

# Requirements for Distributed Photopolymer Manufacturing: AM-General Quality Benchmarking, Local Supply, and Site-Equivalence Evidence Gaps

*Industrial economics and deployment*

**Juan Seguro**

3Dresyns by Resyner Technologies S.L.

© 2026 Juan Seguro. All Rights Reserved.

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

**ER-476 · Engineering Review · Version 0.1 · 12 October 2026**

## Abstract

Distributed additive manufacturing can be compared across production centres and can be organised around local or cyber-enabled supply arrangements, but the available evidence for this review is additive-manufacturing-general rather than photopolymer-specific [1,2]. Source [1] provides a benchmark analysis of quality across distributed additive-manufacturing centres. Source [2] provides a distributed-AM supply-chain case study that includes quality-assurance, traceability and governance challenges. Neither establishes process or site equivalence for distributed photopolymer manufacturing. This review therefore treats photopolymer deployment as a target qualification problem: AM-general benchmarking and local-supply evidence define useful categories, while site equivalence and governance remain requirements that must be demonstrated for the specific photopolymer process. A hierarchical comparison design and an illustrative equivalence interval separate site effects, measurement effects and the absence of demonstrated difference.

**Keywords:** distributed manufacturing · photopolymer manufacturing · quality benchmarking · local supply · site equivalence · governance

## 1. Scope and ownership

ER-476 asks what distributed photopolymer manufacturing would have to demonstrate before sites could be treated as equivalent for a defined product or process. The two controlled sources are AM-general. They do not constitute a distributed-photopolymer quality dataset and do not establish photopolymer process equivalence.

## 2. AM-general quality benchmarking

Source [1] supports the proposition that quality performance can be benchmarked across distributed additive-manufacturing centres [1]. That is methodologically relevant to a distributed photopolymer network, but the evidence is not presented as photopolymer-specific. The transferable element is the need to compare sites using common definitions and controlled measurements, not any specific equivalence result.

## 3. Local supply and distributed production

Source [2] addresses distributed additive manufacturing as a supply-chain architecture and includes quality-assurance, traceability and governance challenges [2]. It supports local/distributed supply as an organisational possibility. It does not show that a photopolymer process transferred between sites will remain equivalent.

## 4. Site equivalence is the missing evidence

For photopolymer manufacturing, site equivalence would require evidence that the material, machine state, exposure conditions, post-processing, environmental controls, measurement system and release criteria produce an acceptable and reproducible result at each participating site. The present sources do not supply that photopolymer-specific evidence. Site equivalence is therefore an evidence gap, not a conclusion.

## 5. Governance as a requirement

Distributed manufacturing also requires governance of controlled files, material identity, change control, deviations, records and release authority. Source [2] identifies governance challenges at AM-general level, but this review does not claim a validated governance framework for photopolymer networks. Governance is retained as a named qualification requirement.

## 6. Minimum comparison architecture

A defensible distributed-photopolymer qualification should define the product or process state to be compared, the participating sites, the common measurement set, the acceptance rule, the handling of site-specific equipment and environmental differences, and the change-control rule after equivalence has been demonstrated. Where equivalence has not been measured, the sites should not be treated as interchangeable by assumption.

## 7. A design that separates site difference from measurement difference

A proposed inter-site comparison should begin with the intended transferable claim. Producing a geometrically similar object is not necessarily the same claim as reproducing a mechanical property, surface state or final function. The comparison would select endpoints and use-specific margins before analysing site results. It would also specify the material, equipment configuration, post-processing and specimen history that define the receiving claim.

A simple hierarchical record would identify site, machine, build, specimen and measurement repetition. Multiple readings from one specimen estimate measurement repeatability; multiple specimens from one build do not by themselves estimate between-build reproducibility. If each site uses a different measurement system, an observed site contrast may include metrology differences. A common reference or a crossed measurement exercise can help investigate that possibility, but its suitability must be established for the endpoint.

The proposed study would avoid changing site and material lot together without a design that can distinguish their contributions. If that separation is impractical, the result should describe the complete route comparison rather than attribute a difference uniquely to the site.

## 8. Equivalence requires a margin and adequate uncertainty

Suppose an illustrative difference between sites is 0.4 units with an uncertainty interval extending from  $-1.2$  to  $+2.0$  units. If the predefined equivalence margin is  $\pm 1.0$  unit, the interval does not demonstrate equivalence. This remains true even though the interval includes zero. The values are hypothetical; they demonstrate the difference between an inconclusive contrast and evidence that a use-specific margin is satisfied.

A mean comparison alone can also miss a change in variation. Two routes may have similar central values but different tails, which may matter when the decision concerns individual parts. The assessment should therefore state whether it is comparing population means, variation, conformance probability or another defined property. Each requires a corresponding evidence basis.

Finally, the accepted comparison should be attached to a configuration and a change rule. A later material, software, equipment or post-process change may invalidate the representation of one site by the original study. The network should then determine which part of the evidence requires renewal. This gives regional manufacturing equivalence a testable meaning without assuming that common printer labels or shared files establish it.

### 8.1. Critical comparison of the evidence and its transfer limits

Verna and Maisano [1] investigate benchmarking of quality among distributed additive-manufacturing centres. A cross-centre benchmark is valuable because it recognizes production location as a possible source of variation and provides a common comparative frame. However, the observed population, technology mix, selected quality characteristics and benchmark methods determine what can be inferred. A comparison of centres is not automatically an equivalence demonstration for a different technology. In particular, it cannot establish that two photopolymer parts have equivalent conversion, extractables, strength or ageing behaviour simply because their dimensions or aggregate quality scores are comparable.

Gladkikh et al. [2] propose and illustrate a cyber-supply-chain architecture using a case study on furniture masking plugs. This establishes an example of digital-file distribution and local, on-demand manufacturing with economic, environmental and operational comparisons within its declared case. Those comparisons are not interchangeable with multicentre resin-process qualification; a favourable supply-chain result does not demonstrate material equivalence or product release competence at independent sites. Thus [1] addresses cross-centre quality benchmarking, whereas [2] emphasizes deployment and supply-chain outcomes. Neither directly reports a controlled multicentre photopolymer equivalence experiment.

ISO/ASTM 52920:2023 [3] sets material- and process-independent requirements for industrial additive manufacturing processes and production sites. It can structure qualification and records but is not a substitute for proving use-specific properties of cured photopolymers. The standard itself does not comprehensively cover environment, health and safety requirements. Accordingly, this review treats the standard as normative process guidance, the two papers as empirical or case-based evidence within their limits, and the photopolymer comparison protocol below as a proposed research and qualification design, not a validated standard method.

### 8.2. Causal structure of site-to-site variation

A site transfer can change material, optical, thermal, mechanical, wash and post-cure histories simultaneously. Nominal wavelength or exposure time does not document delivered spectral irradiance, optical uniformity, layerwise cumulative exposure or local oxygen inhibition. Similarly, a common post-cure duration does not demonstrate equivalent absorbed dose or specimen temperature. Batch-specific changes in resin storage history, inhibitor state and pigment loading may interact with printer differences. These are plausible factors to control, not proven causes of differences in the two distributed-AM studies.

Process transfer must therefore identify which characteristics are fixed design requirements, which are allowed to vary within a justified operating window and which are monitored covariates. A comparison designed around final dimensions alone could miss material-state differences; one designed around conversion alone could miss wash-related surface changes or geometric deviations. The necessary endpoint set depends on the intended function and the release claim, and may include dimensions, surface state, conversion-related measurements, extractables, mechanical response, dimensional drift or performance after a defined ageing schedule. No universal endpoint panel or acceptance margin is asserted.

### 8.3. Study design, statistics and decision logic

A proposed multicentre qualification should predefine the product, released build file, resin identity and lot strategy, printer configurations, washing and cure conditions, acceptance endpoints and reporting unit. A crossed or balanced comparison can distribute material lots among sites and use common reference specimens so that lot effects are not entirely confounded with site effects. Where practical, samples can be measured by both local and reference laboratories, with blinded identifiers and a documented measurement-system study. A single successful build at each site is insufficient to estimate between-build variation or the temporal stability of transfer.

For continuous properties, equivalence is a claim about a prespecified permissible difference and its uncertainty, not about failing to reject a difference. If a two-sided interval extends outside either equivalence bound, the evidence remains insufficient to declare equivalence, even when the point estimate is near zero. For properties governed by the lower tail of individual-part performance, a mean-comparison design may be inappropriate; sampling plans must match the acceptance statistic. A hierarchical analysis may model site, machine, lot, build and specimen, while preserving the distinction between repeated readings and independent production replicates. No sample size or statistical threshold is prescribed here without product-specific variance and risk information.

The release decision should be bounded to the configuration, endpoints and measurement uncertainty actually tested. Change control should identify triggers for partial or full requalification, including replacement of light engines, changes in resin supplier or specification, new washing chemistry, post-cure equipment changes and digital-file revisions. Acceptance of a site for one part family should not silently become approval for a different geometry, load state, contact classification or processing window.

## 8.4. Operational, economic and governance implications

Distributed manufacturing offers possible reductions in physical transport and responsiveness advantages, but such outcomes require scenario-specific evidence. Local fabrication can increase the number of small production cells, inventories of materials and cleaning solvents, quality-control activities and equipment underutilization. Environmental or economic benefits should be evaluated against a declared baseline using accepted-part yield, materials and waste, utilization, energy and logistics. The case result in [2] cannot be generalized to all photopolymer products without recalculating those terms.

A digital provenance chain should link the authorised design revision, manufacturing instructions, material and lot identifiers, machine software and calibration, environmental and processing records, inspection decisions and release authority. Cybersecurity and access control are relevant to file integrity, while the physical process still requires local competence and audit evidence. This is a proposed governance architecture; the cited sources do not validate an end-to-end photopolymer quality system. Defects and complaints should remain traceable to site and process state so that a corrective action is not incorrectly generalized across the network.

## 8.5. Research gaps and minimum reporting recommendations

The priority experiment is a replicated, multicentre comparison of the same photopolymer product under a transparently defined material-process-post-cure state. It should report all participating sites and architectures, resin lots and storage histories, exposure and post-cure measurement methods, metrology comparability, independent build counts, specimen-level data structure, acceptance margins selected before analysis, deviations and any failure to demonstrate equivalence. Negative and inconclusive outcomes are essential to avoid survivor bias.

Future studies should distinguish geometric interchangeability from material-state and functional interchangeability, quantify site and lot interactions, and examine whether qualification remains valid after controlled changes. For a distributed business case, the same study programme should record accepted yield, lead time, transport assumptions and quality-related costs under explicit system boundaries. The current evidence supports the need to ask those questions; it does not yet answer them for a photopolymer production network.

## From multi-site capability to evidence of site equivalence

A distributed production network cannot claim equivalent outputs solely because its sites use the same nominal CAD file, resin family or printer model. A site-transfer study must define the controlled digital input, machine configuration, exposure calibration, material lots, ambient conditions, wash and post-cure history, and accepted-part measurement protocol. It must then test both within-site repeatability and between-site reproducibility. Differences due to measurement system should be assessed before interpreting observed between-site part variation as manufacturing variation.

A qualification plan should include a deliberately challenging geometry, agreed critical-to-quality characteristics, predefined acceptance criteria and independent measurement or interlaboratory comparison where practical. Documenting comparable averages is insufficient if one site has substantially wider dispersion or an intermittent failure mode. ISO/ASTM 52920 provides a broad quality-assurance structure but is not, by itself, proof that particular sites are technically equivalent. The proposed evidence hierarchy differentiates network-readiness claims from actually demonstrated part interchangeability.

## A statistical study design for site-equivalence claims

Product conformity at two facilities is not by itself proof of equivalent process capability. A shared drawing can conceal differences in optical dose distribution, liquid residence history, cleaning, post-cure and metrology practice. Site-transfer experiments should therefore include common reference geometry, controlled materials, calibrated instruments, and a predefined rationale for permissible differences.

A nested sampling design can distinguish within-build variation, batch variation and site-to-site variation. Replication must reflect the intended production envelope rather than a single demonstration build. Measurements of different sites should be performed under the same measurement protocol, with gauge reproducibility and systematic offsets explicitly assessed before comparing part results. An overlap of observed ranges is not an equivalence test.

For regulated or function-critical products, proposed equivalence limits must flow from intended use and accepted risk. Passing a generic machine-qualification standard is necessary context for a quality programme but cannot substitute for product-specific verification. The receiving site should document unresolved differences and changes that trigger renewed studies.

## 9. A qualification protocol for distributed sites

Distributed photopolymer manufacturing is a controlled replication problem, not simply deployment of matching printer models. Site differences may arise from spectral power distribution, optical nonuniformity, temperature, resin age, oxygen access, washing efficiency, secondary cure and operator handling. Site equivalence therefore has to be assessed against a defined intended use and product acceptance set, with traceable lot and equipment records.

A practical study design would include a common reference artifact, identical released digital definition, coordinated resin lots and separately recorded local process parameters. Where feasible, blinded measurement of parts from multiple sites by a common metrology laboratory helps isolate measurement-system differences. Crossed factors such as site, machine, operator and material lot should be represented explicitly; confounding all factors within one site defeats attribution. Repeated production windows are necessary to distinguish an isolated successful build from sustained capability.

Equivalence is not demonstrated by failure to detect a statistically significant difference. Before testing, engineering teams must define margins based on functional requirements and the measurement uncertainty. Distributional tails, not just mean geometry, may govern fit-critical or load-bearing applications. The outcome should record both the predefined interval of acceptable site differences and the observed uncertainty of the comparison. When sample numbers cannot support that inference, the status is evidence insufficient, not equivalent.

ISO/ASTM 52920:2023 supplies AM-general production-site qualification principles, but its material-independent scope must not be misrepresented as a validated photopolymer-specific equivalence protocol. Distributed production also requires change notification, training, local environmental and occupational controls, and a common release authority. The technical transfer claim is bounded to the tested product, equipment state and material window.

## **10. Evidence transfer boundary**

The AM-general evidence can support the structure of the qualification question but not the photopolymer-specific answer. No distributed-photopolymer quality dataset is claimed here, and no result from one additive-manufacturing process is treated as evidence of photopolymer process equivalence.

## **11. Conclusions**

Distributed-AM literature supports cross-centre quality benchmarking and distributed/local supply architectures [1,2]. For photopolymer manufacturing, however, the decisive question is site equivalence under a controlled material-process-workflow state. That evidence remains to be established, with governance retained as a necessary but not yet validated layer.

## **References**

1. Verna E, Maisano DA. A benchmark analysis of the quality of distributed additive manufacturing centers. *International Journal of Quality & Reliability Management*. 2022;39(6):1488-1505. <https://doi.org/10.1108/IJQRM-07-2021-0214>.
2. Gladkikh MN, Shan Y, Ayers JI, Tackett E, Mao H. Blueprint and case study for the cyber supply chain: Distributed additive manufacturing enables resilience and sustainability. *Manufacturing Letters*. 2025;44 Supplement:1699-1707. <https://doi.org/10.1016/j.mfglet.2025.06.189>.
3. ISO/ASTM 52920:2023. Additive manufacturing — Qualification principles — Requirements for industrial additive manufacturing processes and production sites. International Organization for Standardization, 2023. <https://www.iso.org/standard/76911.html>.

## **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.

## **Copyright**

© 2026 Juan Segurola. All Rights Reserved.