

Minimum-Information Standard for Photopolymer Additive-Manufacturing Studies: Material, Machine, Process and Specimen State

A reporting floor designed for independent interpretation, transfer assessment and later evidence synthesis rather than for administrative completeness

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Abstract

Many photopolymer additive-manufacturing studies cannot be compared because the material, machine, exposure, post-processing or specimen state is incompletely reported. This review proposes a minimum-information standard for studies intended to support engineering interpretation. The standard is organised around four coupled blocks: material identity and state, machine and optical state, process history, and specimen/test state. It distinguishes mandatory information from optional enrichment and treats missing state descriptors as a limitation on transfer, not as a minor editorial omission. The proposal is deliberately technology neutral and complements, rather than replaces, existing test standards.

Keywords: minimum information; reporting standard; vat photopolymerisation; reproducibility; specimen state; process history

1. Minimum information is a transfer requirement

A result can be internally valid yet unusable for transfer if the conditions that generated it are missing. MIAME established the useful precedent that a reporting standard should specify the information required to interpret and independently verify an experiment rather than prescribe one software format [1]. Photopolymer AM needs the same separation: the minimum-information content is the scientific requirement; JSON, spreadsheets or laboratory information systems are implementation choices.

2. Material identity must include state and version

A commercial label or resin family is not enough. Reports should identify formulation or product version, batch when relevant, storage/conditioning history, filler or pigment state if these affect optics or mechanics, and any material preparation before printing. The standard does not require disclosure of confidential composition. It requires enough identity control to determine whether two studies tested the same declared material state.

Table 1. Core minimum-information blocks.

Block	Mandatory fields	Why omission matters
material	identifier/version, batch if relevant, conditioning	identity and state cannot be reconciled
machine	technology, wavelength, exposure setting, layer thickness	process cannot be transferred
post-process	wash, dry, post-cure, ageing interval	network state is unknown
specimen	geometry, orientation, preparation	property is detached from specimen state
test	method, environment, deviations, replicate count	measurement comparability is unknown

3. Machine reporting must describe delivered processing conditions

Machine make and model are necessary but insufficient. Wavelength, nominal or measured irradiance, exposure strategy, layer thickness, optical calibration state and relevant thermal conditions determine the processing envelope. ISO/ASTM 52900 supplies common AM vocabulary [2], but a minimum-information standard must additionally bind settings to the actual specimen build. A value copied from a machine specification should be labelled as nominal rather than measured.

4. Process history extends beyond the print job

Wash chemistry, wash time, drying, post-cure wavelength, irradiance or energy proxy, temperature and duration are state descriptors whose omission can prevent a reader from establishing whether two studies or specimens are comparable. Age between printing and testing should be reported when it is plausibly relevant. The process history is therefore a chain of transformations, not a single exposure time.

Table 2. Controlled status for fields.

Status	Meaning	Acceptable use
measured	value obtained for this study	highest traceability
nominal	manufacturer or machine setting	allowed but labelled
derived	computed from reported inputs	formula and inputs required
not measured	relevant but unavailable	explicit limitation
not applicable	outside claim or method	reason recorded

5. Specimen and test state close the chain

Geometry, build orientation, location on platform when relevant, surface finishing, test environment, conditioning, test standard and deviations from that standard are required to interpret measured properties. A test designation without specimen preparation is incomplete. FAIR principles support identifiers and reuse [3], while PRISMA 2020 illustrates the value of explicit reporting items for later synthesis [4].

6. Mandatory does not mean universally measured

The standard distinguishes reportable from measurable. If irradiance was not measured, the report should state that it was not measured and identify the nominal source of the setting. Explicit absence is more informative than silent omission because reviewers can classify the resulting uncertainty. The minimum-information standard therefore includes controlled missingness states such as measured, nominal, not measured and not applicable.

Table 3. Claim-specific extension examples.

Claim type	Additional minimum information
cure depth	working curve protocol, threshold definition, optical path
mechanical	specimen standard, strain rate, conditioning, orientation
optical	thickness, spectral range, instrument geometry, surface state
biological	extraction/contact protocol, sterilisation, endpoint
durability	environment history, cycle definition, baseline state

7. Conformance is graded by interpretability

A study can be complete for one claim and incomplete for another. Mechanical comparison may tolerate missing optical spectra that an optical-clarity claim cannot. Conformance should therefore be reported per evidence claim, with a core block required for all studies and claim-specific extensions. This prevents a checklist from becoming a substitute for engineering judgement.

8. Scope boundary and neighbouring reviews

ER-392 owns the reporting floor for material, machine, process and specimen state. ER-391 owns the semantic vocabulary that gives those fields machine-interpretable meaning, and ER-393 owns the product-level passport that carries controlled state and history across lifecycle stages. ER-392 specifies what must be reported, not the ontology or lifecycle container.

9. Core fields and conditional modules

A minimum-information standard should distinguish universal core fields from conditional modules. Universal fields identify material revision, machine, build, exposure route, cleaning, post-cure, specimen geometry, conditioning, test method and uncertainty-bearing result. Conditional modules are activated by the phenomenon being studied: filled systems require filler identity, loading and dispersion descriptors; optical studies require wavelength and spectral information; biocompatibility studies require extraction and finished-article state; thermal ageing requires temperature-time-atmosphere history; and multimaterial studies require interface construction and spatial registration. This modular design avoids two failures at once: a universal checklist so large that authors omit fields indiscriminately, and a minimal core so small that important state variables disappear.

10. Exposure history must be reconstructable, not merely named

Reporting an exposure time without irradiance, wavelength or calibration state is not enough to reproduce a VPP condition. Conversely, reporting nominal machine power without the exposure logic used at the layer is also incomplete. The record should identify the controllable variables actually available for that platform and state whether they are measured, set, inferred or proprietary. When delivered irradiance cannot be independently measured, the limitation should be explicit and the machine state should still be captured through firmware, optical configuration, exposure setting, layer thickness and calibration artefacts. Minimum information is therefore not synonymous with perfect observability; it is a requirement to distinguish known, measured, set and unknown quantities.

11. Specimen lineage closes the material-to-result chain

A reported mechanical property is not attached directly to a liquid resin. It is attached to a specimen with a specific lineage. The minimum record should connect formulation and batch to build position, orientation, support strategy, wash history, drying delay, post-cure, machining if any, conditioning and test timing. This lineage matters because two nominally identical specimens can occupy different states after washing, oxygen exposure, post-cure or ageing. ISO/ASTM 52900 provides general AM vocabulary [2], but the reporting problem here is more granular: the state variables required to interpret a property must remain linked to the result rather than being scattered across methods text.

12. Conformance levels and missing-data semantics

A binary complete/incomplete label is often too crude. ER-392 therefore proposes three conformance levels. Level A contains the core fields and every conditional field needed to interpret the primary claim. Level B contains the core but has declared gaps that limit transfer without invalidating the local result. Level C lacks at least one state variable necessary to determine what was measured or how to reproduce it. Importantly, an explicit 'not measured' or 'not available' can be more informative than a blank field because it distinguishes absence of evidence from an extraction failure. Conformance should be assessed claim by claim; a paper may support one well-reported mechanical claim while remaining inadequate for a thermal or biological inference.

13. Machine-readable validation and human-readable reporting

The reporting standard should be usable in both forms. Human-readable tables support peer review and engineering interpretation; machine-readable records support corpus-scale audit. The same field definitions should drive both representations so that the machine

record is not a lossy afterthought. Validation rules can then detect unit mismatches, impossible state ordering, missing identifiers or absent conditional modules before publication. This is the point at which minimum information becomes an operational quality gate rather than an aspirational checklist. FAIR principles support the reuse objective [3], while the MIAME precedent shows how a minimum-information specification can define what must accompany a scientific claim without prescribing one experimental design [1].

14. Required, recommended and conditional fields

Not every field has the same evidentiary weight. A required field is one whose absence makes the primary claim uninterpretable; a recommended field improves transfer or troubleshooting; a conditional field becomes required when a specific mechanism or application is in scope. This classification should be explicit in the specification and tied to claim types. For example, specimen orientation may be required for an anisotropic mechanical claim but only recommended for a bulk optical transmission measurement on a homogeneous plaque. The standard should therefore avoid a static checklist divorced from the research question. A machine-readable rule set can activate conditional requirements from the declared claim class.

15. Replication, uncertainty and statistical reporting

Minimum information also includes how repeated measurements are organised. The record should distinguish technical repeats on the same specimen, multiple specimens from one build, independent builds, independent resin batches and independent machines. These levels cannot be pooled casually because they represent different variance components. The reported uncertainty should identify whether it reflects instrument uncertainty, repeatability, specimen-to-specimen variation, build variation or a combination. If only descriptive statistics are reported, the denominator and replication hierarchy must remain available. This is essential for deciding whether a result describes one specimen, one build or a transferable process state.

16. Publication package and auditability

A conforming publication package should preserve the human-readable article, machine-readable minimum-information record, data or justified data-availability statement, code where analysis is non-trivial, and stable identifiers that bind the components. The package should also record the schema version used for validation. When a field is corrected after publication, the corrected record should receive a new version and preserve the superseded record. This allows later reviewers to know which metadata were available when a claim was first assessed. The objective is not bureaucratic completeness; it is to make the material-machine-process-specimen chain reconstructable without contacting the original authors.

17. Claim-to-field dependency matrix

A minimum-information standard becomes more useful when every required field is linked to the claims that depend on it. Mechanical anisotropy claims depend on build orientation, specimen geometry, conditioning and test direction; exposure-response claims depend on wavelength or spectrum, delivered dose, temperature and atmosphere; ageing claims depend on the initial state, exposure history and post-exposure conditioning. The standard should therefore publish a claim-to-field dependency matrix rather than a single undifferentiated checklist. When a field is missing, the validation report can then say which claims lose interpretability. This also prevents over-reporting: metadata that do not affect the declared claim can remain recommended rather than mandatory. The result is a minimum-information standard designed around engineering inference rather than documentation volume. [1-4]

18. Worked conformance example

Consider a study reporting tensile strength after UV post-cure. A Level-A record may identify only resin name, printer and tensile result. A stronger record identifies formulation revision, printer model, layer thickness, build orientation, wash route, post-cure wavelength, irradiance or dose, temperature, delay to test, specimen standard, strain rate and replicate hierarchy. If the article claims transfer to another printer or formulation, additional machine and material-state fields become required. The conformance decision should distinguish 'missing but non-critical', 'missing and claim-limiting' and 'internally contradictory'. This is more informative than a binary complete/incomplete label because it shows exactly which conclusions remain supportable.

19. Governance and evolution of the minimum-information standard

The standard itself must be version controlled. New printing architectures, exposure systems, process sensors or measurement methods can create fields that were not previously necessary. Changes should be proposed with use cases, tested against existing records and classified by compatibility. A new optional field is usually backward compatible; changing the meaning of an existing field or making it mandatory can invalidate historical conformance. Published datasets should retain the schema version under which they passed. Where a later version adds a critical field, older records remain historically valid but should be flagged as incomplete for the new use case rather than silently reclassified.

20. Limitations and research priorities

A minimum-information proposal can become burdensome if it asks for every conceivable field, yet become ineffective if it omits the variables that control interpretation. The key research need is empirical validation of the claim-to-field dependencies proposed here. Multi-laboratory studies should test which missing fields actually prevent reproduction or explain between-site differences, and which fields add little decision value. Priority should also be given to machine-readable conformance examples for representative VPP, SLA/DLP/LCD and post-processing workflows, including intentionally incomplete records. The standard should evolve from those failures rather than from checklist expansion alone. Until a community validation exercise exists, ER-392 should be read as an engineering minimum-information architecture, not as a formally adopted reporting standard. [1-4]

References

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L.; ER-392 is a methodological engineering review and does not provide a comparative commercial recommendation.

Data availability

ER-392 is a literature-based engineering review; no new experimental dataset was generated.