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APPLICATION OF CONTEMPORARY MATERIALIZATION OF INTERIOR PARTITION IN INDUSTRIAL BUILDINGS AS AN ACOUSTIC CHALLENGE

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Abstract. *In recent years, the construction of industrial buildings in local areas has been dynamically increasing. In the context of modern architecture and construction, besides functionality in terms of meeting basic structural requirements, technological processes, and building design, achieving acoustic comfort within the workspace has become one of the primary design challenges. Analyzing contemporary design trends in the field of industrial building architecture reveals an increasing prevalence of using "flexible" interior partitions, both in their materialization and in architectural-functional organization. The tendency to use "light materialization," which aims to provide visual interaction as well, represents a unique engineering-architectural challenge. This paper investigates the impact of applying modern materialization of interior partitions, through a case study of an industrial building in Niš, on the potential to achieve adequate acoustic comfort. The aim of the study is to explore to what extent and in what way the application of different types of materialization, determined by the functional requirements of the space, influences the creation of an appropriate acoustic environment. The paper will analyze the possibilities of optimizing the materialization of interior partitions to achieve adequate acoustic ambiance while respecting architectural- design requirements. By simulating the acoustic performance of several models of modern materializations of interior partitions, an analysis of their acoustic characteristics (insulation power) will be conducted. The simulation of the models was carried out using the INSUL program, specialized for calculating sound insulation through various elements and construction assemblies. The obtained results will provide a preliminary "path to follow" in the architectural search for adequate acoustic comfort in the interior spaces of industrial buildings.*

Key words: *industrial architecture, interior wall partitions, contemporary materials, acoustic insulation*

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1. INTRODUCTION

Thanks to the industry's dynamic development in recent decades, industrial architecture has become an increasingly essential branch. Due to the significant size of these objects, intensive development has led to the need for the construction of assembly and "lightweight" structures, as well as flexible internal partitions that must meet basic functional and technological requirements. The use of "light" materialization, in combination with glass segments, allows for interaction among employees and their engagement in the production process. It also allows for quick partition rearrangement, enabling the production process to be reorganized in a concise time frame in case of a need for change. In light of these facts, the disruption of acoustic comfort within the workspace represents a significant design challenge that should be considered.

As manufacturing halls often represent sources of noise that can harm users' health, acoustic comfort is an important aspect when designing modern industrial architecture. The development of innovative materials and construction techniques increasingly enables the creation of internal partitions with insulating properties that achieve high-quality spatial response and sound aesthetics, thus contributing to smooth operation and health preservation.

Partitions' physical properties always limit the effects of sound insulation on reducing noise in industrial buildings. The paper investigates the influence of the application of various modern materials for internal partitions on the transmission of sound between the manufacturing hall and the administrative part of the building. An industrial building in Niš was selected for the case study to determine the most favorable materials for internal partitions with the fulfillment of minimum acoustic comfort requirements through software calculation, comparative analysis, and optimization. Methodologically, the paper uses the case study method and experimental modeling as the primary research approaches. In addition, unique scientific methods such as quantitative analysis, comparative analysis, and induction and deduction are applied.

The paper is divided into five chapters. After the introduction chapter gives an overview of the research problem, the second chapter focuses on the importance of modern industrial buildings, the principles of their design, and the application of modern materials in their construction. The third chapter explains in detail the applied methodology, including the definition of the internal partition model and the input data necessary for the simulation using Insul's specialized software. The fourth chapter provides an analysis of the generated results and their discussion, while the last chapter contains a synthesis of the research conclusions. At the very end, there is a list of used literature.

2. ON THE SIGNIFICANCE OF INDUSTRY AND THE IMPLEMENTATION OF CONTEMPORARY MATERIALS

Modern industrial buildings are designed to meet the complex requirements of technological processes, providing optimal conditions for work and integrating advanced technologies. In the design process, it is essential to consider the rational use of resources, material recycling, reduction of negative environmental impacts, and improvement of energy efficiency. This approach includes the application of sustainable materials, energy-efficient systems, and technologies to minimize the ecological footprint, and the creation of flexible spaces that can be adapted to market changes and technological trends [1]. This is reflected in simple architectural solutions that enable efficient space organization. As a result, manufacturing spaces feature unique structural assemblies of supporting structures, which differ from architectural solutions in other types of buildings [2]. Industrial buildings can be classified based on their shape or the technological process. Based on their shape, they are divided into low halls, high halls, and multi-story buildings. In terms of the technological process, buildings are classified based on horizontal or vertical organization [3].

In industrial facilities, width often presents a challenge due to the dimensions of machinery, traffic aisles, and working space. It can vary from a few meters to several tens of meters, which can result in the presence of internal columns[3]. On the other hand, the placement and dimensions of machinery require a considerable amount of free space. In light of these considerations, many modern industrial production halls are designed as single-story structures with large spans, as this approach allows for optimal integration of functionality and construction efficiency [4].

In modern design, which is based on the appropriate selection of location, definition of spatial solutions, and the shapes of industrial buildings, the careful choice of natural and recycled materials plays a crucial role, not only in terms of ecological sustainability but also in achieving optimal working conditions. When selecting materials, it is essential to consider their ability to contribute to acoustic comfort within the space, as noise can significantly impact productivity and worker well-being. Sound-absorbing materials and adequate insulation can reduce noise levels and create a more pleasant working environment, enhancing both the psychological and physical comfort of space users. Achieving the right acoustic balance allows for uninterrupted task performance, reduces stress, and contributes to the overall satisfaction of employees in industrial buildings [5].

Internal partitions, such as walls and intermediate floor structures, must be designed to reduce sound transmission to achieve an optimal level of sound insulation. According to their structure, partitions can be classified as single-layer (composed of one material), double-layer (composed of two materials), or multi-layer (composed of multiple different materials) [6]. Multi-layer partitions significantly reduce sound transmission, especially when heavier and more rigid layers are combined with lighter and more flexible ones. Additionally, multi-layer partitions filled with low-rigidity insulating materials often provide higher sound insulation than single-layer partitions of the same surface mass. Regardless of the partition type, their purpose is to isolate rooms from potential noise sources. The level of this insulation is measured as sound insulation (R), expressed in decibels (dB) [6]. Appropriate calculations can provide approximate values of sound insulation, which, while involving some degree of approximation, are sufficiently accurate to serve as a basis for partition design. Additionally, proper joint sealing and avoidance of sound bridges further reduce sound transmission through partition walls [7].

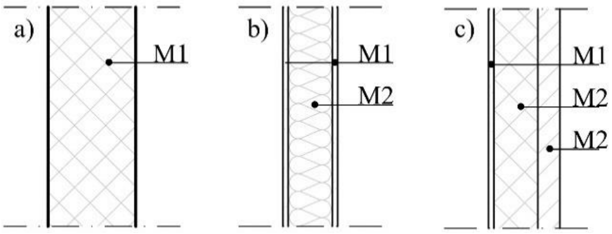

Fig. 1 Type of partition: a) Single-layer, b) Double-layer, c) Multi-layer [5]

3. MODELING THE CHARACTERISTIC INTERNAL PARTITION AND SIMULATION OF ITS ACOUSTIC PERFORMANCE

3.1. INSUL – predicting sound insulation software

INSUL is a program for predicting the sound insulation of walls, floors, roofs, ceilings and windows and impact sound and rain noise of floors and roofs. It has been available for over 20 years, and evolved over many releases into a very easy-to-use tool which has been refined by continued comparison with laboratory tests to provide acceptable accuracy for a wide range of constructions. The programme can make good estimates of the Transmission Loss (TL) or Impact Sound (Ln) in 1/3 octave bands and Weighted Sound Reduction Index (Rw) or Impact Rating (LnTw) for use in noise transfer calculations or acoustical design or specification. Also, it takes account of finite size effects and can be used to quickly evaluate new materials and systems, or to investigate the effects of changes to existing designs. Like any prediction tool, INSUL is not a substitute for measurement. However, comparisons with test data indicate that programme reliably predicts Rw values to within 3 dB for most constructions.

Since the INSUL is adapted to most regions in the world, it will greatly enhance the ability of acoustic consultants and product manufacturers to quickly and confidently specify constructions in order to achieve the desired airborne sound insulation [8].

3.2. Analysis of the characteristic internal partition and simulation of the optimization of its acoustic performance

In modern industrial architecture, the demand for flexible spaces and employee interaction makes acoustic comfort a key challenge for designers. This study will focus on optimizing the characteristic internal partition (Fig. 2) using the example of the ”Integrated Micro Electronics - IMI” industrial facility in Niš. Analyzing the performance of partitions through various modern material variations aims to achieve optimal acoustic comfort in the early stages of design, thus preventing discomfort in the working environment. The analysis also underscores the necessity of a thorough design approach to ensure that the minimum sound insulation values of partitions meet the requirements of the standard JUS U.J6.201:1989 (Acoustics in Building Construction - Technical Requirements for the Design and Construction of Buildings), which specifies a minimum sound insulation of 57 dB between operational and office spaces [9].

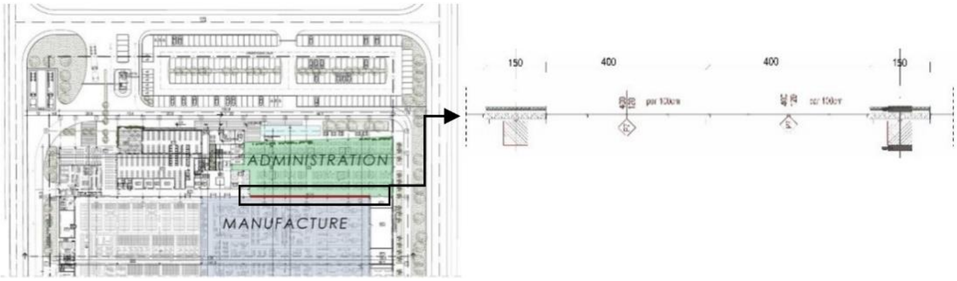

Fig. 2 Detail of the analyzed wall between administration and manufacture

Table 1 provides an overview of the analyzed models and types of partitions, with a detailed depiction of the wall structure and glass surfaces.

Table 1 Overview of the characteristics of the models used for analysis

	Type of partition	Structure of partition	Window/Glazing	Total thickness
MODEL 0	Triple	▪ Gypsum plasterboard 2x1,25 cm ▪ Mineral wool insulation 5 cm ▪ Air space 10cm ▪ Panel with mineral insulation 15 cm	Window: 2 x 400/120 cm	31,75 cm
MODEL 1	Triple	▪ Gypsum plasterboard 2x1,25 cm ▪ Mineral wool insulation 5 cm ▪ Air space 10 cm ▪ Panel with mineral insulation 15 cm	Window: 2 x 200/120 cm	31,75 cm
MODEL 2	Triple	▪ Gypsum plasterboard 2x1,25 cm ▪ Mineral wool insulation 5 cm ▪ Air space 10 cm ▪ Panel with mineral insulation 15 cm	Window: 0	31,75 cm
MODEL 2’	Triple	▪ Gypsum plasterboard 2x1,25 cm ▪ Mineral wool insulation 15 cm ▪ Panel with mineral insulation 15 cm	Window: 0	31,75 cm
MODEL 3	Triple	▪ Glass 6 mm ▪ Air space with argon gas 15 cm ▪ Glass 4 mm ▪ Air space with argon gas 15 cm ▪ Glass 6 mm	Glazing: 100%	31,60 cm
MODEL 3’	Triple	▪ Laminated Glass 6 mm ▪ Air space with argon gas 15 cm ▪ Laminated Glass 4 mm ▪ Air space with argon gas 15 cm ▪ Laminated Glass 6 mm	Glazing: 100%	31,60 cm

The width of the analyzed partition segment is 950 cm, while its height is 500 cm. The partition wall, whose characteristics are taken from the design documentation of the industrial facility, represents MODEL 0. It is a triple-layer wall consisting of a self-supporting wall cladding with a steel substructure and a double-layer of gypsum plasterboard (d=2x1.25 cm), filled with mineral wool insulation (d=5 cm), and an air space (d=10 cm) between the facade panel and the facade panel (steel coated sheet - mineral wool - steel coated sheet) with mineral wool insulation (d=15 cm), resulting in a total thickness of 31.75 cm. The construction is designed to position the wall panel closer to the production area for greater impact resistance and easier maintenance. At the same time, the gypsum plasterboard is closer to the administrative area. The triple-glazed window, measuring 2×400/120 cm, which allows visual communication between the administrative and production areas, consists of 6 mm thick glass, an air-filled with argon gas of 150 mm thickness, 4 mm thick glass, another air-filled with argon gas of 150 mm thickness, and 6 mm thick glass.

Partitions MODEL 1, MODEL 2, and MODEL 3 represent modifications of the designed partition MODEL 0, with variations in their characteristics, while the length and height of the partitions remain unchanged across all models. Partition MODEL 1 has the same structural characteristics as the designed MODEL 0, with the only difference being that the window area in MODEL 1 is reduced by 50%, measuring 2x 200/120 cm. The glass structure is the same as in the designed MODEL 0. The subsequent partition, MODEL 2, also has the same structural characteristics as the previous two models. However, it does not include a window for visual communication between the administrative and production areas.

Unlike the models mentioned above, MODEL 3 represents an entire glass partition, also classified as a ”light” modern construction commonly used for partitioning office spaces. This glass partition provides complete visual interaction among employees, offering a view of the production process at all times and from any angle. MODEL 3 is a triple-glazed glass partition consisting of 6 mm thick glass, an air-filled with argon gas of 150 mm thickness, 4 mm thick glass, another air-filled with argon gas of 150 mm thickness, and 6 mm thick glass.

To achieve the minimum sound insulation value of 57 dB specified by the standard JUS U.J6.201:1989, optimization of partitions MODEL 2 and MODEL 3 has been carried out. The newly designed partition MODEL 2' retains the same width and similar characteristics as MODEL 2, with the difference being in the thickness of the insulating layer between the gypsum plasterboard and the facade panel, which is now 15 cm. The newly designed partition MODEL 3' also maintains the same width as MODEL 3. However, the difference lies in the type of glass, where regular glass has been replaced with Laminated Glass (1 mm Acoustic Resin).

4. RESULTS AND DISCUSSION

The Insul program [8] is a significant tool in the initial design phase - conceptual design, whose analyses are sufficiently accurate to enable effective material and construction choices, ensure acoustic comfort, and provide a pleasant environment, which is particularly important for facilities such as industrial buildings.

Figures 3 to 8 show the reference values of insulation performance obtained through software calculations. International standards that describe methods for quantifying sound insulation arose from the need to compare the obtained values, which are inherently frequency-dependent, uniformly and to compare them with established criteria that need to be met [8]. The curves of the insulation performance for the analyzed models, which depend on the frequency and are calculated and measured in 1/3 octave frequency bands, are displayed in Figures 3 to 8 [6].

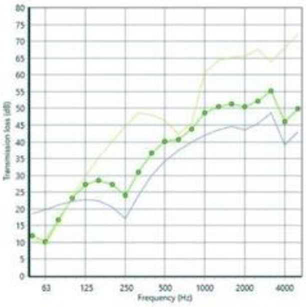

Fig. 3 Model 0

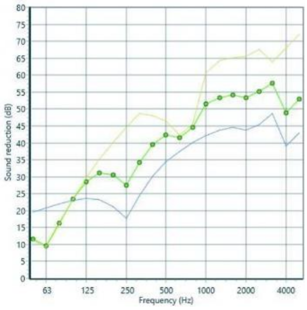

Fig. 4 Model 1

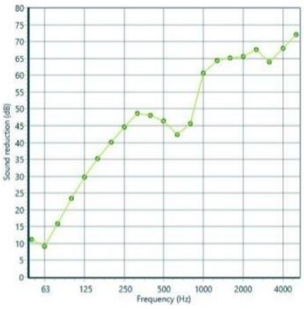

Fig. 5 Model 2

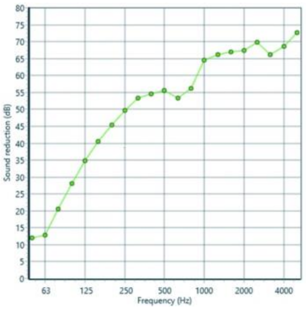

Fig. 6 Model 2’

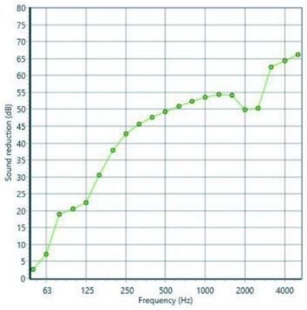

Fig. 7 Model 3

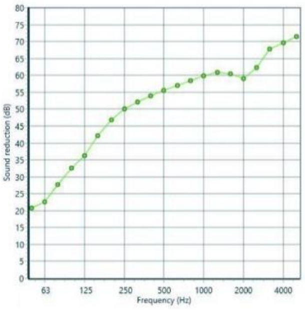

Fig. 8 Model 3’

Reference values in third-octave frequency bands from 63 Hz to 4000 Hz, which need to be compared with each other, are numerically provided in Table 2.

Table 2 Values of the reference curves for the analyzed partitions

	Frequency (Hz)							IzolacionamoćRw (dB)
	63	125	250	500	1000	2000	4000	
MODEL 0	10	27	24	40	49	50	46	**39**
MODEL 1	10	29	28	42	52	53	49	**44**
MODEL 2	9	30	45	46	61	66	68	**49**
MODEL 2’	13	35	50	56	65	67	69	**57**
MODEL 3	7	22	43	49	54	50	64	**48**
MODEL 3’	23	36	50	56	60	59	70	**57**

Frequency analysis results show that the designed partition MODEL 1 has the lowest insulation performance (39 dB), which is 10 dB lower compared to partition MODEL 2 (49 dB), which has the same characteristics as MODEL 1 but without glass partitions, i.e., without windows. This indicates that the presence of windows leads to a significant deterioration in acoustic comfort. The insulation performance of the glass partition MODEL 3 (48 dB) is nearly identical to MODEL 2 (49 dB).

The optimized partition MODEL 2, MODEL 2', increases the insulation layer without changing the width of the partition, leading to a significant improvement in acoustic performance, meeting the minimum requirement of the standard (57 dB). Similarly, for partition MODEL 3' (57 dB), changing the type of glass compared to MODEL 3 (48 dB) also significantly increases insulation performance, ensuring better acoustic comfort and meeting the standard's minimum requirement of 57 dB.

When calculating the insulation performance of partitions using software, it is essential to remember that the obtained results often cannot be fully realized under actual conditions. Therefore, these values should be cautiously approached, as achieving the planned sound insulation in constructed partitions can be challenging. M. Mijić recommends selecting partitions with a calculated insulation performance of several decibels (dB) higher for specific lightweight partitions to mitigate such issues [10].

5. CONCLUSION

This study used experimental modeling to analyze and optimize the interior partition of the industrial facility ”IMI” for acoustic comfort. Six partitions were examined, showing that MODEL 0 (a base wall with many windows) had the lowest sound insulation (39 dB). Reducing the glass area improved insulation, with MODEL 2 (a windowless wall) achieving the highest level (49 dB). MODEL 2 was then optimized to meet sound insulation standards. The research also explored glass partitions, often used in modern buildings, for visual interaction between production and administrative areas. Analysis of a glass partition of the exact dimensions as the designed one revealed that not all glass types provide adequate acoustic performance. MODEL 3, with ordinary glass, had nearly 10 dB less insulation than required, underscoring the need for optimization to meet acoustic standards.

Increasing the thickness of partitions is not an optimal solution for improving sound insulation; understanding material properties and their proper use is essential. Sound insulation depends on the partition and surrounding constructions, including vertical and horizontal elements that can affect overall acoustic performance [11]. Future research will focus on sound insulation field measurements to validate the accuracy of software calculations and refine the methods for achieving effective acoustic solutions.

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