

Chain-of-Custody Records for Distributed Photopolymer Manufacturing: Traceability Architecture and the Separate Requirement for Material-Identity Verification

Lifecycle assurance and responsible innovation

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Abstract

Distributed additive manufacturing requires records that preserve custody of digital and physical production information across sites, but a traceability record is not itself proof of material identity. The two sources available to this review address AM traceability, blockchain-based provenance, supply-chain transactions and digital part records [1,2]. They are AM-general rather than photopolymer-specific, and the second uses a metal material-extrusion demonstration. This review therefore defines a chain-of-custody record architecture for distributed photopolymer manufacturing while treating material-identity verification as a separate qualification requirement. It also preserves boundaries with material passports, corpus provenance and extended-producer-responsibility/product-passport models. A synthetic split-and-loss ledger and bidirectional tracing exercise distinguish arithmetic reconciliation from verification of physical material identity.

Keywords: chain of custody · distributed photopolymer manufacturing · traceability · material identity · files · sites · release records

1. Scope and ownership

ER-489 concerns chain-of-custody records for distributed photopolymer manufacturing. It asks how files, sites, production records and release records can remain traceable across a distributed workflow. It does not claim that a traceability record verifies resin identity.

2. Evidence base and process limits

Source [1] addresses blockchain-based traceability and management for additive manufacturing, including design files, IoT records, supply-chain transactions and provenance [1]. Source [2] addresses a digital AM part record for traceable quality documentation and demonstrates that record on a metal material-extrusion process [2]. Both are AM-general rather than photopolymer-specific evidence.

3. The chain-of-custody object

A chain-of-custody record should preserve the relation among the authorised digital definition, the manufacturing site, the material lot or declared material identifier, the process record, the produced item or batch, and the release decision. The purpose is continuity of evidence across transfers, not certification that every declared field is true.

4. Files and versions

The record should identify which digital files were authorised, their version or cryptographic identity where used, and the site or system that received them. A later file change should create a new traceable state rather than silently replacing the earlier one.

5. Sites and production records

Distributed production requires each manufacturing site to be identifiable and each production event to be linked to that site. Process records, inspection records and deviations should remain associated with the item or batch they concern. This is a traceability requirement and does not by itself establish process equivalence between sites.

6. Release records

A release record should identify the evidence reviewed, the decision state and the item or batch released. If a release is conditional, reworked or rejected, that state should remain in the custody chain rather than being overwritten by the final disposition.

7. Material identity is a separate verification problem

A record can preserve a material identifier supplied to it, but that does not demonstrate that the resin physically used was the declared material. Material-identity verification therefore requires an independent control appropriate to the intended qualification state. ER-489 owns the custody relation between the declared material record and the production event; it does not claim that the relation proves chemical or lot identity.

8. Boundaries with ER-393, ER-394 and ER-460

The controlled corpus defines ER-393 as the review of machine-readable material passports for photopolymer products, with composition boundaries, process history and end-of-life fields. ER-489 therefore does not own the complete material-passport schema. ER-394 owns provenance and citation-graph methods for engineering-review corpora, so ER-489 does not own literature-claim provenance or corpus version governance. ER-460 owns extended-producer-responsibility and product-passport models for photopolymer products, including data, collection and accountability; ER-489 therefore does not own EPR collection/accountability models. ER-489 is limited to custody continuity across distributed manufacturing events.

9. Minimum chain-of-custody record

At minimum, retain the authorised file identity, site identity, declared material record, production-event identity, relevant process/inspection records, produced-item or batch identity, transfer events, release disposition and timestamps or ordering information sufficient to reconstruct custody. A missing field should remain missing rather than be reconstructed from a later state.

10. A physical and digital event model

The proposed custody model treats receipt, subdivision, mixing, processing, transfer and disposition as different events. Each event would identify its inputs, outputs, quantity basis, actor, time and supporting evidence. A new identifier should be created when necessary to preserve a distinguishable physical state, while the relationship to the preceding identifiers remains traceable. The record should not imply that a file hash proves the chemical identity of the material it describes.

For a synthetic mass-balance example, a received lot contains 10 kg on a declared measurement basis. It is divided into 6 kg and 4 kg. The 6 kg portion is later recorded as 5.7 kg of retained output and 0.3 kg of documented loss. This ledger reconciles arithmetically. It does not establish that the scales were accurate, that the containers contained the named material or that the loss explanation is correct. Those facts need their own evidence.

If an output of 6.2 kg appears without an additional input, the ledger identifies an inconsistency requiring investigation. The system should preserve the original event and the correction history rather than overwrite the discrepancy so that the ledger appears always to have balanced.

11. Test the link between records and objects

A proposed verification exercise would trace a selected delivered object back through its material and manufacturing events and then follow an identified input forward to its recorded destinations. These directions answer different questions: reconstructing one successful object does not establish that all affected outputs of a suspect lot can be located. The test should include splits, merges and dispositions rather than only a linear transfer.

Mixing requires a record of every contributing input and the output identity. A batch label that retains only the last added lot loses part of the genealogy. The quantity basis should also remain explicit, particularly where units or measurement states change. A quantity in volume cannot be reconciled with a quantity in mass without an applicable conversion basis.

Digital controls can preserve record integrity and make alterations visible, but incoming identification, measurement and physical handling remain separate controls. The proposed method is therefore judged by whether it detects inconsistent events and supports object reconstruction under declared conditions. It does not claim that blockchain or another storage architecture can independently establish material truth.

Supplementary critical engineering analysis: Digital custody and physical identity: A cryptographically protected transfer record can show that a file or batch identifier was not altered after signing; it does not by itself prove that the dispensed resin, cured article or shipped part matches the declared composition. Physical identity requires independent evidence such as controlled lot reconciliation, material acceptance records, documented container transfers and fit-for-purpose analytical checks where justified. The strength of the claim must be limited to the weakest link between the digital record and the physical object.

Distributed production reconciliation: An auditable chain should link customer requirement, approved design revision, manufacturing site, material lot, equipment configuration, production log, post-processing history, inspection result and shipment. Unplanned substitutions and reprints must create new linked events rather than silently replacing earlier evidence. Permission management, clock consistency and retention policy are essential for reconstructing events, but they are governance requirements rather than proof of physical product equivalence.

Critical evidence synthesis: Custody continuity versus material identity: A tamper-evident digital record can demonstrate continuity of documented events but cannot independently prove that the physical resin in a container matches its label. Controls for that question may include secured sampling, retained aliquots, validated material identification methods and reconciliation of container identifiers with transfer records. The review must distinguish identity verification, provenance claims and conformity of measured material properties; success in one layer does not imply success in the others.

Distributed manufacture introduces additional reconciliation events when material is split, blended, returned or consumed. An audit trail should account for material balance, operator actions, equipment status and deviations, including corrections to erroneous entries without deleting the history. Cross-site data schemas can improve comparability, but only if fields have consistent definitions, units and time bases. Any claim of cryptographic security must be bounded by the quality of the physical observation and the integrity of the people and devices supplying the initial record.

Physical identity, event ordering and reconciliation: A chain-of-custody ledger documents who handled a material or digital artifact and when; it does not chemically authenticate the item. The verification architecture should therefore distinguish transaction integrity, physical-container identity, batch composition and cured-part provenance. A digital signature can authenticate a record while leaving an incorrectly labelled container undetected.

At minimum, record immutable event identifiers, role-based authorization, material lot, received mass, consumed mass, recovered mass, quarantine disposition, printer identifier, build-file revision and post-processing history. Mass-balance mismatches and duplicated lot identifiers should trigger investigation, not silent reconciliation by adjusting inventory fields.

When manufacturing spans sites, clock synchronization and offline event buffering introduce sequence ambiguity. The record must distinguish event occurrence time from upload time and identify the authority that approves corrections. Corrections should be append-only with reason, original value and reviewer. Deletion of a failed run obscures the denominator needed for yield and reliability analysis.

For qualification, challenge the custody system with deliberate label swaps, interrupted network synchronization, duplicated files and mismatched material certificates. Success means detecting and containing the discrepancy, not merely writing a complete-looking audit trail. Physical sampling or validated spectroscopy may be needed to establish material identity independently.

12. Limitations

The evidence base is AM-general. Source [2] is additionally limited here to publisher-abstract depth and a metal material-extrusion demonstration. No study-level claim is imported from that source. The article defines a traceability architecture, not a validated photopolymer-specific blockchain implementation.

Proving provenance is not proving identity: A digitally complete custody trail can still describe the wrong physical item if labeling or sampling is compromised at the start. Digital signatures and cryptographic hashes show integrity of records or files under defined trust assumptions; they cannot demonstrate that the resin inside a container matches its declared chemistry. Identity assurance must link independently verified physical attributes to the recorded lot and to any subsequent split, blend or transfer. The confidence of each link should be assessed separately.

An adversarial qualification protocol should introduce realistic failures: duplicate identifiers, label swaps, delayed uploads, revoked permissions, altered build files and missing post-cure records. Investigators should measure whether the system detects, localizes and prevents release of the affected lot. The protocol must also specify recovery behavior when connectivity fails. Traceability is valuable because it enables targeted investigation and containment; it should not be described as proof of material equivalence or final-part fitness.

13. Conclusions

Distributed photopolymer manufacturing can use AM traceability concepts to structure custody of files, sites, production events and release records [1,2]. That architecture can preserve a declared material identity but cannot verify it by recordkeeping alone. Material identity, material-passport content, corpus provenance and EPR/product-passport governance remain separate qualification layers.

References

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. The company develops and supplies photoresins and related process materials. No proprietary formulation, manufacturing sequence, process window or comparative product recommendation is disclosed.

Data availability

No new experimental dataset was generated.

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