Expanding Application of Perforated Metal Materials in Construction and Architecture

V Mironovs¹, A Tatarinov¹ and S Gorbacova¹
¹Riga Technical University, Faculty of Civil Engineering, Kipsalas Street 6a, Riga, LV–1048, Latvia
E-Mail: victors.mironovs@rtu.lv

Abstract. Perforated metal materials (PMM) combine a range of properties, including rigidity, strength, lightweight, small thickness, a dosed transparency and decorative attractiveness. All these bring new application effects in construction industry and architecture. Nowadays, PMM are widely used in design of facades and interiors all over the world, becoming more popular in Latvia as well. The paper touches several aspects of PMM applications, including its decoration function, shadowing of sunlight, sound and noise barrier function and the problem of corrosion when exploited outdoors. Possible perfection may include using different coatings, multi-layer design variants and integration with other constructional materials in order to provide better sound absorption, corrosion resistance and functionality.

1. Introduction
Among a variety of applications of perforated metal materials (PMM), the architectural one is the most prominent. It includes but is not limited to cladding of facades, decoration of interiors, covers of columns, staircases design and arrangement of protective walls and enclosures [1]. In addition to decorative aesthetic design, PMM provide architects and builders with additional benefits such as sunshade, noise reduction, lightweight fencing, energy saving and access control.

Figure 1. Architectural facades of student’s service building in Perth (Australia) (a) and of private house in Portugal (b) decorated by PMM.
Perforated facades amaze with its diversity and artistic imagination. PMM are used not only to decorate buildings of commercial companies and social infrastructure, but also to create new image of private houses. Two samples of modern trends are shown in figure 1. The first one shows Ngoolark Student Services building in Perth, Australia designed by JCY Architects & Urban Design [2]. Made of the Alucobond aluminum composite material the perforated exterior provides similarly shimmering and light-changing abilities. Several shades of gold shimmer from dark to light, metallic to rose, depending on the way the sun hits the building. In contrast, architects José Cadilhe and Emanuel Fontoura (Portugal) used almost oblique stainless steel panels perforated with pattern of certain symbols. These panels have not only decoration function, but also practical – they act like shutters, allow to open the windows and doors [3].

An interesting transformation experienced Dream Downtown Hotel in New York [4]. Originally, building was designed for the Maritime Unions in 1966 with heavily featured porthole type windows on its facade, but in 2006 Handel Architects using idea of the circular theme in facade and interior, made a number of adjustments. On the south, the skin of the building is constructed of two perforated stainless-steel layers, which perfectly reflects both – daylight and artificial lighting what gives a good contrast of the hotel and environment (figure 2a). Top sheet of the southern facade replicates northern facade punched - window design (figure 2b), but the inner sheet is a regular perforation pattern.

![Figure 2](image-url)

**Figure 2.** South (a) and north (b) sides of facade facing in Dream Downtown Hotel in New York.

PMM may perform a significant role in regulation of temperature and air ventilation of buildings, along with a dosed light permeability providing illumination from outside. One of such cases is successfully illustrated by the new building of the Military History Museum in Dresden (figure 3).
PMM are becoming more common in architectural design in Latvia too. PMM are used as facade facing material, fencing construction for motorways and sidewalks, benches, enclosure for garbage cans or shed for bicycles. There is a growing tendency to introduce PMM as decorative elements in building’s facades, windows and constructive elements (figure 4).

In a laboratory of the Building Production Department at the Riga Technical University, a certain experience is gained in studying of steel PMM applicability for solving a number of technical issues, including: reinforcing brick masonry, junction connecting, floor concreting and others [5]. Perforated metal sheet is technological and can be used for noise reduction, since the holes in the metal sheet are involved in sound absorbing. Perforated material can also be effectively used for shielding electromagnetic fields [6]. A great effect of PMM can be achieved when they are used as barrier for solar radiation and wind.
2. Reduction of solar radiation and sunshading

Nowadays, glass panels of building’s windows and doors are well insulated and therefore in cold seasons of the year less energy is consumed for heating premises. The use of perforated material not only serves as a shielding, but also is able to contribute to the formation of the necessary cooling to reduce energy consumption with using solar screens. Investigation of the direction of solar radiation on the windows of the building at different times of the year and day shows that quite often sun rays directly shining right into the windows of the building. Well-known oblique horizontal constructions separating loggias and balconies can not prevent from the direct sunlight entering the room, especially in the morning hours, since the sun’s rays during this period are much lower.

PMM can scatter direct sunrays and provide better comfort protecting from the excess of direct light. There are two solutions possible. The first one is to make curved PMM canopy-type shells for movable or permanent shutters shadowing the window all daytime or all seasons. The second one is to design PMM shutters on the windows opening or closing depending on falling sunrays. Both solutions are depicted in figure 5. The last presented solution radically transforms the facade view being closed or open. It allows to vary angle of opening thus to regulate amount of light entering the room.

3. Formation of PMM elements for decorative function

By now, designers have tried numerous techniques and forms to enhance decorativeness of PMM. Some expressive examples from Internet classified by approach are presented in figure 6. Different patterns of perforations along with regular round holes can form a texture of PMM sheets in serial production proposing to a customer a certain choice. By variation of size and density of perforations by the surface area purposeful artistic effects are achieved ranging from abstractions to specific visual forms reproducing architectural elements or photographic images. These art works are mostly designed by orders. By managing the spatial orientation of PMM sheets, including mutual arrangement of the sheets at angles, bending them or making curved surfaces, facades and walls are transformed from the flat type to a structured one, where characteristic spatial patterns are featured by light and shadows play. This may favorably enrich view of public buildings with large open surfaces and give them a unique view. Another approach of modifying PMM surfaces is shaping by depth. It can be achieved either by periodic indentation or by creating structures consisting of two or more layers of PMM sheets of the same or different textures. Along with decorative purpose, this brings concomitants beneficial properties such as increased rigidity, thickening and modified permeability.
Experiments conducted at the Faculty of Civil Engineering of Riga Technical University were aimed at creation of spatial structures of two or more superimposed perforated sheets or by deformation of elastic thin-walled PMM elements (figure 7). The goal was to impact decorative properties of PMM obtained as waste products from metal processing at the Ditton factory (Daugavpils, Latvia) for further use as constructive elements in local construction works. In both cases, a change of through transmittance of light by reducing the clearance area and increase of the stiffness were achieved. The structures were fixed by periodic contact welding.

**Figure 6.** Different techniques applied by designers to enhance decorative function of PMM. (Examples borrowed from Internet).
Figure 7. Changes of the area of through holes by superimposing perforated sheets (a) and by deforming the sheet (b).

4. Sound and noise barrier function
One of the PMM functions is related to shielding of sound waves in specific frequency ranges. The acoustic function of PMM is illustrated in figure 8. There are two possible mechanisms of obstruction of sound propagation – reflection of sonic waves by the facial surface and absorption of sound energy by the internal structure transforming it into thermal energy. The effectiveness of sound barrier is estimated by the ratio of intensities of incident and transmitted waves. Since the acoustic impedances of a metal (steel or aluminum) surface of PMM and of air differ in several orders, the largest portion of sound energy should reflect from the surface if the latter is continuous. It has a positive shielding effect on the protected side but can enhance noise level at the side from where sound is emitted due to summing with the echo. Presence of perforations allows some portion of sound waves come in and involve absorption mechanisms. In the case of PMM, these are two. The first one is damping of sound energy by passing the wave through perforated holes due to friction losses of oscillating air molecules interacting with the hole’s walls. The efficiency of damping is greater the larger is the contact area, which is determined by the ratio of PMM thickness $T$ to the hole’s diameter $D$. In thin-walled PMM, $D$ should be comparable or lesser than $T$ to make the effect notable. Amount of holes per square determined by its spacing $S$ also plays role in the variation of the ratio reflected sound energy and passed through PMM. It was found that micro-perforated PMM where the perforations are reduced to millimeter or sub-millimeter size present very effective sound absorption without any additional classical absorbing material. Micro-perforated sheets are widely applied in machinery, aerospace, aircraft construction and different industrial enclosures. The second mechanism is of Helmholtz resonator type. In this case, a rigid wall stands behind a PMM sheet at a distance $L$, reflecting sound waves. The absorption occurs due to oscillation of the air column enclosed between the wall and the hole. The oscillations are supported by springy response of air volume compressed by the sound wave coming through the hole from one side and reflected from the wall from another side. Maximum absorption occurs at a frequency of resonance, determined by geometrical parameters of the system $L$, $D$ and $T$. To make barriers the most soundproof, the construction implies additional absorbers from porous or woven materials having a substantial thickness ranging from a few centimeters to more than ten centimeters. In such type of panels, PMM take mainly protective and decorative functions, whilst the main sound absorption is performed by the absorber. The acoustical shielding panels are used in industry, offices, and acoustical buildings, as well as at highways and railways shielding the dwelling environment from noise.
Figure 8. General layouts of sound absorption by PMM (explanation in text).

At the present, there are numerous manufacturers all over the world proposing acoustical panels with PMM combining the durability of a perforated metal shell and the superior noise control provided by customized absorbing materials inside. Some examples of such products are shown in figure 9.

Figure 9. Examples of commercial PMM as acoustic absorbers: microperforated acoustic ceilings Silk Metal™ of Architectural Surfaces Inc (a); modular PMM acoustic panel with mineral wool core of Custom Audio Designs Ltd for industrial use (b); customized Acoustimetal™ shells of Acoustical Surfaces Inc for indoor and outdoor use (c).

Despite achieved high performance, different types of acoustic panels have one of certain limitations: not enough lightweight, contain degradable absorbing material, not transparent or not air-permeable. Single PMM without absorbers are not enough effective as acoustic barriers in broadband audible range. That is why there is a demand and ongoing research for creation of new types of PMM with high sound absorbing, frequency selective and frequency band broadening properties. In particular, it is dealt with application of multi-leaf PMM [7], investigation of variations of holes shape [8] and design of new PMM with extended tubes from the perforations in order to move absorption peak to low frequencies [9].

5. Environmental impact assessment.
The most common manufacturers offered PMM are: 1) cold-rolled steel; 2) hot-rolled steel; 3) galvanized steel; 4) stainless steel; 5) aluminum; 6) copper; 7) titanium zinc. PMM that are used as decorative and protective elements are exposed to the environment. There is need to protect the surface as long as possible to maintain the original appearance of the facade. Atmospheric corrosion is a process that occurs in the metal layer and at its surface at the same time. A higher degree of corrosion will occur under humid climatic conditions and with long-term exposure to moisture (ISO 9223: 1992). Perforated metal elements are more likely to undergo corrosion if they are exposed to the open air under the influence of polluting gases or aerosols. Sulphates and chlorides also increase corrosion development probability. A higher probability of corrosion is appearing when relative humidity is above 80% at medium temperatures near to 0° C [10]. The data of research showed that using the screen dying
technology from 1.0 mm thick perforated steel sheet weight loss is 4-6 times greater than in the case of preliminary galvanizing.

Inspection of fences in new maintained area of the Riga Technical University for a year of exploitation get significant damage because of corrosion (figure 10). It showed that a little attention was paid to corrosion before the installation of galvanized steel sheets. Inadequate anticorrosive primer thickness whether it is provided by zinc coatings or galvanizing is the major cause of edge corrosion and the major cause of coating failure generally on steelwork.

**Figure 10.** Fence from PMM: general view (a) and a fragment (b) after exploitation.

### 6. Conclusion

PMM are good choice to use them in architectural design possessing such advantageous properties as decorativeness, lightweight, partial transparency, rigidity, durability and diversity of shapes. In addition to cladding function, it can provide such helpful features like sun shading, noise protection, and ventilation. Its limitations are corrosivity if not well protected against and insufficient sound protection if applied without classical absorbers. This opens new rooms for perfection, particularly, of using different coatings, multi-layer design variants and integration with other constructional materials.

### References

[1] Industrial Perforators Association 1993 *Designers, Specifiers And Buyers Handbook For Perforated Metals*

[2] *Innovative Student Services Building Clad in Shades of Gold Alucobond*. Available from: https://www.alucobondusa.com/blog/innovative-student-services-building-clad-in-shades-of-gold-alucobond

[3] *House L27 / DIONISO LAB*. Available from: http://www.archdaily.com/office/dioniso-lab

[4] *Dream Downtown Hotel. Handel Architects*. Available from: http://www.archdaily.com/232361/dream-downtown-hotel-handel-architects

[5] V Mironovs and M Lisicins 2011 Šūnu struktūras no perforētās metāliskās lentes un to izmantošana. (Cellular structures from perforated metal bands and its uses) (in Latvian) (RTU, Riga, Latvia)

[6] V Mironovs, M Lisicins, I Boiko, T Koppel, V Zemēnkovs, V Lapkovskis and A Šiškins 2014 Cellular structures from perforated metallic tape and its application for electromagnetic shielding solutions *Agronomy Research* (Tartu, Estonia) pp 279–284

[7] K Sakagami, M Yairi and M Morimoto 2010 Multiple-leaf sound absorbers with microperforated panels: an overview *Acoustics Australia* 38(2) pp 76–81

[8] X Wang, W Zhang and L Ying 2014 Acoustic performance of a plate with varying perforations *Inter-noise* (Melbourne, Australia) pp 1-6
[9] D Li, D Chang, B Liu and J Tian 2015 A perforated panel sound absorber for low frequencies 22 Int. Congress on Sound and Vibration (Florence, Italy) pp 1-7
[10] C Dolling, R Hudson and C Plc 2003 Corrosion Protection Steel Buildings ed R Pope (London: The British Constructional Steelwork Association Ltd) chapter 12 pp 107-113