

Cellular and TPMS Photopolymer Architectures in Vat Photopolymerisation: Relative Density, Topology and Mechanical Qualification

Juan Seguro

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Correspondence: info@3Dresyns.com · www.3Dresyns.com

ER-026 · Engineering Review · Version 1.1 · 2026

Statement of Significance

Architected photopolymer parts cannot be qualified from bulk-resin data alone. A solid resin, a porous lattice and a triply periodic minimal-surface (TPMS) structure are different mechanical systems because topology, relative density, unit-cell size, wall thickness, orientation and manufacturing error redistribute stress and alter failure. This review separates material properties from architecture properties and proposes a qualification chain from CAD geometry to realised geometry, effective density, mechanical response and application-level function. The central engineering claim is intentionally narrow: no lattice performance should be inferred from resin modulus, porosity or topology name in isolation.

Keywords: vat photopolymerisation; TPMS; gyroid; lattice; cellular materials; relative density; architected materials; metamaterials; mechanical scaling; stereolithography; DLP

Abstract

Vat photopolymerisation (VPP) can fabricate cellular and TPMS architectures with smooth curved walls, thin features and high geometric complexity. Recent experiments show that the realised mechanical response depends simultaneously on base photopolymer, topology, relative density, number of unit cells, wall-thickness fidelity and loading mode. Large VPP datasets on gyroid lattices further demonstrate that nominal porosity alone does not collapse the response across different photopolymers. This Engineering Review organises the evidence around five distinctions: solid-material state versus architected state; designed versus realised relative density; topology versus scale; tensile versus compressive response; and coupon behaviour versus functional structure. A minimum reporting framework is proposed for CAD definition, printing/post-cure state, dimensional metrology, density, orientation, specimen size, loading and failure mode. 3Dresyns products are included only as commercial implementation examples and are not assigned lattice-level performance without geometry-specific testing.

1. Introduction

Cellular structures are often described with compact labels such as lattice, foam, gyroid or metamaterial. Those labels are useful for geometry classification but do not define a mechanical property. In VPP, the same nominal architecture can behave differently when printed from a brittle glassy resin, a tough network or a highly compliant elastomer. Conversely, the same resin can produce markedly different stiffness, strength, energy absorption and failure modes when relative density, topology, cell count or orientation are changed [1-5].

Recent VPP-specific work makes the separation especially clear. Baghous and co-workers showed that sheet-based TPMS tensile properties depend on both relative density and the number of unit cells represented across the specimen, with bulk-like behaviour emerging only after sufficient repetition of the unit cell [1]. Garzon et al. compared multiple stereolithography-printed TPMS topologies using a metrologically consistent solid-resin normalisation, showing topology-dependent elastic scaling rather than a universal density law [2]. Peloquin and co-workers assembled hundreds of VPP gyroid specimens across twenty commercial photopolymers, demonstrating that base-material properties and realised porosity jointly control tensile response [3,4].

This review therefore treats architected photopolymers as material-geometry systems. It does not attempt to rank commercial lattice products, prescribe one topology, or review tissue-regeneration biology. The scope is mechanical and metrological qualification of cellular VPP structures.

2. Five states must be separated

State	Primary measurement	Dominant dependencies	Claim boundary
Base solid	Tensile/compressive/DMA properties of dense coupon	Cure state, orientation, conditioning	Does not determine lattice response
CAD architecture	Topology, cell size, nominal wall, designed relative density	Implicit equation or lattice generator	Does not prove printed geometry
Realised architecture	Wall thickness, pores, defects, realised density	Optics, exposure, wash, post-cure, feature size	Does not by itself establish strength
Mechanical structure	Effective modulus, strength, plateau, failure	Material + topology + density + scale + direction	Valid only for tested state
Functional component	Energy absorption, damping, compliance or other output	Boundary conditions, interfaces, duty cycle	No transfer to untested application

Table 1. Distinct states in architected-photopolymer qualification.

3. Relative density is necessary but not sufficient

Relative density is a central descriptor because it connects the volume of solid to the external volume of the cellular specimen. However, two structures with the same nominal relative density can differ in wall-thickness distribution, surface area, curvature, node geometry and local stress concentration. Printing error adds another layer: overcure can thicken walls and close pores, while cleaning or post-cure can deform thin features. The density used in scaling should therefore be measured or reconstructed from the realised specimen rather than assumed from CAD whenever the discrepancy is material to the result [1-4].

The size of the representative volume also matters. Baghous et al. observed a strong dependence of tensile response on the number of TPMS unit cells across the specimen before a plateau was approached [1]. A one- or two-cell coupon can therefore be a boundary-dominated structure rather than a representative bulk lattice. Specimen dimensions, unit-cell count and grip/interface design belong in the reported test state.

4. Topology changes deformation and failure

Topology controls whether load is carried primarily through membrane/stretching modes, bending, local buckling or combinations of these mechanisms. Garzon et al. reported topology-dependent scaling among Gyroid, Diamond, Schwarz P, Lidinoid and Split-P structures printed by stereolithography [2]. Other polymer studies show that geometric transformations can tune anisotropy and energy absorption without changing the base chemistry [5]. A topology name should therefore be treated as a structural hypothesis that must be tested at the relevant density and loading mode.

5. Tension and compression answer different questions

Many lattice publications emphasise compression because cellular structures can show long plateau regions and substantial energy absorption. Tensile failure probes different weak links, including thin walls, surface defects and boundary transitions. The 2026 VPP TPMS study found that tensile and compressive trends were not interchangeable across topology and density [1]. Reporting only compression cannot support a tensile-load claim, and vice versa.

6. Printability and geometric fidelity are part of the material system

For thin-walled architected structures, the process-material interaction can be comparable in importance to the nominal architecture. Optical broadening, layer discretisation, cure depth, trapped uncured resin, wash forces and post-cure shrinkage can alter the realised cross-section. Gabrieli et al. demonstrated stereolithographic production and mechanical characterisation of TPMS scaffolds and explicitly related architecture and relative density to realised behaviour [6]. A defensible study should therefore measure the printed geometry rather than relying exclusively on the STL model.

Block	Minimum information	Why it matters	Claim limit
Material	Resin ID/composition class; dense-coupon properties; cure/post-cure	Defines base solid	Bulk modulus is not lattice modulus
CAD	Topology; equation/software; cell size; wall; nominal density	Defines intended architecture	CAD is not realised geometry
Printing	Process, wavelength, layer, exposure, orientation, supports	Controls thin-feature fidelity	No cross-printer transfer without calibration
Metrology	Wall/pore dimensions, mass/volume or CT, defects	Quantifies realised architecture	Nominal porosity alone is insufficient
Mechanical test	Mode, rate, fixtures, specimen size, cell count, replicates	Defines effective response	Tension and compression are not interchangeable
Failure	Location, buckling/fracture sequence, residual deformation	Reveals controlling mechanism	Peak load alone does not describe failure

Table 2. Minimum reporting set for VPP cellular structures.

7. 3Dresyns implementation examples

The following commercial examples illustrate different material starting points for architected VPP structures. They are implementation examples, not independent evidence of lattice-level stiffness, strength, energy absorption or durability.

3Dresyn PP SEA10. Manufacturer documentation describes a super-elastic, ultra-soft VPP photopolymer. In an architected-material study it can represent a compliant base-material regime, but no TPMS or lattice performance should be inferred without geometry-specific testing [M1].

The 3Dresyns 3D printed resin metamaterials web page describes a material-selection context for architected designs, but the live collection currently lists no products. It is therefore cited only as a programme/context page, not as evidence of an available product set or of lattice performance [M2].

Source basis: current manufacturer product documentation and web context, accessed 20 August 2026. Final structural performance depends on material, realised geometry, printing, post-processing and test conditions.

8. Conclusions

- Architected photopolymer performance is a coupled material-geometry response and cannot be inferred from dense-resin properties alone.
- Relative density is essential but does not replace topology, unit-cell count, wall-thickness fidelity or orientation.
- Designed and realised geometry should be reported separately, particularly for thin-walled TPMS structures.
- Tensile, compressive, cyclic and energy-absorption tests answer different structural questions.
- A minimum defensible claim links the base material, realised architecture, test mode and boundary conditions to the measured output.

Limitations

This review is a literature-based engineering synthesis rather than a systematic review or meta-analysis. The cited studies span different resins, printers, geometries and test methods, so numerical lattice properties are not pooled. Biological scaffold performance is outside scope; scaffold examples are used only where they clarify architected-material mechanics and metrology.

Author contributions

Juan Seguro: conceptualisation, literature synthesis, engineering framework, writing and critical review.

Competing interests

The author is affiliated with 3Dresyns by Resyner Technologies S.L. Commercial 3Dresyns materials are identified only as implementation examples supported by controlled product documentation. They are not treated as independent peer-reviewed evidence and no proprietary formulation composition is disclosed.

Data availability

No new experimental dataset was generated for this review. Scientific statements are attributed to the cited literature; commercial examples are separated from the independent evidence base.

Company information

Legal company name: 3Dresyns by Resyner Technologies S.L. Registered tax address: General Etxague 15B, 20003 Donostia / San Sebastián, Gipuzkoa, Spain VAT number: ESB24827511 Contact email: info@3Dresyns.com Company website: www.3Dresyns.com

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Manufacturer documentation

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