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Selection of Materials Using Multicriteria Decision Making. a Case Study on Cellular Materials

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***Abstract*— In recent years, many companies have been striving to transition towards a sustainable, circular economy, focusing on the efficient use of materials and environmental protection. This has become a strategic necessity. One promising approach is the replacement of traditional sheet metals with cellular metal materials, such as perforated metal sheets, expanded metal, welded picket fences, and woven wire mesh. This substitution offers both environmental and economic benefits, while also supporting eco-technological innovations in regional industries. To evaluate the applicability of specific cellular metal materials, several factors must be considered, including the potential for weight reduction, noise reduction, and other environmental impacts. This article presents a multi-criteria decision-making methodology applied to the category of cellular materials, using the example of a perimeter fence in an urban environment. It provides a detailed overview of the types of materials, production methods, and the most significant factors of advantage. The main objective is to highlight the benefits of cellular materials. The primary objective is to highlight the benefits of cellular materials. A group expert assessment method was employed in this study. Findings indicate that perforated metal materials are most popular in properties to Cellular Materials (CMs). However, experts assess that CMs offer unique advantages in construction, design, and environmental sustainability compared to braided or expanded alternatives.**

Keywords* — Assessment, benefits, cellular materials, circular economy, environmental sustainability, manufacturing efficiency, perforated materials, raw materials.

I. INTRODUCTION

In the industrial world, sustainability is gaining in importance, and it is the main issue in research and development regarding manufacturing. Looking for higher resource efficiency and lightweight components results in a continuously increasing use of parts made by additive manufacturing and cellular materials [1].

Recent technological advances have led to an increased availability of production processes for a wide range of cellular metals and alloys. In contrast to many of the materials available before, cellular metals, which can be produced nowadays, are less expensive, therefore being suited for wide-ranging applications in mass markets [2]. Studies on the application of cellular structures have progressed and have been applied in various fields, including vehicles, aircraft industries, and even military applications [3].

Characteristics of sustainable production are therefore efficient for use of lightweight products made from metal, e.g. cellular metal, by providing cheaper resources, reduced waste generation and pollution and enhanced resilience [4]. The additive manufacturing process is a suitable technology to meet the demand for resource efficiency. Due to the principle of placing material only at locations where it is needed, additive manufacturing reduces the material consumption during manufacturing and the energy consumption during the lifetime of vehicles and aircraft. The localised production minimises transport, and hence emissions are reduced.

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The property profile exhibited by cellular metals identifies several applications, especially in technologies requiring multifunctionality. Their specific property attributes suggest implementation as: ultralight panels/shells, energy absorbing structures and heat dissipation media, as well as for vibration control. Connections between the properties that govern these performance benefits and the cellular architecture, cell morphology and density have been made. Cellular metals are engineered structures that use significantly less base material by introducing voids in the form of pores or perforations. This not only reduces the overall consumption of materials but also aligns with resource-efficient design strategies [5].

From an ecological-economic standpoint, the adoption of cellular metals contributes to:

- Reduced material extraction and associated environmental degradation, as cellular structures require significantly less raw material compared to solid sheets, which reduces mining and processing impacts [2].
- Lower energy consumption during production, transportation, and operation, due to the lightweight nature and reduced volume of material used [6].
- Enhanced recyclability and reuse potential in product life cycles, as metallic foams and perforated metals can be reprocessed similarly to conventional metals, often with fewer sorting requirements [7].
- Lower production costs over time, particularly in high-volume sectors such as automotive, aerospace, and construction, due to material efficiency and streamlined logistics.
- These outcomes align with regional sustainability goals while promoting green industry development, especially in resource-constrained or environmentally sensitive regions [8].
- The integration of cellular metal technologies within regional industries supports ecotechnological innovation by enabling their use in:
- Renewable energy systems (e.g., heat exchangers, solar collectors) due to high thermal conductivity and lightweight design.
- Building envelopes and facades, improving energy efficiency while reducing structural load.
- Sustainable mobility solutions, where weight reduction contributes to energy savings and emissions reduction [8].

Moreover, the design flexibility of cellular metals allows for local adaptation and supports decentralised manufacturing models, such as additive manufacturing or closed-loop recycling, which enhance regional technological resilience and reduce dependency on global supply chains.

Incorporating cellular metals into regional development strategies reflects a systemic approach to sustainable growth, as it:

- Encourages smart specialisation in green material science, aligning with the EU's Smart Specialisation Strategy (S3), which promotes innovation-led growth tailored to regional strengths, including clean and advanced materials [9].
- Stimulates eco-industrial clusters and innovation hubs, fostering collaboration between research institutions, manufacturing sectors, and clean-tech start-ups — key components of regional resilience and sustainable industrial policy.
- Aligns with regional climate neutrality targets and investments in green infrastructure, as emphasised in the European Green Deal and Just Transition Mechanism, both of which advocate for climate-resilient, low-carbon regional economies supported by eco-innovation and sustainable materials.

These strategies are especially relevant for regions aiming to participate in major policy frameworks such as the European Green Deal, the Just Transition Mechanism, and the UN Sustainable Development Goals. Replacing traditional sheet materials with cellular metal structures—such as perforated or foam metals—offers a strategic advantage in regional development by reducing the use of critical raw materials, lowering environmental impact, and enhancing material efficiency. This shift supports ecological-economic goals by promoting resource conservation, lowering emissions in production and transport, and enabling cost-effective manufacturing. At the same time, it drives ecotechnological innovation, encouraging the development of advanced, sustainable materials and production methods. Integrating such technologies strengthens regional resilience, supports green industrial growth, and aligns with broader goals of the circular economy and climate-neutral development.

Modern construction and mechanical engineering demand new materials that are both lighter and stronger. Among these, cellular materials are gaining prominence.

As for the manufacturing methods of the periodic cellular metal, Wadley et al. [10] - [13] have been conducting research in this field for many years. Specifically, Wadley [13] gave an overview of various cellular metals manufacturing, and subsequently he also introduced various manufacturing processes for the periodic cellular metal, including honeycomb, corrugated topologies, lattice truss structures and so on. The development of new composite CMs is advancing rapidly [14], with their most practical applications emerging in construction and architecture [15].

Particularly noteworthy is the group of materials comprising four main types: wicker, perforated, expanded, and cellular flooring (see Fig. 1), which are produced in the largest volumes.

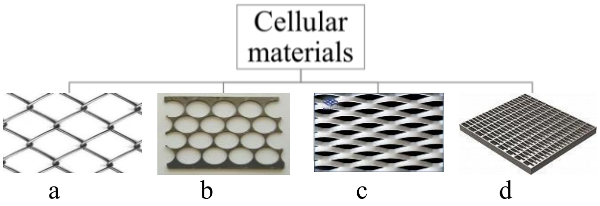


Fig. 1. Types of cellular materials: a) wicker; b) perforated, c) stretched; d) cellular flooring.

They are used in the fabrication of barriers, filters for construction materials, concrete reinforcement, protective screens, and more (see Fig. 2). All these types of cellular materials share a key advantage: they are significantly lighter than solid materials. However, selecting the most suitable material for specific purposes requires evaluating additional factors, such as cost-effectiveness, load resistance, durability, recyclability, and other properties.

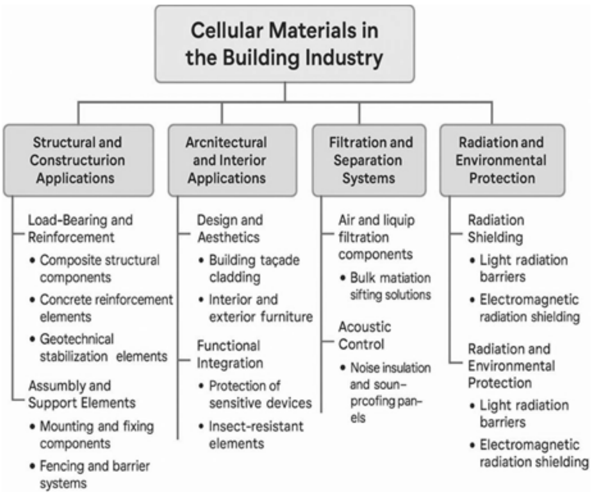


Fig. 2. Main areas of application of cellular materials for the building industry.

On 5 January 2023, the Corporate Sustainability Reporting Directive entered into force. Similar initiatives aiming to contribute to the transition toward a more circular economy are increasingly numerous. Cellular woven structures (CWS) are composed of aluminium or steel wires with diameters typically ranging from 0.5 to 5.0 mm (see Fig. 3). The weaving process results in the formation of cells of various sizes and shapes. For instance, aluminium CWS are frequently utilised in contemporary interior design across a variety of applications. In the construction sector, plaster mesh—constructed from galvanised or PVC-coated wire—finds widespread use. Additionally, CWS are employed in the sifting of loose materials, the filtration of solutions, and are commonly incorporated in the manufacturing of fences, enclosures, and other types of barriers [16].

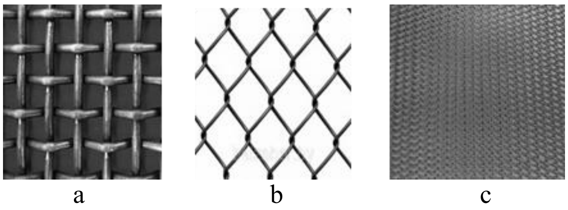


Fig. 3. Metal wire cellular woven structures: for a) interiors; b) fencing; c) damping.

Cellular woven meshes (CWM) are produced from galvanised, non-galvanised, and stainless steel. Galvanised steel mesh is known for its durability and reliability. It has high strength and is resistant to moisture, harsh environments, and temperature fluctuations, making it ideal for use in fences, barriers, and screens (see Fig. 4) [17]. This type of mesh is also used as a sieve to separate fine particles from bulk construction materials. For woven meshes, low-carbon steel wire with a thickness of 0.6 to 2.0 mm is typically used [18], [19].

CWM is widely applied in construction and finishing work, such as reinforcing plaster layers. It is also used for various other tasks, including separating sections of concrete structures during sequential concrete pouring, screening materials (such as limestone or gravel) under foundations, creating drainage layers, filtering bulk construction materials and gaseous mediums, and constructing lightweight barriers [20].

Fig. 4. Cellular woven mesh.

Welded wire meshes are also utilised in construction. The most practical option from a technological perspective is the mesh with square or rectangular openings, produced through the contact welding method (see Fig. 5).

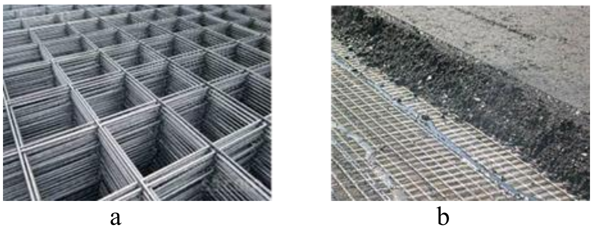


Fig. 5. Welded wire mesh (a) and its use in road construction (b).

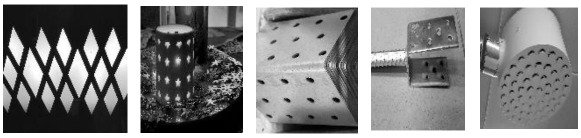
The primary applications of CWS include partitions, building facades, and machinery enclosures. From industrial to commercial uses, wire mesh is a versatile metal product with limitless potential. Often overlooked as a facade solution, wire mesh offers numerous advantages and features when used to create screens. These qualities make it a viable construction material [21].

A. Cellular metal materials advantages

The application of cellular metal materials in construction, design, and environmental protection requires numerous benefits and advantages to be selected through the development of materials, and the production and end-user qualities, e.g. against noise, light, and electromagnetic radiation [11].

Another significant advantage of perforated metal materials (PMM) is their capacity to facilitate innovative design solutions [15].

Furthermore, CM has great potential for manufacturing components of ventilation systems [22]. These materials not only ensure reliable ventilation but also protect against insects that may enter through the ventilation openings (see Fig. 6).



a b c d e

Fig. 6. Applications of PMM in Construction and Architecture: for Fencing (a); in Lighting Fixtures (b); for Structural Support (c, d); in Ventilation Systems (e).

The main methods for producing CM discussed in and shown in Fig. 7 are also important factors when selecting the necessary advantages for companies.

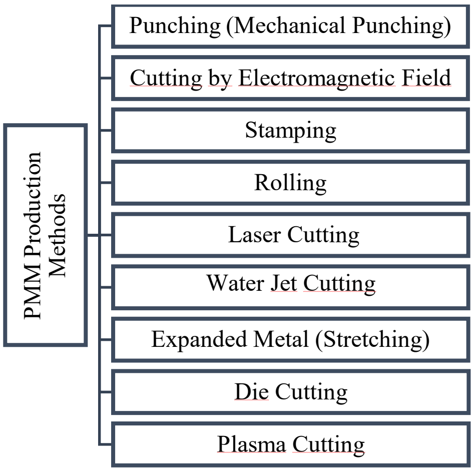


Fig. 7. Basic methods of production.

Cellular metal is widely used for end-user noise reduction, sun protection, and its aesthetic appeal, making it a versatile and effective material in various fields, particularly in construction and architecture [23] - [26]. New configurations, sizes, shapes, materials, compositions, and properties of perforated metal have become significant factors in enhancing the combination of essential characteristics needed across different industrial sectors [25].

II. MATERIALS AND METHODS

Based on a comprehensive literature review, ten universal key factors were identified to evaluate the benefits of using different materials, specifically in terms of their contribution to performance and functionality. These factors provide a framework for understanding how materials offer distinct advantages in various applications. After the literature review authors have selected a list of advantages – factor groups:

1. Radiation Shielding Effectiveness. This factor directly impacts the material's ability to act as a protective shield.

2. Mechanical Strength. This factor evaluates the material’s durability and its ability to withstand environmental stresses, making it suitable for use in protective screens that need to resist mechanical wear and tear.

3. Corrosion Resistance. The material's ability to resist degradation from exposure to elements such as moisture, salt, and chemicals [27].

4. Environmental Barrier Properties. The material’s ability to function as a comprehensive protective barrier against various environmental factors, including thermal exposure, airborne particulates (such as dust), and gaseous pollutants (such as smoke and industrial emissions).

5. Acoustic Insulation (Noise Reduction). The material’s effectiveness in blocking sound transmission, reducing noise pollution, and ensuring the creation of quieter environments.

6. Light Transmission and Visibility. The extent to which the material allows light to pass through while still providing protection. A balance between blocking harmful radiation and maintaining visibility or natural light transmission is crucial, especially in architectural and interior applications.

7. Aesthetic and Design Flexibility. The material’s ability to accommodate various design options, including perforation patterns, colours, and finishes, for architectural and decorative purposes. This factor assesses the material’s potential for integration into design while maintaining its protective functions.

8. Recyclability and Sustainability. Social, Environmental, and Governance (ESG). The material's potential for recycling after use and its environmental impact throughout its life cycle. This factor includes evaluating the material’s resource efficiency, ability to be reused, and minimal environmental degradation during production and disposal.

9. Durability and Long-Term Performance. This includes factors like weather resistance, fatigue under stress, and the material’s ability to function effectively over an extended period without significant degradation.

10. Ease of Manufacturing and Installation. The simplicity and efficiency of the manufacturing process and installation. This includes assessing factors such as material handling, required processing steps (e.g., perforation, treatment), ease of installation, and the associated labour costs.

During the last decade a lot of the research efforts have been made to incorporate the vagueness of the initial information for the solution of the complex nature practical problems by multi-criteria decision making (MCDM) methods. There are a lot of the cases when solving multicriteria decision making problems it is necessary to deal with uncertain, imprecise and inconsistent information.

There are many debates about indicators and its interpretation – how to represent and what to represent [14], [18], [28] - [30] Several recent papers have demonstrated high disagreement among existing social, environmental, and governance rankings (e.g., [31], [32]).

However, these factors alone do not provide a comprehensive assessment of the advantages of using CM and could be very subjective in different projects. Also, some factors could be factor groups and consist of numerous sub-elements. It is essential to evaluate additional aspects such as production and delivery costs, corrosion resistance, durability, strength characteristics, and the potential for reuse and recycling.

The selected factors are universal, identified using the method of taxonomy, and can be applied to various cases where choosing the right option, such as the material, is essential. These 10 factors were presented to 10 experts for assessing their relative importance.

The experts have been tasked with comparing the factors that characterise the importance of assessing the benefits of using the material for a fence. The fence will be constructed in the city centre for parking cars, and it should protect the vehicles while also ensuring long-term durability. Additionally, the fence should maintain its primary function of protecting cars and be designed to minimise noise pollution for citizens. It should also offer protection from radiation.

After evaluating the factors, the experts were presented with four materials for a case study to assess their suitability for the fence project. The materials included:

- Cellular woven meshes
- Expanded mesh
- Perforated metal
- Welded mesh

To conduct a cost-benefit analysis, the average price in the Latvian market was included. While prices are not stable and can fluctuate due to various factors, including geopolitical situations, the same analysis method can still be applied. In the event of price changes, the only adjustment needed is to replace the price, and the cost-benefit analysis will provide the final result for selecting the most appropriate material.

III. RESULTS AND DISCUSSION

The expert method discussed in the literature was utilised to assess the benefits of using cellular metal materials for specific applications. This approach was selected based on the premise that experts, employing robust scientific and technical reasoning, can effectively conduct cost-benefit analyses to evaluate the advantages of CM and other materials.

The required number of experts is estimated based on the hypothesis that expert agreement is 0.5 or more [32].

$$N = (K \cdot P_g)/(T_{ow} + W) = (10 \cdot 0.95)/(0.2 + 0.5) = 14, \quad (1)$$

Where

K - number of assessed factors, K =10;

P_g - probability belief, $P_g = 0.95$;

T_{ow} - tolerable error, $T_{ow} = 0.2$

From 14 experts, 10 experts with a competence of 0.75 and above were selected. The ten experts by using the paired assessment method, evaluated ten factors among themselves and created an ordered series of factors:

$$F9>F4>F2>F8>F3>F5>F10>F7>F1>F6 \quad (2)$$

For this series of factors, the authors applied the formula to calculate the relative importance of each factor. This was done using the following formula (1), for each criterion value.

$$\omega\,(F_i) = \omega_i = \frac{2(m - j(F_i) + 1)}{m(m+1)}, \quad (3)$$

Where

$j(F_i)$ - factor Fi position number in a ranking sequence (see Formula 1)

The results of the assessment of the significance of the factors for material assessment are presented in Table 1. A case study was presented to assess the selection of metal materials for protective screens. Experts were then asked to perform a paired comparison between different materials to determine their relative effectiveness using these factors for different materials (Table 1).

TABLE 1 FORMATION OF A GROUP OF EXPERTS BASED ON THE METHOD OF SELF-ASSESSMENT OF EXPERT COMPETENCE (TABLE CREATED BY THE AUTHORS)

Factors		Advantage assessment. Likert				
		Relative score for factors	***Cellular woven meshes***	***Expanded mesh***	***Perforated metal***	***Welded mesh***
F1	Radiation Shielding Effectiveness	0.036	2	3	5	4
F2	Mechanical Strength	0.145	3	4	4	5
F3	Corrosion Resistance	0.109	3	4	5	4
F4	Environmental Barrier Properties	0.164	2	3	5	4

F5	Acoustic Insulation (Noise Reduction)	0.091	2	3	5	2
F6	Light Transmission and Visibility	0.018	5	4	2	4
F7	Aesthetic and Design Flexibility	0.055	3	4	5	3
F8	Recyclability and Sustainability. ESG	0.127	4	4	5	4
F9	Durability and Long-Term Performance	0.182	3	4	5	5
F10	Ease of Manufacturing and Installation	0.073	4	3	2	4

The results of expert assessments regarding the beneficial use of certain materials for different materials are given in Table 2.

TABLE 2 ASSESSMENT OF THE SIGNIFICANCE OF FACTORS BY AN EXPERT GROUP (TABLE CREATED BY THE AUTHORS)

Factors		Assessment of relative advantage			
		Cellular woven meshes	***Expanded mesh***	***Perforated metal***	***Welded mesh***
F1	Radiation Shielding Effectiveness	0.07	0.11	0.18	0.40
F2	Mechanical Strength	0.44	0.58	0.58	0.73
F3	Corrosion Resistance	0.33	0.44	0.55	0.44
F4	Environmental Barrier Properties	0.33	0.49	0.82	0.66
F5	Acoustic Insulation (Noise Reduction)	0.18	0.27	0.46	0.18
F6	Light Transmission and Visibility	0.09	0.07	0.04	0.07
F7	Aesthetic and Design Flexibility	0.17	0.22	0.28	0.17
F8	Recyclability and Sustainability. ESG	0.51	0.51	0.64	0.51
F9	Durability and Long-Term Performance	0.55	0.73	0.91	0.91
F10	Ease of Manufacturing and Installation	0.29	0.22	0.15	0.29
	Total	2.95	3.64	4.58	4.09
	Relative advantage of certain material (Benefit, B)	0.19	0.24	0.30	0.27
	Advantage Rankings	IV	III	I	II

As we can conclude, perforated material receives priority, while the most important factors are F9 (Durability and performance; 0.182); F4 (Environmental Barrier; 0.164); F2 (Mechanical Strength; 0.145) and F8 (Recyclability and Sustainability, ESG; 0.127).

At the end, it is necessary to give an example of approximate cost-benefit analysis based on recent material prices (Table 3). Cost (C) is defined as the relative share of the cost of a material in a group of four materials being analysed.

Experts estimate that currently, the benefits of using PMM in construction, design, and environmental protection surpass those of woven and stretched materials, but other materials could be giving a similar cost-benefit advantage.

TABLE 3 RESULTS OF THE COST-BENEFIT ANALYSIS (TABLE CREATED BY THE AUTHORS)

Material	**Benefit (B)**	**Cost, EUR/m^2**	**C**	**C/B**	**Rank**
Cellular woven meshes (1)	0.19	130	0.19	1.01	II
Expanded mesh (2)	0.24	200	0.29	0.83	IV
Perforated metal (3)	0.30	210	0.30	0.99	III
Welded mesh (4)	0.27	150	0.22	1.24	I

IV. CONCLUSIONS

Following the evaluation of cellular metal materials for the specific application, the results indicate that perforated metal materials demonstrate the most advantageous properties among CMs. In construction, design, and environmental protection, woven and stretched/expanded metal materials are the most comparable alternatives to PMM, highlighting the unique advantages of PMM in these fields.

Experts estimate that the benefits of using PMM in construction, design, and environmental protection are most factors outweigh those of woven and stretched materials.

Nonetheless, PMM requires additional labour costs relative to solid sheet metal; its overall cost is 10-20% lower, with non-ferrous metals seeing reductions of up to 30%. Other mesh materials could bring a similar cost-benefit advantage. This cost efficiency positions PMM as a financially viable option for various applications from the cost-benefit perspective.

Furthermore, it is important to mention the expert evaluation method used. For the specific case of a perimeter fence, an analysis of responses from 10 experts using the group assessment methodology led to the selection of the cellular material option in the form of a welded picket fence. This method is simple, dynamic and effective for addressing specific technical solution choices in construction and mechanical engineering. The method is also applicable to a wide range of materials and is particularly useful for critical raw materials, whose limited availability requires careful selection for specific applications. The efficient choice for their application is essential, especially to ensure sustainability and optimise their use.

The decreasing costs of PMM are driven by increasing production volumes and the effective recycling of production waste, which minimises losses. These factors contribute to the sustainability and economic attractiveness of PMM in the market.

The findings suggest that PMM not only offers economic benefits but also supports sustainable practices in construction and design. As the demand for innovative materials continues to grow, PMM is well-positioned to meet both performance and environmental standards, making it a valuable asset in modern construction methodologies.

References

[1] I. I. Dani, W.G. Drossel, N. Milaev, H. Korn, C. Hannemann, J. Hohlfeld, R. Wertheim, “Sustainability of industrial components using additive manufacturing and foam materials,” Procedia Manuf., vol. 43, pp. 10–17, 2020, doi: 10.1016/j.promfg.2020.02.102.

[2] J. Banhart, “Manufacture, characterisation and application of cellular metals and metal foams,” Prog. Mater. Sci., vol. 46, no. 6, pp. 559–632, 2001, doi: 10.1016/S0079-6425(00)00002-5.

[3] R. Setiawan, A. I. Komara, and B. Budiwantoro, “Numerical and experimental investigation of aluminum double arrowhead cellular

structure manufactured using sheet metal forming," Results Eng., vol. 26, 2025, doi: 10.1016/j.rineng.2025.104667.

[4] Q. Zuo, K. He, H. Mao, X. Dang, and R. Du, "Manufacturing process and mechanical properties of a novel periodic cellular metal with closed cubic structure," Mater. Des., vol. 153, pp. 242–258, 2018, doi: 10.1016/j.matdes.2018.05.011.

[5] A. G. Evans, J. W. Hutchinson, and M. F. Ashby, "Cellular metals," Curr. Opin. Solid State Mater. Sci., vol. 3, no. 3, pp. 288–303, 1998, doi: 10.1016/S1359-0286(98)80105-8.

[6] European Commission, "Critical raw materials resilience: Charting a path towards greater security and sustainability." [Online]. Available: https://ec.europa.eu/docsroom/documents/42849[Accessed April 15, 2025].

[7] United Nations Development Programme, "Transforming our world: The 2030 agenda for sustainable development." 2015, [Online]. Available: https://sdgs.un.org/2030agend[Accessed April 15, 2025].

[8] European Commission, "The European Green Deal," 2019, [Online]. Available: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en[Accessed April 15, 2025].

[9] K. Morgan, "Smart Specialisation: Opportunities and Challenges for Regional Innovation Policy," Reg. Stud., vol. 49, no. 3, pp. 480–482, 2015, doi: 10.1080/00343404.2015.1007572.

[10] H. Ruiz, P. Cobo, T. Dupont, B. Martin, and P. Leclaire, "Acoustic properties of plates with unevenly distributed macroperforations backed by woven meshes," J. Acoust. Soc. Am., vol. 132, no. 5, pp. 3138–3147, 2012, doi: 10.1121/1.4754520.

[11] X. Li, Q. Wu, L. Kang, and B. Liu, "Design of multiple parallel-arranged perforated panel absorbers for low frequency sound absorption," Materials (Basel)., vol. 12, no. 13, 2019, doi: 10.3390/ma12132099.

[12] M. Mironovs, V.; Lisicins, "Perforated metal materials and their use possibilities," RTU Publ. House, 2015.

[13] G. W. Kooistra and H. N. G. Wadley, "Lattice truss structures from expanded metal sheet," Mater. Des., vol. 28, no. 2, pp. 507–514, 2007, doi: 10.1016/j.matdes.2005.08.013.

[14] Z. Wang, "Recent advances in novel metallic honeycomb structure," Compos. Part B Eng., vol. 166, pp. 731–741, 2019, doi: 10.1016/j.compositesb.2019.02.011.

[15] V. Mironovs, A. Tatarinov, and S. Gorbacova, "Expanding Application of Perforated Metal Materials in Construction and Architecture," IOP Conf. Ser. Mater. Sci. Eng., vol. 251, p. 012027, Oct. 2017, doi: 10.1088/1757-899X/251/1/012027.

[16] A. Shishkin, T. Koppel, V. Mironov, I. Hussainova, J. Locs, and H. Haldre, "Microwave Reflectance and Transmittance Properties of Conductive Composite Materials," Energy Procedia, vol. 113, pp. 354–361, May 2017, doi: 10.1016/j.egypro.2017.04.006.

[17] M. C. S. de Abreu, F. N. H. Ferreira, J. F. Proença, and D. Ceglia, "Collaboration in achieving sustainable solutions in the textile industry," J. Bus. Ind. Mark, vol. 36, no. 9, pp. 1614–1626, Oct. 2021, doi: 10.1108/JBIM-01-2020-0041.

[18] Z. Zhao, Y. Peles, and M. K. Jensen, "Properties of plain weave metallic wire mesh screens," Int. J. Heat Mass Transf., vol. 57, no. 2, pp. 690–697, Feb. 2013, doi: 10.1016/j.ijheatmasstransfer.2012.10.055.

[19] J. Yip and S. P. Ng, "Study of three-dimensional spacer fabrics: Physical and mechanical properties," J. Mater. Process. Technol., vol. 206, no. 1–3, pp. 359–364, Sep. 2008, doi: 10.1016/j.jmatprotec.2007.12.073.

[20] A. G. Evans, J. W. Hutchinson, and M. F. Ashby, "Cellular metals," Curr. Opin. Solid State Mater. Sci., vol. 3, no. 3, pp. 288–303, Jun. 1998, doi: 10.1016/S1359-0286(98)80105-8.

[21] C. Wang, K. Shankar, and A. Fien, "Finite element simulation of impact response of wire mesh screens," EPJ Web Conf., vol. 94, p. 04033, Sep. 2015, doi: 10.1051/epjconf/20159404033.

[22] M. K. Sharma, S. Preet, J. Mathur, A. Chowdhury, and S. Mathur, "Thermal performance analysis of naturally ventilated and perforated sheet based double skin facade system for hot summer conditions," Int. J. Vent., vol. 21, no. 4, pp. 263–283, Oct. 2022, doi: 10.1080/14733315.2021.1901003.

[23] G. W. Kooistra and H. N. G. Wadley, "Lattice truss structures from expanded metal sheet," Mater. Des., vol. 28, no. 2, pp. 507–514, Jan. 2007, doi: 10.1016/j.matdes.2005.08.013.

[24] G. Martínez, E. Casanova, and C. Graciano, "Failure response of expanded metal meshes subject to transversal impact," Lat. Am. J. Solids Struct., vol. 20, no. 7, 2023, doi: 10.1590/1679-78257585.

[25] G. Martínez, C. Graciano, and P. Teixeira, "Energy absorption of axially crushed expanded metal tubes," Thin-Walled Struct., vol. 71, pp. 134–146, 2013, doi: 10.1016/j.tws.2013.05.003.

[26] C. Graciano, G. Martínez, and D. Smith, "Experimental investigation on the axial collapse of expanded metal tubes," Thin-Walled Struct., vol. 47, no. 8–9, pp. 953–961, Aug. 2009, doi: 10.1016/j.tws.2009.02.002.

[27] M. D. Nouri, H. Hatami, and A. G. Jahromi, "Experimental and numerical investigation of expanded metal tube absorber under axial impact loading," Struct. Eng. Mech., vol. 54, no. 6, pp. 1245–1266, Jun. 2015, doi: 10.12989/sem.2015.54.6.1245.

[28] E. D. G. Fraser, A. J. Dougill, W. E. Mabee, M. Reed, and P. McAlpine, "Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management," J. Environ. Manage., vol. 78, no. 2, pp. 114–127, 2006, doi: 10.1016/j.jenvman.2005.04.009.

[29] A. De Pascale, R. Arbolino, K. Szopik-Depczyńska, M. Limosani, and G. Ioppolo, "A systematic review for measuring circular economy: The 61 indicators," J. Clean. Prod., vol. 281, 2021, doi: 10.1016/j.jclepro.2020.124942.

[30] S. Harris, M. Martin, and D. Diener, "Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy." Sustain. Prod. Consum., vol. 26, pp. 172–186, 2021, doi: 10.1016/j.spc.2020.09.018.

[31] I. Voronova and V. Shatrevich, "Sectoral risk assessment: a case of the Latvian forestry sector," Jun. 2020. doi: 10.3846/bm.2020.621.

[32] A. Efimenko, I. Zlobin, A. Avilov, and A. Markov, "Application of expert evaluation method for realization of tasks in construction industry," E3S Web Conf., vol. 91, 2019, doi: 10.1051/e3sconf/20199108034.