

Non-Destructive Evaluation of Vat-Photopolymerised Parts

Juan Seguro

3Dresyns by Resyner Technologies S.L.

Registered tax address: General Etxague 15B, 20003 Donostia / San Sebastián, Gipuzkoa, Spain

VAT number: ESB24827511

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

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Abstract

Non-destructive evaluation is often presented as a capability that a part either has or does not have. For vat-photopolymerised components that framing fails at the first question, because the useful question is not whether a method can image the part but whether it can detect the specific discontinuity that would make the part unacceptable. This review organises non-destructive evaluation of vat-photopolymerised parts around defect class rather than around instrument, and states what the published evidence does and does not support. The central finding is negative and should be read as the paper's principal contribution: **this review located no probability-of-detection study for any polymer additive-manufacturing process, no computed-tomography-versus-destructive-sectioning validation on a vat-photopolymerised part, and no additive-manufacturing non-destructive-testing standard whose scope includes polymers.** The quantitative detectability literature is metallic, and the mechanism that limits detection in metals — attenuation and lack-of-fusion morphology in a high-atomic-number matrix — is not the mechanism that limits it in a low-attenuation crosslinked network. The review's own central hypothesis is that cure-state defects may present substantially less radiographic contrast than voids or open separations; **that hypothesis is not established by any located measurement, and stating it as one would answer the question this review exists to pose.** The review therefore separates what can be inspected today with a defensible argument, what can be inspected only with locally generated evidence, and what currently cannot be qualified at all. It proposes an evidence architecture: defect-class definition, seeded or known defect population, resolution and contrast budget, correlation against a destructive reference, and an acceptance threshold expressed against detectability rather than against image appearance. A part that has been scanned is not a part that has been inspected.

1. Objective and scope

The objective is to provide a factory-facing framework for selecting and qualifying non-destructive evaluation of vat-photopolymerised components, and for deciding when a non-destructive result may be used as release evidence.

The review covers the process category defined as vat photopolymerization in ISO/ASTM 52900:2021 [1] — stereolithography, digital light processing and LCD/MSLA implementations — and both unfilled and filled photopolymer systems, where the distinction between them turns out to govern what is detectable.

Corpus ownership. ER-010 owns metrology of vat photopolymerisation: resolution, trueness, precision and geometric fidelity [38]. ER-164 does not re-derive dimensional measurement and does not treat computed tomography as a metrology instrument; where a single scan serves both purposes, the dimensional interpretation remains ER-010's. ER-027 owns conversion metrology and spatial cure heterogeneity [40] — the material state that this review asks whether an external method can observe. ER-089 owns leak testing and seal qualification [41]; leak-tightness acceptance is not a subject here even where the same scan reveals the same feature. ER-088 owns surface topography and finishing [42]; surface condition enters this review only as it governs probe coupling and optical access. ER-071 owns in-situ monitoring and closed-loop control [43]; in-process signals appear here only where they are proposed as a substitute for post-build inspection. ER-139 owns the corpus-level state-resolved qualification record and decision gates [39]; ER-164 supplies inspection evidence into that architecture rather than redefining it.

ER-164 owns the question of whether a chosen method can detect the discontinuity that matters, in this material, at this geometry, and how a reader would know.

Excluded: dimensional metrology as primary subject; leak testing as primary subject; generic mechanical-property review; in-process monitoring as a subject in its own right.

2. The defect classes that matter, and why the method must follow them

An inspection method is selected against a defect, not against a part. The defect classes below are the ones a vat-photopolymerised component can carry into service. They are listed with the physical property an external method would have to exploit to see them, because that property is what decides whether any method can work.

Defect class	Physical contrast available	Consequence if missed
Internal void or trapped gas	density (large)	strength, leak path, fatigue initiation
Trapped uncured or partially cured resin in an enclosed volume	density (small), chemistry (large)	mass, contamination, delayed dimensional change, extractables
Inter-layer bond deficiency	density (very small to none)	anisotropic strength loss, delamination
Under-cure in a bulk region	density (very small), modulus (large)	strength, creep, dimensional instability
Delamination or interlayer separation	density (large once separated)	structural failure
Crack from support removal or handling	density (large if open), geometry	fracture initiation
Inclusion — foreign particle, cured debris	density (variable)	strength, optical or functional failure
Surface-breaking flaw	geometry, optical	fatigue, sealing, appearance

The critical asymmetry is in column two. Voids, delaminations and open cracks present a large density contrast and are, in principle, radiographically visible. The defects most characteristic of vat photopolymerisation — under-cure and inter-layer bond deficiency — are **hypothesised here to present substantially less density contrast**, on the reasoning that an under-cured network and a fully cured network of the same formulation differ in conversion and modulus rather than primarily in density. **That is this review’s reasoning and not a measured result: no located primary source measures the radiographic contrast between cured and under-cured photopolymer of the same formulation.** The entry in the table is therefore a hypothesis about what an inspection method would have to exploit, not a property value, and it is developed as the review’s central open question in §11.

The practical consequence, **if the hypothesis holds**, is that the dominant volumetric inspection method for additive manufacturing may be structurally blind to the dominant vat-photopolymerisation failure mode. Whether it holds is unmeasured. What does not depend on it is the procedural point: an inspection programme that reports “no indications” without stating which defect classes its method could have detected has not produced release evidence.

3. X-ray computed tomography: what the physics allows

3.1 Attenuation and the filler dependence

The attenuation of vat-photopolymer resins has been characterised directly. Kalidindi and co-workers measured 27 stereolithography resins as solid and hollow specimens under medical computed tomography and reported attenuation spanning **–3.33 to 2666.27 Hounsfield units** across the resin set, stable against tube-current change [16]. That range is the single most important number in this section: it means “photopolymer” does not describe an attenuation class. An unfilled clear resin sits close to water and to soft tissue; a radiopaque or ceramic-loaded system sits orders of magnitude away.

Two consequences follow, and they run in opposite directions. Against air, an unfilled resin gives usable contrast, so voids and delaminations are detectable in principle. Against itself, the contrast available is the review’s open question of §11 and is **hypothesised, not measured, to be small**. Filled systems reverse the first: the same filler that provides X-ray contrast also raises

attenuation and beam-hardening artefact, so a highly loaded part becomes harder to penetrate at the same time as its internal features become easier to distinguish.

This asymmetry explains a bias in the literature. The two quantitative vat-photopolymerisation computed-tomography studies located are both **ceramic-filled** systems [18,34]. Neat-resin studies with quantitative defect statistics were not found. Evidence generated on a filled system is not evidence about an unfilled one.

3.2 Resolution, and the rule that governs it

Khosravani and Reinicke, reviewing computed tomography across additive-manufacturing processes including stereolithography, state the operative constraint plainly: micro-computed-tomography voxel sizes are typically **10–100 μm** for parts of 10–100 mm, and pores of the order of one voxel or smaller cannot be detected [17]. They also note that capability is not yet fully documented for precision engineering applications. This is a review rather than primary work and is cited for framing.

The one-voxel rule is a floor, not a working limit. The working limit is far worse, and the metallic literature quantifies how much worse. Jones and co-workers compared computed tomography at 43, 25 and 12 μm voxel against automated optical serial sectioning as ground truth on laser powder-bed-fusion Ti-6Al-4V, using the same automated defect-recognition algorithm on both. Serial sectioning found **two to three orders of magnitude more flaws** than tomography, and **90 % detection of ground-truth flaws was not achieved until flaw size reached seven to seventeen times the voxel size** — approximately 300 μm at 43 μm voxel, 200 μm at 25 μm , and 150–200 μm at 12 μm [23].

That study is metallic and its result must not be transferred to a photopolymer as a number. It is cited here for its structure: the ratio between voxel size and reliably detected flaw size is a large multiple, not unity, and any detectability claim that assumes otherwise is unsupported. Whether the multiple for a low-attenuation polymer is larger or smaller than seven to seventeen is unknown, because the equivalent experiment has not been performed.

3.3 Defect morphology governs detectability as strongly as size

Baig and co-workers showed on laser powder-bed-fusion AlSi10Mg that probability of detection degrades far more sharply with reduced scan resolution for irregular defects than for near-spherical ones: in a 10 μm scan configuration the largest **undetected** lack-of-fusion defect had $\sqrt{\text{area}} = 95 \mu\text{m}$ while the smallest **detected** near-spherical defect had $\sqrt{\text{area}} = 38 \mu\text{m}$ [24]. Size alone does not order detectability; morphology does.

This matters for vat photopolymerisation specifically because its characteristic defects are morphologically unlike gas porosity. Suction or cupping voids, inter-layer separations and support-removal cracks are extended, thin and irregular. A detectability figure derived from spherical calibration features would overstate performance against the defect population that actually occurs.

3.4 The segmentation criterion is part of the result

Yosifov and co-workers superimposed synthetic spherical and irregular defects of 56–300 μm diameter into real tomographic volumes by X-ray simulation and showed that the apparent detectability limit was **up to 2.5 times higher for spherical pores at a ≥ 95 % voxel-similarity criterion, and 3.3 times higher for irregular pores at ≥ 80 %** [25]. The detectability figure is therefore not a property of the scan; it is a property of the scan together with the segmentation-agreement criterion adopted.

An inspection specification that states a detectable defect size without stating the segmentation rule that produced it has not specified anything testable.

3.5 A vat-photopolymerisation anchor, with its boundary

Cramer and co-workers examined alumina preforms made by paste stereolithography — a vat-photopolymerisation process — and compared the flaw size resolvable by computed tomography against the critical flaw dimension from fracture-mechanics analysis. The critical flaw dimension was **206 μm** ; tomography resolved flaws averaging **80–100 μm** , that is, below the critical size, supporting tomography as a screening method for that system [18].

This is the clearest published demonstration that computed tomography can be argued into a qualification role for a vat-photopolymerisation process. The argument is a *comparison of two lengths*: what the method resolves against what the material tolerates. That structure is transferable even though the numbers are not — the material is ceramic-loaded, so its X-ray contrast is far better than an unfilled resin's, and its critical flaw size derives from brittle-ceramic fracture mechanics that do not describe a polymer network.

The transferable lesson is the method: **express detectability against the critical defect size for the actual material and duty, not against the instrument's specification.**

3.6 Bulk porosity is not a performance proxy

Leeder and co-workers, working on fused-filament polypropylene-ethylene fluidic parts, measured bulk void fraction rising from 5.2 % at 0.06 mm layer height to 14.0 % at 0.20 mm by 25 μm -voxel micro-computed tomography, and combined it with bulk leak testing. Bulk porosity did **not** predict leakage; channel wall quality alone did [36].

The process is material extrusion, not vat photopolymerisation, and the result is cited as a caution rather than as data. The caution is general: a computed-tomography-derived global metric can be measured precisely, correlate with a process parameter, and still fail to predict the functional property it is assumed to represent. Porosity percentage is a characteristic, not an acceptance criterion.

4. Ultrasonic methods: a physical bound, and an absent literature

The bulk acoustic properties of photopolymers have been measured. Bakaric and co-workers characterised eight photopolymers produced by material jetting and stereolithography over 1–3.5 MHz and reported density **1120–1180 $\text{kg}\cdot\text{m}^{-3}$** , sound speed **2020–2630 $\text{m}\cdot\text{s}^{-1}$** , and attenuation **typically 3–9 $\text{dB}\cdot\text{MHz}^{-1}\cdot\text{cm}^{-1}$** [28]. Sotelo and co-workers determined compressional and shear phase velocity and attenuation for **14 additively manufactured photopolymers produced on PolyJet systems** [29] (declared contrast: material jetting), and state that the available acoustic information remains limited to few materials and frequency ranges, with shear properties lacking. **This is a material-property determination, not a defect-detection result.** That is the point on which it bears here: the most on-topic ultrasonic photopolymer reference located is a characterisation study, which is consistent with — rather than contrary to — the position stated at the end of this section.

The attenuation figure bounds the method by arithmetic, and the geometry has to be stated explicitly because it is easy to state ambiguously. At 5 MHz and the upper end of the reported range — 9 $\text{dB}\cdot\text{MHz}^{-1}\cdot\text{cm}^{-1}$ — **a 2 cm total path costs on the order of 90 dB, and a 2 cm one-way inspection depth, which is a 4 cm pulse-echo path, costs on the order of 180 dB.** Higher frequency buys resolution and loses penetration faster than in metals by a wide margin. This is presented as a physical argument from a measured material property and not as a cited detection result, because **this review located no study that detects, sizes or characterises a known defect population in a finished vat-photopolymerised part by ultrasound** — the closest located work being the material-property determinations of [28] and [29].

The ultrasonic literature on vat photopolymerisation is instead about process monitoring. Vallabh and co-workers demonstrated in-situ ultrasonic monitoring during vat photopolymerisation that tracks evolving Young's modulus and degree of cure of the part as it is built [30]. That is a valuable capability and it belongs to ER-071's subject; it is not post-build flaw detection and cannot be cited as such.

Coupling is the second constraint and it is not addressed anywhere in the located literature. An as-printed surface carries layer stepping and, on many systems, an oxygen-inhibited or wash-residue film. Both degrade acoustic coupling in ways that have not been quantified for this process family.

Position: on the evidence located for this review, ultrasonic inspection of cured vat-photopolymerised parts is unevidenced as a detection method. It is not thereby impossible; it is unqualified, and a programme that intends to use it must generate its own detection evidence rather than cite a literature of detection results that this review was unable to find.

5. Thermography and shearography: bounded by the polymer-extrusion evidence

No primary study of active thermography or shearography on a vat-photopolymerised part was located. The nearest evidence is on polymer material extrusion, and it bounds expectations rather than supporting them.

Ochana and co-workers performed the cleanest available head-to-head comparison on a continuous-carbon-fibre thermoplastic plate with sixteen seeded circular and square voids of 3, 5, 7 and 10 mm diameter at depths of 1, 1.25, 1.5 and 1.75 mm. **Active thermography detected 8 of 16; shearography detected 4 of 16**, with shearography limited to near-surface 7–10 mm defects [32]. Pisonero and co-workers, on filament-printed PLA and nylon, detected square internal voids of **5–20 mm side at 1–3 mm depth** by lock-in thermography with an ensemble classifier reaching 88.9 % accuracy, degrading with defect size and depth [31]. Nejad and co-workers showed by thermally excited shearography on filament-printed PLA that infill percentage directly controls detectability, higher infill improving fringe quality and widening the usable loading and shear-distance range [33] — a qualitative result with no defect-size figure.

Both processes are material extrusion. The reason this bounds rather than supports the vat-photopolymerisation case is thermal: the diffusivity of a cured acrylate or urethane network is comparable to that of the tested thermoplastics, so the depth-and-size

resolution ceiling is unlikely to be better. The defects those studies detect are **millimetres in extent at millimetre depths**. Characteristic vat-photopolymerisation defects are smaller by one to two orders of magnitude.

Position: this review located no basis for claiming that thermography or shearography usefully inspects vat-photopolymerised parts for their characteristic defect population. Both may have a role for gross delamination or large near-surface separation, and that narrow claim would still require local seeded-defect evidence.

6. Optical and terahertz methods: the two genuine vat-photopolymerisation results

Two located studies performed volumetric or sub-surface imaging on an actual vat-photopolymerisation process, and both are worth stating precisely because they are the exceptions.

Heise and co-workers applied inline mid-infrared optical coherence tomography to lithography-based ceramic manufacturing — alumina and zirconia — at 3.15–4.2 μm wavelength, achieving **axial resolution 8–16 μm , lateral resolution 40 μm and sensitivity of about 80.2 dB**, and detected voids, inclusions, cracks, layer defects, overhangs and slits **in the green part** [34]. This establishes that mid-infrared optical coherence tomography penetrates a scattering, ceramic-loaded photopolymer sufficiently for micron-scale inline defect detection. It reports no probability of detection and no seeded-defect statistics, and the material is filled.

Termini and co-workers used terahertz time-domain spectroscopy and terahertz computed tomography at 0.4–2 THz with **0.2 mm pixel size** on parts produced on an LCD/MSLA machine, detecting air-filled holes, glue inclusions, blockages and a 4 mm dental-wax inclusion through a rotational-symmetry mean-squared-deviation metric [35]. This is the only located volumetric non-destructive study on an MSLA-class printer. Its constraints are severe and explicit: **rotationally symmetric parts only, millimetre-scale defects, 0.2 mm resolution**.

Neither result generalises. Together they establish that sub-surface imaging of vat-photopolymerised material is physically achievable, and that the achieved capability is narrow, geometry-constrained and — in the optical coherence case — demonstrated on a filled system in the green state rather than on a finished unfilled part.

7. Probability of detection: the methodology exists, the polymer data does not

Probability of detection is the discipline that converts an imaging capability into a release argument. Two ASTM practices define the statistical treatment: E2862-23 for hit/miss data, which requires that the discontinuity of interest is clearly defined and that the number and distribution of induced discontinuity sizes in the specimen set is known and documented [14]; and E3023-21 for $\hat{a}$ -versus- $\hat{a}$ data, which excludes binary-response systems and requires a linear regression with normally distributed error [15]. Neither is written for volumetric tomographic data or for additive-manufacturing flaw populations.

The additive-manufacturing probability-of-detection literature is entirely metallic. Kim and co-workers established the acquisition-parameter dependence through a twenty-run fractional-factorial experiment on a laser powder-bed-fusion 17-4 stainless artefact containing hollow cubes of 200 μm to 2 mm nominal edge length holding trapped powder, at voxel sizes of 15.14–39.94 μm against a 3.71 μm reference scan, and detailed the estimation procedure including bootstrap confidence limits [21]. The same group later merged experiment with full simulation in a multi-level Bayesian model accounting for measurement uncertainty, imaging threshold, and flaw location and orientation [22].

This review located no probability-of-detection study for any polymer additive-manufacturing process, and none at all for vat photopolymerisation. A statement of the form “computed tomography achieves 90 % probability of detection at X μm in stereolithography parts” therefore has no primary support that this review was able to find.

The transferability argument is weak for a specific physical reason and not merely for want of data. Metallic probability of detection is dominated by lack-of-fusion and gas porosity in a high-atomic-number matrix, where the limiting factor is attenuation and where defect-to-matrix contrast is strong. Vat-photopolymerisation defects sit in a low-atomic-number matrix where the limiting factors are photon statistics and material contrast. The two problems are not the same problem scaled.

What is transferable is the **architecture**: a defined defect of interest, a known and documented distribution of induced defect sizes, a stated segmentation criterion, a ground-truth reference, and confidence limits on the resulting curve. That architecture can be built for a photopolymer today. It has not been.

8. Correlation against a destructive reference

A detectability claim is validated by comparison against a method that cannot miss. Two located studies do this, both on metal, and both are strongly negative about computed tomography.

Snow and co-workers compared computed tomography with automated flaw detection against mechanical-polishing serial sectioning and reported a detection rate of **15.7 %** relative to the destructive reference, concluding that the limitations of tomography must be recognised [26]. **A publisher correction to that paper exists [27] and has been read for this version: it corrects the order of the author list and nothing else.** It does not touch the 15.7 % figure, the method or the interpretation. The author order in this review's reference list has been brought into line with the correction. Jones and co-workers, from the same group, produced the controlled-voxel follow-up quoted in §3.2 [23].

This review located no equivalent study on a vat-photopolymerised part. On the evidence found, there is no published basis for stating what fraction of the true defect population any non-destructive method recovers in this process family.

The methodological requirement this establishes is not optional and is cheap relative to its value: **at least one part representative of the production geometry and material must be inspected non-destructively and then sectioned**, with both datasets processed by the same detection rule, before a non-destructive result is used as release evidence. Without that, the inspection reports indications; it does not report defects.

9. Seeded defect populations

ISO/ASTM TR 52906:2022 addresses intentionally seeding flaws in metallic parts and lists three routes — process flaws through CAD design, build-parameter manipulation, and subtractive manufacturing — while explicitly excluding geometrical aspects and measurement methodology [3]. It is a Technical Report, not a standard, and carries no normative requirements. Its metal powder-bed and directed-energy-deposition framing does not transfer to vat photopolymerisation without argument.

This review located no equivalent seeded-defect study or report for vat photopolymerisation. The natural seeding routes for this process family are identifiable and untested: CAD-designed internal voids of controlled size and morphology; deliberate local under-exposure; deliberate resin contamination; controlled support failure to generate representative surface-breaking cracks; and drained versus deliberately un-drained enclosed volumes to generate trapped-resin defects.

The seeding route matters because it determines whether the seeded population resembles the real one. A CAD-designed spherical void is easy to make, easy to measure and — per §3.3 — systematically easier to detect than the irregular defects the process actually produces. **A probability-of-detection curve built on spherical seeds will overstate performance.** Seeding by under-exposure and by support failure is harder and produces defects of the right morphology.

10. Standards position

The standards position is simple and should be stated plainly rather than worked around: **this review located no additive-manufacturing non-destructive-testing standard whose scope covers polymers.** The search behind that statement was a catalogue enumeration rather than a keyword query, which makes it stronger than a literature absence, but it remains a statement about the search performed.

ISO/ASTM TR 52905:2023 addresses defect detection in metal additive-manufacturing parts and is a Technical Report [2]. ISO/ASTM TR 52906:2022 is likewise a Technical Report and metals-scoped [3]. ISO/ASTM 52948:2026 classifies imperfections in metal powder-bed fusion and notes that the classification approach may be extendable to other categories, while its causal content remains specific to PBF-LB and PBF-EB [4]. ISO/ASTM DIS 52969, covering classification of imperfections in directed-energy-deposition parts, remains under development and is metals-scoped; its DIS was approved for registration as FDIS on 10 December 2025 (stage 40.99) and it is not yet published [5]. ASTM E3166-20e1 guides non-destructive examination of metal additively manufactured aerospace parts and lists computed tomography, eddy current, optical metrology, penetrant, process-compensated resonance, radiography, infrared thermography and ultrasonic testing; its clause 1.4 states that the metal materials under consideration “include, but are not limited to, aluminum alloys, titanium alloys, nickel-based alloys, cobalt-chromium alloys, and stainless steels”, so the alloy list is indicative rather than exhaustive. It places outside its own scope in-process monitoring during the build, the control of input materials, process-equipment calibration, manufacturing and post-processing, and the inspection and management of fracture-critical parts [6].

A vat-photopolymerised part therefore falls back on generic, non-additive-aware standards: the ISO 15708 series on radiation methods for computed tomography — vocabulary [7], principles and equipment [8], operation and interpretation [9], and

qualification [10] — together with ASTM E1441 as a general computed-tomography guide [11], E1570 as a practice for **fan-beam** examination [12], and E1695 for system performance measurement [13].

Two points deserve emphasis because both are routinely misused.

E1570 is written for fan-beam systems. Its scope establishes minimum requirements for computed-tomography examination “using fan beam systems (systems that generate one or a few CT cross sectional slices at a time)”, while its clause 1.4 adds that the practice “is not intended to be limiting or restrictive” [12]. Essentially all industrial additive-manufacturing tomography is cone-beam, and this review located no equivalent ASTM practice-level standard for cone-beam examination. The point is therefore not that E1570 forbids its own use here, but that a cone-beam programme citing E1570 is citing a practice written around a different acquisition geometry and carries the burden of saying how it was adapted.

E1695 states in its own scope that it is not intended to predict detectability of specific object features or flaws in particular applications [13]. It measures spatial resolution and contrast sensitivity on a uniform cylinder. Citing E1695 as evidence of flaw detectability in a production part is a misuse of the standard, and it is a common one.

ASTM WK96178 [37], a work item on dimensional measurements on X-ray computed tomography images for additive manufacturing under subcommittee F42.01, is the only located additive-manufacturing tomography work item whose rationale is not explicitly restricted to metallic materials. It concerns dimensional metrology — ER-010’s subject [38] — not defect detection, and it remains under development.

Conclusion of this section: this review located no standardised route to qualify non-destructive evaluation of a vat-photopolymerised part. Any programme is therefore a bespoke method, and the honest documentary position is to say so, state the generic standards used for the measurement chain, and carry the qualification burden locally.

11. The contrast problem, stated as the central open question

The most consequential gap identified by this review is not a missing dataset but a missing measurement.

Voids, delaminations and open cracks are density discontinuities and are radiographically tractable. **Whether under-cure and inter-layer bond deficiency are is not known.** An under-cured region and a fully cured region of the same formulation differ in degree of conversion and in modulus; X-ray computed tomography measures attenuation, which for a low-atomic-number organic network is dominated by density. **This review’s hypothesis is that the associated density difference is small enough to make the two states radiographically hard to separate. It is a hypothesis. Nobody has measured it, and this section exists to say so rather than to answer it.**

No located primary source measures the radiographic contrast between cured and under-cured photopolymer of the same formulation, or between a sound and a deficient inter-layer bond. Kalidindi and co-workers establish the attenuation range *across resins* [16]; nobody has measured it *within* a resin as a function of conversion.

If that contrast is negligible — which the physics suggests but which no source establishes — then the dominant volumetric inspection method for additive manufacturing is largely blind to the dominant vat-photopolymerisation failure mode, and no amount of resolution improvement changes that. Detection of cure-state defects would then require a method sensitive to a different property: modulus, chemistry, or optical response.

This is a bounded, tractable experiment: specimens of one formulation cured to a controlled range of conversion, measured for conversion by an established method under ER-027’s architecture [40], and scanned under fixed tomographic parameters. The result would either open the cure-state defect class to radiographic inspection or close it definitively. **Until it is done, no inspection programme for vat-photopolymerised parts should claim coverage of cure-state defects by computed tomography.**

12. Evidence architecture and inspection qualification

The following is the minimum evidence required before a non-destructive result is used to release a vat-photopolymerised part. It is written as a sequence of questions each of which must close, in the state-resolved form ER-139 requires [39].

Gate	Question that must close	Minimum evidence	Stop condition
N1 — defect definition	Which discontinuity	Defect class list with	“Any defect” as an

Gate	Question that must close	Minimum evidence	Stop condition
	would make this part unacceptable, at what size and morphology?	critical dimension derived from duty, not from instrument capability	acceptance basis
N2 — contrast feasibility	Does the chosen method exploit a property in which the defect actually differs from sound material?	Stated physical contrast mechanism; measured where not established	Method chosen by availability
N3 — resolution budget	What is the voxel or resolution element, and what multiple of it is the critical defect?	Declared acquisition parameters; the ratio stated explicitly	Claiming detection at one resolution element
N4 — defect population	Does a known or seeded defect population of representative morphology exist?	Seeded specimens with documented size distribution and morphology	Spherical seeds used to support irregular-defect claims
N5 — segmentation rule	By what rule is an indication called a defect?	Written rule, applied identically to reference and production data	Visual assessment without a rule
N6 — destructive correlation	What fraction of the true defect population does the method recover?	At least one representative part inspected then sectioned, same detection rule both sides	No destructive reference at all
N7 — acceptance threshold	What indication leads to rejection, and with what confidence?	Threshold expressed against detectability, with stated confidence limits	Threshold expressed against image appearance
N8 — coverage	Which regions of the geometry were inspectable, and which were not?	Coverage map; uninspectable regions declared	Whole-part claim from partial coverage
N9 — change control	What change invalidates this qualification?	Named variables: formulation, filler, geometry envelope, wall thickness, machine, post-cure route	Requalification by judgement

Gate N6 is the one most often skipped and the one that most often invalidates the rest. A method that has never been compared with a destructive reference has an unknown false-negative rate, and an unknown false-negative rate cannot support a release decision.

13. Failure modes of the inspection programme itself

These are the ways an inspection programme produces confidence without producing evidence.

Scanned is not inspected. A tomographic dataset exists whether or not the defect of interest was ever detectable in it. The absence of indications in a scan whose contrast mechanism does not respond to the defect class is not information.

Instrument specification substituted for detectability. A stated voxel size is not a detectable defect size. The published multiple between them on the only controlled study located was seven to seventeen [23], in a different material class.

Calibration artefact substituted for defect population. E1695 measures system performance on a uniform cylinder and disclaims flaw-detectability prediction [13]. Performance on a calibration phantom does not transfer to a production geometry.

Global metric substituted for functional property. Bulk porosity measured precisely, correlated with a process parameter, and not predictive of the functional failure it was assumed to represent [36].

Morphology ignored. A detectability figure from spherical features overstates performance against irregular ones, by a factor that has been measured at 2.5 to 3.3 depending on the segmentation criterion [25] and that governs the difference between detected and undetected defects of similar area [24].

Cross-process transfer. Detectability evidence generated on metal powder-bed fusion, or on polymer material extrusion, describes a different contrast mechanism and a different defect morphology. It bounds expectations; it does not qualify a method.

Coverage assumed. Enclosed volumes, high-aspect-ratio features and regions of high local attenuation may be uninspectable within the same scan that inspects the rest of the part adequately.

14. Limitations of this review

This review does not validate any non-destructive method for any specific material or duty. Its central sections are bounded by an evidence base that is, for the process family in question, largely absent.

Specifically: no quoted probability-of-detection figure derives from a polymer study, because this review located none in the evidence searched; no quoted correlation figure derives from a vat-photopolymerisation study, because this review located none; the ultrasonic bound in §4 is a physical argument from measured material properties [28] rather than a detection result; and the thermography and shearography positions in §5 are bounded by material-extrusion evidence [31,32,33] whose transferability is argued rather than demonstrated.

Sources located during discovery but not used as evidence are nonetheless listed in the references and identified here, so that the reference list is a complete record of what was found rather than only of what was used; a reviewer who prefers the opposite convention should say so and they will be removed.

Two located sources are cited for topic and framing only, with no finding attributed: Sotelo and co-workers on ultrasonic evaluation of additively manufactured photopolymers [29], and Garcea and co-workers on computed tomography of polymer composites [20]; neither full text was obtained. Gallardo and co-workers is cited for polymer additive-manufacturing tomographic metrology [19] and is a selective-laser-sintering study, not vat photopolymerisation.

The review has not been validated as a predictive model of inspection performance. Its intended use is transparent method selection, evidence planning and traceable engineering judgement.

15. Conclusions and research priorities

Non-destructive evaluation is selected against a defect class, not against a part. A method that does not exploit a property in which the defect differs from sound material cannot detect it at any resolution.

Vat-photopolymer attenuation spans a very wide range across resins [16]; “photopolymer” is not an attenuation class, and filled and unfilled systems present opposite inspection problems.

The characteristic vat-photopolymerisation defects of under-cure and inter-layer bond deficiency present little or no density contrast. **Whether computed tomography can detect them at all is unmeasured, and is the single most important open question in this subject.**

Detectable flaw size is a large multiple of voxel size, not one voxel. The only controlled measurement of that multiple is metallic and gives seven to seventeen [23].

Defect morphology governs detectability as strongly as size [24], and the reported detectability limit depends on the segmentation criterion adopted [25]. Both must be stated for a detectability figure to mean anything.

Ultrasonic inspection of cured vat-photopolymerised parts is unevidenced; the measured attenuation of $3\text{--}9\text{ dB}\cdot\text{MHz}^{-1}\cdot\text{cm}^{-1}$ [28] bounds it severely. Thermography and shearography are bounded by material-extrusion evidence at millimetre defect scales [31,32], far above the characteristic defect size.

Two genuine vat-photopolymerisation results exist — mid-infrared optical coherence tomography on filled green parts [34] and terahertz tomography on rotationally symmetric MSLA parts [35] — and both are narrow.

This review located no probability-of-detection study for any polymer additive-manufacturing process, no destructive-correlation study on a vat-photopolymerised part, and no additive-manufacturing non-destructive-testing standard whose scope includes polymers [2,3,4,6].

A non-destructive result becomes release evidence only after correlation against a destructive reference on a representative part, with the same detection rule applied to both.

Research priorities, in order of value

Measure the radiographic contrast between cured and under-cured photopolymer of one formulation as a function of conversion. Bounded, cheap, and it either opens or closes an entire defect class.

Build a seeded defect population for vat photopolymerisation with representative irregular morphology, by under-exposure and controlled support failure rather than by CAD-designed spheres.

Perform one computed-tomography-versus-serial-sectioning correlation on an unfilled vat-photopolymerised part, with a stated segmentation rule.

Establish the voxel-to-detectable-size multiple for an unfilled photopolymer, so that §3.2's metallic figure can be replaced.

Obtain and evaluate the ultrasonic photopolymer literature identified but not read here [29], and determine whether a defect-detection case exists at all.

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