

Online Configuration of Multifunctional Photopolymer Systems: A Multivariable, Multiobjective Framework for Vat Photopolymerisation

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Statement of Significance

A configurable photopolymer is not a catalogue item with independent checkboxes. Selecting printer class, viscosity, cure speed, colour and added functionality changes a coupled formulation-process system. A scientifically defensible online configuration architecture must therefore treat each resulting formulation as a constrained multiobjective design state that requires renewed optical, rheological, printing and end-use validation.

Keywords: vat photopolymerisation; configurable materials; multifunctional photopolymers; multiobjective optimisation; resin formulation; colour; viscosity; cure kinetics; DLP; LCD/MSLA; SLA; functional additives; working curve; Curing Rate Table; materials informatics

Abstract

Online material configuration can expose a large photopolymer design space to users, but only if configuration is treated as engineering rather than as unrestricted combinatorics. This review develops a multivariable framework for configuring vat-photopolymerisation resins across five interacting axes: printing platform, viscosity state, cure-speed/reactivity target, colour/optical state and added functionality. The literature shows that resin composition, viscosity, curing kinetics and mechanical properties form coupled trade-offs, while pigments, fillers and functional additives can alter light attenuation, scattering, recoating, sedimentation and network formation [1–8]. Data-driven and active-learning studies further show that multiobjective optimisation can navigate such coupled spaces more efficiently than sequential one-variable-at-a-time selection [1–3]. A manufacturer implementation example is then analysed: the 3Dresyns online configuration corpus exposes printer selection, LV/HV branches, fast/intermediate/slow reactivity, a broad colour system, and four additional functionality slots drawn from more than 50 selectable functional entries. These choices are interpreted as configuration inputs, not universal compatibility claims. The proposed qualification workflow requires every materially changed configuration to re-establish its cure window, rheology, dimensional behaviour and application-specific performance before equivalence can be asserted.

1. Scope and evidence-selection method

This Engineering Review addresses configurable photocurable resin systems for vat photopolymerisation (VPP), with emphasis on the scientific consequences of exposing multiple formulation and process variables through an online selection interface. Peer-reviewed sources were selected for direct relevance to multiobjective photopolymer design, formulation-process-property coupling, resin rheology, cure-depth calibration and optical attenuation. Manufacturer documentation is segregated in Section 7 and is used only to describe one implementation architecture. No proprietary recipes, ingredient concentrations, source code, predictive equations or internal optimisation rules are disclosed. This note is a topic-specific Engineering Review in the 3Dresyns ER series; the shared evidence-to-decision and qualification method is defined once in RP-02, Evidence-to-Decision Qualification Framework for Vat Photopolymerisation, and is not reproduced here.

The review does not assume that a user-selected combination is chemically compatible or print-ready. The central premise is the opposite: every additive, pigment, viscosity modifier or photokinetic change can shift one or more process-critical responses. Accordingly, a configuration engine should be interpreted as a constrained design interface whose outputs remain subject to compatibility screening and empirical qualification.

2. Configuration is a constrained design problem

Photopolymer formulation is intrinsically multiobjective. Erps et al. demonstrated data-driven multiobjective optimisation for 3D-printing materials, while Jain et al. used active learning to navigate acrylate composition space and target mechanical properties [1,2]. More recently, Song et al. explicitly treated viscosity and cure time alongside mechanical performance, showing why processability constraints must enter the objective function rather than be checked only after a mechanically attractive formulation is found [3].

For configurable VPP materials, the design vector can be represented conceptually as $x = \{\text{platform, wavelength/irradiance state, viscosity branch, reactivity target, colour state, functionality set, post-processing state}\}$. The response vector is broader: cure depth, critical exposure, lateral cure, flow/recoat behaviour, sedimentation stability, release force, dimensional accuracy, conversion, mechanical properties and the selected functional outputs. The mapping $x \rightarrow y$ is coupled and non-linear; therefore independent menu choices do not imply independent physical effects.

Table 1. Core configuration axes and why they cannot be treated independently.

Configuration axis	Typical selectable state	Primary physical consequence	Required re-check
Printing platform	LCD/MSLA, DLP, SLA laser, other VPP-related branch	Changes optical field, pixel/spot exposure, separation/recoat dynamics and usable viscosity window.	Printer wavelength, real irradiance, exposure strategy, layer thickness and calibration.
Viscosity state	LV versus HV; potentially heated processing for HV systems	Changes refill/recoat time, peel/separation forces, filler/pigment suspension and temperature sensitivity.	Rheology at stated temperature/shear history; layer refill and process stability.
Cure speed / reactivity	Fast, intermediate, slow; platform-specific non-reactive or tuning branches	Changes exposure requirement, process throughput, cure depth and resolution trade-off.	Working curve / CRT, critical exposure, penetration depth and dimensional test.
Colour / optical state	Clear, process colours, basic/special effects, custom RAL/NCS and other families	Pigments/dyes can absorb or scatter actinic light and can modify cure depth, lateral cure and required dose.	Optical attenuation and working curve after colour addition.
Added functionality	Up to four selected functional additions in the implementation example	Functional species may alter rheology, optical attenuation, interfacial chemistry, cure kinetics and final properties.	Compatibility screen, dispersion/stability, cure/rheology and function-specific validation.

3. The five interacting configuration axes

3.1 Printing platform and optical process

SLA, DLP and LCD/MSLA are all VPP processes, but their light delivery and layer-formation mechanics differ. The same formulation can therefore require different exposure, rest, lift/separation or recoating conditions. Bennett showed that the practical cure behaviour of commercial photopolymers can be characterised through critical exposure (E_c) and penetration depth (D_p), while Allonas et al. linked these quantities more directly to photochemical efficiency and light attenuation [5,6]. A configurable resin should consequently be anchored to the actual printer and measured optical state rather than to a generic technology label alone.

3.2 LV/HV is a processing branch, not a simple quality ranking

Viscosity governs self-levelling, recoating, pigment/filler suspension and separation forces. High-viscosity formulations can retain high-molecular-weight oligomers or functional loading that would otherwise be diluted for easier printing, but the resulting process window can require heating, slower refill or different layer mechanics. Recent VPP literature explicitly frames viscosity as a printability constraint coupled to cure kinetics and mechanical response [3,4,8]. Therefore LV and HV should be treated as alternative process states with different equipment and calibration requirements, not as “basic” and “premium” grades.

3.3 Fast/intermediate/slow reactivity changes more than cycle time

Changing photoinitiator/sensitiser/absorber balance or adding cure accelerants and resolution-control species can modify critical exposure, penetration depth, yellowing, lateral cure and conversion. A faster system may reduce nominal layer exposure but can also narrow the geometric process window; a slower or more strongly attenuated system may improve confinement while demanding more dose. The scientifically meaningful variable is therefore not the menu label “fast” or “slow”, but the re-established exposure-response curve for the selected printer and layer height [5,6].

3.4 Colour is an optical formulation variable

Colour selection must be treated as part of the photochemistry. Soluble dyes primarily add wavelength-dependent absorption, whereas particulate pigments and fillers can add both absorption and scattering. The Beer–Lambert/Jacobs framework predicts that increased attenuation changes penetration depth, but real VPP systems can deviate because scattering, photobleaching and repeated exposure history complicate the light field [6,7]. Consequently, colour-equivalent appearance does not imply cure-equivalent behaviour. A clear, black, white, fluorescent, metallic or custom RAL/NCS configuration should not inherit another colour’s exposure settings without verification.

3.5 Added functions create interaction terms

Functional additives can target conductivity/ESD behaviour, UV stability, surface friction, wear, adhesion, release, sedimentation control, opacity, ceramic reinforcement, radiation interaction, fire response, texturing, degradability or other outputs. But a functional addition is rarely orthogonal to printing. Conductive or ceramic particles may raise viscosity and scattering; an anti-sedimentation strategy changes rheology; a coloured UV-protection package changes actinic attenuation; an adhesion promoter can alter interfacial chemistry; and a cure accelerator can shift both throughput and resolution. Selecting several functions therefore introduces interaction terms that must be screened experimentally rather than assumed additive.

Table 2. Examples of coupling between configuration variables.

Change	Potential benefit	Coupled risk	Minimum evidence
Increase viscosity / choose HV	Retain higher oligomer or functional loading; improve suspension in some systems.	Slower reflow, higher separation force, temperature dependence.	Rheology + printer-specific refill/recoat test.
Add dark/strongly absorbing colour	Visual/optical target; potential cure confinement.	Higher required dose, lower D_p , incomplete interlayer cure if not recalibrated.	UV-vis/working curve + dimensional test.
Add white/particulate pigment	Whiteness/opacity.	Scattering, lateral cure, sedimentation and viscosity changes.	Dispersion stability + D_p/E_c + XY/Z accuracy.
Add conductive/composite filler	Electrical, thermal or reinforcing function.	Viscosity, scattering, agglomeration, sedimentation and anisotropy.	Dispersion/rheology + cure + function-specific test.
Add cure accelerator	Higher apparent print speed.	Overcure, reduced resolution, altered yellowing/network development.	CRT/working curve + feature test + post-cure equivalence.
Combine several functions	Multifunctional final part.	Non-linear chemical, optical and rheological interactions.	Combination-specific compatibility and full qualification; do not inherit single-additive data.

4. Multiobjective and data-driven formulation logic

The scientific value of online configuration is not the number of possible combinations; it is the ability to structure a high-dimensional design space. Multiobjective optimisation is appropriate because many desirable responses conflict. Low viscosity can favour recoating but may require diluents that change network properties. Higher photoreactivity can increase throughput but may reduce optical confinement. Pigment loading can deliver colour while also attenuating curing light. Functional fillers can provide electrical, thermal or mechanical behaviour while simultaneously increasing viscosity and scattering.

Erps et al. showed that data-driven optimisation can accelerate discovery under multiple objectives [1]. Jain et al. demonstrated active learning in a ternary acrylate composition space, reducing the experimental burden needed to target mechanical properties [2]. Song et al. extended the principle by including viscosity and curing time as explicit design targets alongside modulus and elongation, identifying a processable high-performance region rather than optimising mechanics in isolation [3]. Together these studies support a configuration philosophy based on constrained feasible regions and Pareto trade-offs rather than “best” values for individual variables.

An industrial configuration system can therefore be conceptualised in three layers: (i) a user-facing choice layer expressing desired process and function; (ii) a compatibility/constraint layer that rejects or modifies chemically or physically incompatible combinations; and (iii) a verification layer that generates or confirms the empirical process window for the final formulation. The user interface is only the first layer.

5. Qualification workflow for a configured material

A configuration should be released as a controlled formulation-process pair rather than only as a material name. The minimum workflow below is intentionally sequential: a later-stage pass cannot compensate for failure of an earlier compatibility or printability gate. Where the gates below call for rheological or mechanical measurement, the applicable method must be named with its edition: rotational and oscillatory rheometry follows the terminology and general principles of ISO 3219-2:2021 [S1], while tensile and flexural characterisation of the cured material follow ISO 527-1:2019 [S2] and ISO 178:2019 [S3] respectively. Both plastics standards currently sit at ISO stage 90.92 with revisions in development, so the edition in force must be confirmed at the time of testing.

Table 3. Minimum qualification sequence after configuration.

Gate	Question	Typical measurement / record	Decision
G0 Identity	What exact configuration was selected?	Base family, colour, LV/HV, printer branch, reactivity target, added functions, lot/version.	Freeze configuration identity before testing.
G1 Compatibility	Can the selected components coexist without gross instability or adverse reaction?	Visual stability, phase separation, dispersion, short-term storage screen.	Reject/reformulate if incompatible.
G2 Rheology	Can the formulation refill/recoat and remain stable in the intended process?	Viscosity/rheology at controlled temperature; settling/thixotropy where relevant.	Set temperature, wait/recoat strategy or change viscosity branch.
G3 Photokinetics	What exposure window does the final coloured/functional formulation require?	Working curve / CRT: cure depth versus exposure; Ec and Dp where appropriate.	Establish exposure range for target layer thickness.
G4 Geometry	Does the calibrated process reproduce critical features?	Dimensional artefact, thin walls/holes, XY/Z accuracy, release observations.	Confirm printer-specific operating window.
G5 Part state	Does post-processing preserve the intended properties?	Wash, post-cure, conditioning and appearance records.	Lock post-processing state.
G6 Function	Does the finished part deliver the selected function(s)?	Application-specific electrical, thermal, optical, mechanical, surface or other test.	Release only the functions actually validated.
G7 Change control	Has any colour/additive/process variable changed?	Version/lot/configuration comparison and delta assessment.	Re-run affected gates; do not assume equivalence.

6. Working curves and CRT as the process-equivalence gate

The Jacobs-type working curve remains a practical bridge between formulation and printer. Bennett measured Ec and Dp for commercial photopolymers across wavelengths and exposure conditions [5], while Allonas et al. showed how critical energy and penetration depth arise from underlying photochemical and optical processes [6]. For a configurable material, these quantities should be considered state variables of the final formulation, not permanent constants of the base resin.

This has a direct consequence for colour and functionality. A resin calibrated when clear is not automatically calibrated after black pigment, white particulate pigment, a UV absorber, a conductive filler or a ceramic concentrate is added. Likewise, a “fast” version and a “slow” version should not share exposure data unless equivalence has been demonstrated. A Curing Rate Table (CRT) or equivalent cure-depth-versus-exposure dataset can therefore function as a practical release gate for each materially distinct configuration.

7. 3Dresyns implementation example: an online configurable-material architecture

Manufacturer documentation is included in this section only as an implementation example. It is not used as peer-reviewed evidence that any particular combination has universal compatibility or performance. The description below is drawn from the captured online configuration corpus [M1], the controlled overview documentation for the multivariable and multifunctional resin offering [M2], and the controlled colour-system and custom RAL/NCS documentation [M3], all accessed in August 2026.

The captured 3Dresyns online configuration corpus exposes the following design variables for selected photopolymer families:

- Viscosity branch: LV for lower-viscosity processing and HV for higher-viscosity/thermally assisted workflows in applicable products.
- Printer branch: LCD/MSLA, DLP, SLA laser and an “Other” route, with printer model/specification requested separately; specialised product families can expose different platform-specific branches such as 2PP or inkjet.
- Printing reactivity: Fast, Intermediate and Slow selections; specialised branches can expose additional tuning states.
- Colour: a representative configuration snapshot captured in August 2026 contained 41 selectable entries, and a re-check of the live colour option on 21 August 2026 returned 42 spanning clear, non-settling NextGen process colours, basic colours, special/metallic effects, Bio colour families, an ultra-black/matt option and custom RAL or NCS colour. Manufacturer documentation separately describes up to 2000 custom RAL/NCS choices.
- Added functionality: four independent functionality fields are exposed. Across the captured corpus, more than 50 functional entries are present; the exact active set is product- and version-dependent.
- Process control: the interface can offer a CRT package and requests printer information so that exposure calibration can be tied to the actual optical system.

The captured interface contains commercial option labels and product names carrying safety, biological and food-related wording - for example colour entries named “Basic & ultra safe”, “Special & ultra safe” and “Food grade bio”, and service tiers describing indirect or direct food and pharmaceutical contact. These were confirmed to be live and selectable on the public site on 21 August 2026; they are current commercial labels, not merely historical names, and this review does not describe them as superseded. They are reproduced here only as configurator nomenclature and carry no evidentiary weight: nothing in this review should be read as establishing safety, non-toxicity, biocompatibility, food-contact suitability, regulatory compliance or finished-device suitability for any configured material. The manufacturer's own current guidance pages state that safety characteristics are product-specific

and that suitability for biomedical, dental, food-contact or other regulated applications depends on the specific product and version. Reconciling the option-label layer with that guidance layer is an action for the manufacturer's document control and lies outside the scope of this review; until it is done, the label wording and the guidance wording are not consistent with each other.

Table 4. Functional-additive families represented in the captured 3Dresyns configuration corpus [M1]. Entries are configurator nomenclature describing an intended design target only. In particular, the bioactive/degradation entries name intended microorganism-control or degradation concepts and are not claims of antimicrobial efficacy - such claims are regulated (in the EU under Regulation (EU) 528/2012) and none is made here - and the radiation entries name intended radiopacity or neutron-interaction concepts without any claim of suitability for nuclear, shielding or dosimetric applications.

Functional family	Representative codes in captured corpus	Primary intended design target	Important interaction to control
Photokinetics / resolution	FT2P, FT3, FT4 variants, FT5 variants, FT6P, FT7, LB2, LB Cyan, LB Black	Cure speed, spectral response, resolution/confinement.	Ec/Dp, colour, yellowing and printer wavelength.
Electrical / ESD	ESDA Clear/Black, GrapEK1 Bio	Static dissipation or electrical conductivity.	Particle/network percolation, viscosity, scattering, dispersion.
Optical / stability	UVP1, UVP2, NY1, OPAQUER1, TiO2	UV protection, non-yellowing strategy, opacity/whiteness.	Actinic absorption/scattering and cure depth.
Surface / tribology	MATT1, Anti-Slip1, Anti Scratch1, WRA1, SLIP1, MicroText1P, MacroText1P	Matting, friction, scratch/wear response, texture.	Surface cure, dispersion, roughness and dimensional fidelity.
Process / interface	NSA1, AA1, AA2, ASC1, AWA1, STAB1	Release, adhesion, sedimentation, warpage or storage control.	Interfacial chemistry, rheology, cure kinetics and aging.
Ceramic / reinforced composite	CCA1-3, CCF1, CCZ1, CCQ1, RCC1-3	Ceramic appearance/reinforcement or insulation functions.	High solids, viscosity, scattering, sedimentation and shrinkage.
Radiation / fire response	ROC1, FRA1, FRC1, NAC2, NAC3	Radiopacity, flame/fire response, neutron-absorbing concepts.	Loading-dependent optical/rheological shifts; application-specific standards.
Bioactive / degradation-related	CuVK1/2, MGI-1, 3Dresyn-ase EBC1, ODC1	Microorganism-control or accelerated degradation concepts.	Regulatory/biological evidence, chemistry compatibility and functional durability.
Magnetic interaction	MHC	Attraction/holding to magnetic materials.	Particle loading, sedimentation and mechanical/optical effects.

Table 5. How the implementation example should be interpreted scientifically.

Interface choice	What it means	What it does NOT mean
Select LCD/DLP/SLA/Other	Define the intended process family and start printer-specific qualification.	That one exposure time or viscosity window applies to every printer in the class.
Select LV or HV	Choose an intended rheological/process branch.	That HV is intrinsically better, or that heating has no effect on cure/stability.
Select Fast/Intermediate/Slow	Choose a target reactivity regime.	That speed changes without consequences for resolution, cure depth or final network state.
Select colour	Define optical/appearance target.	That the clear-resin working curve remains valid.
Select 1–4 functions	Define desired functional targets.	That effects are independent, additive, mutually compatible or validated in combination.
Repeat order by reference lot/specification	Preserve configuration identity for manufacture and comparison.	That a change in raw-material lot, printer or post-process is automatically equivalent.

8. A practical multiobjective decision architecture

A robust online system should optimise in the order of hard constraints first, preferences second. A useful hierarchy is: (1) application and safety/regulatory boundary; (2) printer/process feasibility; (3) viscosity/recoat feasibility; (4) photokinetic/cure-window feasibility; (5) colour/optical target; (6) functional targets; (7) mechanical/thermal/other performance; and (8) manufacturing preferences such as speed. This ordering prevents a visually or functionally attractive choice from masking a basic process incompatibility.

From an optimisation perspective, configuration can be represented by a feasible set F defined by hard constraints (chemical compatibility, printer wavelength, rheological limits, cure-window limits and mandatory application requirements). Within F , soft objectives such as print speed, resolution, colour fidelity, mechanical properties, sustainability metrics or number of added functions can be treated as a Pareto problem. The relevant output is therefore a set of acceptable trade-offs, not a single universal “best resin”.

9. Claim boundaries and failure modes

Table 6. Failure modes specific to configurable multifunctional systems.

Failure mode	Why it occurs	Control
Checkbox independence assumption	User interface visually separates choices although chemistry does not.	Compatibility matrix and combination-specific validation.
Inherited calibration	Exposure from base/clear resin is reused after colour or functional changes.	Re-establish working curve/CRT for materially changed optical state.
Hidden viscosity shift	Several additives cumulatively move the formulation outside the refill/recoat window.	Measure final formulation rheology, not component datasheets alone.
Function-function antagonism	One additive adsorbs, reacts with, dilutes, screens or disperses another.	Combination screen and function-specific test on final part.
Overclaim from additive name	A marketed function is interpreted as a validated finished-device property.	State target function separately from validated performance and regulatory status.
Lot/configuration ambiguity	Reorders or datasets cannot be traced to exact option set.	Unique configuration identifier, versioning and change control.

10. Conclusions

- Online photopolymer configuration is scientifically credible when treated as constrained formulation-process design, not unrestricted menu combinatorics.
- Printer class, viscosity, cure speed, colour and added functionality are coupled variables; a change in one can move optical, rheological, mechanical and functional responses simultaneously.
- The literature supports multiobjective and data-driven strategies for navigating these coupled trade-offs, especially when viscosity and cure kinetics are explicit constraints rather than afterthoughts [1–4].
- Colour is part of the cure system because absorbers and pigments modify actinic attenuation and, for particulate systems, scattering [6,7].
- A system exposing up to four functional additions should treat the selected combination as a new qualification state; single-additive evidence cannot simply be summed.
- Working curves/CRT, final-formulation rheology, dimensional validation and application-specific testing provide a defensible release architecture for configured materials.

Limitations

This is a literature-based engineering review and implementation analysis, not an experimental validation of the 3Dresyns configurator or of every possible option combination. The online option inventory is versioned and product-dependent; counts reported here describe the captured August 2026 configuration corpus and should not be treated as permanent catalogue totals. The review does not disclose proprietary formulations or algorithms, and it does not establish regulatory, biological, safety or application suitability for any configured material.

Author contributions

Juan Seguro: conceptualisation, engineering framework, manufacturer-system interpretation, literature synthesis, writing, review and final approval.

Competing interests

The author is founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. The manufacturer implementation is therefore segregated from the peer-reviewed evidence and identified explicitly as a manufacturer example.

Data availability

No new experimental dataset was generated for this review. Scientific claims derive from the cited literature and standards. The manufacturer implementation description derives from the captured 3Dresyns online configuration corpus and controlled technical documentation available in August 2026.

Company information

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