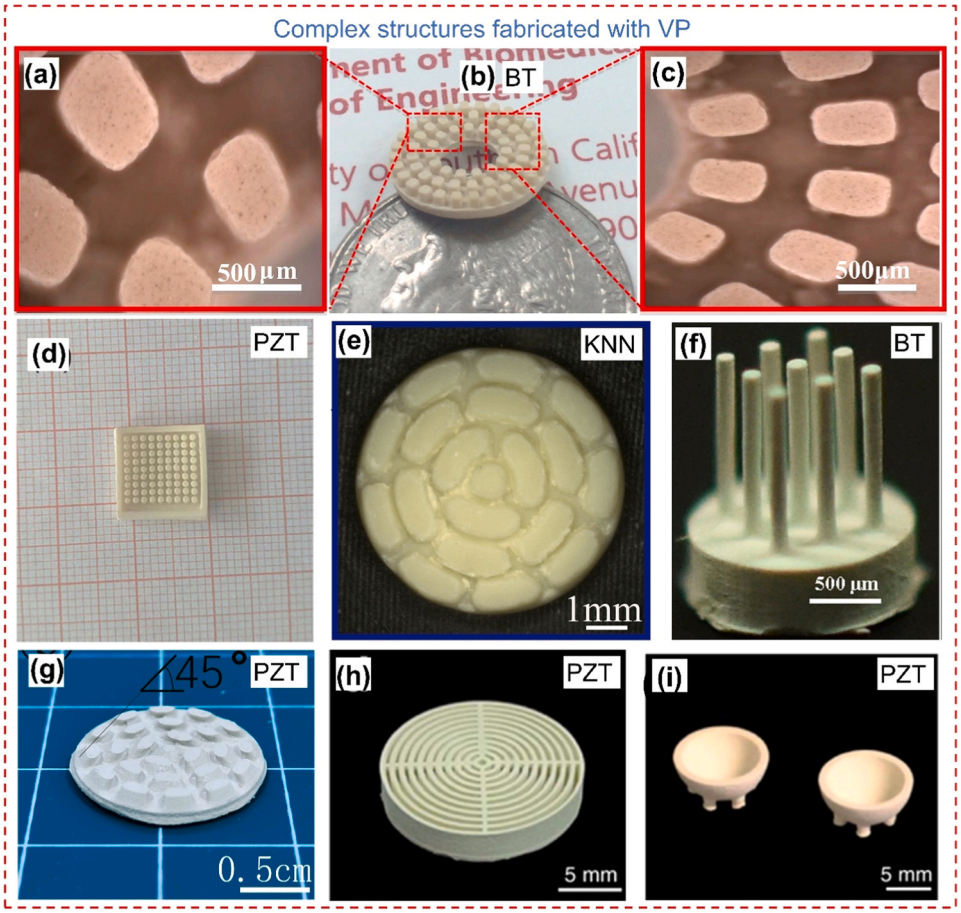

Fig. 48. Optical microscopy images of different types of sintered arrays that can be used for several applications [146,171,179,180,186,188].
Reproduced from Ref.: (a-c) [179], (d) [186], (e) [180], (f) [146], (g) [171], with permission from Elsevier. (h-i) [188], Open access article distributed under the terms of the Creative Commons CC BY license.

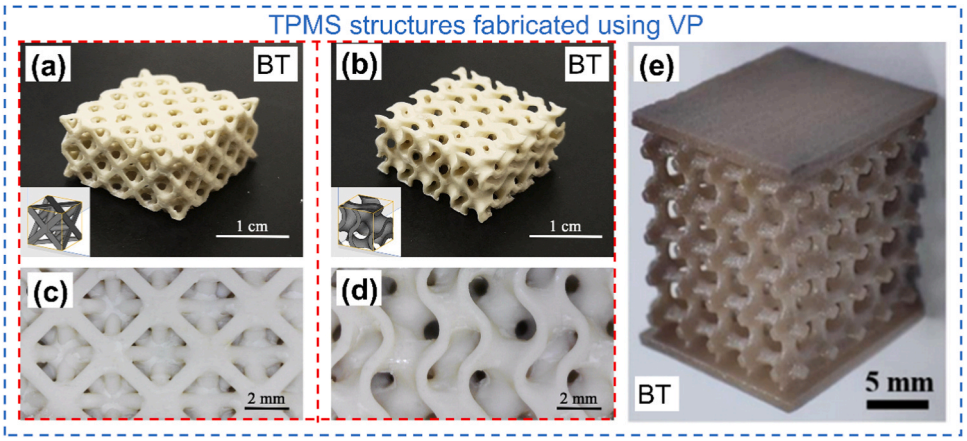

Fig. 49. Optical images of complex TPMS structures [139,143].
Reproduced from Ref.: (a-d) [139], with permission from Elsevier. (e) [143], Open access article distributed under the terms of the Creative Commons CC BY license.

heating and cooling rates often leading to finer microstructures. It is also important to keep in mind the sintering atmosphere, as it plays a important role and hence it should be carefully chosen.

(vii) Unavailability of commercial piezoceramic filaments or slurries (for DIW or VP)

The absence of easily accessible commercial piezoceramic filaments or slurries for Direct Ink Writing (DIW) or Vat Photopolymerization (VP) is an important challenge that restricts the industrial use of AM technologies. This slows down the development process as a lot of time is required in optimizing the piezoceramic formulation. Manufacturing piezoceramic materials internally may result in variations in both quality and performance due to variations in raw materials, processing conditions and handling.

To summarize, AM technologies open up new opportunities for the

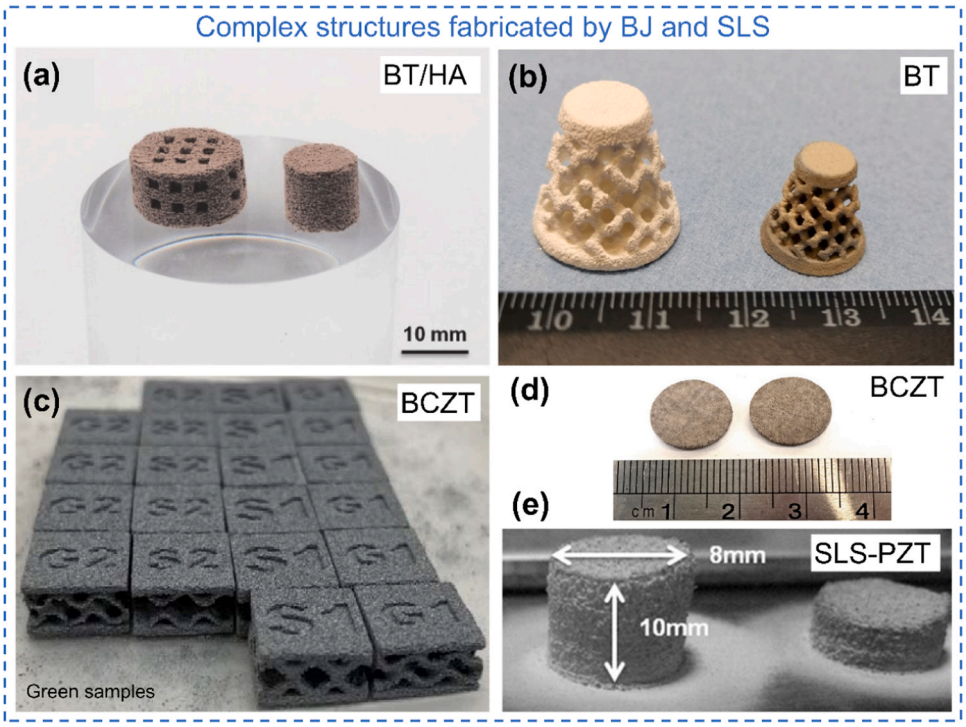

Fig. 50. (a-d) Optical images of scaffold structures fabricated using binder jetting [191,192,194,197]. The circular samples showed in (d) are typically usually used for the property measurements, which holds true for other AM techniques as well. (e) Simple cylinder fabricated using SLS [210].
(a) [197], (b) [194], (c-d) [192], Open access article distributed under the terms of the Creative Commons CC BY license. Reproduced from Ref. (e) [210], with permission from Elsevier.

Table 12
Classification of the additively manufactured piezoceramic components according to their application.

Additive manufacturing	Material	Applications
Direct ink writing	BST	Bone tissue engineering [96]
	BT -based	Heating element[71]
	PZT	Transducer [83], Sensor [54,69,98]
	BCZT	Bone graft substitute [97]
Fused filament fabrication	PZT	Actuator [99,103,130,133], Transducer [122]
	BST	Antenna [126]
	BT	Antenna [110], Bioactive scaffolds [111]
Vat photopolymerization	PZT, PMNT	Transducer [142,176,188,239], sensor [188]
	BT, KNN	Transducers [146,147,168,179,180,186], Ultrasonic array [224], Energy harvesting [169,184], Bone scaffolds [144]
Binder jetting	BT	Bone tissue engineering [217]

fabrication of complex and high-precision piezoceramic parts with properties almost similar to the conventional ones. Despite several challenges, this field is rapidly progressing with notable developments. These technological breakthroughs are enabling the exploration of new opportunities in the fields of sensors, actuators and energy harvesting systems. As research and development progresses, the possibility of AM revolutionising the production and functioning of piezoceramic materials becomes more and more real, holding the promise for improved performance and the introduction of new capabilities in several key sectors.

CRediT authorship contribution statement

Gaurav Vajpayee: Writing – original draft, Funding acquisition. **Subhadip Bhandari:** Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization, Writing – review & editing. **Manuel Hinterstein:** Writing – review & editing, Validation, Supervision, Funding acquisition. **Lucas Lemos da Silva:** Writing – review & editing, Funding acquisition. **Paolo Colombo:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Giorgia Franchin:** Writing – review & editing, Validation, Supervision, Project administration.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Subhadip Bhandari reports financial support was provided by Foundation of the Savings Bank of Padua and Rovigo (CARIPARO). Manuel Hinterstein, Gaurav Vajpayee, Lucas Lemos da Silva reports financial support was provided by Fraunhofer Internal Programs for financial support under grant no. Attract 40-04857. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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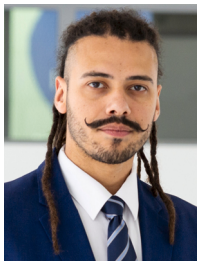

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