SHEng
SMART HEALTHCARE ENGINEERING
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3D Printing technologies and materials for safety engineering

Class content material

This document is part of a training materials collection developed within the Erasmus+ project “Smart healthcare engineering”, SHEng, project No. 2023-1-RO01-KA220-HED-000159985.

The collection is intended for engineering students and professionals working in the healthcare sector. It covers technical subjects relevant to hospital infrastructure, equipment, materials and support services, helping readers understand how engineering contributes to safe patient care and the reliable operation of healthcare facilities.

These materials support classroom teaching and independent study. They should be used alongside the project handbook and the presentations, courses and other learning resources available on the project website. Each document addresses a specific subject, while the collection provides a broader understanding of the responsibilities and practical challenges of healthcare engineering.

The content is educational. Its application in practice requires consideration of the conditions of each healthcare facility, the applicable standards and the instructions provided by equipment manufacturers.

Project website: www.smarthealtheng.com

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SMART HEALTHCARE ENGINEERING

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3D Printing technologies and materials for safety engineering

Additive manufacturing (AM), commonly known as three-dimensional (3D) printing, has emerged as an innovative manufacturing approach with more than significant potential for improving industrial safety, occupational health, and workplace risk prevention.

The ability to manufacture customized components with complex geometries, controlled internal architectures and mechanical properties creates opportunities for developing protective equipment, ergonomic devices, safety-related components, and advanced materials for industrial environments.

Compared with conventional manufacturing methods, additive manufacturing offers considerable design flexibility, rapid prototyping capabilities, reduced tooling requirements, and the possibility of producing customized solutions for specific industrial applications.

The potential applications include impact-absorbing protective structures, customized personal protective equipment, machine protection devices, vibration-damping systems, acoustic barriers, electrical insulating components, chemical-resistant devices, and safety-related tooling.

The printing parameters, internal geometries, material selection, and post-processing operations on the performance of safety components influence the final products.

Industrial safety represents a fundamental requirement in modern manufacturing environments, where workers, machinery, and production systems may be exposed to mechanical, thermal, chemical, electrical, and acoustic hazards.

The development of advanced protective equipment and safety systems is therefore essential for preventing occupational accidents, reducing exposure to harmful environmental factors, and improving workplace ergonomics.

Conventional manufacturing technologies, including injection molding, machining, casting, and thermoforming, are widely used in the production of protective equipment and industrial safety components. However, these technologies may present limitations when complex geometries, customized designs, small production batches, or rapid product modifications are required.

Additive manufacturing provides an alternative approach based on the layer-by-layer fabrication of components directly from digital three-dimensional models. This technology enables the production of customized structures with optimized geometries, variable wall thicknesses, controlled porosity, and internal architectures designed for specific functional requirements.

One important advantage of additive manufacturing in industrial safety is the possibility of adapting protective equipment and workplace components to individual users or specific operating conditions. For example, customized ergonomic supports can be designed using three-dimensional scanning, while impact-absorbing structures can incorporate lattice geometries that modify energy absorption and deformation behaviour.

Another promising application concerns the reduction of occupational noise and mechanical vibrations. Additive manufacturing permits the fabrication of acoustic panels and damping structures with complex internal configurations, including cellular, honeycomb, gyroid, and graded lattice architectures.

Material Extrusion Technologies for Industrial Safety

Material extrusion is particularly relevant to industrial safety because it enables rapid fabrication of customized polymer components with relatively low equipment and material costs.

1. Fused Filament Fabrication (FFF)

Fused filament fabrication involves heating a thermoplastic filament and depositing it through a nozzle according to a predefined CAD model.

The principal materials include PLA, ABS, PETG, PC, TPU, PA, PEEK, and fiber-reinforced thermoplastics.

PETG and polycarbonate are attractive candidates for protective casing and some barriers because of their toughness, although their sustainability depends on the specific conditions and printed-part quality.

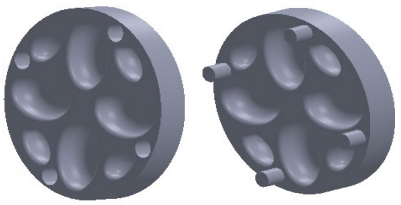
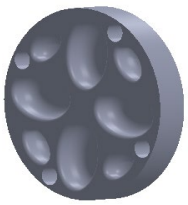
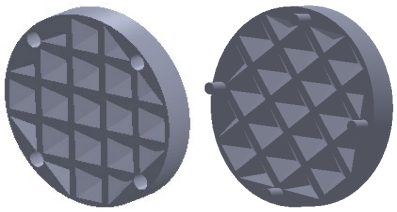
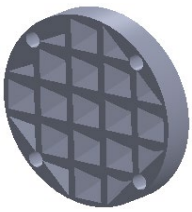
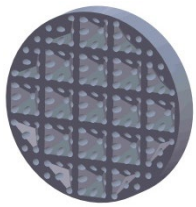
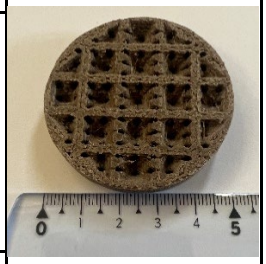
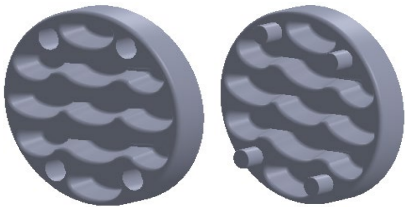
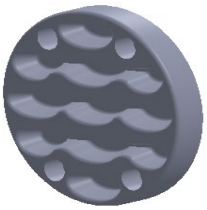
TPU can be used to fabricate flexible protective structures, vibration-isolating components, ergonomic supports, and impact-attenuating elements.

High-performance polymers such as PEEK and PEKK are relevant to industrial environments requiring elevated thermal resistance, chemical stability, or high mechanical performance.

However, FFF components often exhibit anisotropic behaviour, with interlayer bonding representing a potential weakness under tensile, impact, or fatigue loading.

Many studies have shown that, in the case of FFF additive manufacturing, the material used, the nozzle diameter, and the internal configuration have a major influence on the sound-absorption properties of 3D-printed panels.

Table 1. The 3D-printed samples used for acoustic testing with different profiles. [4]

	Acoustic Test Specimens			
	Double panel	Single panel	Panels with drilling holes (Drill gage)	3D-printed panels with holes
Circular profile				
Triangular profile				
Corrugated profile				

In table 1 three types of materials—PLA with a mixture of 40% ground coconut wood particles, PLA with a mixture of 40% ground birch wood particles and plain PLA, with three internal configurations (circular, triangular, and corrugated) and at five filling densities (20%, 40%, 60%, 80% and 100%), manufactured via the FFF process, were presented.

The acoustic performance was measured and obtained a maximum value of $\alpha = 0.4$ and STL = 64 dB. The acoustic results for the double panels (16 mm thickness) indicate excellent sound transmission resistance for all types of materials used, which determines good acoustic insulation, and these types of materials can be successfully used in the aviation, automotive, and construction fields for sandwich panels with the aim of sound attenuation.

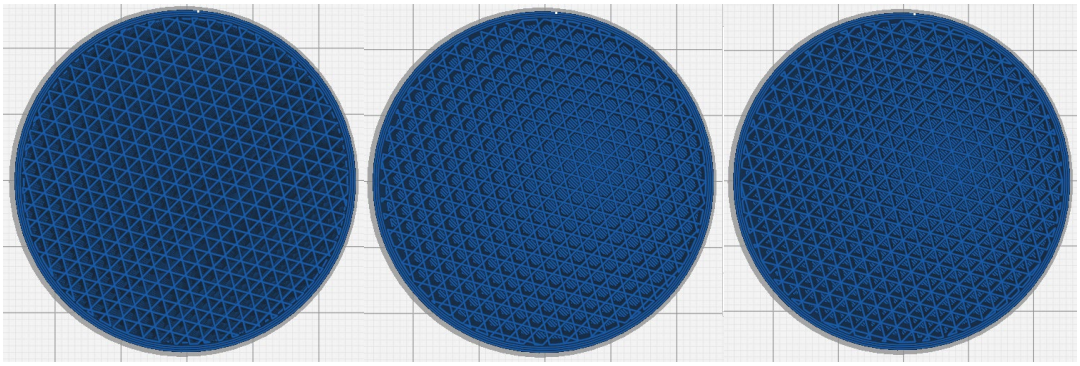
After several tests, a compromise solution was reached that involved form iterations, panel perforations, and porosity optimization to increase the acoustic performance of the samples considerably, with values ranging from 72% to 122%.

In the 3D-printed samples with rhombic holes, an increase of 16% in the absorption coefficient of the PLA material with a mixture of 40% ground birch wood particles (α = 0.93) was obtained compared to the samples with round holes.

The authors determined that the predominant factors that influenced sound-absorbing properties in this study were the triangular configuration model, which exhibited the highest performance for all three material types, and filling density, which also played an important role in the acoustic tests of the samples manufactured via the FFF process; thus, it was determined that the highest acoustic performance was obtained at 40% and 60%.

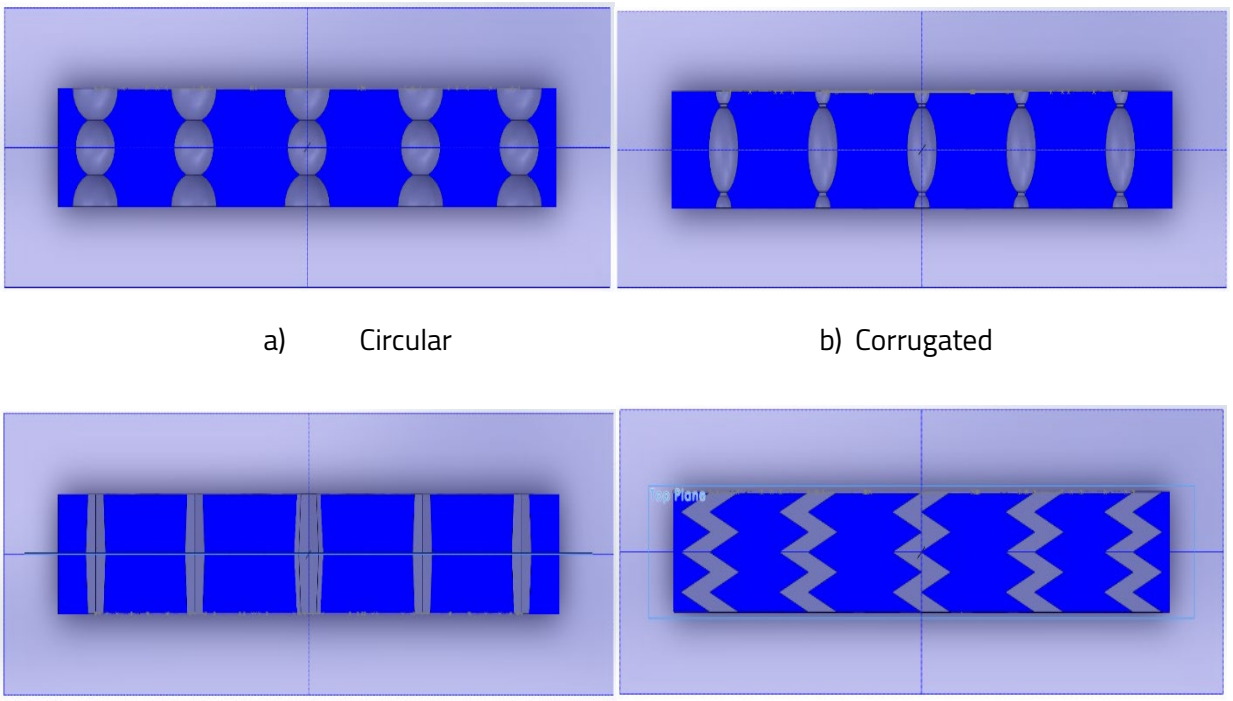
As a general observation made by the authors, the initial idea to obtain highway sound protection panels with the highest possible mechanical resistance and very good sound absorption properties was achieved via FFF technology.

Other studies focused on evaluating the acoustic properties of panels, considering the geometry of the infill, the geometry of the holes (circular, corrugated, triangular, zig-zag) as well as the distribution of these holes across at the surface.



a) b) c)

Fig. 1. The geometry of the infill: a) cubic; b) tri hexagonal; c) triangular. [6]



a) Circular b) Corrugated

c) Triangular d) Zig zag

Fig. 2. The geometry of holes: a) circular; b) corrugated; c) triangular; d) zig zag. [6]

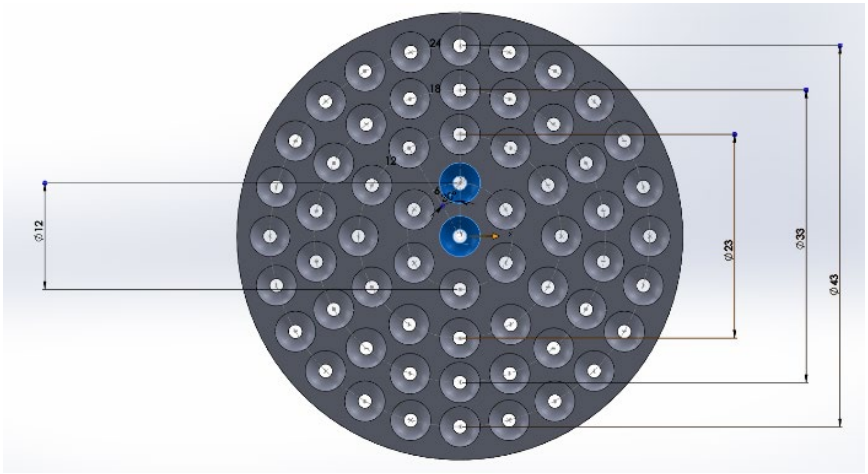


Fig. 3. Arrangement of holes at the surface [6]

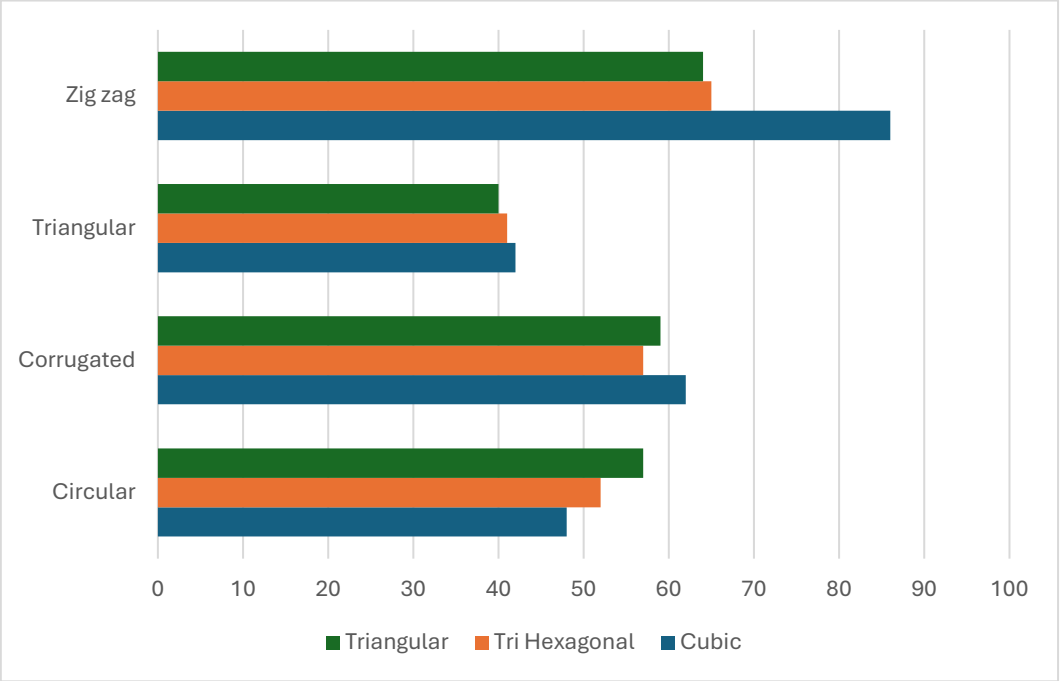


Fig. 4. The results obtained for sound absorption. [6]

The authors succeeded in increasing the sound absorption coefficient with the help of the configuration: 60% infill value + cubical infill shape + 61 zig zag voids arranged in concentric circles, thus resulting in a coefficient value of phonic absorption α = 86% at 500 and 1600 Hz, and at 1000 Hz α = 73%.

At the same time, it was determined that besides the geometric shape of the gaps, the angle of incidence of the sound on the perforations (gaps) has a major influence on the insulative behavior of the material.

Since the zig-zag perforations do not provide a gap on the central axis as is the case with circular or corrugated perforations, this case resulted in obtaining very good sound-absorbing properties, and the proposed architectural combination presents physical-mechanical properties close to and even greater than those reported in the literature.

2. Fused Granulate Fabrication (FGF)

FGF processes polymer granules directly, offering advantages for large components and experimental composite materials.

Potential industrial safety applications include large acoustic panels, machine protective cases, vibration-damping structures, and customized workplace barriers.

FGF is particularly attractive for developing recycled polymer composites containing rubber particles, cork, mineral fillers, or reinforcing fibres.

The use of recycled materials improves the resource efficiency, but the mechanical and thermal properties must be assessed because repeated processing can alter polymer molecular weight, viscosity, and mechanical performance.

Personal protective equipment (PPE) includes helmets, face protection barriers, respiratory protective equipment, hearing protection, gloves, and protective footwear.

Additive manufacturing contributes to the design and development of customized PPE components, particularly where individualized geometry or improved ergonomics is required.

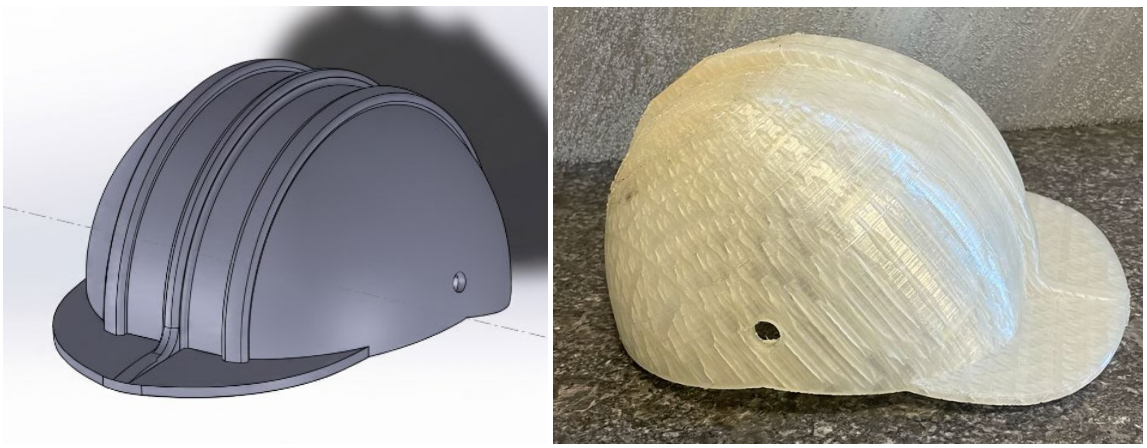
Cellular lattice structures manufactured from elastomeric polymers can be investigated as energy-absorbing elements.

Potential the best geometries include honeycomb, gyroid, and graded-density lattices.

Their performance depends on deformation mechanisms, loading direction, strain rate, material stiffness.

However, a 3D-printed helmet shell or liner must not be assumed to provide adequate protection without testing and certification to the relevant helmet standard.

Customized safety helmet design



a) b)

Fig. 2.1 a) CAD model; b) printed model printed via FGF technology [7]

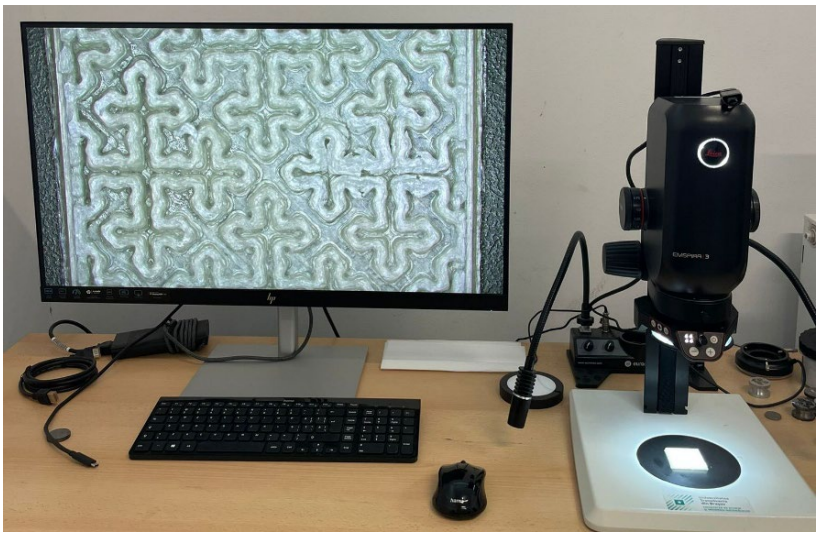


Fig. 2.2 Cross shape of the internal structure [7]

This work successfully demonstrated that, through an in-depth understanding of composite materials and the application of state-of-the-art FGF manufacturing technologies, polymer waste can be transformed into high-performance safety equipment.

The integration of glass fibre into a PLA matrix, at a controlled internal density, represents a technologically mature and economically cost-effective solution that is perfectly aligned with the era of Industry 4.0.

The regulatory requirements applicable to an additively manufactured safety component depend on its intended function, market, and operating environment.

Important standards and regulatory frameworks include:

Standard or regulation	Relevance
ISO/ASTM 52900:2021	AM terminology and process classification
ISO/ASTM 52920:2023	Qualification principles for industrial AM processes and production sites
ISO 12100:2010	Machinery safety and risk assessment
ISO 14120:2015	Safety of machinery — Guards
ISO 13857:2019	Safety distances to prevent access to hazard zones

ISO 13849-1:2023	Safety-related parts of control systems
ISO 45001:2018	Occupational health and safety management systems
EN 397	Industrial safety helmets
EN 166 / EN ISO 16321 series	Eye and face protection, subject to applicable product requirements
EN 352 series	Hearing protectors
EN 388	Protective gloves against mechanical risks
EN ISO 20345	Safety footwear
Regulation (EU) 2016/425	Personal protective equipment placed on the EU market
Regulation (EU) 2023/1230	EU machinery regulatory framework, generally applicable from 20 January 2027

The applicability and current edition of each standard must be verified during product development.

Importantly, the material certification, the printer, and the component certification are distinct activities. A printed component incorporated into a safety system must satisfy the applicable requirements for its final intended use.

Coclusions

- Additive manufacturing offers considerable potential for developing customized components and advanced materials that support industrial safety and occupational risk prevention.
- Future research on additive manufacturing for industrial safety is expected to focus on multifunctional materials, optimized cellular architectures, and intelligent protective systems.
- Promising directions include functionally graded structures, polymer composites combining acoustic and vibration damping performance, flame retardant materials, and components incorporating embedded sensing elements.
- Hybrid manufacturing processes may combine 3D printing with conventional machining, coating technologies, and surface treatments to improve functional performance.

- An especially relevant research direction involves the development of multifunctional polymer composites capable of simultaneously providing mechanical protection, acoustic absorption, vibration damping, and improved environmental resistance.
- Material selection remains critical. Thermoplastic polymers, high-performance engineering polymers, elastomers, metals, ceramics, and reinforced composites offer different combinations of mechanical, thermal, acoustic, and chemical properties.
- Internal architectures, such as lattice structures and graded cellular geometries, provide additional opportunities to optimize impact response, vibration damping, and acoustic performance.
- Nevertheless, the implementation of additive manufacturing in safety-critical applications requires rigorous process qualification, functional testing, risk assessment, and compliance with applicable standards.

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[7] Doncioiu Laurentiu Mihai (2026), UNITBV student work.

Acknowledgments

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