in an impedance tube. Furthermore, this chapter included the research results of nonwovens and air gaps combined with fabrics of different layers.

The fifth chapter focused on studying the optimization of fabrics by combining different weave structures, as well as the impact of fabric arrangement in relation to the air gap and nonwoven arrangement within the sample.

The sixth chapter presented the key relationships, conclusions, and recommendations regarding the structure of multilayer sound-absorbing materials based on the conducted research.

## 2. Scientific Rigor of the Dissertation

### 2.1 The ability to justify the research problem

The literature review in the doctoral dissertation is comprehensive and has been divided by the doctoral candidate into various areas of interest. The candidate demonstrates a thorough understanding of the existing body of knowledge related to the research topic. The review covers a wide range of relevant sources, providing a solid foundation for the research conducted in the dissertation. The ability to justify the research problem based on the extensive literature review showcases the doctoral candidate's competence in identifying gaps in knowledge and formulating relevant research questions.

The conclusions from the literature review were formulated in a specific and relevant manner, aligning with the research objectives. The accuracy and adequacy of the conclusions drawn from the literature review indicate a thorough and comprehensive examination of existing research and theories in the field of textile sound-absorbing materials.

### 2.2 Clarity of the formulated research hypotheses

In connection with the stated objectives of the thesis, the doctoral candidate proposed the following research hypotheses to be verified and confirmed:

Primary hypothesis: The primary hypothesis of the doctoral dissertation aimed to investigate the effect of woven fabric on the level of sound absorption at low frequencies in porous materials. It was hypothesized that the woven fabric would enhance the sound absorption capability in the porous material.

Secondary hypotheses: In addition to the primary hypothesis, the doctoral candidate put forth two secondary hypotheses. The first secondary hypothesis suggested that the sound absorption performance of multilayer fabrics would improve with an increase in the number of woven fabric layers. This hypothesis aimed to explore the relationship between the layer numbers of woven fabrics and the overall sound absorption efficiency of the multilayer fabrics. The second secondary hypothesis proposed that the sound absorption efficiency of a fabric would depend on its roughness properties. This hypothesis aimed to investigate the influence of fabric roughness on its ability to absorb sound.

These research hypotheses were clearly defined and aligned with the objectives of the thesis, providing a solid framework for the empirical investigation and analysis conducted throughout the dissertation.

### 2.3 Selection of research methods and statistical tools for data analysis

The doctoral candidate demonstrated a good understanding of the methods used to address the research questions.

The candidate properly justified the choice of raw materials to produce sound absorbing fabrics. To understand the impact of yarn properties on the fabric structure, samples were prepared using exclusively textured polyester fibers, twisted fibers, and cut fibers. Four basic weave structures were selected: plain, twill, satin, and herringbone, assuming that their porosity would be different. The Sample Dobby Loom SL 8900 S was used to prepare 12 types of fabrics.

Yarn, such as yarn twist per meter, hairiness, and yarn evenness, were examined based on the methodologies specified in the relevant standards. Similarly standard based methods were used to determine fabric properties such as warp and weft density, fabric thickness, mass per unit area ( $\text{g/m}^2$ ), crimp percentage, cover factor, porosity, roughness, and air permeability.

The acoustic properties of the fabrics were measured using two methods: first using anechoic chamber and the second using impedance tube (while integrating woven fabric with additional nonwoven fabric and adding air gaps on different layers of woven fabric). The use of selected methods was justified, proper for the intended scope of testing and explained in a clear and visually engaging way.

In terms of the statistical analysis, there was no explicit mention of the application of normality and equality of variance tests. However, given that nonparametric tests were employed, it could be inferred that these tests might have been conducted. To improve the clarity and transparency of the analysis, it would be beneficial to state specifically if such tests were performed. Furthermore, the precise post-hoc tests used to discern differences among the groups were not specified. For a more comprehensive understanding of the methodology, the specific post-hoc tests employed should be clearly indicated.

#### 2.4. Presentation of the results

The dissertation's presentation of results is generally clear and readable. The candidate effectively employed a variety of formats, including tabular representation and various types of charts - bar, scatter, and line graphs. This diversity in representation allows for a comprehensive overview of the findings.

However, there are a few areas that raise concerns. Firstly, the scatter plots use large-sized "balls" to represent data points, which can make it challenging to interpret the exact values. Reducing the size of these markers or using an alternative representation could enhance the legibility of these plots. Secondly, there is inconsistency in the notation of units on the axes. The author alternates between square and round brackets, which can potentially cause confusion for the reader. A more consistent approach to the notation could have been adopted for the sake of clarity.

Another area of concern relates to the use of abbreviations in the charts. Many of these are not explained in the figure captions, which may leave readers unsure of their exact meaning, of course they are explained in the main body of the respective chapters. Lastly, most of the graphs lack uncertainty values. Including these values would give the reader deeper understanding of the data, as they provide a measure of the results' reliability and confidence.

Overall, while the author demonstrates a strong ability to present data in multiple formats, these improvements would significantly enhance the clarity and readability of the presented results.

## **2.5 Critical analysis of results and the ability to interpret them against the background of subject literature**

The doctoral candidate has appropriately described the results presented in both graphical and tabular forms, effectively highlighting trends, and relationships among the data. This level of detailed reporting aids in understanding the full scope of the findings. Moreover, results of the analysis are substantiated with statistical analysis. This provides further confidence in the findings and ensures the conclusions are based on robust, statistical evidence. It's also commendable that a part of the results is contextualized with literary data, presenting previous research findings. This comparison adds value as it situates the research within the broader field and provides a benchmark against which the current study's results can be evaluated.

However, a few areas raise concerns. One of them is the absence of a discussion concerning the limitations of the study and their impact on the results. A comprehensive dissertation should always include a reflection on the potential weaknesses or limitations of the research design and methodology, as they might affect the interpretation of the results. Similarly, there is no attempt to propose future research directions. Suggestions for future research, would show how the research fits into the larger academic dialogue and suggest how subsequent research could continue to advance understanding.

## **2.6 Clarity and Correctness of Conclusions**

The doctoral candidate's ability for synthesizing and analysing the research findings is commendable. The comprehensive documentation accompanying the research work provides a clear demonstration of the achievement of intermediate objectives, all of which contribute to the validation of the proposed hypotheses.

What warrants particular emphasis is the consistency displayed in analysing research results and deducing interim conclusions. This approach enriches the readability of the work and streamlines the process of deriving answers to posed research questions.

## **3. Editorial correctness of the dissertation**

The doctoral dissertation contains all the information that logically and comprehensibly illustrates the doctoral candidate's cognitive journey from formulating the research problem to its solution. The main substantive content is presented in six chapters, arranged in a clear and correct manner. The first two chapters serve as an introduction to the research problem, including the rationale for formulating the research hypotheses and an extensive literature review on the topic. The next two chapters, 3 and 4, constitute the core of the doctoral dissertation. They present the course of design and production work on sound-absorbing fabrics, as well as their evaluation methods. The chapters have a similar structure in terms of presented content and include research results and their discussion. Chapter 5 discusses the process of modelling the geometric parameters of fabric and nonwoven structures with a focus on optimizing their ability to absorb low and high-frequency sounds. The doctoral dissertation concludes with Chapter 6, which provides a summary of the obtained results, focusing on demonstrating the achievement of the research hypothesis.

In addition to the main content, the doctoral dissertation includes a comprehensive list of selected abbreviations and terms, which facilitate navigation through the multi-threaded arrangement of the discussed topics.

The doctoral dissertation contains 9 tables and 49 appropriately described figures. Most of them are authored by the doctoral candidate, with references to the literature sources provided for the remaining figures. They illustrate the results of conducted technological tests, as well as the structures of the produced fabrics and sound-absorbing material systems. I also highly appreciate the documentation related to the measurement setups and the explanations of the research procedures. The figures and tables are referred to chronologically and appropriately in the text of the dissertation. They enrich the presented content and facilitate a proper understanding of the research results.

The bibliography is presented in a standardized form. The doctoral candidate analysed 106 literature sources, including the latest publications from 2023.

The doctoral dissertation is written in correct language and its graphical layout is at a good level.

#### 4. Critical Comments

1. The doctoral candidate titled the last 6th chapter as "Summary and Recommendation". However, I did not find in this chapter an attempt to refer to the possibility of starting production of new sound-absorbing materials. I consider this aspect to be extremely important when undertaking work on new materials, whose properties favour the improvement of the health and safety of the public. Therefore, I believe that addressing the issues of implementation and economics would be an argument that strengthens the significance of the cognitive results achieved.
2. While the dissertation presents results in diverse and generally clear formats, the interpretation of data is hampered by large markers in scatter plots, inconsistent unit notation, unexplained abbreviations, and the omission of uncertainty values in most of the graphs.
3. Although the candidate effectively presents and validates the results, the dissertation would benefit from discussing the study's limitations and suggesting directions for future research.

#### 5. Final assessment

The doctoral candidate has achieved a significant accomplishment in developing a new multilayer porous material capable of effectively absorbing high and low-frequency sounds. This achievement was made possible by designing the appropriate fabric geometry for low-frequency sound absorption and incorporating it into a multilayer structure based on nonwoven materials. The incorporation of fabric in the construction of the porous sound-absorbing material, which is an original contribution by the doctoral candidate, has improved its mechanical properties and durability while also opening new possibilities for material design used in noise reduction. There is potential for increased usability of such materials in homes, offices, and production areas designated for worker rest in noisy work environments.

The doctoral dissertation submitted for review represents an independent and original contribution by the candidate in the following areas:

- Selection of combinations of fabric structural parameters to achieve effective low-frequency sound absorption.
- Design, fabrication, and examination of sound-absorbing material packages capable of effectively absorbing high and low-frequency sounds.

The doctoral candidate has demonstrated extensive knowledge of fabric design, manufacturing, and methods for evaluating their properties related to acoustic parameters. A constructive analysis of research results was conducted, and appropriate conclusions were drawn. It is worth emphasizing the systematic approach in striving for a comprehensive solution to the research problem, as well as the fact that the dissertation, in addition to its unquestionable cognitive merits, also has practical implications. This demonstrates the candidate's modern thinking and curiosity for knowledge.

The candidate's publication record is also noteworthy. She has authored 5 internationally scoped articles, 4 of which have been published, with 3 of them listing the candidate as the first author. The knowledge gained during the research work has been disseminated through the presentation of 3 papers, including 2 at international conferences.

The critical remarks raised in the review have a polemic character and do not detract from the overall positive evaluation of the doctoral dissertation presented for review.

Based on the above, I confirm that the reviewed doctoral dissertation titled "Acoustic Properties of Weave Structure Depending on Their Internal Geometry," prepared by Ms. Eng. Bethalihem Samuel, meets the requirements stipulated in Article 187 of the Act of 20th July 2018, Law on Higher Education and Science. Consequently, I recommend to the Council for Scientific Degrees at the Lodz University of Technology, in the fields of mechanical engineering and materials engineering, to proceed with the further stages of the doctoral procedure for Ms. Eng. Bethalihem Samuel.

A handwritten signature in blue ink, appearing to be 'A. Szymanski', is located in the lower right quadrant of the page. The signature is fluid and cursive, with a long vertical stroke extending downwards from the end of the name.