# Recycled Paper Acoustic Panel Production System with YOLOv11-Based Defect Detection

Tambua, Rojane S.[1]; Cabalquinto, Yvaine B.[2]; Luciano, Joshua Amiel B.[3]; Te, Jeffrey E.[4]; Toledo, Gian Marco A.[5]; Paolo Roberto O. Lozada[6]; Tommy A. Ditucalan[7]

[1,2,3,4,5]Student, College of Engineering, San Sebastian College–Recoletos de Cavite, Cavite City, Philippines
[6,7]Faculty, College of Engineering, San Sebastian College–Recoletos de Cavite, Cavite City, Philippines

Publication Date: 2026/04/16

**Abstract: This study developed a semi-automated recycled paper acoustic panel production system with a YOLOv11-based defect detection to improve product consistency and reduce dependence on manual inspection. The produced system consists of a shredding unit, a washing motor for pulping and ingredient mixing, a molding chamber, a drying setup, and a Raspberry Pi for defect detection. Manual operations were limited to paper feeding, panel flipping, and a minimal button intervention. The YOLOv11 model was trained to detect surface defects limited to cracks, deformations, and incorrect perimeter in real time, achieving more than 85% accuracy, 80% precision, 85% recall, a 90% F1- score, and 85% mAP. The prototype successfully produced panels within ±3 mm of the target dimensions and maintained perimeter error rates below 1.5%. Moreover, the average time required to produce one panel was 1 hour. Acoustic evaluation showed that the produced panels achieved a NRC of 0.7 and favorable STL values very close to those of commercially available acoustic panels. These results demonstrate that this system provides an effective and sustainable solution for manufacturing high-quality recycled paper acoustic panels.**

***Keywords:*** *Acoustic Panel Production System, Industrial Automation, Quality Control System, Sustainable Engineering, Yolov11 Detection.*

**How to Cite:** Tambua, Rojane S.; Cabalquinto, Yvaine B.; Luciano, Joshua Amiel B.; Te, Jeffrey E.; Toledo, Gian Marco A.; Paolo Roberto O. Lozada; Tommy A. Ditucalan (2026) Recycled Paper Acoustic Panel Production System with YOLOv11-Based Defect Detection. *International Journal of Innovative Science and Research Technology*, 11(3), 3948-3953. https://doi.org/10.38124/ijisrt/26mar1843

## I. INTRODUCTION

Noise has become a matter of public concern in increasing amounts since it has been found to have detrimental impacts on health and quality of life in general. This event where exposure to harmful noise levels became a common problem, this led to the search for efficient noise mitigation strategies. One of them is the sound-absorbing materials, which serve to prevent the transmission of noise and this will ensure more comfortable environments in urban settings when it comes to sound and acoustics [1].

In recent years, there has been a noticeable shift toward using sustainable materials in acoustic applications. Paper, which is largely composed of cellulose fiber, is one of the most sustainable natural resources that can be seen in nature. This renders recycled paper among the finest raw materials applied in the production of acoustic panels, and a sustainable method of addressing noise pollution. Use of recycled paper as a sound absorbing material promotes eco-friendly development for building and construction [2].

Gross defects on the production can decrease the acoustics of recycled paper panels. More accuracy is gained by automatic defect detection than through traditional manual methods of inspection, more environmental sustainability, and higher operation capacity [3]. Manual inspection has always been slow and time-consuming, and automating the inspection process could lead to enhanced speed, accuracy, and reliability in remanufacturing evaluations [4].

In the context of Philippine schools, noise pollution is a problem that affects classroom environments. Based on an interview conducted in San Sebastian College-Recoletos de Cavite with at least six available professors or teachers that work in school, there is a need of making an acoustic panel and attaching it in school settings, such as walls or doors. These teachers confirmed that most of the time, students are loud outside the classrooms and distract students from learning.

To validate the relevance of the study, a survey was also conducted through Google Forms to gather ECE professionals and sound engineers an opinion related to the

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar1843

development of a defect detection system for recycled paper acoustic panels.

This research entitled, "Recycled Paper Acoustic Panel Production System with YOLOv11-Based Defect Detection," aimed to develop a semi-automated production system for recycled paper acoustic panels with a YOLOv11-based defect detection. This setup allowed the researchers to maintain the efficiency of automation while allowing flexibility at the same time for manual adjustments when needed. Overall, this system demonstrated how automation and human operation could work together to promote sustainability and improve the quality of recycled material production.

## II. RESEARCH METHODOLOGY

➢ *Research Design*

In this study, the researchers employed an experimental research design because the study aims to create a system where recycled paper can be used as primary material for making acoustic panels, which then underwent a YOLOv11-based model for detecting defects. This approach allows for the comparison of very disparate sample groups (defect-free and defective) and, therefore, assists in the goals of determining system needs, testing the YOLOv11 detection process, and assessing its contribution to production quality, efficiency, and sustainability.

➢ *Materials and Data Sources*

The data sources for this research were limited to the premises of San Sebastian College–Recoletos de Cavite in Cavite City, Philippines. Recycled paper waste was collected from offices and students within San Sebastian College–Recoletos de Cavite, Philippines. Approximately 46 kg of paper were gathered during the initial collection phase, followed by additional materials for prototype testing. These types of papers were non-glossy finishes, and these were processed into pulp and molded into 300 mm x 300 mm x 10 mm acoustic panels, and 200 mm x 200 mm x 10 mm acoustic panels.

For defect detection, images of the panels were captured using a camera module connected to a Raspberry Pi 4. The dataset in this study consists of 1200 labeled images that are categorized into four classes which are Cracks, Deformations, Incorrect perimeter, and Non-defective panels. Image annotation was performed with the help of Roboflow, and training was conducted in Google Colab using the Ultralytics YOLOv11 framework.

➢ *Panel Final Scale of Ingredients*

Multiple experimental trials were conducted by the researchers in order to know the optimal mixture composition of both 12 x 12 and 8 x 8 panels. The final formulation is summarized in Table 1.

Table 1 Final Scale of Ingredients.

| Component | 8 in x 8 in x 1 cm Panel | 12 in x 12 in x 1 cm Panel |
|---|---|---|
| **Paper** | 8 sheets (36 g) | 18 sheets (80 g) |
| **Water** | 750 mL | 1.25 L |
| *Dissolved Borax* | 2 g | 4 g |
| *Resulting Pulp Volume* | 650 mL (medium-thick) | 1.05 L (medium-thick) |
| **Wet: Boysen Clear Acrylic Emulsion B-700** | 120 mL | 200 mL |
| **Dry: Cocopeat (sifted)** | 18 g | 40 g |
| **Dry: Sawdust (medium-coarse)** | 11 g | 25 g |
| **Dry: Gypsum Powder** | 12 g | 25 g |
| *Oven Drying (210 °C)* | 45 min | 45 min |
| *Final Thickness After Pressing* | 1.0 cm | 1.0 cm |

Table 1 shows the summary of the final ingredients used in this study, and the selected mixture showed optimal bonding, minimal surface defects, and dimensional consistency.

➢ *System Evaluation Procedures*

System performance was evaluated through Time Trial Test which measured total production time per panel, from pulping to defect scanning. Second is the Molding Chamber Test to verify perimeter accuracy. Lastly, is the Drying Chamber Test to calculate moisture removal efficiency using the formula (W1-W2)/W1 x 100.

The trained YOLOv11 model was evaluated using a 70:30 train-test split [5]. Performance metrics included: Mean Average Precision (mAP), Precision, Recall, and F1-score. Detection results were categorized into four, and these are the True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN). Moreover, accuracy was computed as: (TP + TN) / (TP + TN + FP + FN) × 100.

The dataset used for the defect detection system consisted of 1,200 images categorized into four classes: Good, Cracks, Deformation, and Incorrect Perimeter, with 300 images per class, ensuring balanced data distribution. All

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar1843

images were resized to a uniform resolution of 312 × 312 pixels to maintain consistency during model training. The dataset was divided into 70% for training (840 images), 15% for validation (180 images), and 15% for testing (180 images) to properly evaluate model performance.

Table 2 YOLOv11 Dataset Summary.

| Category | Details |
|---|---|
| Number of Classes | 4 ( Good, Cracks, Deformation, Incorrect Perimeter) |
| Total Images | 1200 |
| Total Images per Classes | Good – 300<br>Crack – 300<br>Deformation – 300<br>Incorrect Perimeter – 300 |
| Image Resolution | 312x312 |
| Data Split | Train – 70% (840 images)<br>Validation and Testing – 30% (360 images) |
| Augmentation Applied | Flip (Horizontal, Vertical)<br>Saturation<br>(Between -25% and +25%)<br>Brightness<br>(Between -15% and +15%)<br>Exposure<br>(Between -10% and +10%)<br>Blur<br>(Up to 0.4px) |

Table 2 shows the YOLOv11 Dataset Summary Table. To improve generalization and reduce overfitting, data augmentation techniques were applied, including horizontal and vertical flipping, adjustments in saturation (−25% to +25%), brightness (−15% to +15%), exposure (−10% to +10%), and blur up to 0.4px.

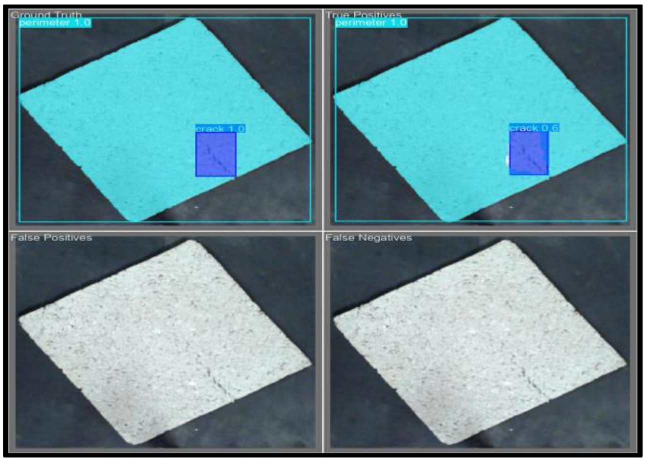


Fig 1 Annotated Dataset.

Figure 1 presents the Annotated Dataset Visualization of Recycled Paper Acoustic Panels. These photos were annotated using Roboflow.

Lastly, two acoustic parameters were evaluated. A speaker was placed outside the test enclosure while a sound level meter was positioned inside. STL was computed from the difference in sound intensity (dB) with and without the installed panel [6].

For NRC testing, the speaker was placed inside the enclosure. Reverberation time (RT60) was measured at octave band frequencies: 500 Hz, 1000 Hz, 1500 Hz, and 2000 Hz [7].

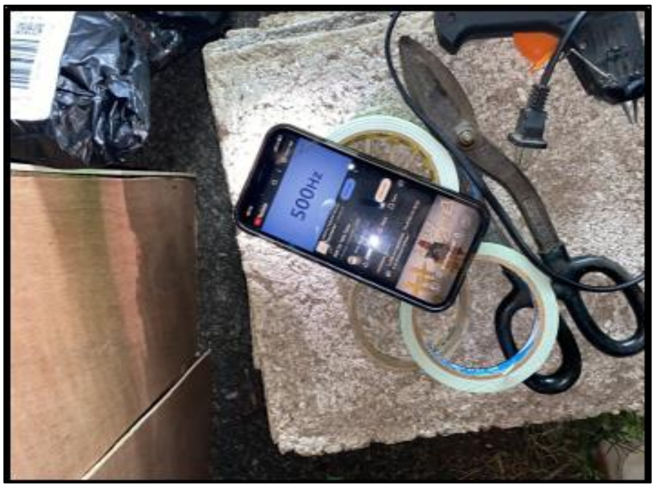


Fig 2 NRC and STL Testing.

Figure 2 shows the documented photo at NRC and STL testing. NRC was calculate as the average absorption coefficient across the measured frequencies.

## III. RESULTS AND DISCUSSIONS

- *Acoustic Performance of the Recycled Paper Panel*

Table 3 Noise Reduction Coefficient of Recycled Paper Acoustic Panel

| Trial | Frequency | A_T (Total Absorption Area) | $\alpha_t$ |
|---|---|---|---|
| 1 | 500 | 0.056 | **0.6** |
| 2 | 1000 | 0.064 | **0.68** |
| 3 | 1500 | 0.074 | **0.79** |
| 4 | 2000 | 0.063 | **0.67** |
| **Summary** | | **NRC (rounded to 0.05)** | **0.685** |

The recycled paper acoustic panel achieved absorption coefficients ranging from 0.60 to 0.79 across 500-2000 Hz. The NRC was computed as the average absorption performance across the standard bands giving an average NRC of 0.685, rounded to 0.70, meaning the panel absorbs about 70 % of incident sound energy. This level of performance is comparable to other porous or fibrous acoustic panels that follow the same standards [8].

Table 4 Sound Transmission Loss of Recycled Paper Acoustic Panel

| Trial | Frequency | Source Sound Level ($L_1$, dBA) | Received Sound Level ($L_2$, dBA) | STL = $L_1 - L_2 + 10 \log_{10}$ (S/A) (dBA) |
|---|---|---|---|---|
| 1 | 500 | 97.4 | 77.6 | **22.002** |
| 2 | 1000 | 102.2 | 80.8 | **23.023** |
| 3 | 1500 | 107.9 | 84.9 | **23.992** |
| 4 | 2000 | 103.2 | 81.9 | **22.991** |
| **Summary** | | | | **23.002** |

Without the acoustic panel installed, the test opening exhibited an average STL of 14.73 dBA, indicating significant sound transmission through the bare plywood enclosure. STL values with the panel installed range from about 22 to 24 dBA, with an average of ≈23 dBA, which is roughly 8 dB higher than the average STL of the bare plywood enclosure. An 8 dB increase in STL corresponds to a several-fold reduction in transmitted sound power, indicating that the recycled paper panel significantly improves the sound-blocking performance of the test partition.

- *Mechanical and Production System Performance*

The shredder was able to handle increasing amounts of paper, where the researchers tested it from 20 pieces up to 200 pieces, and it did not jam. This shows that the purchased shredder is capable of processing a high quantity of paper reliably under normal operating conditions. For both panel sizes (12x12 and 8x8 inches), a mixing time of 20 seconds produced the optimal pulp consistency. Mean pulp weight for 12x12 was 1150.8 g. Mean pulp weight for 8x8 was 652.8 g. Shorter mixing times resulted in coarse mixtures, while longer mixing times caused over-mixing, which makes the pulp watery and less ideal for panel molding. This shows that it has a consistent pulp weight and that each panel has a uniform thickness and density, which directly affects its structural features and overall quality.

Moisture removal increased with temperature. Optimal drying conditions were achieved at 230°C for 60 minutes, producing approximately 50% moisture loss without visible cracks or dimensional defects. Temperatures at or above 250°C resulted in surface cracking and dimensional inaccuracies. Additionally, the internal DC fan operated normally up to 250°C but stopped functioning at 270–300°C, indicating that temperatures above 250°C exceed safe operational limits.

Both 12x12 and 8x8 panels exhibited similar drying behavior, confirming repeatability of the drying system.

Table 5 Average Perimeter and Error Percentage of 12x12 Panel

| Parameter | Mean (mm) | Target (mm) | Tolerance Range | Error (%) |
|---|---|---|---|---|
| **Length** | 297 | 300 | 297-303 | 1% |
| **Width** | 297.4 | 300 | 297-303 | 0.87% |

For the molding accuracy and perimeter analysis, the mean perimeter of the 12x12 panel was 297x297.4 mm with an error percentage of 0.87%–1%.

Table 6 Average Perimeter and Error Percentage of 8x8 Panel

| Parameter | Mean (mm) | Target (mm) | Tolerance Range | Error (%) |
|---|---|---|---|---|
| **Length** | 197.6 | 200 | 197-203 | 1.20% |
| **Width** | 197 | 200 | 197-203 | 1.30% |

For the 8x8 panel the mean perimeter was 197.6x197.4 mm with an error percentage of 1.2%–1.3%.

Approximately 80% of trials met the dimensional tolerance range (±3 mm) [9]. All measured errors were below the acceptable 2.5% threshold for major defects. The means presented are also within tolerance, and the errors are below the acceptable error rate, since the acceptable error rate for major defects is 2.5%, while that for minor defects is 4% [10].

The results also showed that the production time per panel ranged from 1 hour and 10 minutes, and 1 hour and 20 minutes. The average production time across all trials was 1 hour and 14 minutes. This minimal variation of only 9 minutes between the fastest and slowest runs indicates a high level of process stability and repeatability.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar1843

Out of five full production trials, there were four trials that showed no errors. One trial exhibited incorrect defect detection. No hardware failures were recorded. The system maintained stable pulping, molding, drying, and relay operations, confirming reliable end-to-end functionality.

➢ *YOLOv11-Based Defect Detection Performance*

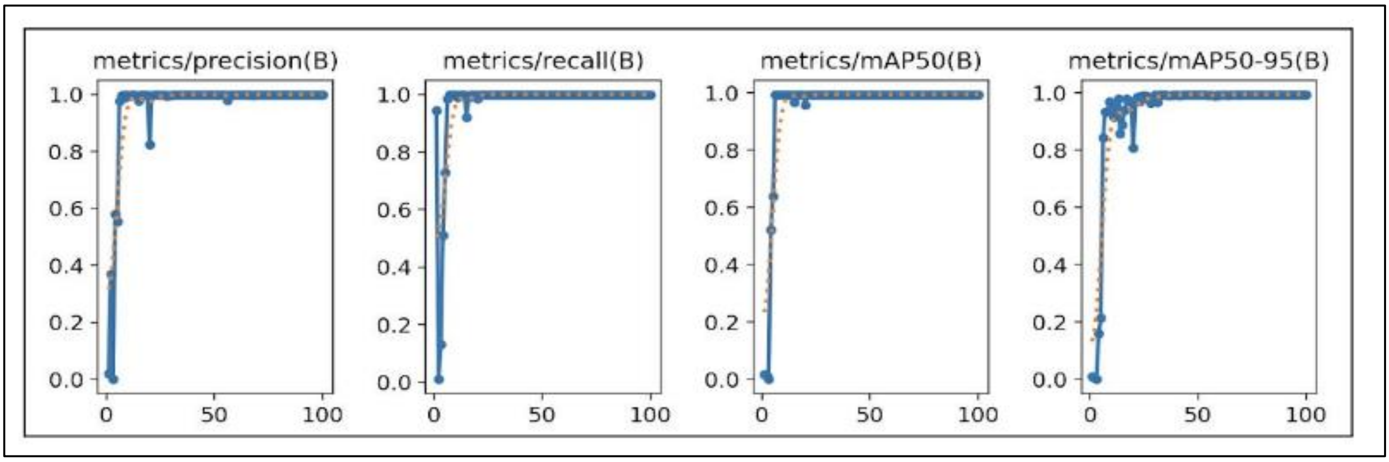


Fig 3 YOLOv11 Model Results

Figure 3 shows the trained YOLOv11 model achieved the following performance metrics: Accuracy: 0.98, Precision: 0.98, Recall: 0.96, mAP@0.5: 0.99, and mAP@0.5–0.95: 0.96. The F1-score reached a maximum of 1.00 at a confidence threshold of 0.923, indicating an optimal balance between precision and recall.

Table 7 Actual vs Predicted Results

| Trial | Actual Condition | Predicted Condition | Confusion Matrix |
|---|---|---|---|
| 1 | Non-Defective | Non-Defective | TN |
| 2 | Non-Defective | Non-Defective | TN |
| 3 | Non-Defective | Non-Defective | TN |
| 4 | Defective | Defective | TP |
| 5 | Non-Defective | Non-Defective | TN |
| 6 | Defective | Defective | TP |
| 7 | Defective | Defective | TP |
| 8 | Defective | Defective | TP |
| 9 | Non-Defective | Non-Defective | TN |
| 10 | Defective | Defective | TP |

The model correctly detected all 5 actual defective panels, which shows a result of 5 true positives and 0 false negatives. It also correctly identified all 5 actual non-defective panels, which resulted in 5 true negatives and 0 false positives. Therefore, this means that the trained model by the researchers made no wrong classifications during the test.

These results exceed the target thresholds defined in the system requirements, confirming that the trained model provides reliable real-time detection of surface and structural defects such as cracks, deformations and incorrect perimeter.

➢ *Comparison with Commercial Acoustic Panel*

Table 8 Comparison of Commercial and Recycled Panel

| Trial | Frequency | $\alpha_s$ (Commercial Panel) | $\alpha_s$ (Recycled Paper Panel) | STL = $L_1 - L_2 + 10 \log_{10}$ (S/A) (dBA) (Commercial Panel) | STL = $L_1 - L_2 + 10 \log_{10}$ (S/A) (dBA) (Recycled Paper Panel) |
|---|---|---|---|---|---|
| 1 | 500 | 0.76 | 0.6 | 24.972 | 22.002 |
| 2 | 1000 | 0.9 | 0.68 | 25.942 | 23.023 |
| 3 | 1500 | 0.91 | 0.79 | 26.991 | 23.992 |
| 4 | 2000 | 0.78 | 0.67 | 25.451 | 22.991 |
| Summary | | 0.85 | 0.685 | 25.839 | 23.002 |

The commercial acoustic panel achieved absorption coefficients between 0.76 and 0.91, resulting in an average NRC of 0.85. Compared to the recycled panel (NRC = 0.70), the commercial panel demonstrated higher overall absorption. However, the recycled panel's 0.60–0.79 range remains within effective acoustic treatment levels for speech-frequency control.

The commercial panel achieved an average STL of 25.84 dBA, compared to 23.00 dBA for the recycled panel. The performance difference of approximately 2–3 dB indicates that while commercial panels provide slightly stronger sound-blocking performance, the recycled panel delivers competitive acoustic behavior.

At distances of 1.5 m, 3.0 m, and 6.0 m, both panels reduced sound levels across all tested frequencies. The recycled paper panel provides about 2-4.4 dB reduction compared with the source, and the commercial panel only

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar1843

adds a small extra improvement of roughly 1-2 dB in most cases.

This means that the difference between the two panels is relatively small, especially at mid to high frequencies, so the recycled paper panel performs closely to the commercial panel. These results suggest that the recycled panel is comparable to typical panels available in the marketplace, making it a promising, potentially more sustainable alternative for sound control applications.

## IV. CONCLUSION AND RECOMMENDATIONS

- *Conclusion*

This study developed a semi-automated recycled paper acoustic panel production system integrated with YOLOv11-based defect detection. The system automated key processes from shredding to drying, with minimal manual intervention. Optimized parameters produced uniform, structurally stable panels. Acoustic testing showed an NRC of 0.7 and an STL of 23 dBA, comparable to commercial panels. The integrated YOLOv11 model accurately detected defects in real time, reducing human error and improving quality control. Overall, the system demonstrates efficient, sustainable production of sound-absorbing panels through hardware–software integration and machine learning–based inspection.

- *Recommendations*

Future studies may explore adapting the prototype to produce other recycled paper products, such as tiles or decorative wall panels, and examine optimal drying times to reduce curing costs. The developed mixing, pulping, and pressing mechanisms can also be applied to alternative materials, expanding its manufacturing potential. System improvements may include automated temperature control with real-time feedback to enhance drying efficiency. Additionally, expanding the YOLOv11 dataset to include more defect categories and increasing validation trials is recommended to further improve detection accuracy and system reliability.

## REFERENCES

[1]. Astrauskas, T., & Grubliauskas, R. (2020). Method to recycle paper sludge waste: production of panels for sound absorption applications. [Online]. Available: https://www.researchgate.net/publication/347825389_Method_to_Recycle_Paper_Sludge_Waste_Production_of_Panels_for_Sound_Absorption_Applications
[2]. Liuzzi, S., Rubino, C., Martellotta, F., & Stefanizzi, P. (2023). Sustainable materials from waste paper: Thermal and acoustical characterization. Applied Sciences, 13(8), 4710.
[3]. Yang, J., Li, S., Wang, Z., Dong, H., Wang, J., & Tang, S. (2020). Using deep learning to detect defects in manufacturing: a comprehensive survey and current challenges. Materials, 13(24), 5755.
[4]. Nwankpa, C. E., Ijomah, W., & Gachagan, A. (2021). Design for automated inspection in remanufacturing: A discrete event simulation for process improvement. Cleaner Engineering and Technology, 4, 100199. [Online]. Available: https://doi.org/10.1016/j.clet.2021.100199
[5]. Aydin, B., & Singha, S. (2023). Drone detection using yolov5. Eng, 4(1), 416-433.
[6]. Irwan, A. I., Sari, K. A. M., & Kosnin, H. (2022). Development of wall panels using recycled paper and cotton polyester fibres for acoustic and thermal performance. Progress in Engineering Application and Technology, 3(1),176–186. [Online]. Available: https://doi.org/10.30880/peat.2022.03.01.020
[7]. Acoustical Surfaces (2020). NRC Rating 101 – Understanding the Noise Reduction Coefficient. [Online]. Available: https://www.acousticalsurfaces.com/blog/acoustics-education/nrc-rating-101/
[8]. Tile Warehouse (2023). What are tile tolerances? [Online]. Available: https://www.tilewarehouse.co.uk/help-advice/what-are-tile-tolerances/
[9]. Banton, C. (2025). Understanding Acceptable Quality Level (AQL) in Quality Control. *Investopedia*. [Online]. Available: https://www.investopedia.com/terms/a/acceptable-quality-level-aql.asp