

Evolutionary Concept Selection in Additive Manufacturing

A Field Report on Structured Idea Generation and Two Rounds of Systematic Self-Correction

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Note on this publication version. Two concepts of this series are under an ongoing IP review. Their process descriptions are withheld in this version. Rating, patent class and the prior art found remain fully included, because the methodology of this work would not be traceable without them. The unabridged version will appear once the review is complete.

Abstract

This report describes an approach to the structured generation and evaluation of technology concepts in additive manufacturing. Over four research cycles, 164 concept candidates were generated and reduced to 28 through an iterative process of analysis, hypothesis formation, theoretical testing, critique and recombination. The methodologically most instructive part emerged afterwards, in two stages. A check against literature from 2020 to 2026 revised four ratings. A subsequent patent and market search revised nine more — including all three concepts that were considered maximally novel after the first correction. Both rounds are fully documented. After the second round, a single concept retains a medium-to-wide claim space. The structural pattern observed in the first round — the most robust concepts unite fabrication and measurement in the same process step — remains valid as a design principle but is partly occupied as an IP position.

Keywords: additive manufacturing, concept selection, state of the art, patent search, multi-axis printing, multi-material, in-process verification

1. Starting Point

Additive manufacturing has three limits that stem not from implementation quality but from the architecture of the process. Cartesian three-axis kinematics enforces planar layering; this entails supports for overhangs, direction-dependent strength and stair-stepping on curved surfaces. Any improvement that leaves the kinematics untouched remains incremental. The search therefore targeted approaches that change the motion geometry, introduce additional physical effects or restructure the process chain elsewhere.

2. Method

The study ran in four cycles of fifteen iterations each: cycle I physical machine concepts, cycle II AI-driven process optimization, cycle III hybrids of both, cycle IV multi-axis kinematics, multi-material and functional integration in filament printing. Concepts were reviewed from nine disciplinary perspectives; a critical role was tasked with rejecting physically implausible, incremental or advantage-free concepts.

Evaluation used seven weighted dimensions: physical plausibility, novelty, hardness of the addressed problem, measurability of the benefit, capital compatibility, time to market and regulatory passability. Plausibility and capital compatibility carried the highest weight.

3. Selection Result

Of 164 candidates, 28 survived at least three critique rounds. Physical implausibility was rarer than expected. The most frequent reason for rejection was unresolved system complexity: a concept with a hundred cooperating mini-robots failed on three simultaneously unsolved sub-problems; reduction to two coordinated arms yielded a viable concept. A micronozzle array failed on thermal crosstalk and became feasible in a smaller form with inter-row cooling.

4. First Correction Round: Literature Review

The first version was produced without a systematic state-of-the-art review. The subsequent literature review revised four concepts:

Concept	before	after	Reason
Magnetic-field-assisted fibre orientation	9.1	7.4	Voxel-wise magnetic alignment commercially available in resin printing (Fortify Fluxprint); FDM feasibility studies published
Multi-axis kinematics with rotating part	8.7	8.0	Multi-axis non-planar printing actively published (Fang et al. 2020: up to 6.35× strength); claim narrowed to the kinematic inversion
Acoustic levitation as support replacement	7.8	6.9	Load capacity of a 40 kHz trap below the mass of a 0.4 mm × 20 mm extrusion
In-process spectroscopy on the print head	8.2	8.6	Upgrade: functional integration in literature mainly via inkjet processes

5. Second Correction Round: Patent and Market Search

After the first round, three concepts were considered maximally novel because literature showed no precursors. The patent search refuted all three:

Concept	before	after	Prior art found	Claim space
Sensor-controlled gradient extrusion	9.5	8.3	US12208450 explicitly describes printing a graded material with laser profilometer and Doppler flow sensor; dense closed-loop patent family (US10647055 et seq.)	narrow-medium
Simultaneous dual-arm bioprinting	9.4	8.9	WO2015066705A1 (bioprinter with at least two simultaneously depositing arms); TwinPrint; two-robot system PMC8961309	medium-wide
AI-controlled electrochemical microstructure	8.6	7.2	US10975485B2 (controllable anode array); LLNL US2025/0043452 (CMOS micro-anode array)	narrow

Six further ratings fell: reactive two-component extrusion (8.4 → 7.3; WO2016085992A1, US11724458, US12036738), micronozzle array for thermoplastic melt (8.2 → 7.5; US10654272B2), in-process spectroscopy (8.6 → 8.3; US10691095, Voxel8), tri-modal sensor fusion (8.7 → 8.2; closed-loop family), electrochemical base idea (8.5 → 7.4). The platform vision of a manufacturer-agnostic AM operating system (9.3 → 7.8) failed not on patents but on the market: Oqton, Materialise CO-AM, 3YOURMIND, AMFG, Authentise and Siemens Opcentre already offer such abstraction layers.

One market gap was positively confirmed in the field of in-process spectroscopy. The details are withheld in this version until the IP review is complete.

The cited patents were assessed on titles, abstracts and descriptions. Legal status and the scope of granted claims were not examined.

6. The Structural Pattern After Two Rounds

After the first correction, the three strongest concepts each united fabrication and measurement in the same process step — gradient extrusion with property verification, printing with spectroscopic process monitoring, scaffold printing with concurrent cell deposition. The second round qualifies this finding without cancelling it. As a design principle, removing the temporal separation between production and inspection remains viable, and it remains relevant for regulated fields: documenting the material properties of every part during its creation meets a requirement on which additive manufacturing regularly fails in approval-bound applications. As an IP position, however, the principle is partly occupied. The exploitable lead thus shifts from patents to implementation head start, accumulated process data and approval documentation.

7. Transferable Lessons

Research belongs before evaluation. The chosen sequence — generate, evaluate, then research — produced thirteen revisions over two rounds.

Literature, patents and market are separate spaces. The first round found in literature what a patent search would not have looked for; the second found in the patent corpus what literature did not show; the market search found a product field that appears as a novelty question in neither space. None of the three searches replaces the others.

Adjacent processes belong in every search. Several precursors came from resin printing, organic vapor jet printing or direct ink writing, not from filament printing.

A precursor rarely destroys the entire claim. In most cases a narrower, real space remained. An honest narrowing is more valuable than a broad claim that collapses in examination.

File first, publish afterwards. In Europe any publication before the filing date destroys a patent's novelty, including one's own. The Austrian utility model grants a six-month grace period.

Rejected concepts are raw material. Two of the remaining approaches emerged from reducing failed precursors.

8. Limitations

This work is a structured concept exploration, not an experimental study; no concept was built or measured. Figures stem from rough estimates and the cited literature. Statements on the patent space are not a freedom-to-operate analysis and do not replace review by a patent attorney. The weighting is tailored to a capital-poor micro-organization; under other conditions the ranking shifts considerably. Market figures from different analysts diverge strongly and should be read as orders of magnitude.

9. Conclusion

The most valuable part of this study is not the concept list but the correction documented in two stages. A method that systematically generates and evaluates ideas equally systematically produces overestimated novelty claims — and a single research stage is not

enough to detect them. The corrections remain visible, because documentation that erases its misjudgements becomes useless as a basis for decisions.

Literature and Patents

Fang, G., Zhang, T., Zhong, S., Chen, X., Zhong, Z., Wang, C. C. L.: Reinforced FDM — multi-axis filament alignment with controlled anisotropic strength. *ACM Transactions on Graphics* 39 (2020).

Cheng, P. et al.: Recent progress in non-planar 3D printing of continuous fiber-reinforced composites. *Composites Part A* 194 (2025), 108900.

Hong, F. et al.: 5-axis multi-material 3D printing of curved electrical traces. *Additive Manufacturing* 70 (2023).

Zaidi, A. A. et al.: Advances in multi-material polymer 3D printing depositions. *Frontiers in Mechanical Engineering* 12 (2026).

Zhou, X. et al.: Heterogeneous material 3D printing. *International Journal of Extreme Manufacturing* 8 (2026), 062001.

Southeastern Louisiana University: Robotic Additive Manufacturing System — six-axis FFF with non-planar slicing (2026).

In-situ NIR monitoring of reactive resins in direct ink writing. *Additive Manufacturing* (2023).

Patents (search status September 2026, legal status unexamined): WO2015066705A1 · US12208450 · US10647055 · US11260580 · US11465340 · US11820073 · US12311595 · US10394202 · US20150331402A1 · US10975485B2 · US2025/0043452 · US20170044680A1 · US20170145584A1 · US10501857 · US10691095 · US10654272B2 · US20090065471A1 · WO2016085992A1 · US11724458 · US12036738 · US6454972 · US4533521.

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Regulatory information as of September 2026.*