

Post-Cure Process Engineering for Vat-Photopolymerised Parts: Dose Delivery, Chamber Geometry, Shadowing, Atmosphere and Thermal Coupling

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Statement of Significance

Post-curing is often specified as a time and temperature in a named chamber. That description is insufficient for engineering qualification. The printed part does not experience a nominal recipe. It experiences a spatially and temporally varying radiation field, a temperature history and an atmosphere, all filtered by the part geometry, optical state, orientation, loading arrangement and material response.

ER-181 treats post-cure as a second manufacturing process rather than a finishing checkbox. It separates commanded settings from delivered dose, chamber capability from part exposure, surface state from through-thickness state, and useful network development from dimensional or appearance penalties. The objective is not to identify one universal post-cure cycle. It is to define the evidence needed to show that a specified part, resin, load arrangement and chamber process reach the intended final state with controlled variation.

Keywords: vat photopolymerisation; post-cure; UV curing; irradiance; radiant exposure; chamber mapping; self-shadowing; oxygen inhibition; thermal coupling; qualification

Abstract

Vat-photopolymerised parts commonly leave the printer in a partially reacted state and are subsequently exposed to light, often with simultaneous heating, to advance the final network state. Direct studies show that post-curing can improve measured properties while also changing dimensional state, and that the response depends on post-cure irradiance, specimen thickness, time, temperature, material and print history [1,4,5]. Separate work on depth of cure demonstrates that UV post-curing through a finite thickness is limited by absorption and depends on wavelength, photoinitiator concentration and irradiation dose in the studied system [2]. Oxygen-inhibition studies further show that atmosphere can alter the surface mechanical state of vat-polymerised structures [3,6].

These findings make a nominal chamber recipe an incomplete process specification. ER-181 defines a qualification architecture based on the field actually delivered to the part: spectral irradiance, exposure time, surface orientation, view factor, self-shadowing, internal accessibility, temperature history and atmosphere. It distinguishes chamber mapping from part dosimetry, and process uniformity from property uniformity. Rotation, reflectors or multidirectional illumination may improve exposure distribution, but none proves uniform cure without measurement. The review therefore proposes worst-case load design, mapping, response verification, routine monitoring and requalification triggers. No published time, temperature, wavelength, dose or atmosphere is transferred as a universal post-cure condition.

1. Scope, terminology and ownership

ER-181 addresses the engineering of post-cure after a vat-photopolymerised part has been printed and cleaned to the state required by its process route. The post-cure unit operation may use near-UV or visible radiation, heat, controlled atmosphere or combinations of these inputs. The review owns how those inputs are delivered to the part and how the resulting process is qualified.

The term **commanded condition** means the settings entered into the curing equipment, such as nominal time, nominal chamber temperature or selected programme. The term **delivered condition** means the radiation, thermal and atmosphere history actually experienced at a defined location on or within the part. **Radiant exposure** is used for time-integrated irradiance at a stated spectral condition. **Load** means the complete arrangement of parts, fixtures and supports placed in the post-cure chamber for one cycle.

ER-020 retains ownership of thermal-property outcomes and thermal test methodology. ER-027 retains conversion metrology. ER-031 retains shrinkage, residual-stress and warpage mechanisms. ER-084 retains detailed photocuring pathways. ER-185 owns thick-section photocuring of bulk-applied putties, gels, sealants and potting compounds. ER-033 owns washing- and drying-induced extraction, property change and dimensional response in printed parts. ER-181 uses those adjacent response classes only to decide whether a post-cure process has delivered the intended final state.

Question	ER-181 owns	Boundary retained elsewhere
What field reached the part?	Irradiance, exposure, geometry, atmosphere, temperature history	Optical-property method development outside this review
Did conversion change?	Use as a response variable in qualification	Conversion metrology: ER-027
Did the part distort?	Use as a process consequence and acceptance response	Shrinkage/warpage mechanisms: ER-031
Did thermal performance change?	Use as a final-state response if required	Thermal-property ownership: ER-020

Question	ER-181 owns	Boundary retained elsewhere
Why did a particular photochemical pathway occur?	Only enough to define process variables	Detailed pathway ownership: ER-084

2. Post-cure is a second manufacturing process

The as-printed state is not simply an unfinished version of the final part. Printing establishes an initial conversion field, layer history, residual monomer population, inhibitor state, local temperature history, anisotropy and residual stress. Post-curing then acts on that inherited state. The same chamber cycle can therefore produce different results when the incoming printed state differs. Wu et al. directly demonstrated that UV post-curing of DLP structures can alter mechanical behaviour and induce shape distortion, with the response linked to printing parameters, post-cure UV intensity and specimen thickness [1]. Cheadle et al. likewise showed in a specific SLA resin that post-cure time and temperature changed tensile strength, degree of conversion and colour, while print orientation also influenced several outcomes [5]. These studies support a process-chain interpretation: final properties are functions of both print history and post-cure history.

A post-cure qualification should consequently define its incoming state. At minimum this includes resin identity and version, printer/process family, relevant exposure state, layer thickness, build orientation where consequential, wash/dry state, elapsed time between printing and curing, and any storage or dark hold. A chamber cycle qualified on one incoming state should not automatically be treated as qualified for a materially different one.

3. Commanded time is not delivered dose

A curing programme may specify ten minutes, thirty minutes or another nominal duration, but time alone does not quantify the photonic input. For a stationary point under constant spectral irradiance, radiant exposure is the time integral of irradiance. Real chambers are not spatially uniform, sources warm or age, parts rotate, surfaces change orientation relative to emitters, and local shadowing can vary during the cycle. The same clock time can therefore deliver different exposure to different surfaces.

The practical distinction is between **equipment time control** and **part exposure control**. Equipment time is easy to record and remains necessary. Part exposure requires at least a defensible estimate or measurement of the radiation field relevant to the part geometry and load arrangement. When the chamber uses rotation, the relevant value may be a cycle-integrated exposure over changing view angles rather than a static irradiance reading.

This distinction also prevents a common false equivalence between two curing units. Two devices set to the same time and nominal wavelength need not deliver the same spectral irradiance, angular distribution, thermal history or atmospheric state. Transfer between devices is therefore a requalification question, not a timer-matching exercise.

4. Spectral compatibility and source state

Photoinitiator response is wavelength dependent. The usable post-cure field is therefore spectral, not merely a single nominal wavelength printed on the equipment. Nitsche et al. studied post-cure depth under different wavelengths and photoinitiator concentrations and showed that penetration and cure depth depended on these variables and on irradiation dose in their urethane-acrylate system [2]. Their numerical depths and settings are system-specific, but the engineering transfer is general: source spectrum and formulation optical/initiator state jointly control how photonic energy is deposited.

Qualification should identify the source type and the spectral quantity that matters for the formulation. A broadband lamp, narrow LED band and multiple-LED chamber can deliver very different action-weighted exposure even when their nominal centre wavelengths appear compatible. Source replacement can also change spectrum while leaving total power similar.

The formulation side is equally important. Pigments, dyes, fillers, photoabsorbers and residual photoinitiator can change absorption or scattering. Post-cure can itself change optical state through photobleaching, oxidation or conversion. Consequently, a transmission or irradiance measurement made with an empty chamber does not by itself establish the field available inside a thick, opaque or strongly absorbing part.

5. Chamber geometry creates a radiation field

A post-cure chamber is an optical enclosure. Emitter location, number, orientation, reflector geometry, wall reflectance, distance to the part, fixture geometry and turntable position determine which surfaces see direct or reflected light. A device can have high average power while still containing local low-exposure zones.

Reflective surfaces, multidirectional illumination and part rotation are engineering strategies that can be used to redistribute irradiation within a curing chamber. Their presence does not establish that a chamber is inherently uniform or that every load receives equal exposure; those outcomes require measurement.

An equipment qualification should therefore begin with mapping. The map can be simple or sophisticated depending on consequence, but it should answer whether the usable chamber volume contains systematic spatial differences under the selected operating mode. Measurements should be made with a detector appropriate to the source spectrum and should preserve geometry, detector orientation and distance. A single centre-point irradiance value is insufficient where parts occupy a substantial fraction of the chamber or where the chamber has multiple emitters with distinct angular fields.

6. Surface orientation, view factor and self-shadowing

Every surface has an orientation relative to the incident field. A face directed toward an emitter can receive strong direct irradiation while a recessed, downward-facing or internal surface receives mainly reflected or scattered light. A hollow part, lattice, deep channel or closely spaced multi-part load can therefore have a broad distribution of delivered exposure even in a well-mapped empty chamber.

This is a view-factor problem before it is a chemistry problem. The process record should identify surfaces or volumes that are difficult to illuminate and determine whether they are functionally critical. A worst-case coupon should reproduce the optical access problem rather than merely reproduce nominal wall thickness.

Self-shadowing is time dependent when a part rotates. Rotation can expose a surface at one angular position and obscure it at another. Fixtures and neighbouring parts can likewise create periodic occlusion. The meaningful process variable is therefore the cycle-integrated exposure of a critical location, not the instantaneous irradiance at one turntable angle.

7. Rotation and repositioning are process variables

Rotation is commonly used to reduce orientation bias. It can convert a highly directional chamber into a time-averaged angular exposure. The principle is credible, but rotation is not a universal cure-uniformity guarantee.

Rotation speed, axis, fixture height, eccentric placement and part symmetry affect the exposure history. A surface that remains shadowed by the part itself throughout a full revolution gains little from rotation. A deep axial cavity can be insensitive to turntable motion. Likewise, a tall object may move through different vertical irradiance zones without averaging them adequately.

If a process requires manual flipping or repositioning, the operation becomes part of the qualified recipe. Orientation before and after repositioning, elapsed time between segments, operator tolerance and fixture repeatability should be recorded. A two-stage cycle is not equivalent to one continuous exposure of the same total time if the thermal or oxygen state evolves between stages.

8. Load configuration and chamber occupancy

Qualification of an empty chamber does not automatically qualify a full production load. Parts can block emitters, change reflection paths, trap heat and create local stagnant gas regions. The load itself is therefore a process variable.

A useful load specification includes number of parts, permitted footprint, vertical envelope, minimum spacing, fixture identity and any orientation restrictions. Where part families vary substantially, the qualification can define load classes rather than one universal arrangement. The worst case should be chosen from the mechanism being controlled. Maximum part count may be worst for mutual shadowing; maximum mass may be worst for thermal lag; deepest cavity may be worst for optical access; largest opaque cross-section may be worst for through-thickness state.

A production instruction that says “fill chamber as required” is not a controlled load definition when chamber occupancy can materially change the delivered process.

9. Through-thickness post-cure and finite optical penetration

Surface exposure does not prove through-thickness state. Nitsche et al. directly measured depth profiles after unidirectional UV post-curing and found finite penetration controlled by absorption, wavelength, photoinitiator concentration and dose in the studied material [2]. The exact numerical cure depths belong to that resin and experiment. Their transferable implication is that a thick wall can preserve a different internal state after a surface appears fully cured.

For transparent or lightly absorbing parts, multiple directions and sufficient exposure may reduce gradients, but the internal field still depends on optical path length and evolving absorption. For pigmented, filled or opaque parts, the surface can be a poor proxy for the core. Internal cavities add an access limitation on top of material attenuation.

Qualification should therefore identify the maximum relevant optical path and the consequence of an under-cured core. When through-thickness state matters, a destructive section, depth-resolved hardness, spectroscopic profile, thermal/mechanical response or another justified measurement may be required. ER-181 does not prescribe one universal method; it requires the measurement to reach the location that controls the claim.

10. Thermal coupling changes the post-cure state

Many post-cure units heat while irradiating. Temperature affects molecular mobility, reaction kinetics and the evolving material state, while the exothermic reaction and light absorption can add local heat. The resulting temperature history need not equal the chamber setpoint.

Bayarsaikhan et al. demonstrated strong time-temperature effects on mechanical and conversion-related responses in a specific dental resin [4]. Cheadle et al. independently observed significant changes in tensile strength, conversion and colour with post-cure time and temperature in another system [5]. A 2026 two-resin study further shows that the mechanical response to post-cure temperature is resin-grade dependent and can involve different flexural-strength, flexural-stiffness and ductility-related tradeoffs [7]. These data support temperature as a controlled process variable but do not justify a universal optimum.

Thermal mass matters. A thin coupon can approach chamber temperature rapidly while a thick part or dense multi-part load lags. Internal cavities can trap warmer or cooler air. Fixtures can conduct heat away or act as thermal reservoirs. Temperature qualification should therefore distinguish chamber-air control from part temperature where thermal history is consequential.

11. Atmosphere and oxygen inhibition

Oxygen can inhibit radical polymerisation near exposed surfaces. Saygin et al. showed that oxygen inhibition can create a softer surface state in vat-polymerised structures and that, for their tested systems, post-print curing in nitrogen produced stiffer structures than post-curing in air [3]. A separate 2022 study of an occlusal-splint material found that post-curing atmosphere affected several measured properties and that the result also depended on printer type [6].

These studies establish atmosphere as a potentially consequential variable. They do not establish that nitrogen post-cure is universally required or universally sufficient. Saygin et al. also show that the atmosphere during printing can leave a material-state consequence that post-cure atmosphere does not erase automatically [3].

If an inerted process is claimed, qualification should define the gas, purge sequence, permitted oxygen level or another justified atmosphere indicator, load configuration and time at condition. Merely connecting a nitrogen hose does not establish the surface environment. Conversely, an air post-cure can be entirely appropriate if the qualified final-state requirements are achieved in air.

12. Coupled optical, thermal and atmosphere histories

Radiation, temperature and atmosphere interact. Heating can accelerate reaction and change mobility. Conversion can change optical absorption. Oxygen consumption and diffusion evolve during exposure. Rotation changes optical direction while the part temperature continues to evolve. A process that is separable on the equipment control panel can therefore be coupled in the material.

This coupling means that matching one scalar parameter is not enough for transfer. If a new chamber doubles irradiance and halves time, nominal radiant exposure may be similar while temperature history and oxygen depletion differ. If a cycle is divided into two exposures with a cooling interval, total time can be unchanged while the thermal and diffusion history changes. If the source spectrum changes, equal broadband power can produce a different photochemical response.

The process specification should therefore identify which variables have been demonstrated to be non-critical and which must be held within a qualified range. Unmeasured equivalence should not be assumed simply because the same resin and total cycle time are used.

13. Property gains can coexist with penalties

Post-curing is commonly intended to increase conversion, hardness, strength, modulus or dimensional stability. The same process can also increase shrinkage-related distortion, reduce ductility, change colour or alter surface state. Wu et al. directly treat UV post-cure distortion as a dimensional-accuracy problem [1]. Cheadle et al. report simultaneous effects on mechanical response, conversion and yellowing [5]. Yang et al. modelled the relationship between degree of cure and tensile strength and hardness in green and UV-post-cured stereolithography resin, supporting the broader point that post-cure state and measured mechanical response are coupled [8]. The 2026 resin-grade study shows that post-cure temperature can shift flexural-strength and deformation-tolerance tradeoffs differently for different resins [7].

The qualification endpoint should therefore be multi-response whenever the application has more than one critical property. Maximising a single metric can be technically wrong. A cycle that maximises stiffness may fail a dimensional, colour or fracture-tolerance requirement. A cycle selected only for dimensional accuracy may leave insufficient surface or core state.

ER-181 uses a **sufficient-state** criterion rather than a maximal-cure criterion: the qualified process should bring each controlled response into its accepted range with adequate margin and repeatability. It need not maximise conversion or exposure.

14. Worst-case part and load selection

Worst case is mechanism-specific. There is no single geometry that is worst for all post-cure risks. A good qualification plan identifies each failure mechanism and chooses a challenge article or instrument placement that stresses it.

Mechanism being challenged	Candidate worst-case feature	Useful evidence
Low external radiant exposure	Surface with minimum chamber view factor	Spectral irradiance or integrated exposure at representative location
Self-shadowing	Recess, underside, lattice interior or mutually shadowed load	Location-specific exposure plus final-state response
Through-thickness under-cure	Maximum relevant optical path in most attenuating qualified resin	Depth-resolved response or sectioned test
Thermal lag	Highest thermal mass or strongest heat-sink fixture	Part-temperature history
Thermal overshoot	Low-mass surface near source or heat-accumulating cavity	Time-resolved temperature and consequence response
Oxygen-inhibited surface	Surface with highest oxygen access under claimed process	Surface-sensitive conversion/mechanical/tack response
Load interaction	Maximum occupancy or minimum spacing	Repeated load mapping and critical-location response

The selected worst case should be documented before testing. Choosing the worst-looking result after data collection is not equivalent to a pre-specified challenge rationale.

15. Qualification experiments and acceptance logic

A defensible qualification separates equipment capability, process capability and part response. Equipment mapping establishes what the chamber can deliver. Process studies establish how the selected cycle behaves across allowed loads and operating conditions. Part-response testing establishes that the resulting material state satisfies the intended requirement.

A practical sequence is:

1. define resin, incoming printed state and intended final-state claims;
2. identify critical optical, thermal and atmosphere variables;
3. map the chamber under relevant operating modes;
4. define permitted load classes and worst-case geometries;
5. instrument or otherwise characterise critical part locations;
6. run repeated cycles across the intended operating range;
7. measure application-relevant final-state responses;
8. establish acceptance criteria before final disposition;
9. document residual limitations and transfer boundaries.

Acceptance criteria should be connected to the intended use or to a justified intermediate state. “No longer tacky” can be useful for a surface observation but cannot automatically qualify through-thickness conversion. A Shore hardness result can be useful at a surface or depth but is not a universal substitute for every mechanical or chemical endpoint. A chamber irradiance tolerance is an equipment control, not by itself proof that every part is acceptable.

16. Routine verification and process monitoring

Once qualified, the process requires evidence that it remains in the qualified state. Relevant drift mechanisms include source ageing, contamination of optical windows, reflector degradation, fan or heater changes, turntable malfunction, temperature-sensor drift and changes in loading practice.

Routine verification can combine equipment checks with periodic part or coupon responses. The frequency should reflect consequence, drift rate and detectability. A highly stable chamber with internal diagnostics may need a different verification plan from an open, manually loaded unit with replaceable lamps and no irradiance feedback.

The monitoring variable should be tied to the qualified mechanism. If uniformity depends on turntable rotation, rotation status is a critical process control. If a narrow spectral band is required, total optical power alone may be insufficient. If inert atmosphere is required, gas flow without evidence of oxygen control may be a weak surrogate.

Trend data are preferable to pass/fail records alone because gradual source loss or heating drift can be detected before a final-state failure occurs.

17. Transfer, change control and requalification

Post-cure qualification is bounded to the tested process family. Changes that can alter delivered radiation, temperature, atmosphere or optical access require a documented impact assessment and, where necessary, partial or complete requalification.

Typical triggers include a new resin formulation or version; a new colour, filler or photoabsorber package; source or LED-board replacement; new chamber model; reflector or window replacement; altered turntable or fixture; changed cycle time or temperature; changed atmosphere; increased maximum part size; new hollow or deeply recessed geometry; changed load density; and changed wash/dry or pre-cure hold state.

Transfer between curing units should compare fields, not only programme names. A matched nominal wavelength and time does not establish equivalence. The transfer package should identify which critical attributes are directly comparable, which are measured by bridging studies and which remain unverified.

18. Minimum reporting set, limitations and conclusions

A technically useful post-cure record should allow another engineer to reconstruct the delivered process. At minimum it should state:

- resin identity and relevant version or formulation state;
- printer/process and incoming part state;
- cleaning, drying and hold condition before post-cure;
- curing-unit identity and source type;
- nominal spectral band and any measured spectral information used for qualification;
- commanded time and temperature;
- irradiance or radiant-exposure evidence at relevant chamber or part locations;
- part orientation, rotation/repositioning and fixture state;
- chamber occupancy and spacing rules;
- atmosphere and its verification where controlled;
- part-temperature history where thermal coupling is consequential;
- worst-case geometry/load rationale;

- final-state measurements and acceptance criteria;
- repeatability evidence;
- routine monitoring and requalification triggers.

The evidence base has important limits. Many published studies use dental or specific commercial resins, and their numerical optima cannot be transferred to unrelated formulations. Nitsche et al. directly establish finite post-cure penetration but in a particular urethane-acrylate system [2]. Nitrogen-atmosphere studies establish that oxygen can matter but do not make inert curing universally necessary [3,6]. Temperature studies establish strong process-property coupling but also show material-specific behaviour [4,5,7]. The available literature is therefore stronger on mechanism and process sensitivity than on universal post-cure recipes.

The engineering conclusion is that post-cure should be controlled as a delivered field, not a timer setting. A qualified cycle links incoming printed state, spectral irradiation, chamber geometry, orientation, shadowing, temperature, atmosphere and load configuration to measured final-state responses. Rotation, reflectors, higher temperature or inert gas can be useful process tools, but each remains a means rather than proof of cure. The strongest claim is correspondingly bounded: for a defined material, part/load family and curing unit, a specified process has been shown to deliver the required final state within stated acceptance limits and monitoring controls.

Related Engineering Review boundaries

ER-020 owns thermal-property outcomes and associated thermal testing.

ER-027 owns conversion metrology.

ER-031 owns cure shrinkage, residual stress and warpage mechanisms.

ER-084 owns detailed photocuring pathway mechanisms.

ER-185 owns thick-section photocuring in bulk-applied putties, gels, sealants and potting compounds.

ER-033 owns washing- and drying-induced extraction, property change and dimensional response in printed parts.

ER-181 owns the post-cure unit operation, its delivered optical/thermal/atmosphere field and its qualification.

References

- [1] Wu, D.; Zhao, Z.; Zhang, Q.; Qi, H.J.; Fang, D. Mechanics of shape distortion of DLP 3D printed structures during UV post-curing. *Soft Matter* 15(30) (2019) 6151-6159. DOI: <https://doi.org/10.1039/C9SM00725C>
- [2] Nitsche, J.; Schlotthauer, T.; Hermann, F.; Middendorf, P. Experimental Study on Depth of Cure During UV-Post-Curing of Photopolymers Used for Additive Manufacturing. In: Weissgraeber, P.; Heieck, F.; Ackermann, C. (eds.), *Advances in Automotive Production Technology - Theory and Application*, ARENA2036, Springer Vieweg, Berlin/Heidelberg (2021), pp. 343-350. DOI: https://doi.org/10.1007/978-3-662-62962-8_40
- [3] Saygin, V.; Snapp, K.; Gongora, A.E.; Kolaghassi, R.; Brown, K.A. Mechanical Consequences of Oxygen Inhibition in Vat Polymerization. *Advanced Materials Technologies* 8(12) (2023) 2202022. DOI: <https://doi.org/10.1002/admt.202202022>
- [4] Bayarsaikhan, E.; Lim, J.-H.; Shin, S.-H.; Park, K.-H.; Park, Y.-B.; Lee, J.-H.; Kim, J.-E. Effects of Postcuring Temperature on the Mechanical Properties and Biocompatibility of Three-Dimensional Printed Dental Resin Material. *Polymers* 13(8) (2021) 1180. DOI: <https://doi.org/10.3390/polym13081180>
- [5] Cheadle, A.M.G.; Maier, E.; Palin, W.M.; Tomson, P.L.; Poologasundarampillai, G.; Hadis, M.A. The impact of modifying 3D printing parameters on mechanical strength and physical properties in vat photopolymerisation. *Scientific Reports* 15(1) (2025) 12592. DOI: <https://doi.org/10.1038/s41598-025-97294-8>
- [6] Wada, J.; Wada, K.; Gibreel, M.; Wakabayashi, N.; Iwamoto, T.; Vallittu, P.K.; Lassila, L. Effect of Nitrogen Gas Post-Curing and Printer Type on the Mechanical Properties of 3D-Printed Hard Occlusal Splint Material. *Polymers* 14(19) (2022) 3971. DOI: <https://doi.org/10.3390/polym14193971>
- [7] Coşa, A.-V.; Şerban, D.-A.; Linul, E. Post-curing temperature-driven optimization of flexural properties in SLA-printed photopolymer resin grades. *Journal of Materials Research and Technology* 43 (2026) 1421-1435. DOI: <https://doi.org/10.1016/j.jmrt.2026.06.163>
- [8] Yang, Y.; Li, L.; Zhao, J. Mechanical property modeling of photosensitive liquid resin in stereolithography additive manufacturing: Bridging degree of cure with tensile strength and hardness. *Materials & Design* 162 (2019) 418-428. DOI: <https://doi.org/10.1016/j.matdes.2018.12.009>

Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability and AI-assistance statement

No new experimental dataset was generated. Scientific statements derive from the cited literature and the controlled Engineering Review corpus. Generative AI assisted drafting, source organisation and document QA but is not an author. Juan Segurola retains responsibility for the final article.